RESPONSE OF FRENCH BEAN TO PHOSPHORUS AND SULPHUR AT DIFFERENT LEVELS OF ALUMINIUM

Thesis
submitted to

NAGALAND UNIVERSITY

in partial fulfillment of requirements for the Degree
of
Doctor Of Philosophy
in
Agricultural Chemistry and Soil Science
by

BEAUTY BORANG
Admn. No. Ph- 182/15 Regn. No. 832/2019

Department of Agricultural Chemistry and Soil Science
School of Agricultural Sciences and Rural Development
Nagaland University, Medziphema Campus – 797106
Nagaland
2020

DECLARATION

I, Miss Beauty Borang, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science.

Date: 7/7/2020
Place: Medziphema

B. Borang
(Beauty Borang)

Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences and Rural Development
Medziphema – 797106, Nagaland

Dr. Y. K. Sharma
Professor
Department of Agricultural Chemistry and Soil Science

CERTIFICATE – I

This is to certify that the thesis entitled "**Response of French Bean to Phosphorus and Sulphur at Different Levels of Aluminium**" submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in the discipline of Agricultural Chemistry and Soil Science, the record of research work carried out by Ms. Beauty Borang, Registration No. 832/2019, under my personal supervision and guidance.

The results of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

Date : 7/7/2020
Place : Medziphema

Dr Y. K. Sharma
Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences and Rural Development
Medziphema – 797 106, Nagaland

CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

This is to certify that the thesis entitled "Response of French Bean to Phosphorus and Sulphur at Different Levels of Aluminium" submitted by Ms. Beauty Borang, Admission No. Ph- 182/15, Registration No. 832/2019 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science has been examined by the Advisory Board and External examiner on 14.12.2020.

The performance of the student has been found **Satisfactory/~~Unsatisfactory~~.**

Member	*Signature*
1. Prof. Y. K. Sharma (Supervisor)	………………… 14.12.2020
2. Prof. R. K. Kumarjit Singh (External examiner)	14/12/2020
3. Dean, SASRD (Pro Vice Chancellor Nominee)	………………… 14.12.20
Members of Advisory committee:	
1. Prof. S. K. Sharma	………………… 14.12.20
2. Prof. P. K. Singh	PKSingh 14/12/20
3. Dr. A P. Singh	apsingh 14.12.2020
4. Prof. Manoj Dutta	………………… 14/12/2020…..

14.12.20
Head
Department of Agricultural Chemistry and Soil Science

14.12.20
Dean
School of Agricultural Sciences and Rural Development, Medziphema Campus

Acknowledgements

First and foremost, praises and thanks to almighty God for his abundant blessings throughout my research works and for enabling me to complete it successfully.

I would like to express my sincere gratitude to my research superviser, Prof. Y. K. Sharma for the continous support for my Ph.D study and research, for his patience, motivation, enthusiasm and immense knowledge.

Besides my advisor, I would like to thank the rest of my advisory committee; Prof. S. K. Sharma, Prof. P. K. Singh, Prof. M. Dutta and Dr. A. P. Singh for their valuable and heartfelt suggestions in crafting, refining and shaping this manuscript.

I am thankfull to the staffs, Department of Agricultural Chemistry and Soil Science for their co-operation and continous support throughout my research work.

I am extremely greatfull to Mr. Pezangulie Chakruno for his enormous help, care and support for the completion of this thesis.

My immense thanks goes to my dear friends Watisenla Imsong, Rokozeno Chalieu, Sentibenla Pongener, Yabi Gadi, Aghali and Mary for their valuable time and helping hands which will always be rememberd, thank you so much and God bless you all.

Above ground, I am indebted to my family for their love, affection, moral support, encouragement and blessings for which I reached this height of my academic life.

Date: 7/7/2020

Place: Medziphema

B. Borang

Beauty Borang

CONTENTS

CHAPTER	TITLE	PAGE NO.
I.	INTRODUCTION	1-6
II.	REVIEW OF LITERATURE	7-36
	2.1 Effect of Aluminium	16-22
	2.2 Effect of phosphorus	22-27
	2.3 Effect of sulphur	22-27
	2.4 Interaction effect of aluminium and phosphorus on plants and soil properties	27-31
	2.5 Interaction effect of aluminium and sulphur on plants and soil properties	31-32
	2.6 Interaction effect of phosphorus and sulphur on plants and soil properties	33-36
III	MATERIALS AND METHODS	37-47
	3.1 Experimental site	37
	3.2 Climatic condition	37
	3.3 Characteristics of the experimental soil	37-38
	3.4 Experimental detail:	38-41
	3.4.1 Experiment-1	38-40
	3.4.2 Experiment-2	41
	3.5. Biometrical observations: (For experiment I and II)	42
	3.5.1. Days to germination	42
	3.5.2. Plant height	42
	3.5.3. Number of branches per plant	42
	3.5.4. Number of pods per plant	42
	3.5.5. Pods length	42
	3.5.6. Number of seeds per pod	42
	3.5.7. Test weigh	43
	3.5.8. Seed yield	43
	3.5.9. Stover yield	43
	3.5.10. Root length	43
	3.5.11. Root mass	43
	3.6. Chemical analysis of plant material	43-44
	3.6.2 Nitrogen	43
	3.6.2 Phosphorus	43

	3.6.3 Potassium	44
	3.6.4 Sulphur	44
	3.6.5 Aluminium	44
	3.6.6 Calcium	44
	3.6.7 Uptake of nutrients by plants	44
	3.6.8 Protein content and its yield	44
	3.7 Soil analysis:	45-46
	3.7.1 Mechanical analysis and texture	45
	3.7.2. Soil Ph	45
	3.7.3 Organic carbon	45
	3.7.4 Available nitrogen	45
	3.7.5 Available phosphorus	45
	3.7.6 Available potassium	46
	3.7.7 Available sulphur	46
	3.7.8 Total potential acidity	46
	3.7.9 Exchangeable Al^{3+}	46
	3.7.10 Exchangeable calcium	46
	3.8 Statistical analysis	47
IV	RESULTS AND DISCUSSIONS	48-180
	4.1 To evaluate the aluminium tolerance of french bean varieties (Experiment-1)	48-107
	4.1.1 Effect on growth and yield	48-71
	4.1.1.1 Days to germination	48-50
	4.1.1.2. Plant height	50-54
	4.1.1.3 Number of branches per plant	54-56
	4.1.1.4 Number of pods per plant	56-59
	4.1.1.5 Pod length	59-60
	4.1.1.6 Number of seeds per pod	60-61
	4.1.1.7 Test weight	61-62
	4.1.1.8 Seed yield	62-65
	4.1.1.9 Stover yield	66-67
	4.1.1.10 Root length	67-68
	4.1.1.11 Root mass	68-71
	4.1.2. Effect on nutrient content	71-84
	4.1.2.1. Nitrogen content	71-74
	4.1.2.2. Phosphorus content	74-76
	4.1.2.3 Potassium content	76-77

4.1.2.4 Sulphur content	77-79
4.1.2.5 Calcium content	79-81
4.1.2.6 Aluminium content	81-82
4.1.2.7 Protein content	82-84
4.1.3 Nutrient uptake	84-98
4.1.3.1 Nitrogen uptake	84-85
4.1.3.2 Phosphorus uptake	86-87
4.1.3.3 Potassium uptake	87-88
4.1.3.4 Sulphur uptake	91-92
4.1.3.5 Calcium uptake	92-93
4.1.3.6 Aluminium uptake	93-96
4.1.3.7 Aluminium content in root of french bean	96-98
4.1.4 EFFECT ON SOIL PROPERTIES	98-107
4.1.4.1 Soil pH and organic carbon	98
4.1.4.2 Available NPKS	98-105
4.1.4.3 Exchangeable calcium, exchangeable aluminium and total potential acidity	105-107
4.2 To study the phosphorus and sulphur requirement of french bean under different levels of aluminium (Experiment 2)	107-180
4.2.1 Effect on growth and yield	107-133
4.2.1.1 Days to germination	107-109
4.2.1.2 Plant height	109-117
4.2.1.3 Number of branches per plant	117-119
4.2.1.4 Number of pods per plant	119-121
4.2.1.5 Pod length	121-123
4.2.1.6 Number of seeds per pod	123-126
4.2.1.7 Test weight	126-127
4.2.1.8 Seed yield	127-132
4.2.1.9 Stover yield	132-133
4.2.2 Effect on nutrient content	134-150
4.2.2.1. Nitrogen content	134-136
4.2.2.2 Phosphorus content	136-138
4.2.2.3 Potassium content	138-140
4.2.2.4 Sulphur content	140-142
4.2.2.5 Calcium content	142-144

	4.2.2.6 Aluminium content	144-145
	4.2.2.7 Protein content	145-148
	4.2.2.8 Protein yield	148-150
	4.2.3 Nutrient uptake	150-169
	4.2.3.1 Nitrogen uptake	150-155
	4.2.3.2 Phosphorus uptake	155-158
	4.2.3.4 Potassium uptake	158-162
	4.2.3.5 Sulphur uptake	162-163
	4.2.3.6 Calcium uptake	163-167
	4.2.3.7 Aluminium uptake	167-169
	4.2.4 Effect on soil properties	169-180
	4.2.4.1 Soil pH and organic carbon	169
	4.2.4.2 Soil available NPK and S	171-175
	4.2.4.3 Exchangeable calcium, aluminium and total potential acidity	175-177
	4.2.4.4 Interaction effect of aluminium, phosphorus and sulphur on soil properties	177-180
V	SUMMARY AND CONCLUSION	181-205
VI	REFRENCES	i-xxix
	APPENDICES	

LIST OF TABLES

TABLE NO.	TITLE	PAGES
3.1	Meteorological observations during experimental period (October –January)	39
3.2	Physiochemical properties of the experimental soil	40
4.1(a)	Effect of aluminium levels and varieties on days to germination of french bean	48
4.1(b)	Interaction effect of aluminium levels and varieties on days to germination of french bean	48
4.2(a)	Effect of aluminium levels and varieties on plant height of french bean	51
4.2(b)	Interaction effect of aluminium levels and varieties on plant height of french bean	52
4.3	Effect of aluminium levels and varieties on number of branches per plant of french bean	54
4.4(a)	Effect of aluminium levels and varieties on number of pods per plant, pod length, number of seeds per pod and test weight of french bean	56
4.4(b)	Interaction effect of aluminium levels and varieties on number of pods per plant and pod length of french bean	57
4.5(a)	Effect of aluminium levels and varieties on seed yield and stover yield of french bean	62
4.5(b)	Interaction effect of aluminium levels and varieties on number of seed yield and stover yield of french bean	63
4.6(a)	Effect of aluminium levels and varieties on root length and root mass of french bean	68
4.6(b)	Interaction effect of aluminium levels and varieties on root length and root mass of french bean	69
4.7(a)	Effect of aluminium levels and varieties on nitrogen content and phosphorus content in grain and stover of french bean	72
4.7(b)	Interaction effect of aluminium levels and varieties on phosphorus content in stover of french bean	74
4.8	Effect of aluminium levels and varieties on potassium and sulphur content in grain and stover of french bean	77

4.9	Effect of aluminium levels and varieties on calcium and aluminium contents in grain and stover of french bean	79
4.10	Effect of aluminium levels and varieties on protein content and protein yield in grain of french bean	82
4.11	Effect of aluminium levels and varieties on nitrogen and phosphorus uptake in grain and stover of french bean	85
4.12(a)	Effect of aluminium levels and varieties on potassium and sulphur uptake in grain and stover of french bean	88
4.12(b)	Interaction effect of aluminium levels and varieties on potassium and sulphur uptake in grain and stover of French bean	89
4.13(a)	Effect of aluminium levels and varieties on calcium and aluminium uptake in grain and stover of french bean	93
4.13(b)	Interaction effect of aluminium levels and varieties on calcium and aluminium uptake in grain and stover of french bean	94
4.14	Effect of aluminium levels and varieties on aluminium content in root of french bean	96
4.15	Effect of aluminium levels and varieties on pH and organic carbon of post experimental soil	98
4.16(a)	Effect of aluminium levels and varieties on available nutrients status of post experimental soil	99
4.16(b)	Interaction effect of aluminium levels and varieties on available nutrients status of post experimental soil	100
4.17	Effect of aluminium levels and varieties on exchangeable calcium, exchangeable aluminium and total potential acidity of post experimental soil	105
4.18	Effect of aluminium, phosphorus and sulphur levels on days to germination	107
4.19(a)	Effect of aluminium, phosphorus and sulphur levels on plant height of french bean	109
4.19(b)	Interaction effect of aluminium and phosphorus on plant height of french bean	110
4.19(c)	Interaction effect of aluminium and sulphur on plant height of french bean	111
4.19(d)	Interaction effect of phosphorus and sulphur on plant height of french bean	112

4.19(e)	Interaction effect of aluminium, phosphorus and sulphur on plant height of french bean	113
4.20	Effect of aluminium, phosphorus and sulphur levels on number of branches of french bean	116
4.21(a)	Effect of aluminium, phosphorus and sulphur levels on number of pods per plant, pod length, number of seeds per pod and test weight of french bean	119
4.21(b)	Interaction effect of aluminium and phosphorus levels on pod length of french bean	123
4.22(a)	Effect of aluminium, phosphorus and sulphur levels on yield and stover yield of french bean	127
4.22(b)	Interaction effect of aluminium and phosphorus levels on test weight, seed yield and stover yield	128
4.23	Effect of aluminium, phosphorus and sulphur levels on nitrogen and phosphorus content in grains and stover of french bean	134
4.24	Effect of aluminium, phosphorus and sulphur levels on phosphorus, potassium and sulphur content in grains and stover of french bean	138
4.25	Effect of aluminium, phosphorus and sulphur levels on calcium and aluminium content in grains and stover of french bean	142
4.26(a)	Effect of aluminium, phosphorus and sulphur levels on protein content and protein yield in grains of french bean	145
4.26(b)	Interaction effect of aluminium and phosphorus on protein yield and protein yield	146
4.27(a)	Effect of aluminium, phosphorus and sulphur levels on nitrogen and phosphorus uptake in grains and stover of french bean	150
4.27 (b)	Interaction effect of aluminium and phosphorus on nitrogen and phosphorus uptake in grains of french bean	151
4.27(c)	Interaction effect of aluminium and phosphorus on phosphorus uptake in stover of french bean	152
4.28(a)	Effect of aluminium, phosphorus and sulphur levels on potassium and sulphur uptake in grains and stover of french bean	158
4.28(b)	The interaction effect of aluminium and phosphorus on potassium uptake in grains of french bean	159

4.29(a)	Effect of aluminium, phosphorus and sulphur levels on calcium and aluminium uptake in grains and stover of french bean	164
4.29 (b)	Interaction effect of aluminium and phosphorus on aluminium uptake in stover of french bean	165
4.30	Effect of aluminium, phosphorous and sulphur levels on pH and organic carbon in post experimental soil	169
4.31	Effect of aluminum,phosphorus and sulphur levels on available nutrients status of post harvest soil	171
4.32	Effect of aluminium, phosphorus and sulphur levels on exchangeable calcium, exchangeable aluminium and total potential acidity of post harvest soil	175
4.33(a)	Interaction effect of aluminium and phosphorus levels on available nutrients of post harvest soil	177
4.33(b)	Interaction effect of phosphorus and sulphur levels on available phosphorus content of post harvest soil	178

LIST OF FIGURES

FIGURE NO.	CAPTION	IN BETWEEN PAGES
3.1	Meteorological observations during the period of investigation (October –January)	39-40
4.1	Effect of aluminium levels and varieties on plant height of french bean	52-53
4. 2	Effect of aluminium levels and varieties on number of branches per plant of french bean	54-55
4.3	Effect of aluminium levels and varieties on seed yield of french bean	63-64
4.4	Effect of aluminium levels and varieties on stover yield of french bean	63-64
4.5	Effect of aluminium levels and varieties on nitrogen uptake in grain and stover of french bean	85-86
4.6	Effect of aluminium levels and varieties on phosphorus uptake in stover of french bean	85-86
4.7	Effect of aluminium levels and varieties on potassium uptake in grain and stover of french bean	89-90
4.8	Effect of aluminium levels and varieties on sulphur uptake in grain and stover of french bean	89-90
4.9	Effect of aluminium levels and varieties on calcium uptake in grain and stover of french bean	94-95
4.10	Effect of aluminium levels and varieties on aluminium uptake in grain and stover of french bean	94-95
4.11	Effect of aluminium levels and varieties on exchangeable aluminium in post harvest soil	105-106
4.12	Effect of aluminium levels and varieties on total potential acidity in post harvest soil	105-106
4.13	Effect of aluminium, phosphorus, sulphur levels and varieties on plant height of french bean	113-114
4.14	Effect of aluminium, phosphorus and sulphur levels on number of branches in french bean	117-118
4.15	Effect of aluminium, phosphorus and sulphur levels on seed yield of french bean	128-129

4.16	Effect of aluminium, phosphorus and sulphur levels on stover yield of french bean	128-129
4.17	Effect of aluminium, phosphorus and sulphur levels on nitrogen uptake in grains and stover of french bean	152-153
4.18	Effect of aluminium, phosphorus and sulphur levels on phosphorus uptake in grains and stover of french bean	152-153
4.19	Effect of aluminium, phosphorus and sulphur levels on potassium uptake in grains and stover of french bean	159-160
4.20	Effect of aluminium, phosphorus and sulphur levels on sulphur uptake in grains and stover of french bean	159-160
4.21	Effect of aluminium, phosphorus and sulphur levels on calcium uptake in grains and stover of french bean	165-166
4.22	Effect of aluminium, phosphorus and sulphur levels on aluminium uptake in grains and stover of french bean	165-166
4.23	Effect of aluminium, phosphorus and sulphur levels on exchangeable aluminium	175-176
4.24	Effect of aluminium, phosphorus and sulphur levels on total potential acidity of post experimental soil	175-176

LIST OF ABBREVIATION

%	--	Percentage
µg	--	Micro gram
Al	--	Aluminium
Ca	--	Calcium
CEC	--	Cation exchange capacity
CD	--	Critical differences
cm	--	Centimeter
cmol	--	Centimol
ºC	--	Degree centigrade
Cu	--	Copper
Cr	--	Chromium
dSm^{-1}	--	Desi simen per meter
EC	--	Electrical conductivity
fig.	--	Figure
g	--	Gram
ha	--	Hectare
K	--	Potassium
kg	--	Kilogram
M.C	--	Moisture content
m	--	Meter
mg	--	Milligram
Mg	--	Magnesium
N	--	Nitrogen
No.	--	Number
NU	--	Nagaland University
P	--	Phosphorus
ppm	--	Parts per million
S	--	Sulphur

SASRD	--	School of Agricultural Sciences and Rural Development
SEm±	--	Standard error mean
SOV	--	Source of varience

CHAPTER I

INTRODUCTION

INTRODUCTION

French bean (*Phaseolus vulgaris* L.) belongs to family leguminoceae and occupies a premier place among grain legumes in the world including India. French bean is quite nutritious and potential source of protein, carbohydrates and minerals. It is an excellent vegetable crop for pods as well as for seed and is of world-wide significance for direct human consumption and a dietary supplement rich in proteins, vitamins and minerals such as calcium, phosphorus, iron and zinc (Broughton *et al*., 2003).

French bean also known as common bean, snap bean, navy bean, kidney bean or *rajmash* (Hindi) belongs to family *Leguminoceae* and sub-family *Papilionaceae*. It has a tap root system with poor nodules formation and is also a self-pollinated crop. Broadly it is classified into two types, bush type and pole/climbing type. It is believed to be originated from the warm and humid regions of South America. It thrives well in a moderately warm to cool climate and the optimum temperature for its cultivation ranges from 15^0 C - 25^0 C. It is generally raised in areas receiving 50-150 cm annual rainfall. The ideal soil pH for growth of french bean is 5.5 - 6.0 and a well drained loamy soil rich in organic matter are best suited for its cultivation.

French bean is also one of the most important pulse crop in North East India and many parts of the country. It is grown for the tender green pods and the dry seeds. In many places the dry fodder is used as a cattle feed. The crop is rich sources of protein, phosphorous, iron and calcium. In Nagaland, french bean was cultivated on 16,750 ha during 2018 with the production of 21,350 tonnes of french bean seeds (Anonymous, 2018).

Aluminium (Al) is the third most abundant natural element of the soil (comprising 7 per cent of its mass) after oxygen and silicon. Al also exists as various ionic species in soil solution as determined by the soil pH. In soil solution at pH < 5, Al is present as the Al^{3+} ions. As the pH increases, Al^{3+} undergoes successive deprotonations to form the monomeric hydroxyaluminium ions, $Al(OH)_2^+$ and $Al(OH)_3$ (Martin, 1988). The $Al(OH)_3$ species formed above pH 5 precipitates, while at alkaline pH the formation of $Al(OH)_4^+$ and $Al(OH)_2^+$ results in Al becoming soluble again. Since the chemical reactions that form different Al species are highly pH dependent, the phytotoxicity of Al also varies with its species. In addition, many other soil factors such as type of clay minerals, organic matter levels, and ionic strength as well as plant factors may influence the extent of phytotoxicity of different Al species. In general, toxicity is decreased when Al is complexed with organic ligands, Fe- and SO_4, whereas the activity of Al^{3+} and Al-hydroxy species are considered to be most phytotoxic (Ritchie, 1989).

Aluminium (Al) toxicity is a major constraint on crop production in acid soils which account for about 40% of the world's arable land. However the mechanism of Al toxicity has not yet been elucidated (Taylor 1995). There is however limited information on how Al affects the common bean (*Phaseolus vulgaris* L.).

Aluminium (Al) is not regarded as an essential nutrient, but low concentrations can sometimes increase plant growth or induce other desirable effects. Aluminium toxicity is an important growth-limiting factor for plants in acid soils below pH 5.0 but can occur at pH levels as high as 5.5 in mine spoils (Foy 1992). Generally, Al interferes with cell division in root tips and lateral roots, increases cell wall rigidity by cross linking pectins, reduces DNA replication by increasing the rigidity of the DNA double helix, fixes phosphorous in less available forms in soils and on root surfaces, decreases root respiration, interferes with enzyme activity governing sugar phosphorylation and the deposition of cell wall polysaccharides, and interfere with the uptake, transport, and also use of several essential nutrients (Ca, Mg, K, P and Fe) (Foy 1992). Aluminium is present in all soils, but Al toxicity is manifested only in acid conditions, in which the phytotoxic form Al^{3+} predominates.

The symptoms of aluminium toxicity are not easily identifiable. In plants, the foliar symptoms resemble those of phosphorus deficiency (overall stunting, small, dark green leaves and late maturity, purpling of stems, leaves, and leaf veins, yellowing and death of leaf tips). In some cases, Al toxicity appears as an induced calcium deficiency or reduced Ca transport problem (curling or rolling of young leaves and collapse of growing points or petioles). Excess Al even induces iron deficiency symptoms in rice, sorghum and wheat (Clark *et al.* 1981).

Symptoms of Al toxicity first appear in roots, but tend to develop less vigorously. Elongation of the main root axis diminishes and laterals and fine roots often fail to develop. Aluminium affected roots are generally stubby, short, swollen, gnarled and brittle with bent brown tips. In the field, poor root penetration into acidic sub soils results in plants that are shallow rooted and therefore inefficient in exploring nutrients and water from deeper soil layers (Foy, 1992). Aluminium also makes the roots more susceptible to pathogen attack in a variety of species. Aluminium apparently does not interfere with seed germination but affect seedling establishment in acid soils because Al inhibits root growth (Nosko *et al.*, 1988)

Aluminium is one of the most abundant elements in the earth's crust, and toxic for many plants when the concentration is greater than 2–3 ppm with a soil pH < 5.5. Exchangeable aluminium content in the soils of Nagaland varied from 1.29 to 2.62 cmol kg^{-1} (Chenithung *et al.* 2014).

Phosphorus is an essential element for photosynthesis, a process through which plants prepare their own food. It is one of the primary structural components of membranes that surround plant cells. It is involved in the synthesis of proteins and vitamins and occurs in important enzymes. It promotes early root formation and growth. Phosphorus when applied to legumes, it enhances the activity of *rhizobia* by increasing nodulation and thereby helps in fixing more atmospheric nitrogen. A deficiency of phosphorus affects not only plant growth, its development and crop yield, but also the quality of the fruit and the formation of seeds. It is therefore clear that there must be adequate, readily available reserves of phosphorus in the soil. Most unmanured soils contain too little readily available phosphorus to meet the large demand of crops, particularly during certain periods of the growing cycle. Most of the Indian soils are low to medium in phosphorus. At present 1.9 percent of Indian soils had adequate available P, 49.3 percent were under low category, 48.8 percent under medium and only 1.9 percent under high category. The phosphorus fertility status of Nagaland state soil is medium and some fraction is low (Motsara, 2002).

French bean also responds well to phosphorus application. Phosphorus deficiency triggers many morphological, biochemical and molecular changes in plants. It affects on nodulation, nitrogen fixation and plant growth in legume crops. This crop responds to the application of phosphorus more and production increases with the increasing phosphorus doses because with phosphorous fertilizer, the plant develops its roots better and increases penetration with a better root system of deeper penetration and thus absorbs more phosphorus which the bean plants need up to the physiological maturation phase. (Siddiqui and Noor, 2010). Phosphorus is needed in relatively large amounts by legumes; in addition to promoting growth of the host legume, it has specific roles in N_2 fixation, nodule initiation, nodule number, growth and development (Schulze *et al*., 2006).

Among secondary nutrients sulphur deficiency is identified as yield limiting factor, particularly in production of pulses and oilseed crops (Shrivastava *et al.*, 2000). Sulphur has been found to be an indispensable element for higher pulse production and it is an integral part of proteins, sulpholipids, enzymes etc, besides it is involved in various metabolic and enzymatic processes including photosynthesis, respiration and legume-*Rhizobium* symbiotic nitrogen fixation (Rao *et al.*, 2001). Sulphur response has been observed for several legume crops including french bean and its application to sulphur deficient soils have been found to increase the crop yield and improve the quality of crop produce (Kumar *et al.*, 2009). The positive effect of sulphur on the growth and yield of leguminous plants results from improvement in the state of nourishment of the host plant and from the stimulation of nitrogen fixation. Sulphur is necessary in the biosynthesis and functioning of enzymatic structures containing Mo (Mendel and Bittner 2006) and it is necessary for the regulation of N_2 fixation mechanisms (Zhao *et al.*,1999).

The effective functioning of the symbiosis between the plant and *Rhizobium* requires a high input of energy. The research on *Vicia faba* sp. minor show that the proper nutrition of plants with sulphur increases the amount of glucose flowing to the roots and ATP biosynthesis (Pacyna *et al.*, 2007). The effect is a larger number of nodules developing on the roots, their higher weight and an increase in the amount of N_2 bound (Scherer and Lange 1996). Sulphur also has positive influence on the biosynthesis of secondary metabolites, which have defensive effect against pathogens (Datnoff *et al.*, 2007).

French bean can absorb sulphur in great quantities and it is necessary to maintain the relation of nitrogen and sulphur in the plant to produce protein (Hendrix, 1967) and application of sulphur between 10-20 kg ha^{-1} can control sulphur deficiency (Van and Voysests, 1991).

Targeting specific nutrients that are deficient in soils and evaluating response to applied nutrients is the key to accurate and profitable fertilizer recommendations. For optimum nutrient balance and increased crop yields, there is a need for soil acidity management and crop productivity improvement like nutrient management on such soils for enhancing food security in the region. Acidity and nutrient management are one of the most important variables that must be controlled to ensure that farmers get high yields of good quality. Thus keeping in mind the above said views, the present investigation entitled “Response of French Bean to Phosphorus and Sulphur at Different Levels of Aluminium” was conducted with the following objectives:

1. To study the performance of french bean varieties under aluminium stress environment.
2. To study the effect of phosphorus and sulphur on soil properties, growth, yield, nutrient uptake of french bean under aluminium levels.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 Effect of Aluminium

2.1.1 Effect on growth and yield

Macleod and Jackson (1964) reported that there was a significant restriction of top and root growth in alfalfa and red clover species with less than 1.00 ppm of aluminium ion while 2.00 ppm was toxic to root growth. Aluminium taken up by plant was concentrated in the roots and only with the concentration of aluminium at 2.00 ppm was the content in the top increased significantly.

Lee and Foy (1986) identified a relationship between resistance to Al toxicity and organic acid synthesis in common beans when they observed increased concentrations of organic acids in root extracts of two bean genotypes when exposed to Al.

Wagatsuma *et al*. (1987) reported that the concentration of Al was high in the roots and generally low in the tops. In sensitive plants, Al was considerably deposited in the root-tips; the root elongation was retarded and finally the top growth inhibited.

In an experiment conducted by Nosko *et al.* (1988), seed germination and the establishment and subsequent growth of seedlings of white spruce (*Picea glauca* (Moench) Voss) subjected to various aluminum treatments were examined. Aluminium concentrations of 50–500 μM did not reduce the cumulative percent germination of seeds but impaired the ability of seedlings to become established. The inability of roots of Al-treated seedlings to penetrate a rooting medium resulted in significant reductions in seedling fresh weight and in the length and dry weight of roots and shoots. When seedlings were established before exposure to Al, the deleterious effects of Al were not as pronounced;

however, root length, root dry weight, and root to shoot ratio were significantly lower for Al-treated seedlings compared with controls. Aluminium stimulated shoot growth, and a trend towards increased shoot length and stem dry weight with increased Al concentration was observed. Increased Al concentration in solution decreased the root to shoot ratio of established seedlings.

According to Göransson and Eldhuset (1991), the following typical root morphology injuries are caused by Al: root darkening, formation of short roots and inhibition of lateral root development. Thus, most studies have shown that the inhibition of root growth is the most visible and immediate result of Al toxicity in plants, and many authors suggest that the primary cause of this symptom is the reduction of mitosis in the root apical meristem cells (Echart and Cavalli-Molina, 2001).

In an experiment conducted by Wang and Guan (1993) on wheat seedling growth and on seed germination, they reported that the growth of seedlings was significantly inhibited by Al. The high concentrations of Al inhibit growth of roots and shoots of germinating seeds.

Lima and Copeland (1994) also used 75 µmol L^{-1} Al, and reported that Al does not affect the aerial part of wheat but that it affects the root system by causing the primary roots to become dark and brittle with brown apices in addition to inhibiting the secondary roots.

Kochian (1995) stated that mechanisms of Al resistance have been studied in several species and susceptible maize plants rapidly inhibit root elongation in specific regions of the root system when exposed to Al while the roots of resistant genotypes continue to grow.

Common bean is considered to be relatively more sensitive to Al toxicity compared to other crops (Thung and Rao, 1999).

Petra and John (2000) showed that Aluminium altered both root and leaf architecture. Low Al concentrations (<5 mg L^{-1}) significantly increased leaf expansion, and high concentrations (>25 mg L^{-1}) reduced leaf expansion. In the Al-sensitive race, KR, there was a loss of apical dominance, and both lateral and primary roots were stunted and swollen, with increasing Al concentrations.

Salvador *et al*. (2000) showed that, when the Al in the nutrient solution ranged from 5 to 10 mg kg^{-1}, the growth and development of the guava plants were higher than in the control (without Al) and when the Al concentrations ranged from 20 to 25 mg kg^{-1}.

Rao (2001) stated that sub soil acidity and Al toxicity limits root growth and increases the risk of drought under rainfed conditions. It also increases the accumulation of toxic ions and decreases nutrient availability.

Thangavel (2002) reported that the biomass of roots showed a significant decrease with an increase in the treatment concentration of Al. The nodule biomass also showed a significant decrease with an increase in the treatment concentration of Al and the stem dry weight showed a significant decrease compared to that of the control with increasing concentration of Al. The leaf dry weight showed a progressive decrease with increasing treatment concentration of Al and above 10 µg of Al g^{-1} of soil it was significantly less than that of the control.

Rangel *et al*. (2007) reported that in common bean, Al applied to elongation zone (EZ) inhibits root growth. Symptoms of Al toxicity in beans include the production of shortened roots with the presence of thickened, but fragile roots that undergo browning. Beans differ from cereals by being quiescent when Al treatment begins and later expressing tolerance components.

Horst *et al.* (2007) reported that in common bean (*Phaseolus vulgaris*) aluminium (Al) inhibits root elongation not only when applied to the transition zone but also to the elongation zone.

Alamgir and Akhter (2009) conducted an experiment on which effects of different concentrations of aluminium (Al^{3+}) on seed germination of high yielding varieties of wheat (*Triticum aestivum* L.) were investigated. Al^{3+} at 500 ppm had inhibitory effect on seed germination, seedling growth and its dry matter. Root growth was more susceptible to Al^{3+} stress than that of shoot.

Recently, Rangel *et al.* (2009) demonstrated that apoplastic Al induces the inhibition of root elongation and that recovery from the stress caused by this element is controlled by reducing Al in the apoplast, thus permitting renewed elongation and cell division.

According to Farias *et al.* (2011), increasing aluminium levels in the nutrient solution led to a decline in the shoot and root dry matter production.

Yang *et al.* (2012) reported that aluminium (Al) toxicity and drought are two major factors limiting common bean (*Phaseolus vulgaris* L.) production in the tropics. Short-term effects of Al toxicity and drought stress on root growth in acid, Al-toxic soil were studied, with special emphasis on Al-drought interaction in the root apex. Root elongation was inhibited by both Al and drought. Al renders the root apex more drought-sensitive; particularly by impacting the gene regulatory network involved in ABA signal transduction and cross-talk with other phytohormones necessary for maintaining root growth under drought.

In an experiment conducted by Batista *et al.* (2012) in a greenhouse with five treatments consisting of aluminium doses (0, 25, 75, 150, and 300 µmol L-1) and six replications. The shoot dry matter, root dry matter and plant height decreased significantly with increasing Al concentrations. Compared to the control plants, it was observed that the root growth of corn plants in Al solutions was inhibited, there were fewer lateral roots and the development of the root system reduced. The leaf anatomy of plants grown in solutions containing 75 and 300 μmol L^{-1} Al differed in few aspects from the control plants. The leaf sheaths of the plants exposed to Al had a uniseriate epidermis coated with a thin cuticle layer, and the cells of both the epidermis and the cortex were less developed. In the vascular bundle, the metaxylem and protoxylem had no secondary walls, and the diameter of both was much smaller than of the control plants.

Aluminium treatment from 50 to 200 mg/L affected the root, shoot and seedling length, seed germination and seedling dry biomass of maize as compared to control (Nasr, 2013).

It is suggested that aluminium toxicity induced increase in accumulation of Cl^- and Al^{3+} with the concomitant decrease in K^+ accumulation in the radicle and plumule might be responsible for Al-induced inhibition of germination of seeds. (*Samad et al.*, 2017)

The inhibition of root elongation is the main symptom of Al phytotoxicity. Root elongation was inhibited much more than NO^{3-} uptake in the presence of high Al concentrations in soybean (Zhao and Shen, 2018).

Foliar symptoms of aluminium toxicity resemble those of phosphorous (P) deficiency i.e. overall stunting, small, dark green leaves and late maturity, purpling of stems, leaves, and leaf veins, yellowing and death of leaf tips (figure 2 b). In some cases, Al toxicity appears as induced calcium (Ca) deficiency or reduced Ca transport problem i.e. curling or rolling of young leaves and collapse of growing points or petioles. Sometimes excess Al even induces iron (Fe) deficiency symptoms in rice, sorghum and wheat. Aluminium toxicity also results in suppression of photosynthetic capacity of shoots in many plants. These results in cellular and ultrastructural modifications in leaves, reduced stomatal movements and CO_2 assimilation, reduction in chlorophyll concentration, chlorosis and necrosis of leaf tissues etc. (Neenu and Karthika, 2019)

2.1.2 Effect on chemical composition

Macleod and Jackson (1964) reported that Phophorus concentration in the roots, which increased with the aluminium ion concentration, was apparently immobilized by aluminium. Percent Ca in the roots increased and in the tops decreased with increasing concentration of aluminium. Content of K and Mg also varied with aluminium concentration.

Andrew *et al.* (1973) in his experiment observed that the principal nutrients that were affected by aluminium treatment were calcium and phosphorus. Aluminium treatment reduced the calcium concentrations in the tops of all selected plant species and there were reciprocal relationships between calcium, magnesium, and potassium concentrations while the high aluminium treatment reduced the phosphorus concentration.

Bennet *et al*. (1985) noted the aluminium toxicity in *Zea mays* and observed nutrient disorders involving the uptake and transport of P, K, Ca and Mg. Phosphorous transport between roots and shoots diminished with increased Al concentration in roots.

Cumming *et al.* (1985) reported that aluminium induced changes in the uptake of most macroelement cations by plant roots, including reductions in the uptake of calcium, magnesium and potassium.

Aluminium is known to alter ion uptake and mineral composition in plants at acidic pH even at fairly low concentration. Accumulation of most divalent cations is reported to be reduced when plants are exposed to Al (Ryan *et al.*, 1986).

The disruption of root tip mucilage by high solution A1 level may also be responsible for reduced nutrient uptake (Korcak, 1989).

Huang *et al*. (1992) reported that net calcium influx at the root apex was strongly inhibited by Al^{3+}. Furthermore, Ca^{2+} flux was affected to a greater extent than the fluxes of other ions. Nichol and Oliveira (1995) noted that Al^{3+} reduced Ca^{2+} influx in barley (*Hordeum vulgare*).

Delhaize and Ryan (1995) reported that high Al concentrations in nutrient solution influenced the uptake of minerals; uptake of divalent cations particularly Ca and Mg was often disturbed by Al.

Rufty *et al*. (1994) showed that NO^{3-} uptake by soybean decreased when Al concentration in solution increased from 10 to 50 µM.

Pintro *et al*. (1996) reported that the concentrations of nitrogen, calcium, magnesium, potassium, and manganese in the shoot and roots of corn cultiver and iron and zinc in the shoot only decreased with the increase of Al levels in solution for corn cultivars. This increase of Al toxicity increased the concentrations of carbon, copper, and boron in the shoot and C, P, Fe, and Cu in the roots of corn cultivars.

Aluminium interacts antagonistically with Ca, Mg and P, therefore, plants grown in external media with high concentration of A1 may display symptoms associated with P deficiency or Ca deficiency or Mg deficiency (Edwards *et al*., 1976). Cations such as Ca and Mg compete with Al for root absorption sites.

Marschner (1997) stated that the major constraints to the plant growth in acid minerals soils are: high hydrogen, aluminium, and manganese concentrations inducing toxicity; low calcium, magnesium, potassium, phosphorus inhibition of root growth and water uptake, inducing nutrient deficiency and drought stress.

Thangavel (2002) reported that the aluminium toxicity is frequently associated with symptoms resembling those of P deficiency. Such P deficiency could result from reduced P uptake and transport, caused by Al-P precipitation on plant roots, or from interference by A1 in the metabolism of P already present in plant shoots.

Pintro *et al.* (2004), working with a clayey soil observed that the pH ($CaCl_2$) values decreased in proportion to an increase in the Al concentration values.

Wang *et al.* (2006) reported that aluminium inhibits absorption of nutrients by plant roots, especially Ca, Mg, Fe and Mo. It also limits availability of P in the soil in addition to promoting Mn and H^+ toxicity.

Kenechukwu *et al.* (2007) narrated that high concentrations of aluminum (A1) in tropical soils often inhibit crop performance. Plant height, shoot biomass, nodule count as well as soil pH, available P, extractable A1 and Mn were recorded during early growth while number and weights of pods were recorded at maturity. Genotypic (G) and G×A1 effects were significant for the growth and yield parameters while A1 effect was insignificant, except on extractable A1 after cropping.

Cristiane and Veronique (2008) reported that in certain rice cultivars, Al treatment decreased Ca, P, K, Mg and Mn concentrations in shoot and K, Mg and Mn in root. It increased Ca and P in root and caused an increase in shoot and root Al contents.

Aluminium inhibits absorption of nutrients by plant roots, especially Ca, Mg, Fe and Mo. It also limits availability of P in the soil in addition to promoting Mn and H^+ toxicity (Wang *et al*., 2006).

The soluble Al in soil makes the plant uptake of several elements difficult, and one of these elements is P (Batista *et al*., 2009).

Miguel *et al.* (2013) reported that increase in Al concentration decreased photosynthetic rate, stomatal conductance and leaf transpiration rate, The Al-treatments decreased content of nitrogen(N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in different plant parts.

2.1.3 Effect on soil properties

Aluminium is known to alter ion uptake and mineral composition in plants at acidic pH even at fairly low concentration. Accumulation of most divalent cations is reported to be reduced when plants are exposed to Al (Ryan *et al.*, 1986).

Ryan *et al.* (1986) also reported that Accumulation of most divalent cations is reported to be reduced when plants are exposed to aluminium

According to Macklon *et al*. (1994), in growth medium, aluminium increases phosphorus fixation by precipitation as Al-P complexes thereby reducing phosphorus availability.

Aluminium interacts antagonistically with Ca, Mg and P, therefore, plants grown in external media with high concentration of A1 may display symptoms associated with P deficiency or Ca deficiency or Mg deficiency (Edwards *et al*. 1976). Cations such as Ca and Mg compete with Al for root absorption sites.

Thangavel (2002) was also of the view that decreasing trend recorded in the phosphorus content of the soil may be due to its precipitation as aluminium phosphate, at a pH below 5.5 (acidic) both iron and aluminium precipitate phosphorus.

Illera *et al*. (2004) reported that exchangeable calcium generally competes with aluminium for exchange sites and replaces aluminium, thereby increasing their stand and availability. Studies have also reported that calcium amendments are commonly used to reduce aluminium in soil or ameliorate aluminium toxicity through the process of cation exchange or replacement (Rengel and Zhang, 2003).

Pintro *et al.* (2004), working with a clayey soil observed that the pH ($CaCl_2$) values decreased in proportion to an increase in the Al concentration values.

Wang *et al.* (2006) reported that aluminium inhibits absorption of nutrients by plant roots, especially Ca, Mg, Fe and Mo. It also limits availability of P in the soil in addition to promoting Mn and H^+ toxicity.

Scheel *et al.* (2008) reported that precipitation of organic matter increased with larger amounts of added aluminium and higher pH hence led to decrease in soil organic carbon which was caused by reduced bioavailability of organic matter after its precipitation.

Batista *et al*. (2009) reported that the pH ($CaCl_2$) values decreased in proportion to an increase in the aluminium concentration values. Pintro *et al*. (2004) work with a clayey soil observed similar results.

Aluminium and nitrogen are known to have an antagonistic relationship, wherein the availability of one reduces the availability of the other. This was well documented by Zhao and Shen (2018) that owing to low nitrogen use efficiency, the huge amount of nitrogenous fertilizer often leads to soil acidification, thereby increasing aluminium toxicity. They are of the opinion that the presence of aluminium lowers the availability of nitrogen and their uptake.

Aluminium stress and calcium deficiency caused negative effects on nutrient content, photosynthetic activity and leaf anatomy of bean plants (Costa *et al*., 2020).

2.2 Effect of phosphorus

2.2.1 Effect on growth and yield

Phosphorus deficiency is also the major constraints to the growth of legumes in many soils (Desta, 1988).

Ahlawat and Sharma (1989) reported increased mean seed yield to the tune of 29.6 and 39.5 percent respectively, with 17.2 and 34.4 kg P ha^{-1}, over no P fertilization.

The effect of low P is primarily through reduced leaf area development rather than reduced photosynthetic capacity of the leaves that develop (Lynch *et al*., 1991).

Baboo (1998) conducted a field experiment in U.P, India, on french bean during rabi season on sandy loam soil with 3 varieties (contender, UPF 626 and PDR 14) 4 level of N (0, 40, 80 and 120 kg/ ha) and three levels of P (0, 50 and 100 kg/ha) and reported that increase in phosphorus level increases the number of grains/pod, 100 seed weight and seed yield.

Tewari and Singh (2000) reported significant increase in number of pods per plant, due to increased P fertilization upto 60 and 120 kg P_2O_5 ha^{-1}.

Rahman *et al.* (2007) conducted a field experiment on french bean by applying different levels of nitrogen and phosphorus (0, 40 and 60 kg P ha^{-1}) and observed that among phosphorus levels 60 kg P ha^{-1} gave the highest pod yield. Paliwal (2009) stated that Paliwal (2009) stated that phosphorus application increased the grain yield of crop over preceding levels upto 60 kg P_2O_5 ha^{-1} however the response at higher level 80 kg P_2O_5 ha^{-1} was found to be almost at par with 60 kg P_2O_5 ha^{-1}.

Sharma and Prasad (2009) in their experiment on mungbean found that the application of DAP @ 17.5 and 35 kg ha^{-1} increases the seed yield over control by 16-34 and 39-49% respectively.

Gidago *et al*. (2011) studied the effect of different levels of phosphorus on french bean (*Phaseolus vulgaris*) and observed that phosphorus significantly hastened physiological maturity of crop. Although the effect of P application was not significant on number of pods per plant, number of seeds per pod, thousand seed weight and straw phosphorus content, its application had significantly increased grain yield. Besides, total biomass was also significantly influenced by phosphorus.

Nkaa *et al*. (2014) reported that phosphorus fertilizer significantly enhanced growth and yield characters of cowpea. Plant height, leaf area, number of leaves and number of branches in all the weeks of measurement were significantly improved. Phosphorus also had a significant effect ($p>0.05$) on seed yield per treatment, weight of 50 seeds, number of nodules, weight of nodules and total above ground dry matter.

Rafat and Sharifi (2015) observed that application of phosphorus fertilizer on french bean had a significant effect on plant height, pod length, number of pods per plant, green pod yield, biological yield, dry matter accumulation and harvest index. Application of 50 kg P ha^{-1} lead to maximum values of plant height, pod size, number of pods per plant and pod yield.

Phosphorus application rate indicated progressive increases in seed yields of increase in P rates in which the highest rate of P fertilizer (30 kg P ha^{-1}) gave the highest seed yield (3176 kg ha^{-1}) while the lowest seed (1715 kg ha^{-1}) was from no P application. The result also showed an increase in biomass production when P application increased from the lowest to the highest rate. The highest biomass yield (8135 kg ha^{-1}) was produced at the rate of 30 kg P ha^{-1} while the lowest (4399 kg ha^{-1}) was produced at 0 kg P ha^{-1}. The highest number of total pods per plant (18.52) was recorded at P application rate of 30 kg P ha^{-1} whereas the lowest number of total pods (10.85) was obtained from control. (Tesfaye, 2015).

Chotchutima *et al*. (2016) reported that maximum rate of P (750 kg ha^{-1}) exhibited the highest plant height and stem diameter compared to the other rates during the 2 year period. A suitable stem diameter (above 2.5 cm) was only found in the 750 kg ha^{-1} P application at the 2^{nd} harvest. The maximum woody stem yield was obtained at the 750kg ha^{-1} P application rate in both the 1^{st} and 2^{nd} harvests and an increased P rate increased the biomass yield, but did not increase the P content of the leucaena woody stem.

Singh *et al*. (2017) reported that application of 60 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1} was found to be significantly superior over control and recorded the highest value of growth attributes *viz.* plant height and dry matter production, number of pods per plant, number of grains per pod, pod length (cm), grain yield and nutrient uptake in mung bean.

Zebire and Gelgelo (2019) reported that the effect of phosphorus significantly ($P< 0.05$) increased bean yield and growth parameters such as leaf area and number of branches per plant, whereas its effect was not significant on plant height. Based on result obtained, application of 46 kg P ha^{-1} is recommended for better production of haricot bean.

2.2.2 Effect on nutrient composition

Fageria (1989) reported beneficial effect of phosphorus application on potassium uptake.

Chavan *et al.* (2000) reported that total phosphorus uptake increased linearly with increase in phosphorus levels.

Paliwal *et al.* (2009) stated that phosphorus application also increased the N-content of soybean significantly upto the level of 60 kg P_2O_5 ha^{-1}, but decreased non-significantly at higher level (80 kg P_2O_5 ha^{-1})

Yadav (2011) reported that application of phosphorus at 40 kg P_2O_5 significantly increased the grain nitrogen content, protein content as well as phosphorus content in grain and stover of cluster bean.

Das *et al*. (2013) found that among different levels of phosphorus (0, 15, 30 and 45 kg P_2O_5 ha^{-1}), 30 kg P_2O_5 ha^{-1} showed best influence with respect to different growth and yield parameters of chick pea. Nitrogen and phosphorus content in seed and straw, total uptake of N and protein content were also highest with 30 kg P_2O_5 ha^{-1}.

Lal *et al.* (2013) found that the protein content of cowpea increased with increase in phosphorus levels upto 90 kg P_2O_5 ha^{-1}.

Girma *et al.* (2014) conducted an experiment on french bean applying 0, 20 and 40 kg P_2O_5 ha^{-1} and reported that the increasing rate of phosphorus showed a substantial improvement in crude protein content and phosphorus uptake by the plants.

Kumar *et al*. (2015) reported that nutrient uptake was significantly highest with phosphorus application upto 75 kg P_2O_5 ha^{-1}. The NPK content in grains and stover of urd bean was also highest with application 75 kg P_2O_5 ha^{-1}.

Zohmingliana *et al.* (2016) reported that increased level of phosphorus resulted in increasing nitrogen content in grains and stover of french bean. In grains, the highest N content (3.41%) was observed where 75 kg P_2O_5 kg $ha^{-1}$was applied and was found to be significantly higher than N content from the other phosphorus levels. Similarly in stover, the nitrogen content was highest in P_{75} (1.20%) but it was at par with P_{50} (1.16%).

Dharwe *et al*. (2019) revealed that application of 40 kg sulphur ha^{-1} and phosphorus 90 kg ha^{-1} to the summer green gram crop significantly increased the sulphur and phosphorus content in seed and straw.

2.2.3 Effect on soil properties

Balaguravaiah *et al.* (1989) found that available phosphorus increased consistently with increase in rates of P application in the soil.

The addition of P increased the adsorption of PO_4^{3-} resulting in a concurrent desorption of SO_4^{2-} anions from colloidal surfaces. Therefore, large doses of P fertilizer may result in increased S mobility and availability in soil (Parischa and Sparks, 1990).

Amba *et al.* (2011) observed that soil pH, organic carbon, total nitrogen and available phosphorus increased in the soil samples collected after harvesting as compared to the soil samples collected before planting of legumes with the application of fertilizers. Application of P increased nitrogen fixation up to 26.4 kg P ha^{-1}, but decline significantly at higher levels of 39.6 kg P ha^{-1} in the cropping seasons. Interaction between phosphorus fertilizer application and legumes show that in a year the application of 13.2 kg P ha^{-1} gave significantly the same amount of nitrogen fixed irrespective of the legumes. It is concluded that the application of phosphorus fertilizer did not only increase the nutrient status of the soil but enhance the nitrogen fixation ability of the legumes for a sustainable legume production and soil fertility management.

Gidago *et al*. (2011) conducted an experiment on french bean in which he applied different levels of phosphorus. He observed that application of different levels of phosphorus did not have any significant affect on available phosphorus, total nitrogen and organic carbon contents of soil.

Yadav (2011) reported that the available P was increased consistently with increasing in level of phosphorus; P content in soil increased from 22.3 kg ha^{-1} in control to 32.9 kg P_2O_5 ha with application of 40 kg P_2O_5 ha^{-1}.

Abdi *et al.* (2014) found evidence that the no tillage (NT) system and P fertilization changed the distribution of P forms along the soil profile, potentially increasing soluble inorganic P loss in surface runoff and organic P in drainage and decreasing bioavailability of inorganic and organic P in deeper soil layer.

Kokani *et al*. (2015) reported that significantly higher values of available phosphorus (41.97 kg ha^{-1}) was recorded with the application of 40 kg P_2O_5 ha^{-1} as compared to 20 kg P_2O_5 ha^{-1} and control. The lowest available phosphorus was recorded under control (37.62 kg ha^{-1}), which was at par with 20 kg P_2O_5 ha^{-1}. The available P status of the soil after harvest of blackgram was improved might be due to residual effect of phosphatic fertilizer.

Nyekha *et al*. (2015) observed that application of phosphorus resulted in significant increase in soil available phosphorus after harvest of green gram.

Sipai *et al*. (2015) reported that an application of phosphorus significantly improved the soil fertility status of soil at harvest in the pooled. An application of P @ 40 kg ha^{-1} resulted in the maximum building up of available N, P_2O_5, K_2O and S content in soil after harvest of crop, which was significantly superior to the rest of levels of P.

In an experiment conducted by Phogat *et al*. (2019), the results revealed that the available and organic phosphorus (kg ha^{-1}) significantly increased with each successive application of phosphorus in soil up to highest level (60 kg ha^{-1}) at 20 days after sowing (DAS) of black gram, while it showed decreasing trend with time intervals of 40 DAS and at maturity of black gram.

2.3 Effect of sulphur

2.3.1 Effect on growth and yield

In common bean crop, Ambrosano *et al*. (1996) recommended the application of 30 kg ha^{-1} of S when aiming at grain yield exceeding 2000 kg ha^{-1}, regardless of the sulfur content in the soil. Crusciol *et al*. (2006), however, also for common bean in no-tillage, required a greater dose, 49 kg ha^{-1} S, to achieve maximum yield of 2,644 kg ha^{-1}.

Scherer and Lange (1996) observed the increase in the weight of broad bean leaves and stems when sulphur was applied.

Naik (2000) found that addition of sulphur promotes nodulation in legumes and produces bold seeds in soybean.

Ghosh and Joseph (2006-2007) conducted an experiment during summer season and reported higher growth, yield and net returns over no S with 30 kg P/ha as SSP and 30 kg S/ha as gypsum gives higher dry weight at 45 days.

Paliwal *et al.* (2009) reported that sulphur application significantly increased the grain yield of soybean upto the level of 40 kg S/ha, however, the higher level 60 kg S/ha showed non-significant increase.

The S deficiency causes a reduction in the formation of branches and in the number of flowers and pods, and consequently on common bean yield (Fageria *et al.*, 2010).

Ganie *et al.* (2014) reported that yield and yield attributing characters recorded significant and consistent increase with increase in doses of sulphur. Various yield attributing characters of french bean like number of pods per plant, number of seeds per pod and 100 seed weight increased significantly as the dose of sulphur was increased. Similarly, application of sulphur increased pod, seed and stover yield significantly up to 45 kg ha^{-1}. The improvement in yield due to increase in sulphur levels might be due to its important role in energy transformation, activation of enzymes and carbohydrate metabolism .With respect to sulphur, the crude protein content in pods and seeds increased significantly up to the dose corresponding to 45 kg ha^{-1}.

Kokani *et al.* (2015) reported that significantly taller plant height of 31.82 cm at 60 DAS and 37.07 cm at harvest and maximum number of branches per plant (5.17) of summer black gram were recorded by sulphur applied @ 20 kg/ha over control.

Chotchutima *et al.* (2016) reported that with the application of two rates of S fertilizer (0 and 187.5 kg ha^{-1}) the plant height, stem diameter, total woody stem and biomass yield of leucaena were significantly increased.

Ravikumar *et al*. (2016) among the different treatments elemental sulphur at 45 kg ha^{-1} along with RDF (40:20:20 kg ha^{-1}) had a positive effect on growth, yield attributes, yield and nutrient uptake in sunflower. The lowest values of growth, yield attributes and yield were recorded by 0 kg S ha^{-1} along with RDF.

The improvement in growth characters with the application of sulphur might be due to its role in the synthesis of chlorophyll. Overall increase in growth attributes of crop may be due to higher availability of sulphur in the rhizosphere system of the plants which might have resulted in increased uptake of nutrients and were used in photosynthesis (Babaleshwar *et al*., 2017).

Nascente *et al*. (2017) reported that S fertilization was important to increase the grain yield of common beans. If farmers had made the fertilization without S, they would have reach only 2,797 kg ha^{-1} On the other hand, if they put around 30 kg ha^{-1} of S, the grain yield would increase to 3,338 kg ha^{-1}. Therefore, this nutrient has importance in the yield of common beans and should be included in recommendations of common bean fertilization. Typically, in common bean cultivation, farmers apply lime and fertilizers such as N, P, and K, but S is seldom applied (Bona and Monteiro, 2010), which also may limit the crop yield.

Arunraj *et al*. (2018) reported that application of 30 kg sulphur along with recommended dose of fertilizer produced significantly higher plant height (30.95cm), number of leaves per plant (18.73), number of branches per plant (7.09), total dry matter production (11.1) and number of pods per plant (10.75), number of seeds per pod (11.91), thousand seed weight (43.55g) higher grain yield of 750 kg ha^{-1}compared to other treatments in green gram.

Głowacka *et al.* (2019) reported that sulphur application had a positive effect on seed yield (13.6% increases) and protein content. Moreover, sulphur improved the biological value of protein by increasing the content of methionine, cysteine, and some macroelements. Considering the yield producing effect and the impact on the biological quality of protein, sulphur fertilization should be included in the crop management for the common bean.

2.3.2 Effect on nutrient uptake and soil properties

Parthasharathy (1993) reported that boron and sulfur deficiency can be controlled by soil application of 1kg B ha^{-1} and 25 kg $ZnSO_4$ ha^{-1} (6-9 kg ha^{-1}) and combined nutrition of N, P, K, S and micronutrient is always beneficial for increasing yield of french bean.

Singh (1993) observed that in black gram, total S uptake progressively improved from 5.37% to 6.62% with the increasing S levels. The protein content also increased significantly with increase dose of S and P over control. Increased S uptake beyond 60 Kg ha^{-1} decreased P uptake significantly over both the years.

Kulhare and Kauraw (2000) reported that sub-surface soil pH was significantly higher at 30 kg S ha^{-1} than at 20 kg S ha^{-1}. The availability of N, K and S in the soil surface increased with S application while ammonium sulphur was better than gypsum for P and S availability in the soil.

Kothari and Jethra (2002) reported that the available sulphur increased with increasing levels of sulphur application.

Acidification of soil through elemental sulphur application may increase plant micronutrient availability and could serve as another option to improve plant production potential (Cui *et al*., 2004).

Sriramachandrasekharan and Muthukkaruppan (2004) reported a significant increase in number of nodules over the roots, nitrogenase activity thereby enhanced biological nitrogen fixation and uptake of N in soybean by sulphur application.

An increase in N content of soybean as a result of S-fertilization has also been reported by (Kulhare *et al*., 2006).

Skwierawska *et al*. (2008) reported that the application of the sulphur rates (20, 40 and 60 kg S ha^{-1}) in general, decreased the calcium uptake with the yield; respective differences, as compared with the no-fertilization treatment, were, on average, as follows: 6.5, 4.7 and 3.7%.

Lakshmi *et al.* (2010) reported that when bentonite, SSP and gypsum were used as sources of sulphur, the pH of the soil was not influenced by the application of sulphur from any of the sources. The influence of all the three sources was on par on the available N, P and S contents of soil. However, with increase in the levels of S, the nutrient contents changed significantly in the soils.

Yadav *et al*. 2010 reported that the soil pH tended to decrease with the progressive increase in added sulphur, but the difference was slightly significant. The EC of soil was significantly reduced (0.228) by sulphur applied @ 60 kg ha^{-1} whereas without application of sulphur (0 kg ha^{-1}) resulted in significant highest EC (0.305). Each successive dose of sulphur resulted in significant increase in available nitrogen, phosphorus and potassium in soil after crop harvest.

A positive relationship between the supply of papilionaceous plants with sulphur and the content and uptake of nitrogen, both in the biomass and in the seeds, was confirmed in the report by (Islam *et al*., 2012).

Singh *et al.* (2013) reported that the maximum total uptake of P, K, S and Fe by urd bean was recorded as 5.34 kg ha^{-1}, 30.21 kg ha^{-1}, 5.22 kg ha^{-1}, 871.57 g ha^{-1} respectively, by using RDF + sulphur 40 + Fe 5.0 kg ha^{-1}, whereas maximum total N uptake (60.03 kg ha^{-1}) was noticed under RDF + sulphur 40 + Fe 2.5 kg ha^{-1}.

Bożena Barczak *et al.* 2014 reported that the factor which significantly determined the nitrogen content in narrow-leaf lupin seeds and its uptake with the yield was the sulphur rate. The greatest increases, as compared to the control treatment, were identified as a result of the application of 60 kg S·ha^{-1} however between the treatments of 40 and 60 kg S ha^{-1}, in general, no significant differences were found.

Karimizarchi *et al.* (2014) reported that application of elemental sulphur at a rate of 0.5 g S kg^{-1} soil decreased soil pH value from the background level of 7.03 to 6.29 but significantly increased availability of Mn and Zn by 0.38% and 0.91%, respectively. This resulted in a 45.06% increase in total dry weight of maize. Further pH reduction due to the acidifying character of elemental sulphur at addition rates of 1 and 2 g kg^{-1} soil increased Mn and Zn availability, but significantly decreased maize performance. Overall, it can be concluded that when used in appropriate amounts, elemental sulphur can efficiently enhance soil fertility and maize performance by providing micronutrients for balanced fertilization.

Kokani *et al.* (2015) reported that higher value of soil pH, EC, organic carbon content, available nitrogen and phosphorus were registered due to application of 20 kg S/ha. Available sulphur in soil was significantly increased with the application of 20 kg S/ha over control.

Parakhia *et al*. (2018) concluded that application of sulphur at various concentrations led to an increase in availability and uptake of phosphorus in soybean.

2.4 Interaction effect of aluminium and phosphorus on plants and soil properties

Bache and Crooke (1981) reported that two acid soils showing different Al solubility as a function of pH were limed to a range of pH values (in 10- 2M $CaCI_2$) between 4.1 and 5.6. The apparent critical pH for the growth of barley in pots was 0.25 lower in the soil showing lower Al solubility. The addition of phosphate reduced exchangeable and soluble Al in the soils, and lowered the apparent critical pH by 0.35 while maintaining the difference between the soils.

The Al concentration at the critical pH, measured after cropping to take account of the treatment effects on soil Al, also varied with soil and with phosphate addition. These apparent critical values of both pH and soluble AI varied linearly with available phosphate, over the range 18 to 73 mg P/kg soil, as follows: pH from 4.9 to 4.3; soluble A1, from 0.010 mM to 0.056 mM; and the soluble Ca/Al mole ratio, from 1270 to 214.

Tan and Keltjens (1990) conducted an experiment to test the response of seedlings of the Al-tolerant sorghum (*Sorghum bicolor* L.) Moench genotype SC0283 in culture solutions containing various levels of Al and P was conducted. Aluminium at a low level (0.4 mg L^{-1}) did not affect the biomass production of this genotype. At a high level (1.6 mg L^{-1}), however, Al severely inhibited plant growth mainly by inhibiting root development. Plant dry matter yield was usually enhanced by increasing the P supply. Under high Al stress, however, the positive effect of a high P supply no longer existed, probably because of enhanced accumulation of Al in/on its roots in close association with the P in sorghum In this regard, the addition of P alleviated Al toxicity by increasing root respiration and nutrient uptake that led to enhanced DMY.

Gessa *et al.* (2005) conducted an experiment in which the results showed that the phosphate's mobility across the soil–root interface is strongly influenced by pH and aluminium: its mobility is much greater at a low pH. The presence of Al slowed down the phosphate even more leading to complete flux impedance in the first 3–5 h at pH 4.00 and 4.50. This impedance is probably not only due to interactions between phosphate and Al but it is also due to structural changes: the interaction of Al (hydrolytic and/or polymeric species) at pH 4.00 and 4.50 with the polygalacturonic chains could lead to a collapse of the porous structure. These results suggest that the apoplastic-bound Al hinders, especially at pH 4.00 and 4.50, the phosphate uptake by plants.

Zheng *et al*. (2005) found that the P content of the root apex of buckwheat was significantly correlated with the immobilization and detoxification of Al, indicating that there can be a significant P by Al interaction in roots.

Exogenous application of P alleviates Al toxicity in a number of plants such as buckwheat (Zheng *et al*., 2005), and wheat (Iqbal 2013) on acid soils.

Al toxicity and P deficiency often co-exists in most acid soils. The greater Al tolerance in buckwheat (*Fagopyrum esculentum*) is related to immobilization and detoxification of Al by P in the root tissues. In rice (*oryza sativa*), P alleviates Al toxicity in both Al tolerant and Al-sensitive cultivars. (Shen and Zhao, 2012)

Hong *et al*. (2006) reported that P addition significantly increased Al tolerance in four soybean genotypes differing in P efficiency. The two P-efficient genotypes appeared to be more Al tolerant than the two P-inefficient genotypes under these high-P conditions. Analysis of root exudates indicated Al toxicity induced citrate exudation, P deficiency triggered oxalate exudation, and malate release was induced by both treatments.

In general, concentrations of both inorganic and organic P in the plants were increased by improving the P supply, particularly at high Al stress. Phosphorus deficiency differed from A1 toxicity in its effect on root morphology, shoot/root ratio and P metabolism. This indicated that there was no Al-induced P deficiency in plants supplied with high A1 and suboptimal P. In the absence of A1 and at the low level of Al, increasing the P supply usually increased root respiration and nutrient uptake. At the high level of Al, however, only minor effects of P were observed, presumably due to the dominant influence of Al. In general, stress associated with high A1 concentration significantly affected plant growth, root morphology and respiration, Al distribution and P metabolism of the Al-tolerant sorghum. (Tan and Keltjens, 1990).

Phosphorus efflux was speculated to be a potential mechanism of Al tolerance in wheat (Pellet *et al*., 1996).

In a study from Dong *et al*. (2004) provided evidence for root Al and P interactions that had an influence on soybean growth and also on the root organic acid exudation patterns induced by Al toxicity and P deficiency.

Jemo *et al.* (2007) reported that Plants growing in acid soils suffer both phosphorus (P) deficiency and aluminium (Al) toxicity stresses. Two experiments were conducted to evaluate eight cowpea genotypes for Al resistance and to study the combined effect of P deficiency and Al toxicity stress on growth, P uptake, and organic acid anion exudation of two genotypes of contrasting Al resistance selected from the first experiment. Relative root inhibition by 30Î¼M Al ranged from 14% to 60% and differed significantly among the genotypes. Al significantly induced callose formation, particularly in Al-sensitive genotypes. P accumulation was significantly reduced (28% and 95%) by Al application for both the Al-resistant and the Al-sensitive genotypes.

Batista *et al.* (2009) experimented in which the corn plants were evaluated with different phosphate fertilizer sources and aluminium (Al) concentrations in a sandy substrate with two corn plants in the pots containing 2 kg of a sandy substrate, two phosphate sources (Triple Super phosphate – TSP or Arad Phosphate – AP) and four Al concentrations. When Al concentrations increased, pH ($CaCl_2$) substrate values decreased. There was an increase in the calcium and phosphorus contents in the sandy substrates that received the TSP and AP sources. The calcium, magnesium, phosphorus, and potassium concentrations of the corn plant's shoot were higher in the TSP than without P and AP sources. When the Al concentration increased, the concentration values of the former elements decreased. The dry mass production of the corn plants responded positively to P sources. As the Al concentration increased, the dry mass values decreased significantly in the TSP source.

Chen *et al*. (2012) provided a threshold of P alleviating Al toxicity based on tested plants, and mentioned if the value of P/Al molar ratio exceeds 5 in the root cells, that plant can alleviate Al toxicity.

Iqbal (2013) observed that P content in wheat seedlings was largely reduced by Al stress (150 mg $AlCl_3$ kg^{-1} soil), conversely pH level was found to be balanced and increased P level after addition of exogenous P (160 mg P kg^{-1} soil) to soil.

Roots of wheat (cv. Atlas 66) with different internal P concentrations were prepared by two methods; split-root and re-rooting in a hydroponic solution using three different P levels (0, 25 and 250μM) to avoid direct precipitation of Al-P in the solution. Al toxicity was evaluated by root elongation inhibition and callose induction. The Al and P concentrations in the root tips were also compared among different treatments. Lower P in the root tips resulted in less Al-induced inhibition of the root elongation, less callose content and less Al accumulation, while higher root P caused a higher Al-induced inhibition of the root elongation, increased callose content and Al accumulation in the root tips. Furthermore, Al in the root cell sap was not altered by different P concentrations, but Al in the root cell wall was increased with increasing in planta P concentrations. It was concluded that Al toxicity in wheat is associated with P in the root cell wall; lower root P enhanced Al tolerance, while higher root P aggravated Al toxicity in wheat. (Ji *et al.,* 2015)

2.5 Interaction effect of aluminium and sulphur on plants and soil properties

Guo *et al.* (2017) conducted an experiment to examine the alleviation of S on Al-toxicity in *C.grandis* seedlings, the effects of S and Al interactions on seedling growth were investigated. Al-toxicity decreased plant height, root, stem, leaf, shoot, and whole plant dry weights (DW), and increased the root DW/shoot

DW ratio, with the exception that root DW was similar between the two Al treatments at 1 mM S. All these parameters did not significantly differ between the two S treatments at the absence of Al, but were higher at 1 mM S than those at 0.5 mM S under Al-toxicity. The only exception was that stem DW was similar between the two S treatments under Al-toxicity. These results indicated that S alleviated the Al-induced inhibition of growth.

The Al-sulfate interaction occurs in acidic soils, whereby relatively high concentrations of trivalent toxic aluminum (Al^{3+}) may hamper root growth, limiting uptake of nutrients, including sulfur (S). On the other side, Al^{3+} may be detoxified by complexation with sulfate in the acid soil solution as well as in the root-cell vacuoles. It is known that Al^{3+} disturbs gene expression and enzymes involved in biosynthesis of S-containing cysteine in root cells. On the other hand, Al^{3+} may induce ethylene biosynthesis, enhance reactive oxygen species production, alter phytohormone transport, trigger root growth inhibition and promote sulfate uptake under S deficiency. (Alarcon *et al.*, 2018)

Rahman *et al.* (2018) reported that several studies have provided evidence that S-containing components alleviate Al toxicity in wheat (Zhang *et al.* 2010), barley (Dawood *et al.* 2012), oilseed rape (Qian *et al.* 2014) and citrus trees (Guo *et al.* 2017). In the above studies S exerts protective functions against Al toxicity through: (i) increasing antioxidant activity and lipid peroxidation levels; (ii) decreasing uptake of Al in roots and shoots; (iii) increasing uptake of several nutrients viz. phosphorus (P), magnesium (Mg), and calcium (Ca); and (iv) enhancing Al-induced secretion of organic acid anions (OAs) from plant roots. The toxicity induced by several heavy metals was alleviated in plants by exogenous S addition, though the efficiency of alleviation mostly depends on the S-application strategies, doses, and sources.

2.6 Interaction effect of phosphorus and sulphur on plants and soil properties

Synergistic effect of S x P interaction on N-content was also reported by Khatik *et al.* (1987) on soybean.

Pasricha and Sparks (1990) reported that addition of P increased the adsorption of PO_4^{3-} resulting in a concurrent desorption of SO_4^{2-} from colloidal surfaces. Therefore, large doses of P fertilizer may result in increased S mobility and availability in soil.

Majumdar *et al*. (2001) found that combined application of P and S @ 60 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1} respectively, increased the number of pods per plant of soybean. The highest number of pods per plant may be due to the fact that, the combined effect of both phosphorus and sulphur had positive effect on the reproductive growth and pod formation.

Tomar *et al.* (2004) also found the positive interaction effect of P and S on the plant height of soybean. The highest plant height might have resulted from the synergistic effect of P and S on the growth processes of the plant. However, non significant effect of P and S on plant population in various crops had been reported by many workers (Akter *et al*., 2013; Bothe *et al.*, 2000)

Jat *et al.* (2005) also reported that Combine application of S and P markedly higher increase in grain and straw compare to alone application of S and P. Phogat and Abidi (2008) found in groundnut the interaction effect of S and P on oil content was found to be non-significant, while oil yield was increased significantly due to combined application of S and P.

A field trial was carried out to evaluate the effect of sulphur and phosphorus application on yield and N, P and K contents of soybean grown on alfisol. It was found that increasing application of sulphur and phosphorus, singly as well as in combination, significantly increased the grain yield and contents of N, P and K upto $S_{40}P_{60}$ level over control. The interaction of S x P exhibited a strong synergistic relationship in soybean nutrition grown on deficient soil. (Paliwal *et al.*, 2009)

Chandra and Khaldelwal (2009) reported that available P and S increased consistently with increase in rates of P and S application respectively, in the soil. Phosphorus application had no effect on the sulphur content of the soil and application of sulphur did not affect available phosphorus significantly in the soil.

Deshbhratar *et al.* (2010) reported that the interaction between sulphur and phosphorus was found to be significant on grain yield, straw yield and yield attributes characters like number of pods per plant, number of grains per pod, yield of grain per plant, straw yield as well as quality like test weight and crude protein percentage of pigeon pea.

Application of S and P improved soil fertility status and S alone did not influence P availability. Hence, in order to maintain the fertility status of the soil at high level, combine application of 20 kg S ha^{-1} with 50 kg P_2O_5 ha^{-1} is essential. (Deshbhratar *et al*., 2010)

Yadav (2011) observed synergistic effect of phosphorus and sulphur on number and weight of nodulesper plant, N, P, S and protein content in cluster bean. The increase in number of nodules per plant might be due to better root development with increasing levels of these nutrients. Phosphorus, being the constituent of nucleic acid and different forms of proteins, might have stimulated cell division resulting in increased growth of plants. The post harvest soil analysis showed that available P content in soil increased from 22.3 kg ha^{-1} in control to 32.9 kg P_2O_5 ha^{-1} with application of 40 kg P_2O_5 ha^{-1}.

Field experiments were conducted during pre kharif 2010, 2011 and 2012 to study the effects of phosphorus and sulphur on yield parameters, yield, nodulation and nutrient uptake of green gram. Experimental results revealed that yield attributing characters and seed yield of green gram were significantly influenced by phosphorus, sulphur and interaction effects of these two factors. Interaction of higher dose of phosphorus and higher dose S found to have a negative impact on yield. Application of varying levels of phosphorus and sulphur significantly improved the nutrient uptake by green gram in a sulphur deficient soil. (Das, 2016)

Dhage *et al*. (2014) conducted an experiment in which the results indicated that grain and straw yield, uptake of phosphorus and sulphur increased with increase in the rate of application of P and S individually as well as in various combinations. Applied various levels of P and S also influenced the quality parameters of soybean i.e. protein content and test weight.

Phogat (2016) experiemental results reported that combined application of P and S showed synergistic effect on seed and stover yield of black gram with increasing levels of P and S upto highest level. The seed and stover yield were 955.50 and 2398.30 kg ha^{-1} with combined application of 60 and 30 kg ha^{-1}, P and S respectively, indicating synergistic effect of P and S on each other as both the nutrients mutually help absorption and utilization by black gram probably due to balanced nutrition.

Kumar *et al*. (2017) reported that both seed and stover yield of soybean increased significantly due to individual as well as combined application of phosphorus and sulphur. Combined application of 45 kg S with 90 kg P_2O_5 produced highest seed (24.39 q ha^{-1}) and stover (43.51 q ha^{-1}) yield of soybean. Application of increasing levels of both phosphorus and sulphur resulted in a significant increase in macro and micronutrient content of soybean seed.

Phogat *et al.* (2019) reported that number of nodules per plant also increased significantly with increasing levels of phosphorus and sulphur up to highest level and the optimum values were recorded with combined application of phosphorus 60 kg ha^{-1} and sulphur 30 kg ha^{-1}. The available and organic phosphorus (kg ha^{-1}) significantly increased with each successive application of phosphorus in soil up to highest level (60 kg ha^{-1}) at 20 days after sowing (DAS) of black gram, while it showed decreasing trend with time intervals of 40 DAS and at maturity of black gram. The application of successive doses of sulphur had no significant effect on available and organic phosphorus at each time interval. Similarly, significant increase has also been recorded in available and organic sulphur (kg ha^{-1}) in soil with each successive application of sulphur up to 30 kg ha^{-1} at 20 DAS of black gram, thereafter, it showed decreasing trend. The application of successive doses of phosphorus had no significant effect on available and organic sulphur at each time interval.

The interaction effect of P×S on seed and straw production of summer green gram was found significant and yield was improved by the application of both of these two (90 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1}) nutrients as compared to control and but statistically at par with 40 kg sulphur ha^{-1}. The percent enhancement were 6.74, 15.92 and 19.48 in seed and 31.60, 54.50 and 69.71 in straw of green gram due to 10, 20 and 40 kg S ha^{-1} over control respectively. Interaction effect was also significant (Dharwe *et al*., 2019).

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Response of French Bean to Phosphorus and Sulphur at Different Levels of Aluminium" was conducted in the pot at the Department of Agricultural Chemistry and Soil Science, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema during *rabi* season, from 3.10.2017 to 5.01.2018 and 2.10.2018 to 3.01.2019. A brief description of experimentation and analytical methods employed for analysis of soils and plant material are given in this chapter under various headings.

3.1 Experimental site

The experimental site lies at 25^0 45' 15.95" N latitude and 93^0 51' 44.71" E longitude at an elevation of 310 meter above mean sea level.

3.2 Climatic condition

The experimental site lies in humid sub-tropical zone with an average rainfall from 1800 – 2500 mm annually spread over 6 months i.e. April to September, while the remaining period from October to March remains dry. The mean temperature ranges from 21^0 to 32^0C during summer and rarely goes below 8^0C in winter due to high atmospheric humidity. The meteorological data during the period of investigation is presented in monthly interval basis in Table 3.1 and Fig. 3.1.

3.3 Characteristics of the experimental soil

The experimental soil was sandy clay loam in texture. Surface soil (0-15 cm depth) was used for filling the pots. Pre-experimentation soil sample was analyzed for some important physicochemical properties. The results of analysis are given in Table 3.2.

3.4 Experimental detail:

Experiment-1: To evaluate the aluminium tolerance of french bean varieties

i.	Aluminium levels:	Control(Al_0), 0.25($Al_{0.25}$), 0.50($Al_{0.50}$) cmol kg^{-1}
ii.	Varieties:	Selection-9 (V_1), Anupam-9 (V_2), Nagaland local (V_3)
iii.	Crop:	French bean
iv.	Replication:	3
v.	Design:	CRD
vi.	Total number of pots:	27

Experimental procedure:

The experimental soil was collected from research farms of Agricultural Chemistry and Soil science, SASRD, NU. The earthen pots of 30 cm diameter were filled with 10 kg of soil. All stubbles and undecomposed weeds were removed and the pots were arranged as per the layout plan of the experiment. Aluminium levels were developed using aluminium chloride ($AlCl_3$). Recommended dose of nitrogen (60 kg N ha^{-1}), phosphorus (80 kg P_20_5 ha^{-1}) and potassium (60 kg K_2O ha^{-1}) were supplied through urea, single superphosphate and murate of potash (MOP), respectively. The seeds were sown on 3rd October, 2017 and 1st October, 2018 at a depth of 5 cm at optimum soil moisture level to ensure proper germination. Thinning was done two weeks after germination and only one healthy plant in each pot was allowed to grow. Weeding was done at regular interval to check the weed growth. Crop was irrigated as and when required.

Table 3.1: Meteorological observations during experimental period (October –January)

2017-18							2018-19						
Standard Weeks	**Month**	**Temperature (^0C)**		**Humidity (%)**		**Rainfall (mm)**	**Standard Weeks**	**Month**	**Temperature (^0C)**		**Humidity (%)**		**Rainfall (mm)**
		Max	Min	Max	Min				Max	Min	Max	Min	
40	Oct 2	31.8	23.7	96	78	33.9	40	Oct 1	32.2	21.7	94	63	0.0
41	Oct 9	32.9	23.6	94	71	3.1	41	Oct 8	28.7	20.5	95	75	63.8
42	Oct 16	30.9	23.7	95	76	17.9	42	Oct 15	29.6	18.6	97	62	0.2
43	Oct 23	27.8	18.4	95	72	44.7	43	Oct 22	30.5	19.0	97	65	0.0
44	Oct 30	26.7	17.7	95	74	30.4	44	Oct 29	28.7	19.5	97	61	9.2
45	Nov 6	29.6	16.5	94	60	0.0	45	Nov 5	28.9	15.9	97	58	0.0
46	Nov 13	27.4	16.9	97	65	6.4	46	Nov 12	28.7	14.3	96	49	4.1
47	Nov 20	28.5	17.0	98	63	10.0	47	Nov 19	26.5	11.7	97	55	0.0
48	Nov 27	28.9	13.2	97	61	0.0	48	Nov 26	27.3	11.4	97	51	0.0
49	Dec 4	26.0	10.9	95	56	0.0	49	Dec 3	25.6	10.5	97	52	0.0
50	Dec 11	24.9	15.3	98	73	31.8	50	Dec 10	25.5	11.4	96	54	0.9
51	Dec 18	25.6	11.5	95	67	0.0	51	Dec 17	22.6	12.9	97	67	49.1
52	Dec 25	25.7	11.5	97	69	0.0	52	Dec 24	24.1	9.4	96	52	0.0
1	Jan 1	23.7	10.8	97	69	23.0	1	Dec 31	23.5	7.4	95	47	0.0
2	Jan 8	22.5	7.5	97	60	0.0	2	Jan 7	24.6	7.9	95	46	0.0

Source: Monthly weather data at ICAR, Jharanapani Nagaland Centre

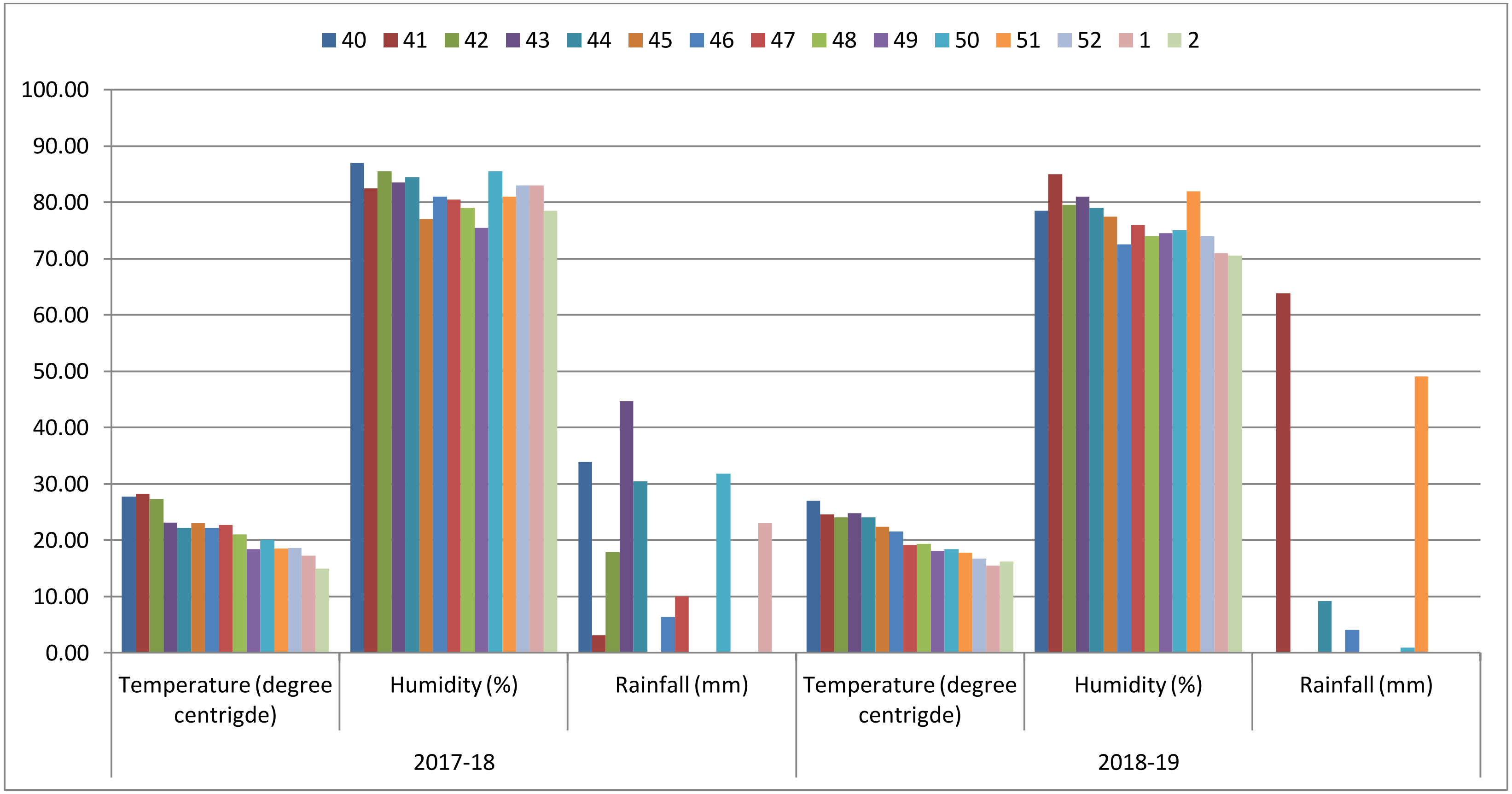

Figure 3.1: Meteorological observations during the period of investigation (October –January)

Table 3.2: Physiochemical properties of the experimental soil

Sl. No.	Particulars	Value	
		2017-18	2018-19
1	Mechanical analysis		
	Sand (%)	50.7	51.2
	Silt (%)	19.3	18.5
	Clay (%)	30	30.3
	Textural class	Sandy clay loam	Sandy clay loam
2	pH	5.4	5.5
3	Organic carbon (g kg^{-1})	17.2	17.7
4	Available nitrogen (kg ha^{-1})	222.2	223.1
5	Available phosphorus (kg ha^{-1})	14.7	14.8
6	Available potassium (kg ha^{-1})	174.6	173.2
7	Available sulphur (kg ha^{-1})	20.2	20.4
8	Total potential acidity (cmol kg^{-1})	9.6	9.75
9	Exchangeable Al^{3+} (cmol kg^{-1})	1.64	1.71
10	Exchangeable Ca^{2+} (cmol kg^{-1})	2.91	2.68

3.4.2 Experiment-2: To study the phosphorus and sulphur requirement of french bean under different levels of aluminium

i.	Aluminium levels:	Control (Al_0), 0.25 ($Al_{0.25}$) cmol kg^{-1}
ii.	Phosphorus levels:	Control (P_0), 30 (P_{30}), 60 (P_{60}), 90 (P_{90}) kg P_2O_5 ha^{-1}
iii.	Sulphur levels:	Control (S_0), 30 (S_{30}), 60 (S_{60}) kg S ha^{-1}
iv.	Varieties:	Selection-9
v.	Crop:	French bean
vi.	Replication:	3
vii.	Design:	CRD
viii.	Total number of pots:	72

Experimental procedure:

The experimental soil was collected from research farms of Agricultural Chemistry and Soil science, SASRD, NU. The pots were filled with 10 kg of soil. All stubbles and undecomposed weeds were removed and the pots were arranged as per the layout plan of the experiment. Aluminium, phosphorus and sulphur levels were developed using aluminium chloride ($AlCl_3$), di-ammonium phosphate (DAP) and elemental sulphur. Recommended dose of nitrogen (60 kg N ha^{-1}) and potassium (60 kg K_2O ha^{-1}) were supplied through urea and murate of potash (MOP), respectively. Recommended dose of nitrogen was supplied after adjusting of nitrogen being supplied through DAP. The seeds were sown on 3rd October, 2017 and 1st October, 2018 at a depth of 5 cm at optimum soil moisture level to ensure proper germination. Thinning was done two weeks after germination and only one healthy plant in each pot was allowed to grow. Weeding was done at regular interval to check the weed growth. Crop was irrigated as and when required.

3.5 Biometrical observations: (For experiment I and II)

3.5.1 Days to germination

The number of days to germination of each seeds in the pots were observed and recorded.

3.5.2 Plant height:

The plant height was measured from the base of the plant to top of the plant.

3.5.3 Number of branches per plant

The numbers of branches were counted in each pot and were recorded as number of branches per plant.

3.5.4 Number of pods per plant

The numbers of pods were counted from each pot after harvest and were recorded as number of pods per plant.

3.5.5 Pods length

The grains of the pods from each pot were counted and the average number of grains was recorded as number of grains per pod.

3.5.6 Number of seeds per pod

The length of all the pods were measured from each pot and the average was recorded as pods size.

3.5.7 Test weight

Test weight is the weight of 1000 grains. 100 viable grains were counted from the threshed grains and their weight was recorded which was multiplied by a factor of 10 for each treatment.

3.5.8 Seed yield

After proper sun drying of the seeds, the seeds weight from each pot was taken and recorded as grain yield.

3.5.9 Stover yield

After all the pods were picked, the plants were cut off at ground level. Each plant was properly sun dried for about a week and the stover weight including pod husk was taken and recorded as stover yield.

3.5.10 Root length (only for Exp 1)

The roots were uprooted from the soil after which it was washed with water and partially sun dried and the lengths of the roots were measured with the help of a scale.

3.5.11 Root mass (only for Exp 1)

The roots from each pot was weighed by electronic weighing balance and recorded as root mass.

3.6 Chemical analysis of plant material

Grain and stover samples were dried at 60^0C for 48 hours in oven and powdered. The powdered samples were stored in plastic bags for further analysis.

3.6.1 Nitrogen

Nitrogen in plant samples was determined by modified Kjeldahl method as described by Black (1965).

3.6.2 Phosphorus

The samples were wet digested with nitric acid (HNO_3) and perchloric acid ($HClO_4$). Ammonium molybdate vanadate (Chapman and Pratt, 1962) method was followed for the determination of phosphorus in the extract

3.6.3 Potassium

The aliquot after wet digestion for phosphorus estimation was diluted to the desirable level and were analyzed for potassium by using flame photometer (Hanway and Heidal, 1952).

3.6.4 Sulphur

Sulphur content was estimated by wet ashing of plants tissue sample (as described under phosphorous diacid digestion) and the sulphate turbidimetry method as described by Tandon (1993).

3.6.5 Aluminium

The samples were wet digested with nitric acid (HNO_3) and perchloric acid ($HClO_4$). Aluminium was determined by AAS method (Hanlon, 1998).

3.6.6 Calcium

The calcium content of the plant samples were determined by versenate method (Tandon, 1993).

3.6.7 Uptake of nutrients by plants

The nutrient uptake was calculated by using the equation:

Nutrient uptake (mg pot^{-1}) = Nutrient content (%) x yield (g pot^{-1}) x 10

3.6.8 Protein content and its yield

The protein content in seed was calculated by the formula:

Protein content (%) = 6.25 x N% in seed

The protein yield was calculated by multiplying protein content in seed with grain yield.

3.7 Soil analysis:

Collection and preparation of soil samples

Soil samples from each pot were collected after crop harvest. The samples were air dried in shade, followed by grounding using wooden pestle and mortar and passed through 2 mm sieve and the cleaned sample was preserved in polythene bags and analyzed for different properties using standard protocols.

3.7.1 Mechanical analysis and texture

Mechanical analysis of soil before experimentation was done using international pipette method. The soil textural class was determined by triangular method.

3.7.2 Soil pH

Soil pH was determined in soil: water (1:2.5) ratio by glass electrode pH meter (Jackson, 1967).

3.7.3 Organic carbon

Organic carbon was determined by employing Walkley and Black method (1934) and the result was expressed in terms of g kg^{-1}.

3.7.4 Available nitrogen

The available nitrogen was determined by alkaline potassium permanganate method suggested by Subbiah and Asija (1956) and the result was expressed in terms of kg ha^{-1}.

3.7.5 Available phosphorus

Available phosphorus was extracted with 0.03 *N* NH_4F in 0.025 *N* HCl solution. The procedure is primarily meant for soils which are moderate to strongly acidic with pH around 5.5 or less (Bray and Kurtz, 1945).

3.7.6 Available potassium

Available potassium was extracted from 5 g of soil by shaking with 25 ml of neutral ammonium acetate (pH 7) solution for half an hour and the extract was filtered immediately through a dry filter paper (Whatman No. 1) and then potassium concentration in the extract was determined by flame photometer (Hanway and Heidal, 1952).

3.7.7 Available sulphur

The sulphate in the soil was extracted using monocalcium phosphate solution (500 pm) and determined turbidimetrically using a spectrophotometer as described by Chesnin and Yien (1950).

3.7.8 Total potential acidity

The total potential acidity of soil includes all the acidity components like extractable acidity, non exchangeable acidity, weak acidic carboxylic and phenolic hydroxyl groups of soil organic matter and partially neutralized hydroxyl Al polymers that coud be present even in soils . The total potential acidity was determined by using $BaCl_2$ -triethanolamine extract buffered at pH 8.0-8.2 as described by Baruah and Barthakur (1997).

3.7.9 Exchangeable Al^{3+}

Exchangeable Al in soil was determined following exchange acidity method by titrating NaoH against a standard acid (0.1N HCl) as described by Baruah and Barthakur (1997).

3.7.10 Exchangeable calcium

The exchangeable calcium content of the soils was determined by versenate method (EDTA, ethylene diamine tetra acetic acid) (Tandon, 1993).

3.8 Statistical analysis

The data related to each character were analyzed statistically by applying the techniques of analysis of variance and the significance of different source of variation was tested by '*F*' test (Cochran and Cox, 1962).

CHAPTER IV

RESULTS AND DISCUSSIONS

RESULTS AND DISCUSSIONS

A research investigation entitled "Response of French Bean to Phosphorus and Sulphur at Different Levels of Aluminium" was conducted during *rabi* season (3.10.2017 to 5.01.2018 and 2.10.2018 to 3.01.2019) with the following objective:-

1. To study the performance of french bean varieties under aluminium stress environment.
2. To study the effect of phosphorus and sulphur on soil properties, growth, yield, nutrient uptake of french bean under aluminium levels.

The salient research findings obtained from this study are discussed below.

4.1 TO EVALUATE THE ALUMINIUM TOLERANCE OF FRENCH BEAN VARIETIES (Experiment-1)

4.1.1 Effect on growth and yield

4.1.1.1 Days to germination

The data recorded on number of days to germination are presented in table 4.1(a). The data indicate that days to germination decreased with increase in aluminium levels. The minimum number of days to germination was recorded in the control (3.33 days) for both the years and pooled. This was followed by $Al_{0.25}$ with 4.00 days for both the year and pooled. The maximum days to germination was recorded in $Al_{0.50}$ with 5.00 and 4.67 days for 2017-18 and 2018-19 respectively, with pooled value of 4.83 days. It is suggested that aluminium toxicity induced increase in accumulation of Cl^- and Al^{3+} with the concomitant decrease in K^+ accumulation in the radicle and plumule might be responsible for Al induced inhibition of germination of seeds (*Samad et al.*, 2017).

Table 4.1(a): Effect of aluminium levels and varieties on days to germination of french bean

Treatments	Days to germination		
	2017-18	**2018-19**	**Pooled**
Aluminium levels			
Al_0	3.33	3.33	3.33
$Al_{0.25}$	4.00	4.00	4.00
$Al_{0.50}$	5.00	4.67	4.83
SEm±	0.11	0.16	0.10
CD (p=0.05)	0.33	0.47	0.28
Varieties			
V_1	4.00	4.00	4.00
V_2	4.00	4.00	4.00
V_3	4.33	4.00	4.17
SEm±	0.11	0.16	0.10
CD (p=0.05)	NS	NS	NS

Table 4.1(b): Interaction effect of aluminium levels and varieties on days to germination of french bean

Aluminium levels	Days to germination		
	Varieties		
	V_1	V_2	V_3
	2017-18		
Al_0	3.00	3.00	4.00
$Al_{0.25}$	4.00	4.00	4.00
$Al_{0.50}$	5.00	5.00	5.00
SEm±	0.19		
CD (p=0.05)	0.57		
	2018-19		
Al_0	3.00	3.00	4.00
$Al_{0.25}$	4.00	4.00	4.00
$Al_{0.50}$	5.00	5.00	4.00
SEm±	0.27		
CD (p=0.05)	0.81		
	Pooled		
Al_0	3.00	3.00	4.00
$Al_{0.25}$	4.00	4.00	4.00
$Al_{0.50}$	5.00	5.00	4.50
SEm±	0.17		
CD (p=0.05)	0.48		

Further the data also show that the effect of different varieties on days to germination was non significant. Variety 1 (Selection-9) and variety 2 (Anupam-R) took 4 days to germinate for both the years that is 2017-18 and 2018-19 with pooled value being the same while variety 3 (local) was recorded with 4.33 and 4.00 days for the year 2017-18 and 2018-19, respectively, with pooled value of 4.17 days.

Considering the interaction effect presented in table 4.1(b), the days to germination ranged from 3 to 5 days. The highest days to germinate was recorded from the treatment combination of $Al_{0.50}V_1$, $Al_{0.50}V_2$ and $Al_{0.50}V_3$ with 5 days each during the year 2017-18, $Al_{0.50}V_1$ and $Al_{0.50}V_2$ with 5 days each during 2018-19 while the pooled value of 5, 5 and 4 days were recorded in Al_0V_1, Al_0V_2 and Al_0V_3.

4.1.1.2. Plant height

The data recorded on plant height are presented in table 4.2(a) and figure 4.1. The data indicate that plant height of french bean decreased with increasing aluminium levels at all the three observation stage. As seen from the data, the maximum plant height was recorded in the control Al_0 with 23.25 and 21.71 cm, 31.10 and 29.08 cm, 32.41 and 30.62 cm at 30 DAS, 60 DAS and at harvest respectively, during 2017-18 and 2018-19 while pooled was 22.48, 30.09 and 31.51 cm. Minimum plant height was observed under $Al_{0.50}$ with 15.24 and 14.64 cm, 21.83 and 20.82 cm, 23.34 and 21.75 cm at 30 DAS, 60 DAS and at harvest respectively, while pooled was 14.94, 21.33 and 22.54 cm.

This show that increase in aluminium levels inhibit the growth and development of plant. In case of plant height at harvest, maximum reduction in plant height was observed under $Al_{0.5}$ level of aluminium during both the year. On the basis of pooled data, $Al_{0.50}$ level reduced the plant height by 33.54%, 29.11% and 28.46% at 30, 60 DAS and at harvest respectively, over control. From the data it was also clear that extent of plant height reduction was more at early stage of the crop as compared to later growth stage.

The decrease in plant height may be due to the reason that aluminium was considerably deposited in the root tips and might have reduced the cell divsion, the root elongation was retarded and finally top growth inhibited. These results are in accordance with Sivasubramaniam and Talibudeen (1971) and Wagatsuma *et al*. (1987). According to Farias *et al*. (2011), increasing aluminium levels in the nutrient solution led to a decline in the shoot and root dry matter production. The result are in accordance with the findings of Thangavel (2002) who reported that as a response to aluminium toxicity, the calcium content in both plant parts and soil became deficient. Calcium is a constituent of the middle lamella of each cell wall and it tends to make cells more selective in their absorption of nutrients. Rapidly growing root tips are especially high in calcium, indicating that calcium is needed in large quantities for cell division. Therefore, the reduction recorded in the growth related parameters may also be the consequence of the observed reduction in the calcium levels in plant parts induced by aluminium.

The data presented in table 4.2(a) further indicate that among the three varieties highest plant height was recorded in variety 1 (Selection-9) (20.96 and 19.38 cm, 27.79 and 26.78 cm, 29.47 and 28.16 cm for 30 DAS, 60 DAS and at harvest with pooled data of 20.17, 27.79 and 28.82 cm) followed by Nagaland Local (18.17 and 17.30cm, 25.61 and 24.25 cm, 26.71 and 24.59 cm at 30 DAS, 60 DAS and at harvest with pooled data of 17.73, 24.93 and 25.65 cm respectively. The minimum plant height was observed in Anupam-R (17.38 and 16.79 cm, 24.04 and 23.57 cm and 25.88, 24.62 cm for 30 DAS, 60 DAS and at harvest with pooled data of 17.09, 23.81 and 25.25 cm)

Yadav (2015) reported that differential response of varieties to plant height might be due to their genetic character and adaptability to growing environment.

Table 4.2(a): Effect of aluminium levels and varieties on plant height of french bean

Treatments	Plant height (cm)								
	30 DAS			60 DAS			At harvest		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels									
Al_0	23.25	21.71	22.48	31.10	29.08	30.09	32.41	30.62	31.51
$Al_{0.25}$	18.02	17.12	17.57	24.52	24.70	24.61	26.31	25.01	25.66
$Al_{0.50}$	15.24	14.64	14.94	21.83	20.82	21.33	23.34	21.75	22.54
SEm±	0.12	0.22	0.13	0.32	0.26	0.21	0.30	0.29	0.21
CD (p=0.05)	0.36	0.65	0.36	0.96	0.78	0.60	0.90	0.86	0.60
Varieties									
V_1	20.96	19.38	20.17	27.79	26.78	27.29	29.47	28.16	28.82
V_2	17.38	16.79	17.09	24.04	23.57	23.81	25.88	24.62	25.25
V_3	18.17	17.30	17.73	25.61	24.25	24.93	26.71	24.59	25.65
SEm±	0.12	0.22	0.13	0.32	0.26	0.21	0.30	0.29	0.21
CD (p=0.05)	0.36	0.65	0.36	0.96	0.78	0.60	0.90	0.86	0.60

Table 4.2(b): Interaction effect of aluminium levels and varieties on plant height of french bean

Aluminium levels	Plant height (cm)								
	30 days			60 days			At harvest		
	Varieties								
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
	2017-18								
Al_0	25.27	21.59	22.88	33.33	28.30	31.67	34.90	30.00	32.33
$Al_{0.25}$	20.34	16.33	17.38	27.05	23.33	23.17	28.37	25.96	24.60
$Al_{0.50}$	17.26	14.23	14.25	23.00	20.50	22.00	25.15	21.67	23.20
SEm±	0.21			0.56			0.53		
CD (p=0.05)	0.62			1.67			1.57		
	2018-19								
Al_0	23.25	20.15	21.73	31.12	27.02	29.10	33.40	29.12	29.33
$Al_{0.25}$	19.55	15.34	16.46	26.77	24.12	23.20	26.27	24.63	24.11
$Al_{0.50}$	15.34	14.88	13.70	22.44	19.57	20.44	24.80	20.12	20.32
SEm±	0.38			0.46			0.50		
CD (p=0.05)	1.13			1.36			1.48		
	Pooled								
Al_0	24.26	20.87	22.31	32.23	27.66	30.38	34.15	29.56	30.83
$Al_{0.25}$	19.95	15.84	16.92	26.91	23.73	23.19	27.32	25.30	24.36
$Al_{0.50}$	16.30	14.55	13.97	22.72	20.04	21.22	24.98	20.90	21.76
SEm±	0.22			0.36			0.36		
CD (p=0.05)	0.62			1.04			1.04		

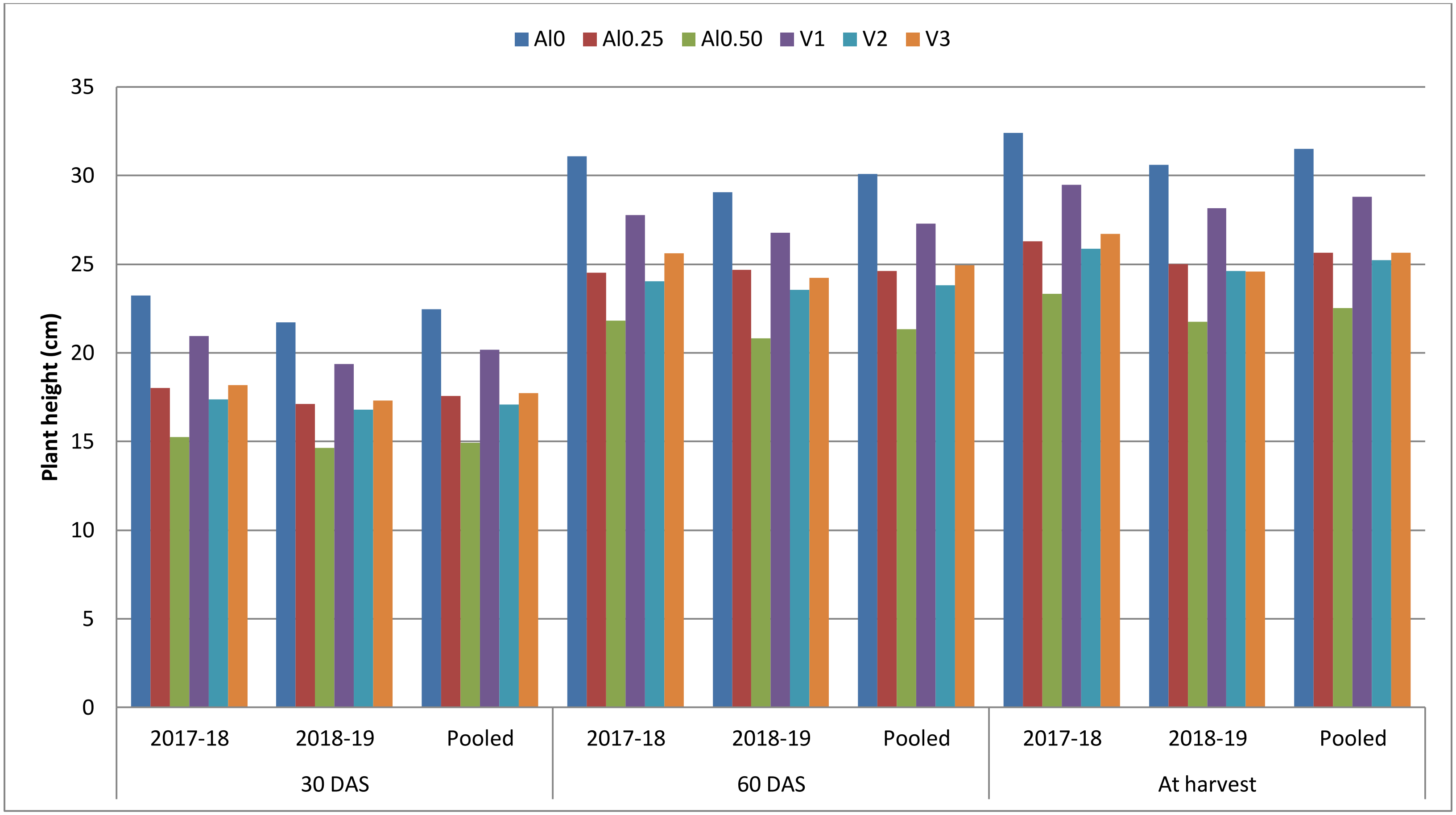

Figure 4.1: Effect of aluminium levels and varieties on plant height of french bean

In this experiment, variation in plant height among the different varieties might be due to the variation in genotypes used for experimentation and growing areas. The results are in accordance with Das *et al.* (2014).

Considering the interaction effect presented in table 4.2(b), the highest plant height was observed in Al_0V_1 with 25.27 and 23.25 cm, 33.33 and 31.12 cm, 34.90 and 33.40 cm at 30 DAS, 60 DAS and at harvest with pooled data of 24.26, 32.23 and 34.15 cm respectively. The minimum plant height was recorded to be different for different growth stages. At 30 DAS, the shortest plant height was observed in the treatment combination of $Al_{0.50}V_2$ (2017-18), $Al_{0.50}V_3$ (2018-19 and pooled), at 60 DAS shortest plant height was recorded in the treatment combination of $Al_{0.50}V_2$ during both the year and pooled. At harvest shortest plant height was recorded in the treatment combination of $Al_{0.50}V_2$ during both the year and pooled.

4.1.1.3 Number of branches per plant

The effect of different aluminium levels and varieties on number of branches at 30, 60 DAS and at harvest is shown in table 4.3 and depicted in figure 4.2. As indicated in the data, the number of branches per plant was found lowest in $Al_{0.50}$ whereas it was highest in control. With every increase in aluminium levels, the number of branchesper plant decreased significantly at all growth stages. At 30, 60 DAS and at harvest, highest number of branches was observed at Al_0 with 3.78 and 3.33, 7.22 and 7.11, 9.67 and 9.33 respectively, while pooled was 3.56, 7.17 and 9.50 followed by $Al_{0.25}$ and $Al_{0.50}$. The pooled branches at harvest were decreased by 2.90% and 17.57% with application of $Al_{0.25}$ and $Al_{0.50}$ over control, respectively.

Aluminium application enhanced its concentration in soil solution and reduced the absorbtion of essential nutrients by plants. Further, more the plant absorbed more Al, it might have reduced the metabolic activities within plant

Table 4.3: Effect of aluminium levels and varieties on number of branches per plant of french bean

Treatments	Number of branches per plant								
	30 DAS			60 DAS			At harvest		
	2017-18	2018-19	Pooled	2017-18	2017	Pooled	2017-18	2018-19	Pooled
Aluminium levels									
Al_0	3.78	3.33	3.56	7.22	7.11	7.17	9.67	9.33	9.50
$Al_{0.25}$	3.22	2.78	3.00	6.44	6.33	6.39	9.44	9.00	9.22
$Al_{0.50}$	2.44	2.22	2.33	5.89	5.78	5.83	7.56	8.11	7.83
SEm±	0.20	0.22	0.15	0.35	0.35	0.24	0.31	0.33	0.23
CD (p=0.05)	0.60	0.66	0.43	1.03	1.03	0.70	0.93	0.99	0.66
Varieties									
V_1	3.33	3.00	3.17	6.89	6.67	6.78	9.11	9.00	9.06
V_2	3.11	2.78	2.94	6.33	6.33	6.33	9.00	8.67	8.83
V_3	3.00	2.56	2.78	6.33	6.22	6.28	8.56	8.78	8.67
SEm±	0.20	0.22	0.15	0.35	0.35	0.24	0.31	0.33	0.23
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

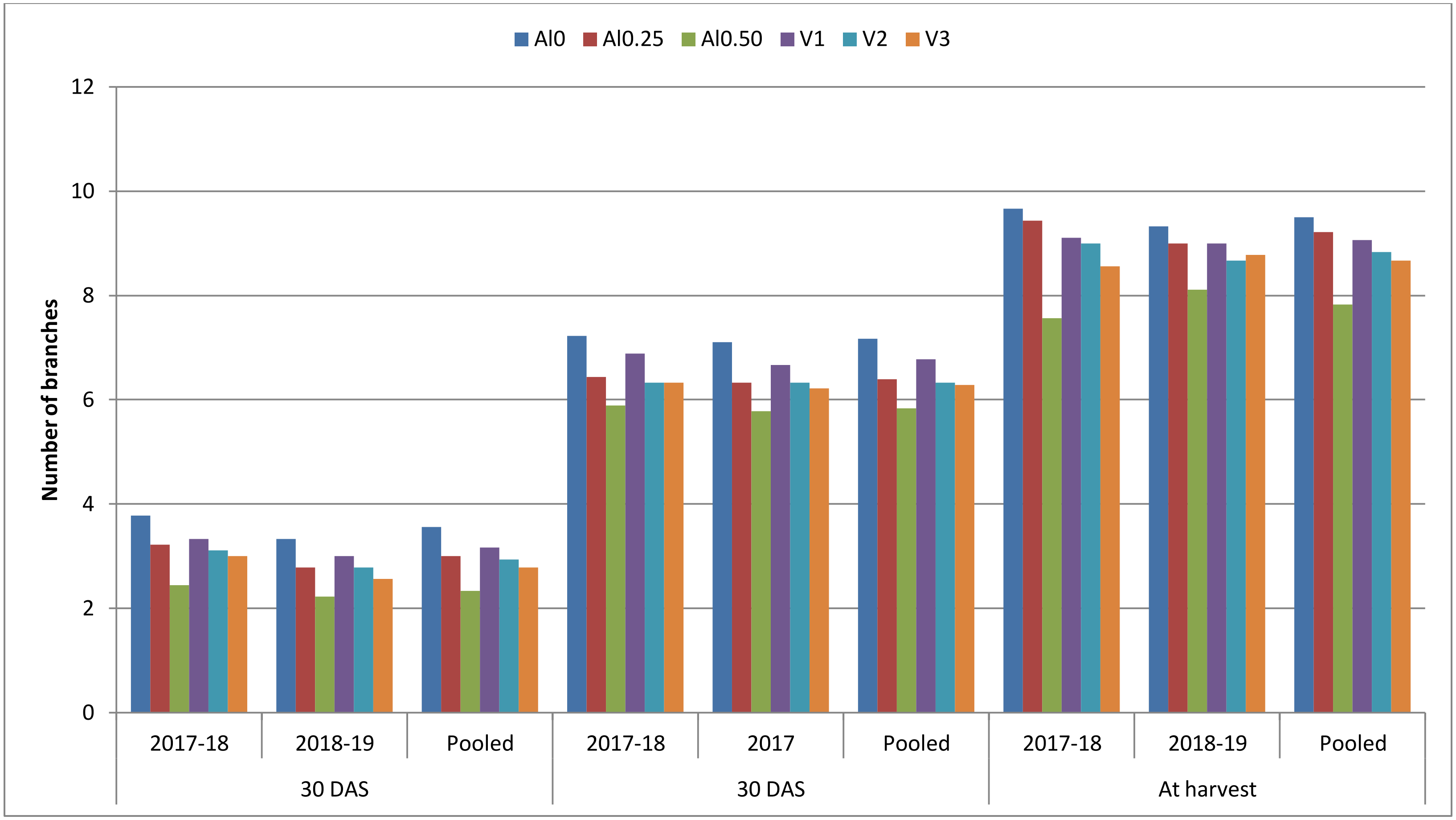

Figure 4. 2: Effect of aluminium levels and varieties on number of branches per plant of french bean

System and ultimately decreased the plant growth. Similar results have been reported by Azevedo and Olive (1989) and Rheinheimer *et al.* (1994).

The data further revealed that the number of branches per plant at 30 and 60 DAS during 2017-18 and 2018-19 was not affected significantly by different varieties but at harvest selection-9 produced higher number of branches in comparision to other varieties.

Interaction effect of aluminium levels and varieties on number of branches per plant of french bean was found to be insignificant.

4.1.1.4 Number of pods per plant

Data presented in table 4.4(a) revealed that different aluminium levels and varieties had significant effect on number of pods per plant. Maximum number of pods per plant was recorded in Al_0, with 14.00 and 13.56 in 2017-18 and 2018-19 with pooled value of 13.78. This was followed by $Al_{0.25}$ with 11.11 and 11.22 during 2017-18 and 2018-19 respectively, with pooled value of 11.17. The minimum number of pods per plant was observed in $Al_{0.50}$ with 8.11 and 7.78 during 2017-18 and 2018-19 respectively, with pooled value of 7.94. Increase in aluminium levels decreased the number of pods by 18.94% for $Al_{0.25}$ and 42.38% for $Al_{0.50}$ over control.

Thangavel (2002) also reported similar results on the number of pods per plant in green gram grown on alfisol generally showed a significant decreasing trend with increasing aluminium treatment concentration above 10 µg of Al g^{-1} of soil. The reason for decline in number of pods per plant with increase in aluminum levels might be probably due to poorely developed root system that limits nutrient and water uptake leading to decrease in growth and yield parameters. Similar results were recorded in cowpea by Kenechukwu *et al.* (2007) and Dong *et al.* (2018) in peanut.

Table 4.4(a): Effect of aluminium levels and varieties on number of pods per plant, pod length, number of seeds per pod and test weight of french bean

Treatments	Number of pods per plant			Pod length (cm)			Number of seeds per pod			Test weight (g)		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	14.00	13.56	13.78	11.74	11.83	11.79	4.92	4.96	4.94	26.71	26.44	26.58
$Al_{0.25}$	11.11	11.22	11.17	9.42	9.61	9.51	3.96	4.08	4.02	28.52	27.59	28.06
$Al_{0.50}$	8.11	7.78	7.94	7.16	7.64	7.40	3.30	3.32	3.31	31.01	31.08	31.04
SEm±	0.22	0.16	0.14	0.26	0.23	0.17	0.19	0.17	0.13	0.78	0.69	0.52
CD (p=0.05)	0.66	0.47	0.39	0.77	0.67	0.49	0.57	0.51	0.37	2.31	2.04	1.49
Varieties												
V_1	11.67	11.78	11.72	9.91	10.06	9.99	4.20	4.28	4.24	27.81	27.34	27.58
V_2	11.44	10.56	11.00	9.54	9.84	9.69	4.13	4.17	4.15	28.51	28.24	28.38
V_3	10.11	10.22	10.17	8.87	9.18	9.03	3.84	3.91	3.88	29.92	29.52	29.72
SEm±	0.22	0.16	0.14	0.26	0.23	0.17	0.19	0.17	0.13	0.78	0.69	0.52
CD (p=0.05)	0.66	0.47	0.39	0.77	0.67	0.49	NS	NS	NS	NS	NS	NS

Table 4.4(b): Interaction effect of aluminium levels and varieties on number of pods per plant a of french bean

Aluminium levels	Number of pods per plant		
	Varieties		
	V_1	V_2	V_3
	2017-18		
Al_0	14.67	14.67	12.67
$Al_{0.25}$	12.00	11.67	9.67
$Al_{0.50}$	8.33	8.00	8.00
SEm±	0.38		
CD (p=0.05)	NS		
	2018-19		
Al_0	14.67	13.00	13.00
$Al_{0.25}$	12.33	11.33	10.00
$Al_{0.50}$	8.33	7.33	7.67
SEm±	0.27		
CD (p=0.05)	0.81		
	Pooled		
Al_0	14.67	13.83	12.83
$Al_{0.25}$	12.17	11.50	9.83
$Al_{0.50}$	8.33	7.67	7.83
SEm±	0.24		
CD (p=0.05)	0.68		

The data also show that among the three varieties, the number of pod per plant was highest in Selection-9 with 11.67 and 11.78 during 2017-18 and 2018-19 respectively, with pooled value of 11.72. This was followed by Anupam-R with 11.44 and 10.56 during 2017-18 and 2018-19 respectively, while the pooled data was 11.00, while the least number of pods per plant were observed in Nagaland local with 10.11 and 10.22 respectively, in the year 2017-18 and 2018-19 with the pooled data of 10.17. In the present study, variation in number of pods per plant in different varieties might be due to genetical inheritance. Neupane *et al*. (2008) also reported that number of pods per plant in common bean was influenced by the variety.

Considering the interaction effect presented in table 4.4(b), the interaction effect between aluminium varieties showed non significant effect during 2017-18 while it showed significant effect only during 2018-19 and in pooled. The number of pods per plant ranged from 7.67 to 14.67. The highest number of pods per plant was recorded in the treatment combination of Al_0V_1 with 14.67 in 2018-19 and 14.67 (pooled value). Selection-9 variety produced significantly higher number of pods per plant under $Al_{0.25}$ level of aluminium in comparisions to other varieties. But under $Al_{0.50}$ level of aluminium, difference between Selection-9 and Anupam-R varieties was found not to be significant.

4.1.1.5 Pod length

The differences in pod length regarding the effect of different aluminium levels and the three different varieities have been represented in the table 4.4(a).

The given data clearly revealed that there was a significant difference among the pod length with respect to aluminium treatment. However, maximum pod length was recorded in control with 11.74 and 11.83 cm during 2017-18 and 2018-19 respectively, with pooled value of 11.79 cm than the aluminium treated ones. The minimum pod length was recorded in $Al_{0.50}$ with 7.16 and 7.64 cm during 2017-18 and 2018-19 with pooled value of 7.40 cm. A critical examination of the data revealed that each enhancing level of aluminium resulted significantly lower pod length as compared to preceeding lower level of aluminum during both the year of experimentation.

The reason for decline in pod length with every increase in aluminum level might be due to poorely developed root system that limits nutrient and water uptake leading to decrease in growth and yield parameters. Similar results were recorded in cowpea by Kenechukwu *et al.* (2007) and Dong *et al.* (2018) in peanut.

The results of varietal performance represent that the highest pod length was obtained from the Selection-9 with 9.91 and 10.06 cm during 2017-18 and 2018-19 respectively, with pooled value of 9.99 cm followed by Anupam-R with 9.54 and 9.84 cm during 2017-18 and 2018-19 respectively with pooled value of 9.69 cm. The shortest pod length was found in Nagaland local with 8.87 and 9.18 cm during 2017-18 and 2018-19 respectively with pooled value of 9.03 cm. The variation in length of pods of french bean varieties observed in the present study may be due to their inherited traits and to some extent by environmental factors. The variability for pod length in different varieties of french bean was also reported by Pandey *et al.* (2012) and Kumar *et al*. (2014) in pea.

Interaction effect of aluminium levels and varieties on pod length of french bean was found to be insignificant.

4.1.1.6 Number of seeds per pod

The data recorded on number of seeds per pod are presented in table 4.4(a). The data indicate that with increasing aluminium levels, there was a decrease in number of seeds per pod during both the year and showed significant differences among the treatments. The highest number of seeds per pod was recorded in Al_0, with 4.92 and 4.96 in 2017-18 and 2018-19 with pooled value of 4.94. This was followed by $Al_{0.25}$ with 3.96 and 4.06 during 2017-18 and 2018-19, respectively, with pooled value of 4.02. The lowest number of seeds per pod was observed in $Al_{0.50}$ with 3.30 and 3.32 during 2017-18 and 2018-19, respectively, with the pooled value of 3.31.

The reason for the decline in number of seeds per pod may be probably due to poorely developed root system that limits nutrient and water uptake leading to decrease in growth and yield parameters. Similar results were recorded in cowpea by Kenechukwu *et al.* (2007) and Dong *et al.* (2018) in peanut. Thangavel (2002) also reported similar results on the number of seeds per pod in green gram grown on alfisol.

Effect of varieties on number of seeds per pods was non significant during both the years. Among the three varieties, Selection-9 produced the highest number of seeds per pod followed by Anupam-R and Nagaland local but there was no significant result found.

Interaction effect of aluminium levels and varieties on number of seeds per pod of french bean was found to be insignificant.

4.1.1.7 Test weight

Significant difference was observed in test weight with different aluminium levels as recorded from table 4.4(a). The highest test weight was recorded in $Al_{0.50}$ with 31.01 and 31.08 g during 2017-18 and 2018-19, respectively with pooled value of 31.04 g followed by $Al_{0.25}$ with 28.52 and 27.59 g during 2017-18 and 2018-19 respectively with pooled value of 28.06g. The minimum test weight was found in Al_0 with 26.71 and 26.44 g pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 26.58g.

The 100 seed weight showed direct positive relation with seed size, these results are in consensus with the findings of Coimbra *et al*. (1998) in french bean.

Untreated seeds produced the smallest size while aluminium treated produced the largest seed size. This may be due to the reason that number of seeds per pod was reduced in aluminium treated plants leading to bolder seed size while untreated plants produced higher number of seeds with smaller size comparatively.

Test weight of french bean was not affected significantly under different varieties. Among the three varieties, Nagaland local showed the highest test weight followed by Anupam-R and Selection-9 but there was no significant result found. Similar findings on test weight of french bean was reported by Kumar *et al*. (2014).

4.1.1.8 Seed yield

The observation recorded on seed yield per plant of french bean varieties after harvest as influenced by different aluminium treatment and genetic variation for both the year 2017-18 and 2018-19 and the pooled analysis has been presented in table 4.5(a) and depicted in figure 4.3.

From the concerned table, it was seen that higher seed yield was obtained from the control (Al_0) with value of 18.77 and 17.89 g pot^{-1} during 2017-18 and 2018-19 respectively, with pooled value of 18.33 followed by $Al_{0.25}$ with 12.82 and 13.21 g pot^{-1} during 2017-18 and 2018-19 respectively, with pooled value of 13.02. The lowest seed yield was found in $Al_{0.50}$ with 8.35 and 8.80 g pot^{-1} during 2017-18 and 2018-19 respectively, with pooled value of 8.58 g pot^{-1}. Irrespective of the treatment and year, the seed yield of french bean ranged from 8.35 to 18.77 g pot^{-1}. A critical examination of the data showed that each increasing level of aluminum significantly reduced the seed yield in comparison to preceeding lower level of aluminium. The $Al_{0.25}$ level reduced the seed yield by 31.6% and 21.6% during the first and second year of experimentation, respectively, over control. However, application of aluminium at 0.50 cmol kg^{1} reduced the seed yield to the extent of 55.5% and 50.8%, respectively, during first and second year of

Table 4.5(a): Effect of aluminium levels and varieties on seed yield and stover yield of french bean

Treatments	Seed yield (g pot^{-1})			Stover yield (g pot^{-1})		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Aluminium levels						
Al_0	18.77	17.89	18.33	34.04	32.83	33.44
$Al_{0.25}$	12.82	13.21	13.02	21.71	24.01	22.86
$Al_{0.50}$	8.35	8.80	8.58	15.48	16.57	16.02
SEm±	0.29	0.17	0.17	0.22	0.24	0.16
CD (p=0.05)	0.85	0.52	0.48	0.65	0.72	0.47
Varieties						
V_1	14.61	14.72	14.66	25.50	26.17	25.84
V_2	13.37	13.45	13.41	23.77	24.61	24.19
V_3	11.98	11.74	11.86	21.95	22.64	22.30
SEm±	0.29	0.17	0.17	0.22	0.24	0.16
CD (p=0.05)	0.85	0.52	0.48	0.65	0.72	0.47

Table 4.5(b): Interaction effect of aluminium levels and varieties on number of seed yield and stover yield of french bean

Aluminium levels	Seed yield (g pot^{-1})			Stover yield (g pot^{-1})		
	Varieties					
	V_1	V_2	V_3	V_1	V_2	V_3
	2017-18					
Al_0	20.17	18.67	17.48	35.31	33.74	33.08
$Al_{0.25}$	14.65	13.09	10.74	23.45	22.10	19.56
$Al_{0.50}$	9.01	8.34	7.71	17.75	15.46	13.22
SEm±	0.50			0.38		
CD (p=0.05)	NS			1.13		
	2018-19					
Al_0	19.05	18.13	16.50	34.56	33.05	30.90
$Al_{0.25}$	15.18	13.46	10.97	25.69	24.02	22.32
$Al_{0.50}$	9.92	8.74	7.73	18.26	16.75	14.70
SEm±	0.30			0.42		
CD (p=0.05)	0.89			NS		
	Pooled					
Al_0	19.61	18.40	16.99	34.93	33.39	31.99
$Al_{0.25}$	14.91	13.28	10.86	24.57	23.06	20.94
$Al_{0.50}$	9.47	8.54	7.72	18.01	16.11	13.96
SEm±	0.29			0.28		
CD (p=0.05)	0.83			NS		

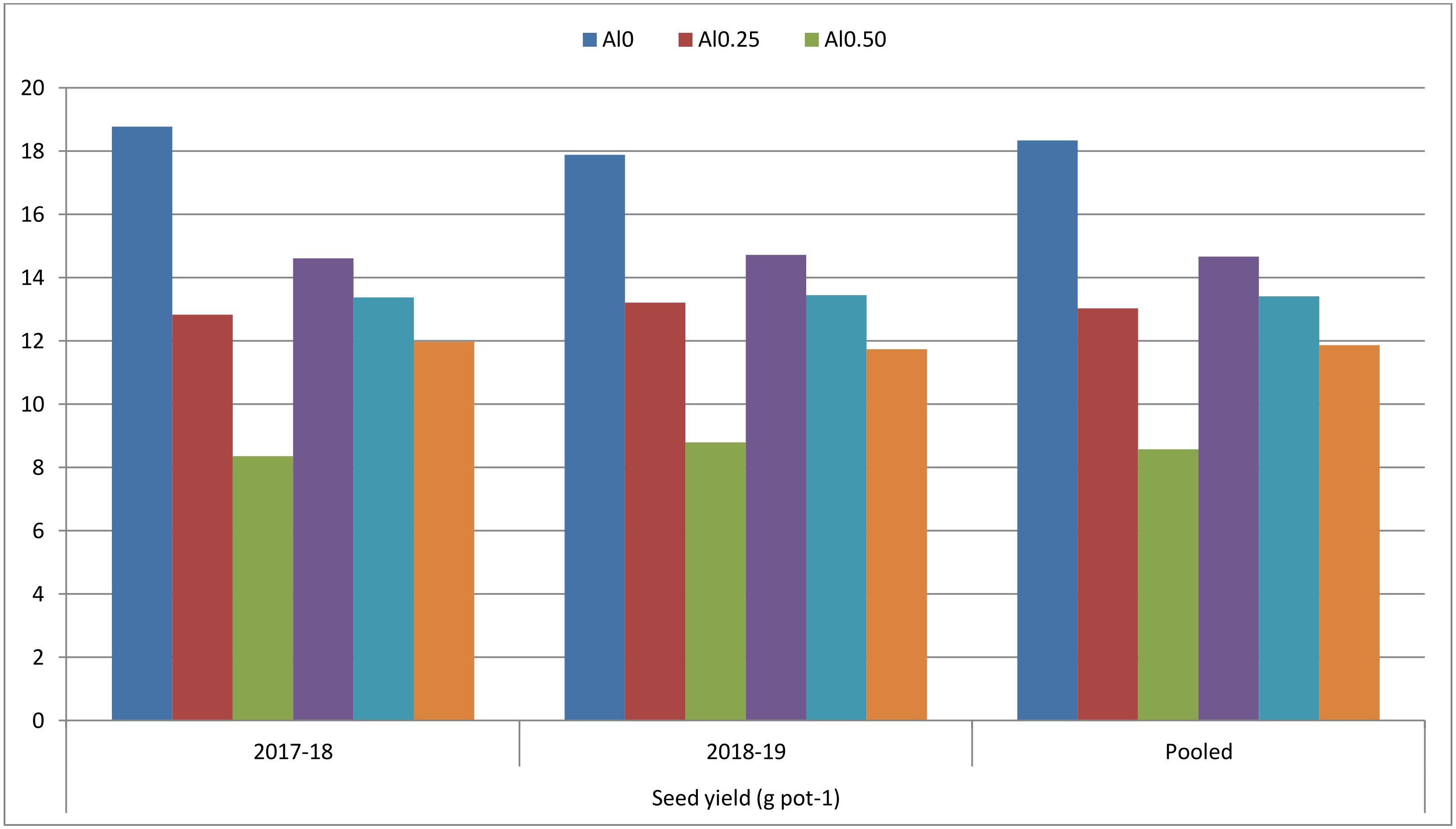

Figure 4.3: Effect of aluminium levels and varieties on seed yield of french bean

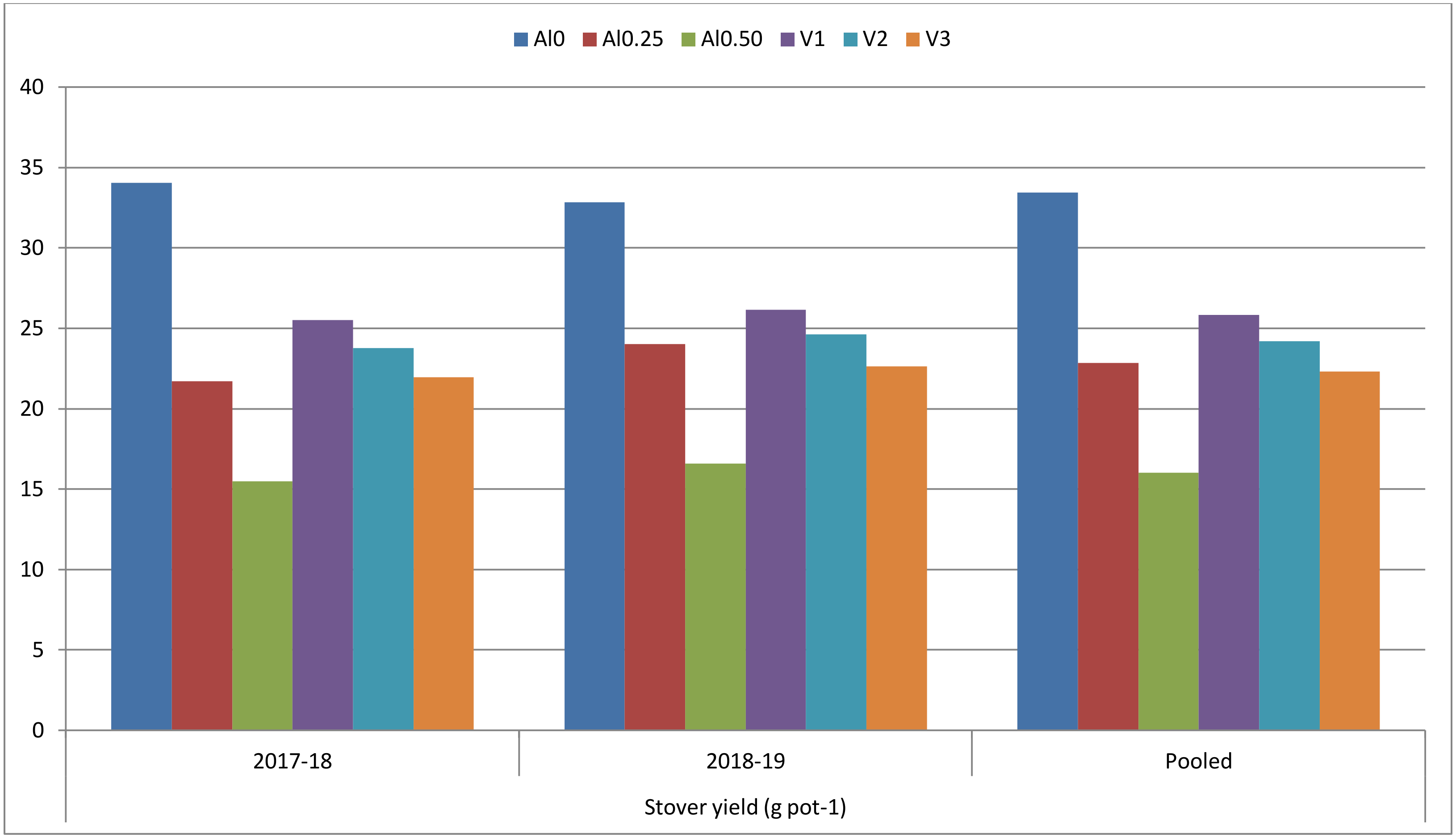

Figure 4.4: Effect of aluminium levels and varieties on stover yield of french bean

experimentation over control. It is clear that extent of seed yield reduction is more between $Al_{0.25}$ and $Al_{0.50}$ as compared to Al_0 to $Al_{0.25}$ during both the years. Reduction of seed yield was recorded 31.6% and 21.6% between Al_0 to $Al_{0.25}$ level and 34.8 and 33.4% between $Al_{0.25}$ to $Al_{0.50}$ level during both the year of experimentation.

Yield is the consequence of yield attributes such as pods per plant, pod length and number of seeds per pod. Reduction of yield attributes due to aluminium may be the reason of reduction in seed yield. These results were in accordance with the findings of Kenechukwu *et al.* (2007) and Dong *et al.* (2018).

Among the different varieties, the highest seed yield was recorded in Selection-9 with the value of 14.61 and 14.72 during 2017-18 and 2018-19 g pot^{-1}, respectively with pooled value of 14.66 followed by Anupam-R with 13.37 and 13.45 g pot^{-1}during 2017-18 and 2018-19, respectively with pooled value of 13.41. The lowest seed yield was obtained from Nagaland local with 11.98 and 11.74 g pot^{-1} during 2017-18 and 2018-19, respectively, with pooled value of 11.86 g pot^{-1}.

Das *et al*. (2014) reported seed yield of 21.94 (g per plant) in Selection-9 and 25.38 (g per plant) in Anupam-R among the varieties under the study in Nadia, West Bengal. In this experiment variation in seed yield is due to genetic inheritance as yield is the polygenic character which is determined by combination of more than ten genes effect.

The data related to interaction effect between aluminium and variety is given in table 4.5(b). Interaction effect was significant during second year of experimentation and pooled values. Considering the interaction effects, the highest seed yield was recorded in Al_0V_1 with 20.17 and 19.05 g pot^{-1} in 2017-18 and 2018-19, respectively with pooled value of 19.61. The least seed yield was recorded in $Al_{0.50}V_3$ with 7.71 and 7.73 in 2017-18 and 2018-19, respectively with pooled value of 7.72.

4.1.1.9 Stover yield

The data presented in table 4.5(a) and depicted in figure 4.4 also indicate that stover yield of french bean decreased significantly with increasing aluminium levels. Maximum reduction n in stover yield was observed at highest level of aluminum during both the years of experimentation. The highest stover yield was recorded in Al_0 with 34.04 and 32.83 g pot^{-1} in 2017-18 and 2018-19, respectively with pooled value of 33.44 g pot^{-1} followed by $Al_{0.25}$ with 21.71 and 24.01 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 22.86 g pot^{-1}. The miniumum stover yield was found in $Al_{0.50}$ with 15.48 and 16.57 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 16.02. The $Al_{0.25}$ level reduced the stover yield by 36.22% and 26.86% during the first and second year of experimentation, respectively, over control. However, $Al_{0.50}$ level reduced the stover yield to the extent of 54.52% and 49.52%, respectively during both the years of experimentation over control.

Batista *et al.* (2012) reported that shoot dry matter, root dry matter and plant height decreased significantly with increasing aluminium concentration. According to Farias *et al*. (2011), increasing aluminium levels in the nutrient solution led to a decline in the shoot and root dry matter production, as demonstrated in our results. The low dry matter accumulation in the shoot may be attributed to the significant effect of aluminium on nutrient absorption and translocation (Azevedo and Oliva, 1989). The soluble aluminium in soil makes the plant uptake of several elements difficult, and one of these elements is phosphorus (Batista *et al*. 2009). The low translocated content of phosphorus to the plant shoots reduces the photosynthetic rate, which causes a lower accumulation of carbohydrates, thereby resulting in lighter leaves with less dry matter production (Rheinheimer *et al*. 1994).

The table further revealed that stover yield ranged from 22.30 to 25.84 g pot^{-1} among the three varieties which showed significant results. Selection-9 showed the highest stover yield with 25.50 and 26.17 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 25.84 g pot^{-1} followed by Anupam-R with 23.77 and 24.61 g pot^{-1}during 2017-18 and 2018-19, respectively with pooled value of 24.19 g pot^{-1}. The least stover yield was obtained from Nagaland local with 21.95 and 22.64 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 22.30 g pot^{-1}.

Stover yield differences are the consequences of the difference in growth related parameters such as the plant height, number of branches per plant and pods per plant of different varieties.

Considering the interaction effects presented in table 4.5(b), the highest stover yield was recorded in Al_0V_1 with 35.31 and 34.56 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 34.93 g pot^{-1}. The minimum stover yield was recorded in $Al_{0.50}V_3$ with 13.22 and 14.70 g pot^{-1} in 2017-18 and 2018-19, respectively with pooled value of 13.96 g pot^{-1}. There were significant differences among the treatment combination only during second year of experimentation.

4.1.1.10 Root length

The results obtained on the root length in different treatments have been presented in table 4.6(a). The highest root length was recorded under Al_0 with 14.00 and 13.84 cm during 2017-18 and 2018-19, respectively with pooled value of 13.92 cm which was followed by $Al_{0.25}$ with 11.91 and 11.21 cm during 2017-18 and 2018-19, respectively with pooled value of 11.56 cm. The shortest root length was observed in $Al_{0.50}$ with 7.29 and 7.19 cm during 2017-18 and 2018-19, respectively with pooled value of 7.24 cm.

Similar results were reported by Batista *et al*. (2012) stated that the root growth of the corn plants grown in the nutrient solution with 75 µmol L^{-1} Al was inhibited and the number of lateral roots was reduced, presenting a less developed root system compared to the control plant. Lima and Copeland (1994) also used 75 µmol L^{-1} Al, and reported that aluminium does not affect the aerial part of wheat but that it affects the root system by causing the primary roots to become dark and brittle with brown apices in addition to inhibiting the secondary roots.

The table further revealed that among the three varieties the highest root length was observed in Selection-9 with 11.75 and 10.80 cm during 2017-18 and 2018-19, respectively with pooled value of 11.28 followed by Nagaland local with the value of 11.50 and 11.23 cm during 2017-18 and 2018-19 respectively with pooled value of 11.36. The shortest root length was recorded in Anupam-R with 9.94 and 10.23 cm during 2017-18 and 2018-19 respectively with pooled value of 10.09 cm.

The variation in length of roots of french bean varieties observed in the present study may be due to their inherited traits and to some extent by environmental factors. Das *et al*., (2014) also reported similar results.

Considering the interaction effects presented in table 4.6(b), the highest root length was recorded in Al_0V_3 with the value 14.67 and 14.79 cm during 2017-18 and 2018-19, respectively with pooled value of 14.73 cm which was at par with Al_0V_1 with 15.33 and 13.65cm during 2017-18 and 2018-19 respectively with pooled value of 14.49 cm. The lowest root length was recorded in $Al_{0.50}$ V_2 with 7.00 cm for both the year and pooled which was at par with $Al_{0.50}V_1$ with the value of 7.26 and 7.25 cm during 2017-18 and 2018-19 respectively with pooled value of 7.26 cm.

4.1.1.11 Root mass

The highest root mass was recorded in Al_0 with 6.87 and 6.78 g pot^{-1} during

Table 4.6(a): Effect of aluminium levels and varieties on root length and root mass of french bean

Treatments	Root length (cm)			Root mass (g pot^{-1})		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Aluminium levels						
Al_0	14.00	13.84	13.92	6.87	6.78	6.83
$Al_{0.25}$	11.91	11.21	11.56	5.70	5.73	5.72
$Al_{0.50}$	7.29	7.19	7.24	3.83	3.75	3.79
SEm±	0.26	0.13	0.15	0.15	0.16	0.11
CD (p=0.05)	0.78	0.38	0.42	0.45	0.48	0.32
Varieties						
V_1	11.75	10.80	11.28	5.64	5.57	5.61
V_2	9.94	10.23	10.09	5.53	5.43	5.48
V_3	11.50	11.23	11.36	5.24	5.26	5.25
SEm±	0.26	0.13	0.15	0.15	0.16	0.11
CD (p=0.05)	0.78	0.38	0.42	NS	NS	NS

Table 4.6(b): Interaction effect of aluminium levels and varieties on root length of french bean

Aluminium levels	Root length (cm)		
	Varieties		
	V_1	V_2	V_3
	2017-18		
Al_0	15.33	12.00	14.67
$Al_{0.25}$	12.67	10.83	12.23
$Al_{0.50}$	7.26	7.00	7.60
SEm±	0.45		
CD (p=0.05)	1.35		
	2018-19		
Al_0	13.65	13.08	14.79
$Al_{0.25}$	11.49	10.59	11.55
$Al_{0.50}$	7.25	7.00	7.33
SEm±	0.22		
CD (p=0.05)	0.66		
	Pooled		
Al_0	14.49	12.54	14.73
$Al_{0.25}$	12.08	10.71	11.89
$Al_{0.50}$	7.26	7.00	7.47
SEm±	0.25		
CD (p=0.05)	0.73		

2017-18 and 2018-19, respectively with pooled value of 6.83 g pot^{-1} which was followed by $Al_{0.25}$ with the value 5.70 and 5.73 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.72 g pot^{-1} {Table 4.6(a)} The minimum root mass was recorded in $Al_{0.50}$ with the value of 3.83 and 3.75 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 3.79 g pot^{-1}.

Bennet *et al*. (1985) reported that an anisotropic growth response of cortical cells with 20-h root exposure to aluminium were associated with the collapse of the conducting tissue of the stele and disintegration of the outer cells of the root may be due to this reason the root mass was reduced in the present investigation. Thangavel (2002) also reported similar results on root mass in green gram grown on alfisol. Furthermore, higher concentration of aluminium reduced the root length which might have caused the reduction of root mass.

The table further revealed that there were no significant differences between the varieties in case of root mass. Irrespective of varieties the root mass ranged from 5.24 to 5.64 g pot^{-1} however the highest root mass was recorded in Selection-9 with the value of 5.64 and 5.57 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.61 g pot^{-1} while the lowest root mass recorded in Nagaland local with 5.24 and 5.26 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.61g pot^{-1}.

The interaction effect of aluminium and varieties on root mass was found to be insignificant.

4.1.2. Effect on nutrient content

4.1.2.1. Nitrogen content

The data given in table 4.7(a) indicate that increased level of aluminium resulted in decreasing nitrogen content in grains and stover of french bean. In grains, the highest nitrogen content was observed in Al_0 with 3.42 and 3.46% during 2017-18 and 2018-19, respectively with pooled value of 3.44%. Whereas the lowest nitrogen content was observed in $Al_{0.50}$ with the value of 3.00 and 3.09% during 2017-18 and 2018-19, respectively with pooled value of 3.05%.

Similarly in stover, the nitrogen content was highest in Al_0 with 1.23 and 1.24% during 2017-18 and 2018-19, respectively with pooled value of 1.24%. whereas the lowest nitrogen content was observed in $Al_{0.50}$ with the value of 1.01 and 1.02 % during 2017-18 and 2018-19, respectively with pooled value of 1.01%.

The increased level of aluminium resulted in decreasing nitrogen content in grains and stover of french bean may be due to the reason that aluminium induces disturbances in the trans-membrane transport of ions nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) in plant roots (Kochian, 1995), becoming indirectly responsible for the impairment of root-shoot transport and metabolic processes in shoots (Mihailovic *et al*., 2008). Root damage can reduce the nutrient uptake and eventually induce mineral deficiencies in shoots (Taylor, 1988). Pintro *et al*. (1996) reported that concentration of nitrogen in the shoot of the corn (*Zea mays*) decreased with the increase of aluminium levels in the soil solution. Ribeiro *et al*. (2013) reported that increasing aluminium levels in growth medium decreased nitrogen content in all plant organs of cacao. He further revealed that increasing aluminium levels in growth medium decreased nitrogen content in leaves by 41 to 77%.

There were no significant differences among the varieties in the nitrogen content in seeds but significant differences were observed in nitrogen content in the stover. The nitrogen content among the three varieties in stover ranged from 1.10 to 1.17%. The highest N content was observed in Selection-9 with the value of 1.17% in both the year and pooled data which was followed by Anupam-R with1.14 and 1.15% during 2017-18 and 2018-19, respectively with pooled value

Table 4.7(a): Effect of aluminium levels and varieties on nitrogen content and phosphorus content in grain and stover of french bean

Treatments	Nutrient content (%)											
	Nitrogen						Phosphorus					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	3.42	3.46	3.44	1.23	1.24	1.24	0.53	0.55	0.54	0.20	0.21	0.20
$Al_{0.25}$	3.28	3.30	3.29	1.16	1.17	1.17	0.48	0.48	0.48	0.15	0.17	0.16
$Al_{0.50}$	3.00	3.09	3.05	1.01	1.02	1.01	0.41	0.42	0.41	0.11	0.13	0.12
SEm±	0.05	0.05	0.03	0.015	0.011	0.009	0.01	0.01	0.01	0.004	0.008	0.005
CD (p=0.05)	0.15	0.14	0.10	0.043	0.031	0.026	0.02	0.02	0.03	0.012	0.025	0.013
Varieties												
V_1	3.30	3.33	3.32	1.17	1.17	1.17	0.48	0.49	0.49	0.17	0.18	0.17
V_2	3.22	3.30	3.26	1.14	1.15	1.14	0.48	0.49	0.48	0.16	0.17	0.16
V_3	3.19	3.22	3.20	1.10	1.12	1.11	0.46	0.47	0.47	0.14	0.16	0.15
SEm±	0.05	0.05	0.03	0.015	0.011	0.009	0.01	0.01	0.01	0.004	0.008	0.002
CD (p=0.05)	NS	NS	NS	0.043	0.031	0.026	NS	NS	NS	0.01 2	0.025	0.013

of 1.14% and Nagaland local with 1.10 and 1.12% during 2017-18 and 2018-19, respectively with pooled value of 1.01%.

The interaction effect between the different aluminium levels and varieties on nitrogen content in grain and stover of french bean were found to be non significant.

4.1.2.2. Phosphorus content

The data in Table 4.7(a) represent the phosphorus content in grain and stover of french bean. The data show that with each increasing level of aluminium, there was a significant decrease in phosphorus content as compare to lower level of aluminium in case of both grain and stover of French bean. The highest phosphorus content in grain was recorded in Al_0 with 0.53 and 0.55% with pooled value of 0.54%, whereas the lowest phosphorus content in grain was observed in $Al_{0.50}$ with 0.41 and 0.42% during 2017-18 and 2018-19, respectively with pooled value of 0.41%.

Similarly in stover, the phosphorus content was highest in Al_0 with 0.20 and 0.21% during 2017-18 and 2018-19 respectively with pooled value of 0.20%. whereas the lowest phosphorus content was observed in $Al_{0.50}$ with the value of 0.11 and 0.13% during 2017-18 and 2018-19 respectively with pooled value of 0.12%. Maximum decline in phosphorus content was recorded at highest level of aluminium.

The results in relation to the phosphorus content are in agreement with those found for aluminium treated *Quercus glauca* (Akaya and Takenaka, 2001) and *Vigna unguiculata* aluminium sensitive genotype, whose phosphorus accumulation were significantly reduced (Jemo *et al*., 2007). According to Macklon *et al*. (1994), in growth medium, aluminium increases phosphorus fixation by precipitation as Al-P complexes thereby reducing phosphorus availability.

Table 4.7(b): Interaction effect of aluminium levels and varieties on phosphorus content in stover of french bean

Aluminium levels	Phosphorus content		
	Stover		
	Varieties		
	V_1	V_2	V_3
	2017-18		
Al_0	0.23	0.19	0.19
$Al_{0.25}$	0.16	0.16	0.14
$Al_{0.50}$	0.13	0.13	0.08
SEm±	0.007		
CD (p=0.05)	0.021		
	2018-19		
Al_0	0.22	0.21	0.20
$Al_{0.25}$	0.18	0.17	0.15
$Al_{0.50}$	0.13	0.12	0.12
SEm±	0.014		
CD (p=0.05)	NS		
	Pooled		
Al_0	0.22	0.20	0.19
$Al_{0.25}$	0.17	0.16	0.15
$Al_{0.50}$	0.13	0.13	0.10
SEm±	0.008		
CD (p=0.05)	NS		

As shown in Table 4.7(a), there were no significant differences among the three varieties in the grain; all the varieties had almost the same phosphorus content. However, in case of stover, significant variation among all the varieties was observed. Highest phosphorus content was observed Selection-9 with 0.17 and 0.18% during 2017-18 and 2018-19, respectively with pooled value of 0.17% followed by Anupam-R and the lowest phosphorus content was recorded in Nagaland local with 0.14 and 0.16% during 2017-18 and 2018-19 respectively with pooled value of 0.15%.

The interaction effect between the different aluminium levels and varieties on phosphorus content in grain were found to be non significant however in stover, presented in table 4.7(b) it was found to be significant with highest phosphorus content with 0.23% in treatment combination Al_0V_1 while the least content with 0.08% was obtained from $Al_{0.5}V_3$.

4.1.2.3 Potassium content

The data regarding potassium content in grains and stover of french bean are presented in table 4.8. A critical examination of data show that potassium content in grains and stover decreased with increase in aluminium level. In grains, potassium content at Al_0 with 0.84 and 0.85% during 2017-18 and 2018-19, respectively with pooled value of 0.85%, was significantly higher than the other which was treated with aluminium. Lowest potassium content was recorded in $Al_{0.50}$ with 0.76 % for both the year and pooled.

In stover, potassium content at Al_0 with 1.53 and 1.52% during 2017-18 and 2018-19, respectively with pooled value of 1.53 was significantly higher than that of $Al_{0.25}$ and $Al_{0.50}$. Lowest potassium content was recorded in $Al_{0.50}$ with 1.41 and 1.42% during 2017-18 and 2018-19 respectively with pooled value of 1.42%. Potassium content in grains was found lower than the potassium content in stover.

The decrease in potassium content with increase of aluminium level up to certain level might be due to the disturbances in trans- membrane transport of ions induced by aluminium. Thronton *et al*. (1986) reported that the nutrient composition of aluminium treated plant parts were significantly lower than that of control plant parts in case of honey locust plants. Cristiane and Veronique (2008) also reported that aluminium decreased Ca, P, K, Mg and Mn concentrations in shoot of rice cultivars.

There was no significant effect found with varieties in influencing potassium content in grains of french bean. However there was a significant difference found between the varieties in potassium content in stover of french bean. In stover, potassium content in Selection-9 with 1.49 and 1.48% during 2017-18 and 2018-19, respectively with pooled value of 1.48 was significantly higher than Nagaland local during both the years.

4.1.2.4 Sulphur content

The results obtained on the sulphur content in grain and stover of french bean in different treatment has been presented in table 4.8. As evident from the data, increased level of aluminium resulted in decreasing sulphur content in grains and stover of french bean. The maximum sulphur content in grain was recorded in Al_0 with 0.30 and 0.31% during 2017-18 and 2018-19, respectively with pooled value of 0.30%. The lowest sulphur content was observed in $Al_{0.50}$ with 0.12 and 0.13% during 2017-18 and 2018-19 respectively with pooled value of 0.12. Similarly in stover, the maximum sulphur content was recorded from Al_0 with 0.13 and 0.14% during 2017-18 and 2018-19, respectively with pooled value of 0.14 while the lowest sulphur content was observed in $Al_{0.50}$ with 0.07 and 0.06% during 2017-18 and 2018-19, respectively with pooled value of 0.07%.

The Al-sulfate interaction occurs in acidic soils, whereby relatively high concentrations of trivalent toxic aluminum (Al^{3+}) may hamper root growth, limiting uptake of nutrients, including sulphur. (Poblete *et al*., 2018).

Table 4.8: Effect of aluminium levels and varieties on potassium and sulphur content in grain and stover of french bean

Treatments	Nutrient content (%)											
	Potassium						Sulphur					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	0.84	0.85	0.85	1.53	1.52	1.53	0.30	0.31	0.31	0.13	0.14	0.14
$Al_{0.25}$	0.80	0.81	0.80	1.46	1.45	1.46	0.23	0.24	0.23	0.10	0.11	0.11
$Al_{0.50}$	0.76	0.76	0.76	1.41	1.42	1.42	0.12	0.15	0.13	0.07	0.06	0.07
SEm±	0.01	0.01	0.01	0.004	0.005	0.003	0.01	0.01	0.01	0.01	0.01	0.01
CD (p=0.05)	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.03	0.02	0.03	0.02	0.02
Varieties												
V_1	0.81	0.82	0.81	1.49	1.48	1.48	0.24	0.25	0.24	0.11	0.12	0.11
V_2	0.80	0.81	0.80	1.46	1.47	1.47	0.22	0.24	0.23	0.11	0.11	0.11
V_3	0.79	0.80	0.79	1.46	1.45	1.45	0.19	0.21	0.20	0.09	0.10	0.09
SEm±	0.01	0.01	0.01	0.004	0.005	0.003	0.01	0.01	0.01	0.008	0.006	0.005
CD (p=0.05)	NS	NS	NS	0.013	0.015	0.010	0.02	NS	NS	NS	NS	NS

Further, the table 4.8 also revealed that the varieties showed significant effect only during the first year in grains but there was no significant difference among the varieties for sulphur content in stovers. The highest sulphur content was recorded in Selection-9 with 0.24% during 2017-18 followed by anupam-R with 0.22% and Nagaland local showed the lowest sulphur content with 0.19%.

4.1.2.5 Calcium content

The data regarding calcium content in grains and stover of french bean are presented in table 4.9. A critical examination of data show that calcium content in grains and stover decreased with increase in aluminium levels during both the years. Calcium content in grain reduced from 0.23% to 0.09% during 2017-18 and from 0.24% to 0.11% during 2018-19 with application of highest level of aluminium. Lowest calcium content was recorded in $Al_{0.50}$ with 0.09 and 0.11% during 2017-18 and 2018-19, respectively with pooled value of 0.10. Similarly in stover, the calcium content was found to be highest in Al_0 with 0.72 and 0.73 % during 2017-18 and 2018-19 respectively with pooled value of 0.73%. The lowest calcium content was observed in $Al_{0.50}$ with 0.47 and 0.48 % during 2017-18 and 2018-19, respectively with pooled value of 0.48%.

Decrease in calcium content in grains and stover with increase in aluminium level may be due to the reason that aluminium interacts antagonistically with calcium therefore, plants grown in external media with high concentration of aluminium may display symptoms associated calcium deficiency (Edwards *et al.*, 1976). Increasing levels of aluminium in the growth medium decreased calcium and magnesium contents in the roots stems and leaves in both cacao genotypes (Ribeiro *et al.*, 2013).

The table also show that among the three varieties there was no significant effect found with variety in influencing calcium content in grains and stover of frenchbean.

Table 4.9: Effect of aluminium levels and varieties on calcium and aluminium contents in grain and stover of french bean

Treatments	Calcium (%)						Aluminium (mg kg^{-1})					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	0.23	0.24	0.23	0.72	0.73	0.73	199.82	200.11	199.96	741.78	742.01	741.89
$Al_{0.25}$	0.13	0.14	0.13	0.57	0.56	0.57	472.24	472.49	472.37	1015.80	1016.46	1016.13
$Al_{0.50}$	0.09	0.11	0.09	0.47	0.48	0.47	682.42	682.57	682.50	1464.54	1463.76	1464.15
SEm±	0.004	0.003	0.003	0.012	0.008	0.008	0.56	0.71	0.80	0.54	1.50	1.08
CD (p=0.05)	0.013	0.008	0.007	0.037	0.023	0.021	1.65	2.11	2.39	1.54	4.44	3.08
Varieties												
V_1	0.15	0.16	0.16	0.60	0.61	0.60	450.70	450.32	450.51	1072.74	1072.91	1072.83
V_2	0.16	0.17	0.16	0.59	0.59	0.59	450.78	451.80	451.29	1073.89	1073.79	1073.84
V_3	0.14	0.15	0.15	0.57	0.58	0.57	453.01	453.04	453.03	1075.50	1075.52	1075.51
SEm±	0.004	0.003	0.003	0.012	0.008	0.007	0.71	0.80	0.54	1.55	1.50	1.08
CD (p=0.05)	NS	NS	NS	NS	NS	NS	2.11	2.39	1.54	NS	NS	NS

The interaction effect between aluminium and varieties on calcium content in seeds and stover of french bean were found to be insignificant.

4.1.2.6 Aluminium content

The results obtained on the aluminium content in grain and stover of french bean in different treatment has been presented in table 4.9. As evident from the data, increased level of aluminium resulted significant increase in aluminium content in grains and stover of french bean. The maximum aluminium content in grain was recorded in $Al_{0.50}$ with 682.42 and 682.57 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 682.50 mg kg^{-1}. The lowest aluminium content was observed in Al_0 with 199.82 and 200.11 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 199.96 mg kg^{-1}. Increase in aluminium level by $Al_{0.25}$ and $Al_{0.50}$ in grains of french bean increased the aluminium content by 136.42% and 241.31%.

Similarly the maximum aluminium content in stover was recorded in $Al_{0.50}$ with 1464.54 and 1463.76 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 1464.15 mg kg^{-1}. The lowest aluminium content was observed in Al_0 with 741.78 and 742.01 mg kg^{-1}during 2017-18 and 2018-19, respectively with pooled value of 741.89 mg kg^{-1}. Increase in aluminium level by $Al_{0.25}$ and $Al_{0.50}$ increased the aluminium content in stover by 36.96 % and 44.09%.

It has been shown that aluminium content in stover was higher than that of grains, this is in accordance with the findings of Thangavel (2002) who reported that among the above ground parts of the control green gram, the accumulation of aluminium was lowest (26.67 ± 9.43 µg g^{-1}) in the grains as compared to leaves and stem and the aluminium content of stems recorded a significant increase with increasing treatment concentration of aluminium. Thronton *et al*. (1986) reported that aluminum concentration of leaves increased with increasing concentration of aluminium and length of exposure to aluminium in solution.

The table also show that among the three varieties, a significant difference was observed in case of aluminium content in grain but there was no significant effect found with variety in influencing aluminium content in stover of french bean.

The highest aluminium content in seeds was recorded in V_3 with 453.01 and 453.04 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 453.03 mg kg^{-1} followed by V_2. The V_1 showed the lowest aluminium content with 450.70 and 450.32 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 450.51 mg kg^{-1}.

The interaction effect between aluminium and varieties on aluminium content in seeds and stover of french bean were found to be insignificant.

4.1.2.7 Protein content

The data regarding protein content and protein yield are given in table 4.10. The data indicated that protein content of french bean grains decreased with increasing aluminium levels. The highest protein content was obtained in control (21.40 and 21.76%) during first and second year, respectively with pooled value of 21.58%, while the lowest protein content was obtained in $Al_{0.50}$ with 18.78 and19.19% during 2017-18 and 2018-19, respectively with pooled value of 18.99%. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the protein content to the extent of 4.6% and 12.09% over control in case of pooled value. It is also apparent from the data that with the increase in aluminium levels, the protein yield decreased significantly. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the protein yield by 31.97 and 58.62 % over control on the basis of pooled value.

The decrease in protein content and protein yield with increase in aluminium level may be due to the reason that that the increase in Al concentration in growth medium decreased the nitrogen content as well as seed yield resulted

Table 4.10: Effect of aluminium levels and varieties on protein content and protein yield in grain of french bean

Treatments	Protien content (%)			Protein yield (g pot^{-1})		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels						
Al_0	21.40	21.76	21.58	4.02	3.87	3.94
$Al_{0.25}$	20.52	20.65	20.59	2.63	2.72	2.68
$Al_{0.50}$	18.78	19.19	18.99	1.57	1.70	1.63
SEm±	0.31	0.30	0.22	0.07	0.05	0.04
CD (p=0.05)	0.93	0.89	0.62	0.22	0.15	0.13
Varieties						
V_1	20.65	20.84	20.74	3.00	3.08	3.04
V_2	20.14	20.56	20.35	2.71	2.75	2.73
V_3	19.92	20.21	20.07	2.51	2.47	2.49
SEm±	0.31	0.30	0.22	0.07	0.05	0.04
CD (p=0.05)	NS	NS	NS	0.22	0.15	0.13

reduction in protein content and yield. These results are in agreement with those of Thangavel (2002) and Ribeiro *et al*. (2013).

The data in table 4.10 also signifies that the varieties had non significant effect on protein content while there was a significant variation among the varieties on protein yield. The highest protein yield was observed in selection-9 followed by Anupam-R and the lowest protein yield was recorded in Nagaland local. In this experiment, variation in protein yield in different varieties might be due to genetic constitution of different varieties and the grain yield of each variety.

The interaction effect between aluminium and varieties on protein content and protein yield in seeds and stover of french bean were found to be insignificant.

4.1.3 Nutrient uptake

4.1.3.1 Nitrogen uptake

From the data presented in table 4.11 and depicted in figure 4.5, it is apparent that the highest nitrogen uptake by grains (642.47 and 619.84 mg pot^{-1}) during 2017-18 and 2018-19, respectively with pooled value of 631.15 mg pot^{-1}, stover(419.75 and 408.21 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 413.98 mg pot^{-1}) was found in Al_0 whereas the lowest uptake by grains (250.63 and 271.81 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 261.22 mg pot^{-1}), stover (156.16 and 168.47 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 162.32 mg pot^{-1}) was recorded in $Al_{0.50}$. The increase in each aluminium level resulted in a drastic significant decrease in nitrogen uptake in seed and stover during both the year of experimentation.

Enhancing level of aluminium reduced the nitrogen uptake in seed and stover might be due to the reduction in nitrogen content and seed and stover yield of french bean. Similar results have also been reported by Ribeiro *et al*. (2013) and (Zhao and Shen, 2018).

The three varieties showed significant variation in nitrogen uptake. The highest nitrogen uptake by grains (479.58 and 492.70 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 486.14 mg pot^{-1}) as well as stover (296.90 and 306.26 mg pot^{-1} during 2017-18 and 2018-19, respectively, with pooled value of 301.58 mg pot^{-1}) was found in Selection-9 whereas the lowest uptake by grains (401.00 and 395.23 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 398.11 mg pot^{-1}) and stover (261.99 and 269.07 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 265.53 mg pot^{-1}) was recorded in Nagaland local.

The interaction effect between aluminium and varieties on nitrogen uptake in seeds and stover of french bean was found to be insignificant.

4.1.3.2 Phosphorus uptake

The data regarding phosphorus uptake are presented in table 4.11 and depicted in figure 4.6. It is clear from the data that phosphorus uptake was greatly influenced by the increased level of applied aluminium. Phosphorus uptake by grains as well as stover decreased significantly with each increasing aluminium levels in comparison to preceding lower levels. The highest phosphorus uptake by grain (100.38 and 97.04 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 98.71 mg pot^{-1}) and stover (68.92 and 68.26 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 68.59 mg pot^{-1}) was recorded in treatment control whereas the minimum uptake (34.13 and 36.30 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 35.22 mg pot^{-1}) in grain and in stover (17.53 and 17.85 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 17.69 mg pot^{-1}) was recorded in treatment $Al_{0.50}$. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased phosphorus uptake to the extent of 36.78% and 64.3% over control in grain while 48.09 % and 74.20% in stover in case of pooled values.

Table 4.11: Effect of aluminium levels and varieties on nitrogen and phosphorus uptake in grain and stover of french bean

Treatments	Nutrient uptake (mg pot^{-1})											
	Nitrogen						Phosphorus					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	642.47	619.84	631.15	419.75	408.21	413.98	100.38	97.04	98.71	68.92	68.26	68.59
$Al_{0.25}$	420.87	435.79	428.33	252.39	281.42	266.90	61.50	63.30	62.40	33.31	37.89	35.60
$Al_{0.50}$	250.63	271.81	261.22	156.16	168.47	162.32	34.13	36.30	35.22	17.53	17.85	17.69
SEm±	11.67	8.05	7.09	3.28	4.33	2.72	2.00	1.26	1.18	1.54	1.53	1.09
CD (p=0.05)	34.66	23.92	20.33	9.75	12.87	7.79	5.94	3.75	3.39	4.58	4.55	3.12
Varieties												
V_1	479.58	492.70	486.14	296.90	306.26	301.58	72.41	73.34	72.87	47.03	45.56	46.30
V_2	433.38	439.52	436.45	269.42	282.76	276.09	63.63	64.97	64.30	35.53	38.52	37.02
V_3	401.00	395.23	398.11	261.99	269.07	265.53	59.97	58.34	59.16	37.20	39.91	38.55
SEm±	11.67	8.05	7.09	3.28	4.33	2.72	2.00	1.26	1.18	1.54	1.53	1.09
CD (p=0.05)	34.66	23.92	20.33	9.75	12.87	7.79	5.94	3.75	3.39	4.58	4.55	3.12

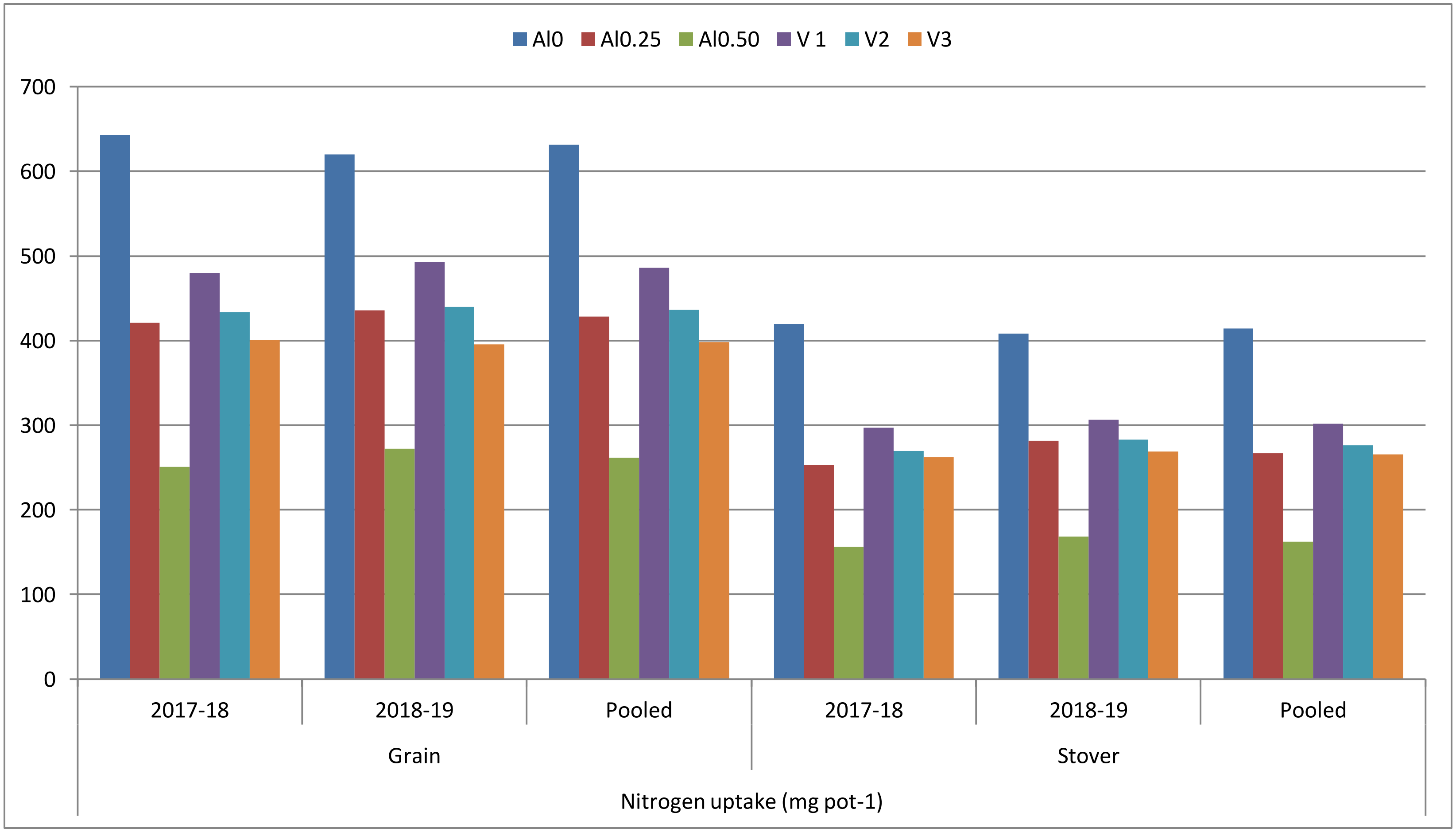

Figure 4.5: Effect of aluminium levels and varieties on nitrogen uptake in grain and stover of french bean

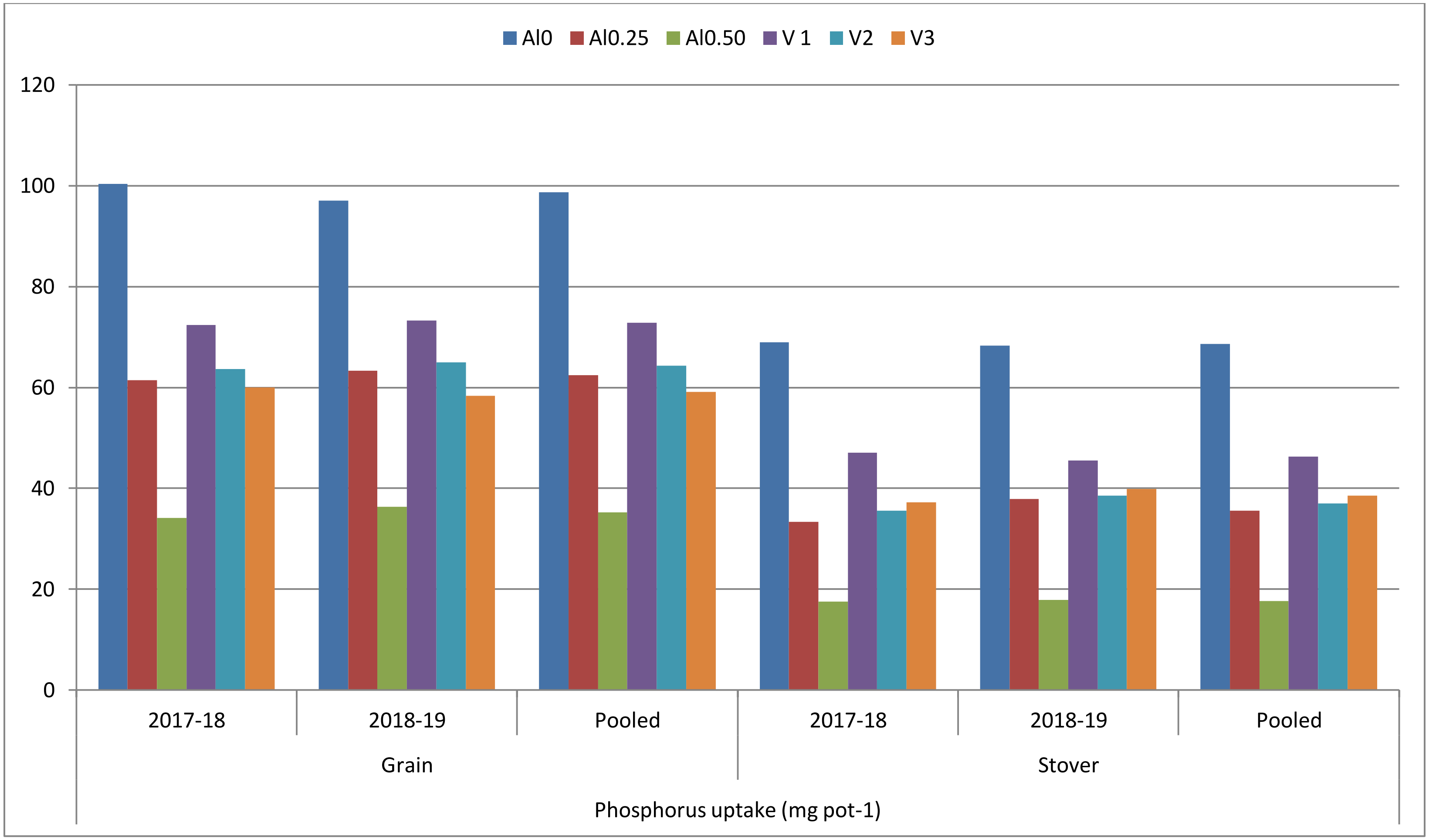

Figure 4.6: Effect of aluminium levels and varieties on phosphorus uptake in stover of french bean

Jan and Pettersson (1989) reported that phosphorus uptake was decreased due to aluminium interference in upland rice. The decreased uptake of phosphorus induced by aluminium levels has been reported in cotton by Lance and Pearson (1969). Clarkson (1965) explained that the binding of phosphorus on root surfaced and cell walls of plant roots may be the cause for the decreased uptake of phosphorus.

The three varieties showed significantly variation in phosphorus uptake. The highest phosphorus uptake by grain (72.41 and 73.34 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 72.87 mg pot^{-1}) as well as stover (47.03 and 45.56 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 46.30 mg pot^{-1}) was found in treatment Selection-9 whereas the lowest uptake by grains (59.97 and 58.34 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 59.16 mg pot^{-1}) was recorded in Nagaland local and stover (35.53 and 38.52 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 37.02 mg pot^{-1}) was recorded in Anupam-R.

The interaction effect between aluminium and varieties on phosphorus uptake in seeds and stover of french bean were found to be insignificant.

4.1.3.3 Potassium uptake

The data regarding potassium uptake are presented in table 4.12(a) and depicted in figure 4.7. It is clear from the data that potassium uptake was greatly influenced by the increasing levels of aluminium. Potassium uptake by grains and stover decreased significantly with each increasing aluminium levels in comparison to preceding lower level. Maximum reduction in potassium uptake was recorded under $Al_{0.50}$ level during both the years of experimentation. The highest potassium uptake by grain (157.91 and 152.06 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 154.99 mg pot^{-1}) and stover (46.43 and 46.71 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 46.57 mg pot^{-1}) was recorded in treatment control whereas the minimum uptake (63.27 and 66.95 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 65.11 mg pot^{-1}) in grain and in stover (218.52 and 233.11 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 225.82 mg pot^{-1}) was recorded in treatment $Al_{0.50}$. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased potassium uptake to the extent of 32.51 % and 57.99 % over control in grain while 34.93% and 55.81% in stover.

Narayanan and Syananda (1989) reported that the uptake of K decreased with increase in aluminium levels exceeding 10 ppm in pigeon pea (*Cajanus cajan L.*). Cumming *et al*. (1985) also reported the same in case of red spruce seedlings.

The tested varieties showed significant variation in potassium uptake. The highest potassium uptake by grains (118.03 and 119.88 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 118.95 mg pot^{-1}) as well as stover (374.31 and 382.72 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 378.52) was found in Selection-9 whereas the lowest uptake by grains (98.70 and 96.69 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 97.70 mg pot^{-1}) and stover (330.07 and 336.99 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 33.53 mg pot^{-1}) was recorded in Nagaland local.

The interaction effect presented in table 4.12(b) indicated that there were no significant differences among the treatment combination in grain but in stover, it showed significant variation among the treatment combination during the first year. The highest potassium uptake (535.82 mg pot^{-1}) was obtained from Al_0 V_1. This treatment combination was significantly superior to all the others. The lowest (189.48 mg pot^{-1}) potassium uptake was recorded in $Al_{0.50}V_{3.}$

Table 4.12(a): Effect of aluminium levels and varieties on potassium and sulphur uptake in grain and stover of french bean

Treatments	Nutrient uptake (mg pot^{-1})											
	Potassium						Sulphur					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	157.91	152.06	154.99	521.67	500.48	511.07	54.20	55.49	54.84	46.43	46.71	46.57
$Al_{0.25}$	102.84	106.35	104.59	317.01	348.02	332.52	29.08	31.34	30.21	22.43	27.42	24.92
$Al_{0.50}$	63.27	66.95	65.11	218.52	233.11	225.82	8.96	11.32	10.14	10.87	11.59	11.23
SEm±	3.01	1.83	1.76	3.37	4.26	2.72	1.27	1.22	0.88	2.02	1.74	1.33
CD (p=0.05)	8.94	5.42	5.05	10.01	12.66	7.79	3.77	3.63	2.53	6.01	5.17	3.82
Varieties												
V_1	118.03	119.88	118.95	374.31	382.72	378.52	38.28	38.56	38.42	29.82	30.77	30.30
V_2	107.29	108.79	108.04	352.82	361.91	357.36	29.77	32.62	31.19	22.91	26.49	24.70
V_3	98.70	96.69	97.70	330.07	336.99	333.53	24.20	26.97	25.59	27.00	28.45	27.73
SEm±	3.01	1.83	1.76	3.37	4.26	2.72	1.27	1.22	0.88	2.02	1.74	1.33
CD (p=0.05)	8.94	5.42	5.05	10.01	12.66	7.79	3.77	3.63	2.53	NS	NS	NS

Table 4.12(b): Interaction effect of aluminium levels and varieties on potassium and sulphur uptake in grain and stover of french bean

Aluminium levels	Nutrient uptake (mg pot^{-1})											
	Potassium						Sulphur					
	Grain			Stover			Grain			Stover		
	Varieties											
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
	2017-18											
Al_0	169.41	154.92	149.41	535.82	517.40	511.78	69.20	56.07	37.33	49.44	40.49	49.36
$Al_{0.25}$	116.19	105.23	87.09	338.58	323.49	288.95	35.15	27.11	24.99	25.79	19.97	21.52
$Al_{0.50}$	68.48	61.73	59.60	248.53	217.56	189.48	10.48	6.13	10.28	14.21	8.27	10.12
SEm±	5.21			5.83			2.20			3.50		
CD (p=0.05)	NS			17.33			NS			NS		
	2018-19											
Al_0	161.90	152.33	141.95	526.45	500.13	474.85	63.48	56.17	46.82	50.70	43.01	46.41
$Al_{0.25}$	122.01	108.12	88.91	367.31	349.92	326.83	37.43	30.99	25.61	28.25	26.38	27.63
$Al_{0.50}$	75.73	65.91	59.22	254.40	235.67	209.27	14.78	10.70	8.48	13.37	10.09	11.31
SEm±	3.16			7.38			2.12			3.01		
CD (p=0.05)	NS			NS			NS			NS		
	Pooled											
Al_0	165.66	153.62	145.68	531.14	508.76	493.31	66.34	56.12	42.07	50.07	41.75	47.89
$Al_{0.25}$	119.10	106.67	88.00	352.95	336.71	307.89	36.29	29.05	25.30	27.02	23.17	24.57
$Al_{0.50}$	72.10	63.82	59.41	251.47	226.62	199.38	12.63	8.41	9.38	13.79	9.18	10.72
SEm±	3.05			4.70			1.53			2.31		
CD (p=0.05)	NS			NS			4.38			NS		

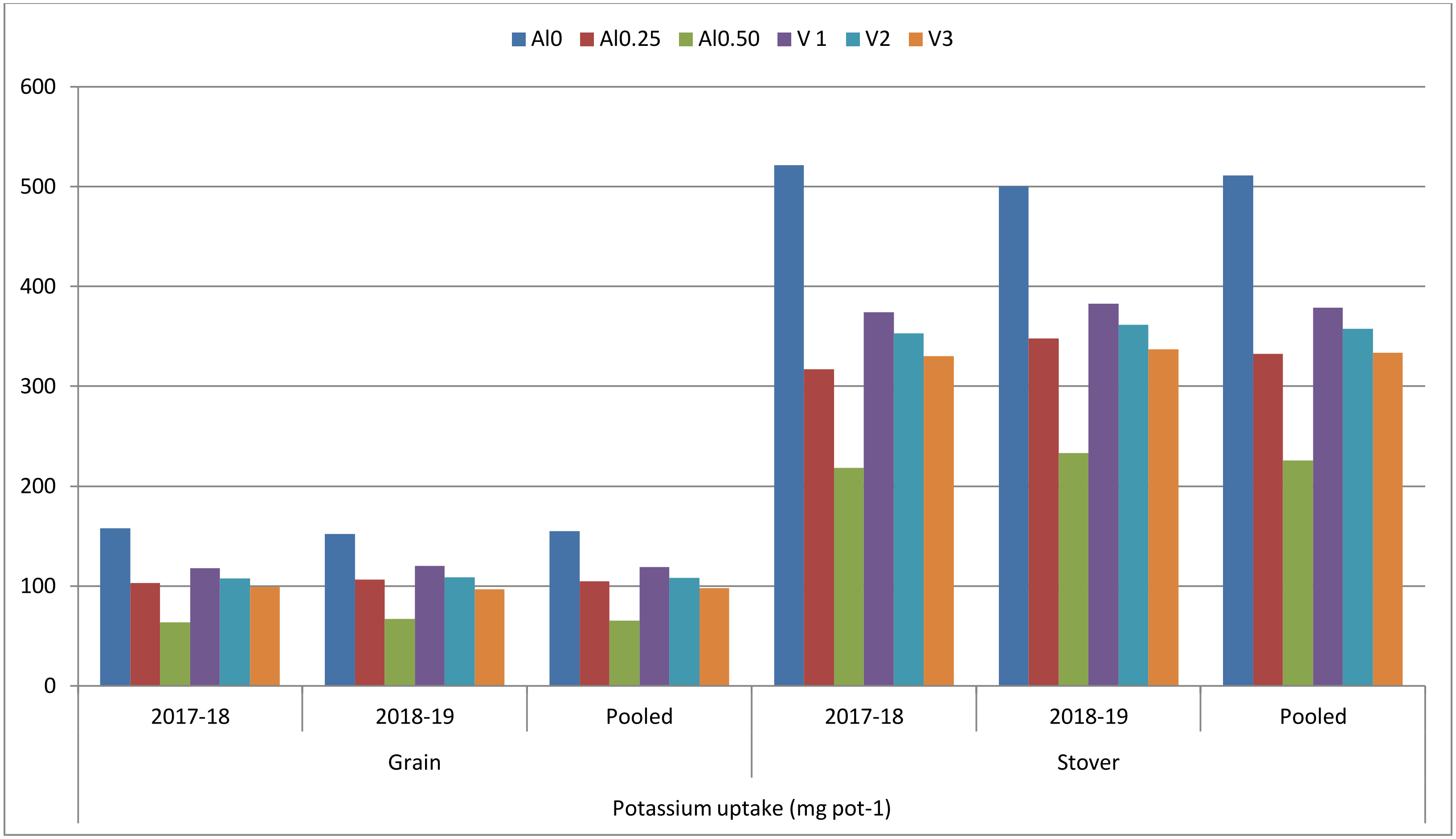

Figure 4.7: Effect of aluminium levels and varieties on potassium uptake in grain and stover of french bean

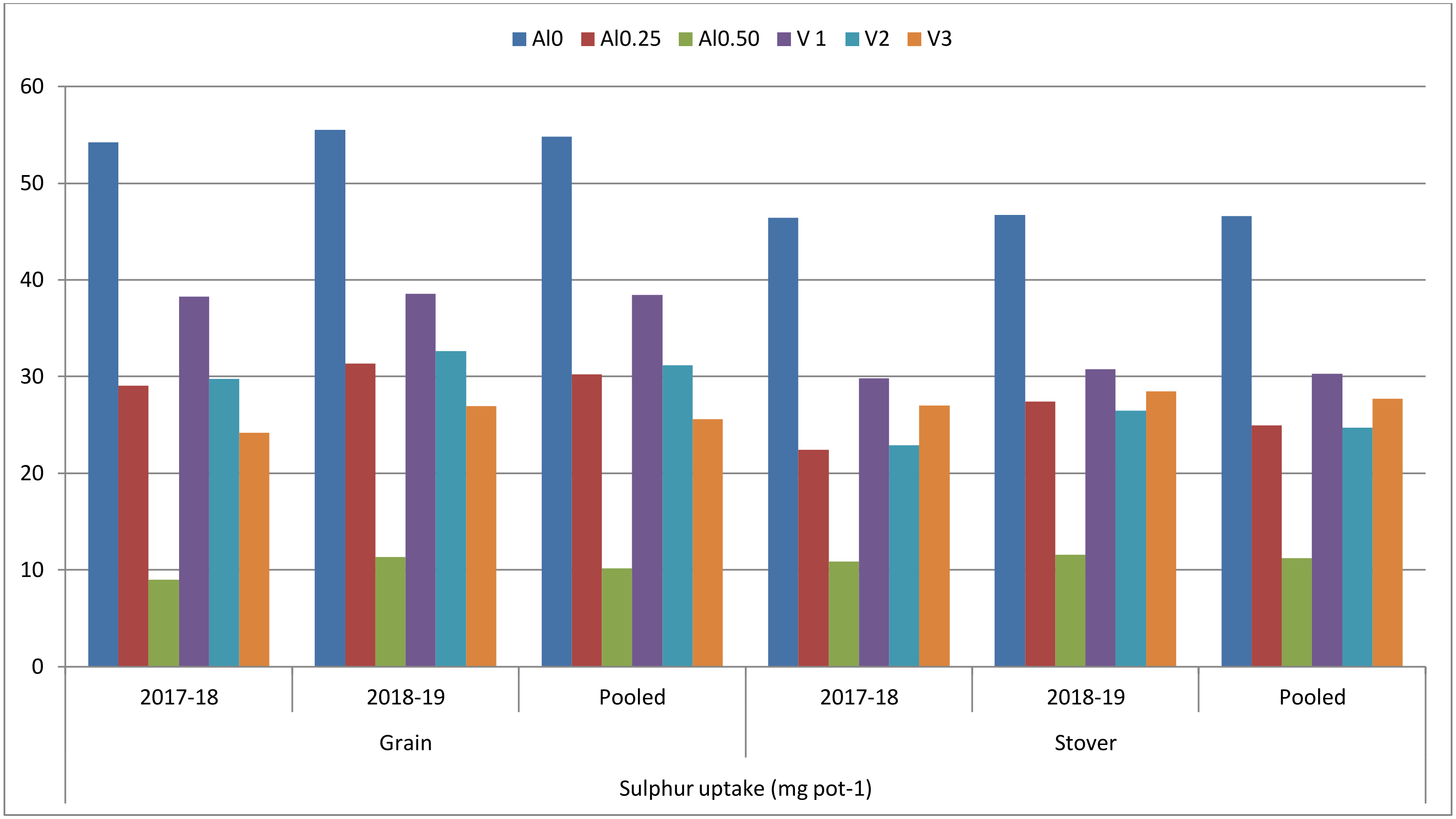

Figure 4.8: Effect of aluminium levels and varieties on sulphur uptake in grain and stover of french bean

4.1.3.4 Sulphur uptake

The data regarding sulphur uptake are presented in table 4.12(a) and depicted figure 4.8. It is clear from the data that sulphur uptake was significantly influenced by aluminium application. Uptake by grains as well as stover decreased significantly with each increasing aluminium levels in comparison to preceding lower level. The highest sulphur uptake by grain (54.20 and 55.49 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 54.84 mg pot^{-1}) and stover(46.43 and 46.71 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 46.57 mg pot^{-1}) was recorded in treatment Al_0 whereas the minimum uptake (8.96 and 11.32 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 10.14 mg pot^{-1}) in grain and in stover (10.87 and 11.59 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 11.23 mg pot^{-1}) was recorded in treatment $Al_{0.50}$. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased sulphur uptake to the extent of 44.91 % and 81.50 % over control in grain while 46.48% and 75.88% in stover on the basis of pooled values.

Alarcón *et al*. (2018) reported that relatively high concentrations of trivalent toxic aluminum (Al^{3+}) may hamper root growth, limiting uptake of nutrients, including sulphur. Furthermore higher concentration of aluminium in soil reduced the sulphur content and yield of french bean caused decrease in sulphur uptake of french bean.

The varieties showed significant difference in sulphur uptake in grain while it did not show any significant differences in stover. The highest sulphur uptake by grains (38.28 and 38.56 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 38.42 mg pot^{-1}) as well as stover (29.82 and 30.77 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 30.30 mg pot^{-1}) was found in Selection-9 whereas the lowest uptake by grain was recorded in Nagaland local during both the years. The interaction effect presented in table 4.12(b) indicated that it showed significant variation among the treatment combination for pooled value only in case of grains with the highest sulphur uptake in Al_0 V_1 (66.34 mg pot^{-1}) and lowest in $Al_{0.50}V_2$ (8.41 mg pot^{-1}).

4.1.3.5 Calcium uptake

The data regarding calcium uptake are presented in table 4.13(a) and depicted in figure 4.9. Calcium uptake by grains as well as stover decreased significantly with each increasing aluminium level in comparison to preceding lower level. The highest calcium uptake by grain (43.28 and 41.83 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 42.55 mg pot^{-1}) and stover (244.24 and 240.54 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 242.39 mg pot^{-1}) was recorded in treatment Al_0 (control) whereas the minimum uptake (7.50 and 8.02 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 7.76 mg pot^{-1}) in grain and in stover (72.74and 78.78 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 75.76 mg pot^{-1}) was recorded in treatment $Al_{0.50}$. On the basis of pooled values, application of $Al_{0.25}$ and $Al_{0.50}$ decreased calcium uptake to the extent of 58.84% and 81.15% over control in grain while 46.31% and 68.74% in stover.

Huang *et al*. (1992) reported that net calcium influx at the root apex was strongly inhibited by Al^{3+}. Furthermore, Ca^{2+} flux was affected to a greater extent than the fluxes of other ions. Nichol and Oliveira (1995) noted that Al^{3+} reduced Ca^{2+} influx in barley (*Hordeum vulgare*). Narayanan and Syananda (1989) noticed that calcium uptake decreased with an increase in aluminium supply even at 10 ppm in pigeonpea (*Cajanus cajan L.*). Aluminium application reduced the calcium content and yield which ultimately decreased its uptake in french bean.

Different varieties of french bean showed significant differences in calcium uptake. The highest calcium uptake by grains (25.40 and 25.39 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 25.39 mg pot^{-1}) as well as stover (159.94 and 162.15 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 161.04 mg pot^{-1}) was found in Selection-9 whereas the lowest uptake by grains (21.29 and 20.64 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 20.97 mg pot^{-1}) and stover (136.96 and 140.20 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 138.58 mg pot^{-1}) was recorded in Nagaland local (V_3).

The interaction effect presented in table 4.13(b) The interaction effects showed significant variation among the treatment combination during the second year only, where it showed highest calcium uptake in grain (46.27 mg pot^{-1}) in the treatment combination of Al_0 V_1 and the lowest calcium uptake (7.30 mg pot^{-1}) was observed in the treatment combination of $Al_{0.50}V_3$ which was at par with $Al_{0.50}V_2$ (7.67 mg pot^{-1}). No significant effect was observed among the treatment combinations in case of stover.

4.1.3.6 Aluminium uptake

The data regarding aluminium uptake are presented in table 4.13(a) and depicted in figure 4.10. The highest aluminium uptake in grain was recorded in $Al_{0.25}$ with 6.05 and 6.23 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 6.14 mg pot^{-1}. The lowest aluminium uptake in grain was recorded in Al_0 with 3.74 and 3.57 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 3.66 mg pot^{-1}. It is clear from the table that, aluminium uptake in grain was increased to the extent of 40.37% by $Al_{0.25}$ while it was reduced by 37.37% at $Al_{0.50}$ over control. The aluminium uptake in stover showed non significant effect.

Andrew *et al.* (1973) reported that increasing solution aluminium concentration often increased aluminium transport to the shoot. Aluminium application increased the aluminium content in grains while reduced the seed yield which resulted in significant increase in aluminium uptake of grains. Different

Table 4.13(a): Effect of aluminium levels and varieties on calcium and aluminium uptake in grain and stover of french bean

Treatments	Calcium (mg pot^{-1})						Aluminium (mg pot^{-1})					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	43.28	41.83	42.55	244.24	240.54	242.39	3.74	3.57	3.66	24.66	24.36	24.51
$Al_{0.25}$	17.31	17.71	17.51	124.83	135.43	130.13	6.05	6.23	6.14	23.45	24.40	23.92
$Al_{0.50}$	7.50	8.02	7.76	72.74	78.78	75.76	5.69	6.00	5.85	23.45	24.25	23.85
SEm±	1.14	0.46	0.61	5.22	3.10	3.03	0.09	0.09	0.06	0.42	0.25	0.24
CD (p=0.05)	3.38	1.37	1.76	15.51	9.20	8.70	0.27	0.27	0.18	NS	NS	NS
Varieties												
V_1	25.40	25.39	25.39	159.94	162.15	161.04	5.68	5.89	5.79	24.99	26.12	25.56
V_2	21.41	21.52	21.47	144.92	152.40	148.66	5.18	5.32	5.25	23.56	24.47	24.02
V_3	21.29	20.64	20.97	136.96	140.20	138.58	4.62	4.60	4.61	23.00	22.41	22.70
SEm±	1.14	0.46	0.61	5.22	3.10	3.03	0.09	0.09	0.06	0.42	0.25	0.24
CD (p=0.05)	3.38	1.37	1.76	15.51	9.20	8.70	0.27	0.27	0.18	1.26	0.74	0.70

Table 4.13(b): Interaction effect of aluminium levels and varieties on calcium and aluminium uptake in grain and stover of french bean

Aluminium levels	Calcium uptake (mg pot^{-1})						Aluminium uptake (mg pot^{-1})					
	Grain			Stover			Grain			Stover		
	Varieties											
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
	2017-18											
Al_0	47.09	41.44	41.31	256.53	232.94	243.24	4.02	3.69	3.53	24.80	24.59	24.58
$Al_{0.25}$	20.99	15.85	15.11	138.36	128.86	107.27	6.89	6.18	5.08	24.21	23.45	22.69
$Al_{0.50}$	8.11	6.93	7.45	84.92	72.95	60.36	6.13	5.69	5.26	25.97	22.64	21.73
SEm±	1.97			9.04			0.16			0.73		
CD (p=0.05)	NS			NS			0.47			NS		
	2018-19											
Al_0	46.27	39.82	39.40	253.45	241.12	227.06	3.77	3.63	3.32	25.59	24.50	22.97
$Al_{0.25}$	20.80	17.09	15.24	143.81	137.05	125.43	7.15	6.35	5.20	26.07	24.40	22.71
$Al_{0.50}$	9.10	7.67	7.30	89.19	79.04	68.10	6.76	5.96	5.28	26.71	24.51	21.53
SEm±	0.80			5.36			0.16			0.43		
CD (p=0.05)	2.37			NS			0.47			NS		
	Pooled											
Al_0	46.68	40.63	40.35	254.99	237.03	235.15	3.90	3.66	3.43	25.19	24.55	23.78
$Al_{0.25}$	20.89	16.47	15.17	141.09	132.95	116.35	7.02	6.27	5.14	25.14	23.92	22.70
$Al_{0.50}$	8.60	7.30	7.38	87.05	76.00	64.23	6.45	5.82	5.27	26.34	23.58	21.63
SEm±	1.06			5.25			0.11			0.42		
CD (p=0.05)	NS			NS			0.32			1.22		

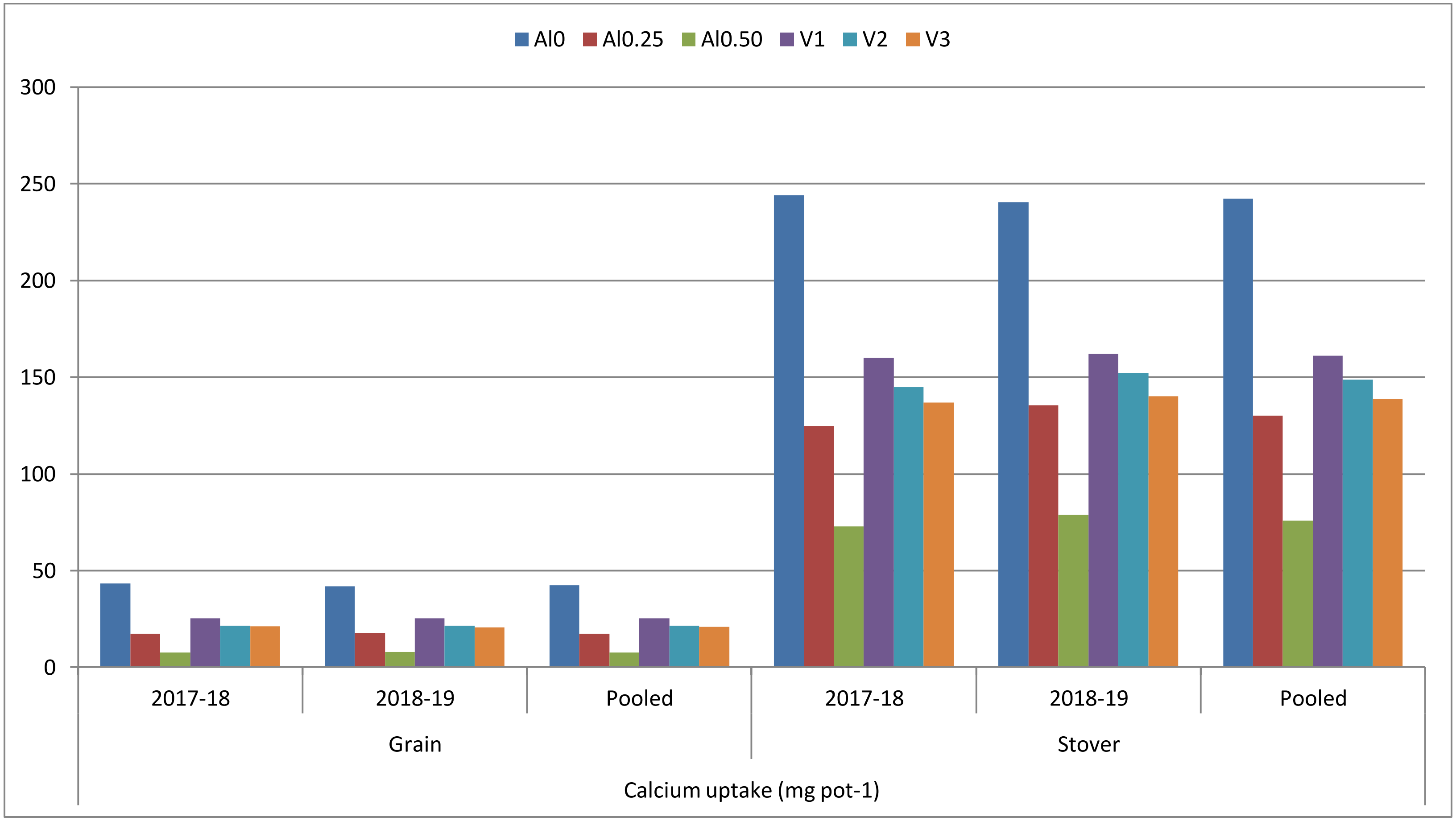

Figure 4.9: Effect of aluminium levels and varieties on calcium uptake in grain and stover of french bean

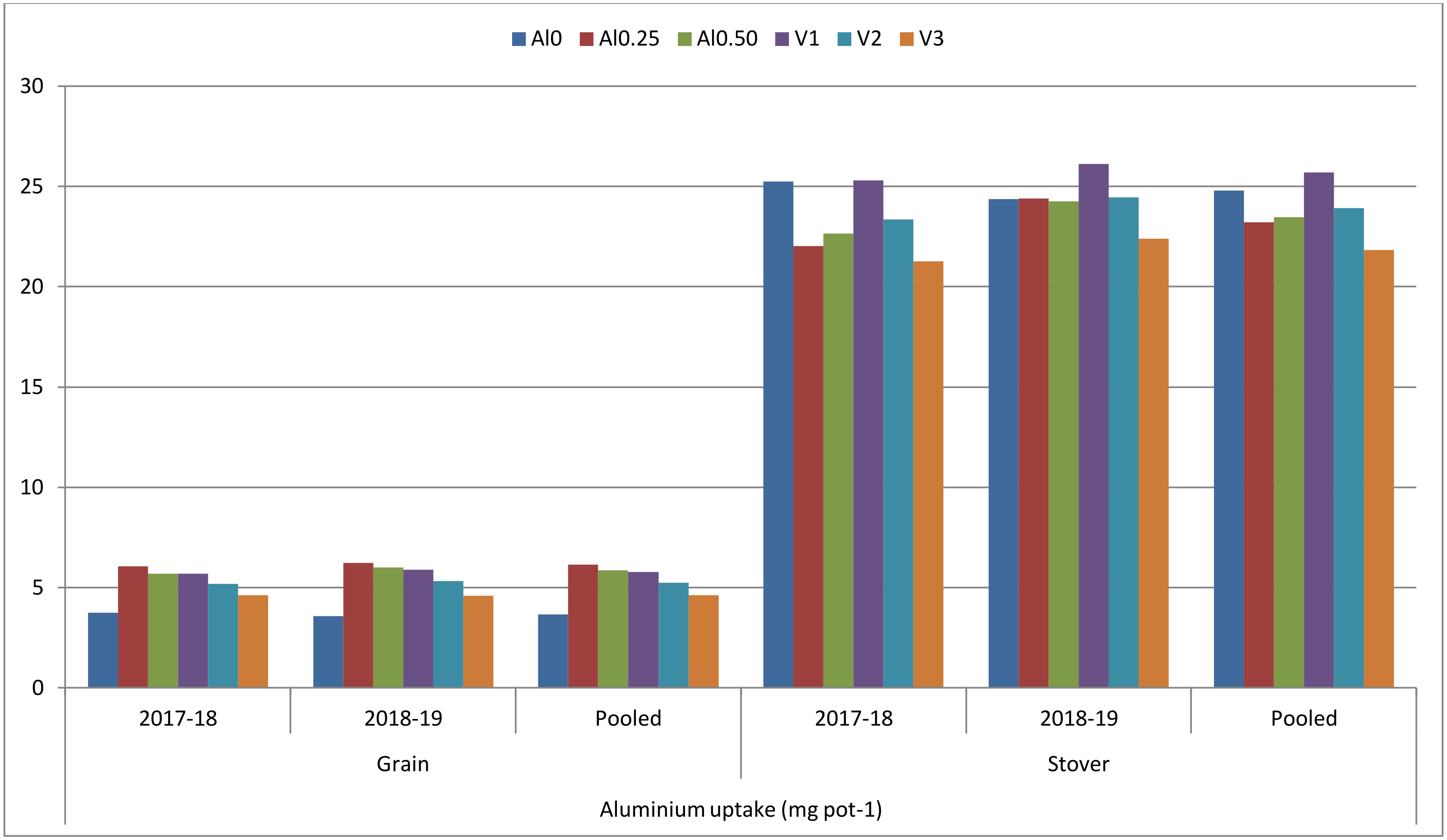

Figure 4.10: Effect of aluminium levels and varieties on aluminium uptake in grain and stover of french bea

varieties of french bean showed significant difference in aluminium uptake. The highest aluminium uptake by grains (5.68 and 5.89 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.79 mg pot^{-1}) was recorded in Selection-9 whereas the lowest uptake (4.62 and 4.60 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 4.61 mg pot^{-1}) was recorded in Anupam-R. The highest aluminium uptake in stover was recorded from Selection-9 with 24.99 and 26.12 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 25.56 mg pot^{-1} and lowest was obtained in Nagaland local with 23.00 and 22.41 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 22.70 mg pot^{-1}). Interaction effect of aluminium levels and varieties on aluminium uptake by grain showed significant effect while aluminium uptake in stover showed non significant effect during both the years. $Al_{0.25}V_1$ was recorded with highest aluminum uptake in grain with 6.89 and 7.15 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 7.02 mg pot^{-1} while lowest aluminum uptake in grain was recorded in the treatment combination of Al_0V_3 with 3.53 and 3.32 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 3.43 mg pot^{-1}.

4.1.3.7 Aluminium content in root of french bean

The results obtained on the aluminium content in root of french bean in different treatment has been presented in table 4.14. As shown in the data, increased level of aluminium resulted in increasing aluminium content in roots of french bean. The maximum aluminium content in root was recorded in $Al_{0.50}$ with 15161.93 and 15160.95 mg kg^{-1}during 2017-18 and 2018-19, respectively with pooled value of 15161.44 mg kg^{-1}. The lowest aluminium content was observed in Al_0 with 6060.13 and 6058.95 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 6059.54 mg kg^{-1}. The $Al_{0.25}$ and $Al_{0.50}$ levels of aluminium increased the aluminium content in root by 45.70% and 60.03% over control

Table 4.14: Effect of aluminium levels and varieties on aluminium content in root of french bean

Treatments	Aluminium content (mg kg^{-1})		
	2017-18	**2018-19**	**Pooled**
Aluminium levels			
Al_0	6060.13	6058.95	6059.54
$Al_{0.25}$	11161.78	11159.49	11160.64
$Al_{0.50}$	15161.93	15160.95	15161.44
SEm±	11.25	11.23	7.95
CD (p=0.05)	33.44	33.37	22.80
Varieties			
V_1	10793.08	10791.97	10792.52
V_2	10794.57	10792.69	10793.63
V_3	10796.19	10794.74	10795.47
SEm±	11.25	11.23	7.95
CD (p=0.05)	NS	NS	NS

respectively. These results were in accordance with the findings of Thangavel (2002) in mung bean. Whereas the varieties did not have any significant effect on aluminium content in root of french bean.

4.1.4 EFFECT ON SOIL PROPERTIES

4.1.4.1 Soil pH and organic carbon

The result obtained on the soil pH and organic carbon in the soil after harvest in different treatment has been presented in table 4.15. From the data, the maximum pH of the soil after harvest was recorded under Al_0 with 5.52 and 5.46 during 2017-18 and 2018-19 respectively, with pooled value of 5.49 and the lowest pH value was recorded under $Al_{0.50}$ with 4.58 and 4.65 during 2017-18 and 2018-19 respectively, with pooled value of 4.61. With regard to organic carbon content, the effect of levels of aluminium was found statistically non-significant on soil organic carbon as shown in table 4.15.

Batista *et al*. (2009) reported that the pH values decreased in proportion to an increase in the aluminium concentration values. Pintro *et al*. (2004) worked with a clayey soil and observed that with every increase in aluminium levels there was a decrease in soil pH which may be because of the reason that aluminium in the soil hydrolyses with release of H^{+1} in soil solution and thereby develops soil acidity (lower pH).

Further, the table also show the effect of varieties on the soil pH and organic carbon in the soil after harvest. The varieties did not have any significant effect both on pH and organic carbon, however the highest pH (5.22) and organic carbon (19.8 g kg^{-1}) in pooled values was observed in V_2.

4.1.4.2 Available NPKS

The data regarding available nutrient content in the soil after crop harvest are presented in table 4.16(a). It is clear from the table that, with increasing

Table 4.15: Effect of aluminium levels and varieties on pH and organic carbon of post experimental soil

Treatments	pH			Organic carbon(g kg^{-1})		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels						
Al_0	5.52	5.46	5.49	2.02	2.02	2.02
$Al_{0.25}$	5.12	5.25	5.18	1.91	1.95	1.93
$Al_{0.50}$	4.58	4.65	4.61	1.86	1.93	1.90
SEm±	0.10	0.08	0.06	0.05	0.03	0.03
CD (p=0.05)	0.31	0.24	0.19	NS	NS	NS
Varieties						
V_1	5.05	5.05	5.05	19.6	18.9	19.2
V_2	5.15	5.20	5.22	20.2	19.4	19.8
V_3	5.01	5.12	5.07	17.8	19.5	18.7
SEm±	0.10	0.08	0.06	0.7	0.5	0.04
CD (p=0.05)	NS	NS	NS	NS	NS	NS

Table 4.16(a): Effect of aluminium levels and varieties on available nutrients status of post experimental soil

Treatments	Available nutrients (kg ha^{-1})											
	Nitrogen			Phosphorus			Potassium			Sulphur		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	244.7	248.0	246.3	13.2	14.6	13.9	176.4	179.1	177.7	18.8	20.4	19.6
$Al_{0.25}$	234.4	239.3	236.8	10.3	11.7	11.0	166.1	169.6	167.8	14.6	16.6	15.6
$Al_{0.50}$	225.3	228.3	226.8	9.2	10.8	10.0	158.2	161.3	159.7	12.1	14.1	13.1
SEm±	0.41	1.89	0.97	0.18	0.72	0.37	0.29	1.85	0.94	0.86	1.47	0.85
CD (p=0.05)	1.22	5.61	2.77	0.55	2.13	1.06	0.85	5.51	2.69	2.56	4.36	2.44
Varieties												
V_1	229.0	233.0	231.0	10.4	11.8	11.1	167.1	169.6	168.4	15.5	16.9	16.2
V_2	236.1	240.4	238.2	11.0	12.4	11.7	169.4	170.6	170.0	14.8	16.8	15.8
V_3	239.4	242.2	240.8	11.4	12.9	12.1	164.1	169.7	166.9	15.2	17.2	16.2
SEm±	0.41	1.89	0.97	0.18	0.72	0.37	0.29	1.85	0.94	0.86	1.47	0.85
CD (p=0.05)	1.22	5.61	2.77	0.55	NS	NS	0.85	NS	NS	NS	NS	NS

Table 4.16(b): Interaction effect of aluminium levels and varieties on available nutrients status of post experimental soil

Aluminium levels	Available nutrients (kg ha^{-1})								
	Nitrogen			Phosphorus			Potassium		
	Varieties								
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
	2017-18								
Al_0	238.3	245.2	250.5	12.6	12.0	15.0	176.9	178.9	173.4
$Al_{0.25}$	229.7	235.9	237.6	9.0	11.2	10.0	167.2	168.9	162.3
$Al_{0.50}$	218.9	227.1	230.0	8.9	9.9	9.0	157.4	160.5	156.8
SEm±	0.71			0.32			0.50		
CD (p=0.05)	2.11			0.95			1.47		
	2018-19								
Al_0	241.1	250.9	252.0	13.9	14.4	15.4	178.6	179.6	179.1
$Al_{0.25}$	235.0	240.3	242.6	10.9	11.9	12.3	169.6	170.6	168.5
$Al_{0.50}$	223.1	230.0	231.9	10.6	10.8	11.1	160.6	161.7	161.5
SEm±	3.27			1.24			3.21		
CD (p=0.05)	NS			NS			NS		
	Pooled								
Al_0	239.7	248.1	251.3	13.2	13.2	15.2	177.7	179.2	176.2
$Al_{0.25}$	232.3	238.1	240.1	10.4	11.5	11.2	168.4	169.7	165.4
$Al_{0.50}$	221.0	228.5	231.0	9.7	10.3	10.0	159.0	161.1	159.1
SEm±	1.67			0.64			1.62		
CD (p=0.05)	NS			NS			NS		

aluminium levels, there was a significant decrease in all the available nutrients. The highest available nitrogen was recorded in Al_0 with 244.7 and 248.0 kg ha^{-1} during 2017 and 2018, respectively with a pooled value of 246.3 kg ha^{-1}and the lowest was recorded in $Al_{0.50}$ with 225.3 and 228.3 kg ha^{-1}during 2017-18 and 2018-19, respectively with pooled value of 226.8. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the soil available nitrogen by 9.5 kg ha^{-1} and 19.5 kg ha^{-1} over control.

Decrease in nitrogen content might be due to reduction of nitrification that transformed NH_4^+ to NO_3^- , because activities of microbs are reduced in aluminium stress condition and soil nitrogen transformations are controlled by microbes. Most microbes are very sensitive to aluminium (Pina and Cervantes, 1996).

Varieties showed significant effect on available nitrogen content in soil after harvest. The highest nitrogen content in soil was recorded from Nagaland local with 239.4 and 240.2 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 240.8 kg ha^{-1}. The lowest was recorded in Selectioon-9 with 229.0 and 233.0 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 231.0 kg ha^{-1}.

The treatment combination effect of different aluminium levels and varieties on available nitrogen content is presented on table 4.16(b). There was a significant difference among the treatment combinations, the highest nitrogen content was observed in the combination treatment of Al_0V_3 with 250.57 and 252.07 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 251.32 kg ha^{-1}. The lowest was recorded in $Al_{0.50}$ V_1 with 218.95 and 223.12 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 221.03 kg ha^{-1}.

The data on available phosphorus content of soil given in table 4.16(a) revealed that the available phosphorus of the soil decreased with increasing aluminium levels. The maximum available phosphorus was recorded in Al_0 with 13.2 and 14.6 during 2017 and 2018, respectively with a pooled value of 13.9 and the lowest was recorded in $Al_{0.50}$ with 9.2 and 10.8 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 10.0. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the soil available phosphorus by 2.8 and 3.8 kg ha^{-1} over control.

Thangavel (2002) was of the view that decreasing trend recorded in the phosphorus content of the soil may be due to its precipitation as aluminium phosphate, at a pH below 5.5 (acidic) both iron and aluminum precipitate phosphorus.

Varieties showed significant difference on available phosphorus content in soil after harvest only during the first year of experimentation. The highest phosphorus content in soil was recorded in V_3 with 11.4 kg ha^{-1} and the lowest was recorded in V_1 with 10.4 kg ha^{-1} during 2017-18.

The treatment combination effect of different aluminium levels and varieties on available phosphorus content is presented on table 4.16(b). There was a significant difference among the treatment combinations, the highest phosphorus content was observed in the treatment combination of Al_0 V_3 with 15.0 and 15.4 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 15.2 kg ha^{-1}. The lowest was recorded in $Al_{0.50}$ V_1 with 8.9 and 10.6 kg ha^{-1} during 2017-18 and 2018-19 respectively with pooled value of 9.0 kg ha^{-1}.

The data presented in table 4.16(a) indicate that the available potassium content of the soil decreased with increasing aluminium levels. The maximum available potassium was recorded in Al_0 with 176.4 and 179.1 kg ha^{-1} during 2017 and 2018, respectively with a pooled value of 177.7 kg ha^{-1} and the lowest was recorded in $Al_{0.50}$ with 158.2 and 161.3 kg ha^{-1}during 2017-18 and 2018-19 respectively with pooled value of 159.7. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the soil available potassium by 9.88 and 17.8 kg ha^{-1} over control.

The increase in the concentration of hydrogen ions (though less in magnitude) and $Al(OH)_2$ naturally displace the macronutrients Na, K, Ca and Mg from their exchange sites thereby paving the way for their loss due to leaching. Accumulation of most divalent cations is reported to be reduced when plants are exposed to aluminium (Clarkson and Sanderson, 1971; Schier, 1985; Ryan *et al*., 1986).

The different varieties showed significant effect only during the first year. Among the varieties, the highest available potassium content in soil was recorded in Anupam-R with 169.4 and 170.6 kg ha^{-1} during 2017 and 2018, respectively with a pooled value of 168.5 and the lowest was recorded in Nagaland local with 164.1 and 169.7 kg ha^{-1}during 2017-18 and 2018-19, respectively with pooled value of 166.9 kg ha^{-1}.

The treatment combination effects of different aluminium levels and varieties on available potassium content are presented on table no. 4.16(b). There was a significant difference among the treatment combinations only during the first year, the highest potassium content was observed in the combination treatment of Al_0 V_1 with 176.9 and the lowest was recorded in $Al_{0.50}$ V_1 with 157.4 during 2017-18.

The data on available sulphur content of soil given in table 4.16 (a) revealed that the available sulphur of the soil decreased with increasing aluminium levels. The maximum available sulphur was recorded in Al_0 with 18.8 and 20.4 kg ha^{-1} during 2017 and 2018, respectively with a pooled value of 19.6 kg ha^{-1} and the lowest was recorded in $Al_{0.50}$ with 12.1 and 14.1 kg ha^{-1}during 2017-18 and 2018-19 respectively with pooled value of 13.1 kg ha^{-1}. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the soil available sulphur by 4.02 and 6.53 kg ha^{-1} over control.

Varieties didn’t show significant difference on available sulphur content in soil after harvest.

The interaction effect of different aluminium levels and varieties on available sulphur was found to be non significant.

4.1.4.3 Exchangeable calcium, exchangeable aluminium and total potential acidity

The data obtained on exchangeable calcium, exchangeable aluminium and total potential acidity are presented on table 4.17. The highest exchangeable Ca was found in Al_0 with 3.28 and 3.24 cmol (p^+) kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 3.26 and the lowest was recorded in $Al_{0.50}$ with 2.39 and 2.38 c mol (p^+) kg^{-1}during 2017-18 and 2018-19, respectively with pooled value of 2.39 c mol (p^+) kg^{-1}.

Illera *et al*. (2004) reported that exchangeable calcium generally competes with aluminium for exchange sites and replaces aluminium, thereby increasing their stand and availability. Studies have also reported that calcium amendments are commonly used to reduce aluminium in soil or ameliorate aluminium toxicity through the process of cation exchange or replacement (Mora *et al*., 2002; Rengel and Zhang, 2003). This possibly explained why the higher dose of aluminium led to a decrease in exchangeable calcium.

There was no significant effect among the varieties on exchangeable calcium content of soil. The interaction effect of aluminium and varieties on exchangeable calcium content of soil were found to be non significant.

The data on exchangeable aluminium content of soil given in table 4.17 and figure 4.11 revealed that the highest exchangeable aluminium was found in $Al_{0.50}$ with 3.27 and 3.81 cmol (p^+) kg^{-1} during 2017-18 and 2018-19 respectively with pooled value of 3.54 cmol (p^+) kg^{-1} and the lowest was recorded in Al_0 with 1.72 and 1.95 cmol (p^+) kg^{-1}during 2017-18 and 2018-19 respectively with pooled value of 1.83 cmol (p^+) kg^{-1}. It is evidently clear that the increment in exchangeable aluminium could well be attributed to the addition of aluminium and

Table 4.17: Effect of aluminium levels and varieties on exchangeable calcium, exchangeable aluminium and total potential acidity of post experimental soil

Treatments	Exchangeable Ca cmol (p^+) kg^{-1}			Exchangeable Al cmol (p^+) kg^{-1}			Total potential acidity cmol (p^+) kg^{-1}		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Aluminium levels									
Al_0	3.28	3.24	3.26	1.72	1.95	1.83	10.67	10.70	10.69
$Al_{0.25}$	2.83	2.70	2.77	2.29	3.04	2.66	12.36	12.44	12.40
$Al_{0.50}$	2.39	2.38	2.39	3.27	3.81	3.54	14.69	14.76	14.72
SEm±	0.12	0.10	0.08	0.13	0.29	0.16	0.28	0.28	0.20
CD (p=0.05)	0.36	0.29	0.22	0.38	0.86	0.45	0.83	0.84	0.57
Varieties									
V_1	2.86	2.78	2.82	2.33	2.87	2.60	12.47	12.55	12.51
V_2	2.78	2.73	2.75	2.40	2.88	2.64	12.54	12.61	12.58
V_3	2.86	2.82	2.84	2.54	3.04	2.79	12.70	12.74	12.72
SEm±	0.12	0.10	0.08	0.13	0.29	0.16	0.28	0.28	0.20
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

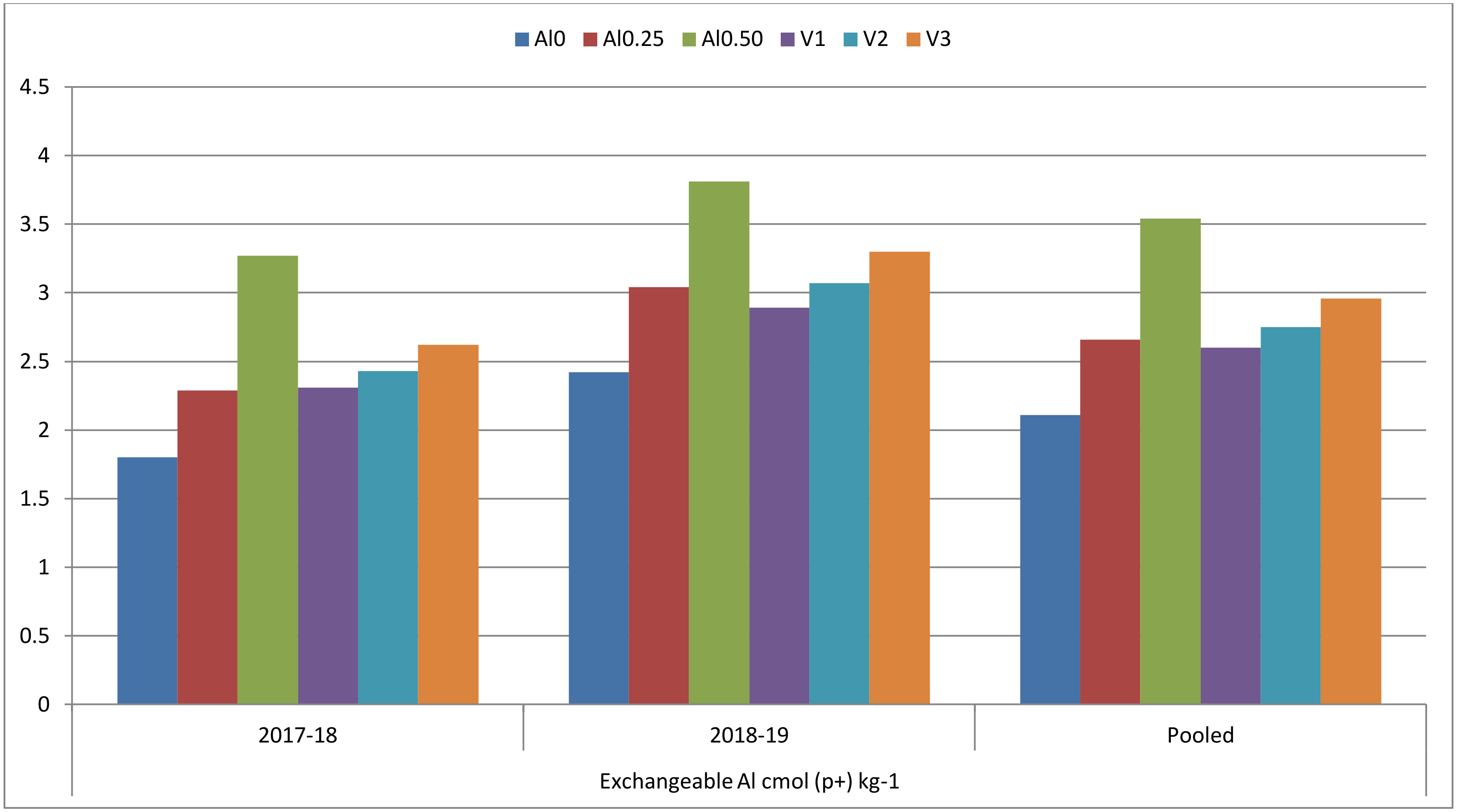

Fig 4.11: Effect of aluminium levels and varieties on exchangeable aluminium in post harvest soil

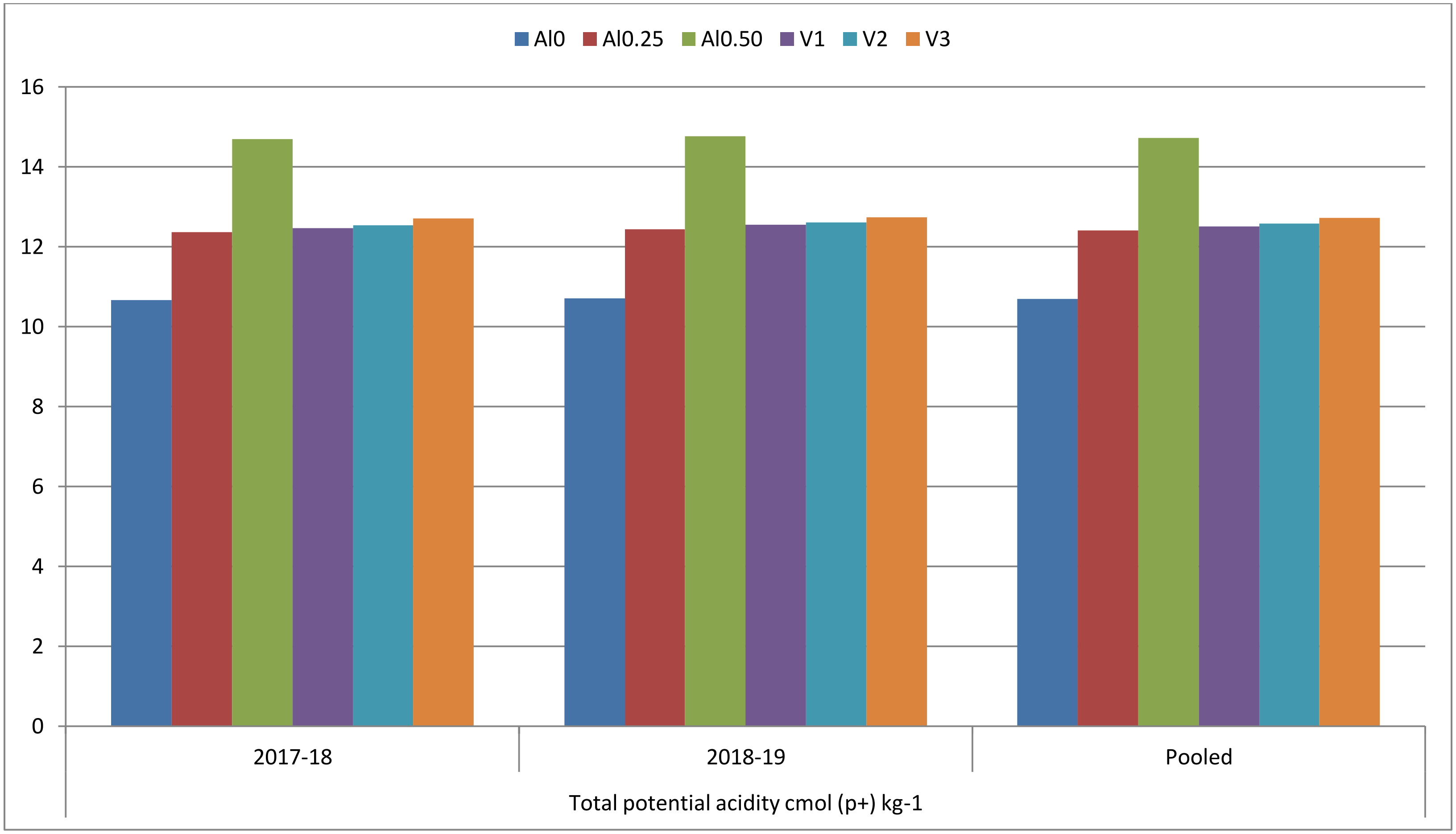

Fig 4.12: Effect of aluminium levels and varieties on total potential acidity in post harvest soil

thus their availability. There was no significant effect among the varieties on exchangeable aluminium content of soil. The interaction effect of aluminium and varieties on exchangeable aluminium content of soil were found to be non significant.

The data on total potential acidity of soil given in table 4.17 and figure 4.12 revealed that the highest total potential acidity was found in $Al_{0.50}$ with 14.69 and 14.76 cmol (p^{+}) kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 14.72 and the lowest was recorded in Al_0 with 10.67 and 10.70 c mol (p^{+}) kg^{-1}during 2017-18 and 2018-19, respectively with pooled value of 10.69 cmol (p^{+}) kg^{-1}. It is evidently clear that the increment in total potential acidity could well be attributed to the addition of aluminium and thus their availability. There was no significant effect among the varieties on exchangeable aluminium content of soil. The interaction effect of aluminium and varieties on total potential acidity of soil were found to be non significant.

4.2 TO STUDY THE PHOSPHORUS AND SULPHUR REQUIREMENT OF FRENCH BEAN UNDER DIFFERENT LEVELS OF ALUMINIUM (Experiment 2)

4.2.1 Effect on growth and yield

4.2.1.1 Days to germination

The data recorded on number of days to germination are presented in table 4.18. The data indicate that days to germination increased with increase in aluminium levels. During both the years, minimum number of days to germination was recorded in the control with 3.50 and 3.48 days during 2017-18 and 2018-19 with pooled value of 3.48. This was followed by

$Al_{0.25}$ with 3.87 and 3.89 days during 2017-18 and 2018-19 while pooled was 3.89 days. It showed that the days to germination were increased by 11.78% due to $Al_{0.25}$ over control.

Table 4.18: Effect of aluminium, phosphorus and sulphur levels on days to germination

Treatments	Days to germination		
	2017-18	**2018-19**	**Pooled**
Aluminium levels			
Al_0	3.50	3.48	3.48
$Al_{0.25}$	3.87	3.89	3.89
SEm±	0.1	0.1	0.1
CD (p=0.05)	0.29	0.29	0.29
Phosphorus levels			
P_0	3.73	3.67	3.67
P_{30}	3.62	3.67	3.64
P_{60}	3.56	3.56	3.56
P_{90}	3.89	3.84	3.87
SEm±	0.14	0.14	0.14
CD (p=0.05)	NS	NS	NS
Sulphur levels			
S_0	3.71	3.63	3.63
S_{30}	3.59	3.59	3.59
S_{60}	3.80	3.84	3.84
SEm±	0.12	0.12	0.12
CD (p=0.05)	NS	NS	NS

It is suggested that aluminium toxicity induced increase in accumulation of Cl^- and Al^{3+} with the concomitant decrease in K^+ accumulation in the radicle and plumule might be responsible for Al-induced inhibition of germination of seeds (*Samad et al.*, 2017).

The effects of phosphorus and sulphur on days to germination are given in table 4.18 which show that phosphorus and sulphur application did not show any significant effect on days to germination.

There was no significant difference among the different treatment combination of aluminium, phosphorus and sulphur on days to germination.

4.2.1.2 Plant height

The data recorded on plant height are presented in table 4.19(a) and depicted in figure 4.13. The data indicate that plant height of french bean decreased with increasing aluminium levels at all the three observation stage. As observed from the data, the maximum plant height was recorded in Al_0 with 24.22 and 23.51 cm, 32.98 and 34.46 cm, 36.73 and 35.37 cm at 30, 60 DAS and at harvest, respectively during 2017-18 and 2018-19 while pooled value was 23.87, 33.72 and 36.05 cm. Minimum plant height was observed under $Al_{0.25}$ (0.25 cmol kg^{-1} Al) with 19.67 and 18.31 cm, 27.75 and 26.53 cm, 28.39 and 29.04 cm during 2017-18 and 2018-19 at 30, 60 DAS and at harvest respectively while pooled was 18.99, 2.71 and 29.91 cm.

Increase in aluminium levels up to $Al_{0.25}$ decreased the plant height by 17.03% over the control. These finding are in accordance with the findings of Kenechukwu *et al*. (2007) who reported that aluminum treatments influenced growth of cowpea plants in that untreated plants were insignificantly taller than those treated with aluminium in the first four weeks of growth. The decrease in plant height may be due to the reason that aluminium was considerably deposited

Table 4.19(a): Effect of aluminium, phosphorus and sulphur levels on plant height of french bean

Treatments	Plant height (cm)								
	30 DAS			60 DAS			At harvest		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels									
Al_0	24.22	23.51	23.87	32.98	34.46	33.72	36.73	35.37	36.05
$Al_{0.25}$	19.67	18.31	18.99	28.39	29.04	28.71	28.99	30.84	29.91
SEm±	0.39	0.08	0.2	0.34	0.88	0.43	0.97	0.36	0.47
CD (p=0.05)	1.11	0.23	0.57	0.97	2.50	1.23	2.76	1.03	1.34
Phosphorus levels									
P_0	20.02	19.80	19.91	28.56	28.57	28.57	29.32	29.65	29.49
P_{30}	21.5	20.90	21.2	29.53	30.61	30.07	31.79	32.57	32.18
P_{60}	24.68	21.46	23.07	31.69	33.41	32.55	34.10	34.50	34.30
P_{90}	21.58	21.49	21.53	32.96	34.39	33.68	36.22	35.70	35.96
SEm±	0.55	0.11	0.28	0.48	1.25	0.61	1.37	0.50	0.66
CD (p=0.05)	1.57	0.32	0.8	1.37	3.55	1.74	3.89	1.42	1.88
Sulphur levels									
S_0	21.63	20.72	21.17	29.72	29.52	29.62	30.33	31.34	30.84
S_{30}	22.27	20.97	21.62	30.79	31.97	31.38	32.97	33.26	33.12
S_{60}	21.93	21.04	21.49	31.54	33.75	32.65	35.28	34.72	35.00
SEm±	0.48	0.09	0.25	0.42	1.08	0.53	1.19	0.44	0.58
CD (p=0.05)	NS	0.26	NS	1.20	3.07	1.51	3.38	1.25	1.65

Table 4.19(b): Interaction effect of aluminium and phosphorus on plant height of french bean

Aluminium levels	30 DAS			
	Phosphorus levels			
	P_0	P_{30}	P_{60}	P_{90}
	2017-18			
Al_0	20.85	23.55	27.52	24.96
$Al_{0.25}$	19.19	19.44	21.82	18.19
SEm±	0.81			
CD (p=0.05)	2.29			
	2018-2019			
Al_0	21.82	23.28	24.79	24.14
$Al_{0.25}$	17.77	18.51	18.12	18.82
SEm±	0.15			
CD (p=0.05)	0.42			
	Pooled			
Al_0	21.33	23.41	26.16	24.55
$Al_{0.25}$	18.48	18.98	19.97	18.51
SEm±	0.41			
CD (p=0.05)	1.15			

Table 4.19(c): Interaction effect of aluminium and sulphur on plant height of french bean

Aluminium levels	30 DAS		
	Sulphur		
	S_0	S_{30}	S_{60}
	2017-18		
Al_0	23.63	24.72	24.32
$Al_{0.25}$	19.62	19.82	19.54
SEm±	0.70		
CD (p=0.05)	NS		
	2018-2019		
Al_0	23.10	23.66	23.77
$Al_{0.25}$	18.32	18.28	18.31
SEm±	0.13		
CD (p=0.05)	0.36		
	Pooled		
Al_0	23.36	24.19	24.04
$Al_{0.25}$	18.97	19.05	18.93
SEm±	0.35		
CD (p=0.05)	NS		

Table 4.19(d): Interaction effect of phosphorus and sulphur on plant height of french bean

Phosphorus levels	30 DAS		
	Sulphur		
	S_0	S_{30}	S_{60}
	2017-18		
P_0	19.88	20.68	19.50
P_{30}	20.66	21.43	22.39
P_{60}	23.77	24.68	25.57
P_{90}	22.19	22.28	20.26
SEm±	0.99		
CD (p=0.05)	NS		
	2018-19		
P_0	19.51	19.89	19.98
P_{30}	20.73	20.95	21.00
P_{60}	21.61	21.13	21.62
P_{90}	20.99	21.90	21.55
SEm±	0.18		
CD (p=0.05)	0.51		
	Pooled		
P_0	19.69	20.29	19.74
P_{30}	20.69	21.19	21.70
P_{60}	22.69	22.91	23.59
P_{90}	21.59	22.09	20.90
SEm±	0.50		
CD (p=0.05)	NS		

Table 4.19(e): Interaction effect of aluminium, phosphorus and sulphur on plant height of french bean

Phosphorus levels	**30 DAS**					
	Al_0			**$Al_{0.25}$**		
	S_0	**S_{30}**	**S_{60}**	**S_0**	**S_{30}**	**S_{60}**
	2017-18					
P_0	20.50	21.26	20.78	19.25	20.10	18.22
P_{30}	22.65	23.48	24.51	18.67	19.38	20.28
p_{60}	26.26	27.78	28.53	21.29	21.57	22.60
P_{90}	25.10	26.34	23.44	19.28	18.21	17.07
SEm±	1.40					
CD (p=0.05)	NS					
	2018-19					
P_0	21.74	21.86	21.84	17.27	17.91	18.11
P_{30}	22.87	23.17	23.78	18.58	18.73	18.22
p_{60}	24.44	24.82	25.11	18.78	17.44	18.12
P_{90}	23.33	24.76	24.33	18.65	19.04	18.77
SEm±	0.26					
CD (p=0.05)	0.73					
	Pooled					
P_0	21.12	21.56	21.31	18.26	19.01	18.17
P_{30}	22.76	23.33	24.15	18.63	19.06	19.25
p_{60}	25.35	26.30	26.82	20.04	19.51	20.36
P_{90}	24.22	25.55	23.89	18.97	18.63	17.92
SEm±	0.71					
CD (p=0.05)	NS					

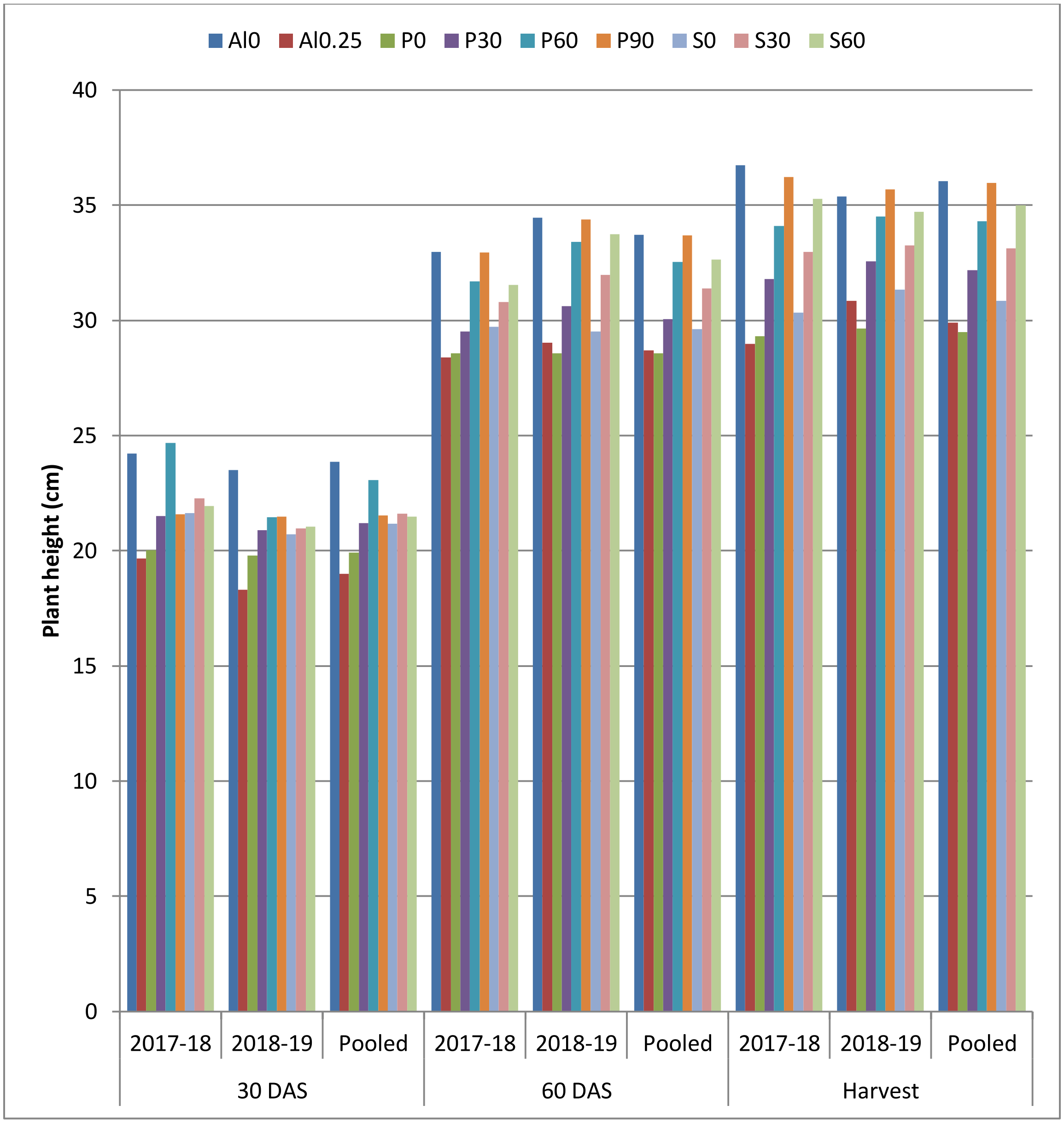

Figure 4.13: Effect of aluminium, phosphorus, sulphur levels and varieties on plant height of french bean

in the root tips and might have reduced the cell divsion, the root elongation was retarded and finally top growth inhibited.

These results are in accordance with Wagatsuma *et al*. (1987) and Sivasubramaniam and Talibudeen (1971). According to Farias *et al*. (2011), increasing aluminium levels in the nutrient solution led to a decline in the shoot and root dry matter production. The result are in accordance with the findings of Thangavel (2002) who reported that as a response to aluminium toxicity, the calcium content in both plant parts and soil became deficient. Calcium is a constituent of the middle lamella of each cell wall and it tends to make cells more selective in their absorption of nutrients. Rapidly growing root tips are especially high in calcium, indicating that calcium is needed in large quantities for cell division. Therefore, the reduction recorded in the growth related parameters may also be the consequence of the observed reduction in the calcium levels in plant parts induced by aluminium.

The data presented in table 4.19(a) further indicate that plant height of french bean at harvest increased upto P_{90} level. At 30 days, significantly highest plant height of 24.68 and 21.46 cm during 2017-18 and 2018-19, respectively with pooled value of 23.07 cm was obtained from P_{60} respectively. At 60 DAS, the highest plant height of 32.96 and 34.39 during 2017-18 and 2018-19 respectively with pooled value of 33.68 cm was obtained from application of 90 kg P_2O_5 ha^{-1}. At harvest, the highest plant height was observed in P_{90} with 36.22 and 35.70 cm during 2017-18 and 2018-19 respectively with pooled value of 35.96 cm. This showed that phosphorus helps in rapid growth and development of the plant. On the basis of plant height at harvest, 60 kg P_2O_5 ha^{-1} was proved optimized dose and this level increased pooled plant height by 16.31% over control. The significant increase in plant height with phosphorus application may be attributed to the fact that phosphorus promotes root growth and development of plants thus enhance the extraction of nutrients and moisture from soil more efficiently leading to better growth and development of plants. There by increases the nutrient uptake by the plant, these results are in accordance with the findings of Okpara *et al*. (2007), Shelke *et al*. (2014), Patel *et al.* (2018) and Dalai *et al*.(2019).

The data presented in table 4.19(a) also indicate that application of sulphur at increasing rates had significant effect on the plant height at all the growth stages. The highest plant height of 22.27 cm (2017-18) was obtained from S_{30}, 21.04 cm (2018-19) obtained from S_{60} and 21.62 cm (pooled) was obtained from S_{30} at 30 DAS, 31.54, 33.75 cm during 2017-18 and 2018-19 with pooled value of 32.65 cm at 60 DAS and at harvest, the highest plant height was obtained from S_{60} with 35.28 and 34.72 cm during 2017-18 and 2018-19 with pooled value of 35.00 cm. On the basis of plant height at harvest, S_{60} was proved optimimum dose and this level increased plant height by 13.48 % over control.

Significant increase in plant height with the increasing levels of sulphur may be attributed to increased metabolic uses of sulphur in plants which seems to have promoted meristematic activities resulting in higher apical growth and expansion of photosynthetic surface (Negi *et al*., 2017). Similar findings were reported by Jadav *et al.* (2010) and Babaleshwar *et al*. (2017).

The interaction effect between aluminium and phosphorus on plant height is presented in table 4.19(b) which showed significant effect only during 30 DAS. At 30 DAS, the highest plant height was recorded from the treatment combination of Al_0P_{60} with 27.52 and 24.79 cm during 2017-18 and 2018-19, respectively with pooled value of 26.16cm while the lowest plant height was recorded from the treatment combination of $Al_{0.25}P_{90}$ with 18.19 cm during 2017-18, $Al_{0.25}P_0$ with 17.77 and 18.48 cm during 2018-19 and pooled.

The interaction effect between aluminium and sulphur presented in table 4.19(c) showed significant effect only during 30 DAS for the year 2018-19 where it was observed that the significantly highest plant height was recorded from Al_0S_{30} with 23.66 cm while the lowest was recorded from $Al_{0.25}S_{30}$ with 18.28 cm.

The interaction effect between phosphorus and sulphur presented in table 4.19(d) showed significant effect only during 30 DAS for the year 2018-19 where it was observed that the highest plant height was recorded from $P_{90}S_{30}$ with 21.90 cm at 30 DAS while the lowest was recorded from P_0S_0 with 19.51 cm.

The interaction effect of aluminium, phosphorus and sulphur on plant height presented in table 4.19(e) showed significant effect at 30 DAS during the year of 2017-18 only, the highest plant height with 25.11 cm was recorded from $Al_0P_{60}S_{60}$ and the lowest 17.27 cm was recorded from $Al_{0.25}P_0S_0$.

4.2.1.3 Number of branches per plant

The effect of different aluminium, phosphorus and sulphur on number of branches at 30, 60 DAS and at harvest is shown in table 4.20 and depicted in figure 4.14. As the data indicate, the number of branches per plant was found lowest in $Al_{0.25}$ whereas it was highest in Al_0. $Al_{0.25}$ levels decreased the number of branches significantly. At 30, 60 DAS and at harvest, higher number of branches was observed at Al_0 with 4.25 and 4.48, 7.87 and 7.75, 8.59 and 8.17, respectively while pooled was 4.37, 7.81 and 8.38. Lowest number of branches was observed in $Al_{0.25}$, at 30, 60 DAS and at harvest, with 3.73 and 3.56, 6.64 and 6.28, 7.59 and 7.31 respectively while pooled data was 3.64, 6.46 and 7.45. On the basis of number of branches at harvest, Al_0 was proved to be the optimum while $Al_{0.25}$ decreased the number of branches by 11.09% from the control.

Aluminium application enhanced its concentration in soil solution and reduced the absorbtion of essential nutrients by plants. Further, more the plant absorbs aluminium, it might have reduced the metabolic activities within plant system and ultimately decreased the plant growth. Similar results have been reported by Azevedo and Olive (1989) and Rheinheimer *et al.* (1994).

Table 4.20: Effect of aluminium, phosphorus and sulphur levels on number of branches of french bean

Treatments	Number of branches								
	30 DAS			60 DAS			Harvest		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels									
Al_0	4.25	4.48	4.37	7.87	7.75	7.81	8.59	8.17	8.38
$Al_{0.25}$	3.73	3.56	3.64	6.64	6.28	6.46	7.59	7.31	7.45
SEm±	0.12	0.13	0.11	0.16	0.18	0.16	0.11	0.15	0.12
CD (p=0.05)	0.35	0.37	0.32	0.46	0.52	0.46	0.32	0.43	0.35
Phosphorus levels									
P_0	3.28	3.23	3.25	6.84	6.50	6.67	7.62	7.23	7.42
P_{30}	3.84	4.12	3.98	7.12	7.00	7.06	8.06	7.67	7.87
P_{60}	4.39	4.39	4.39	7.45	7.34	7.39	8.34	8.00	8.17
P_{90}	4.45	4.34	4.39	7.62	7.23	7.42	8.34	8.06	8.20
SEm±	0.16	0.18	0.15	0.23	0.26	0.23	0.15	0.22	0.17
CD (p=0.05)	0.46	0.52	0.43	NS	NS	NS	0.43	0.63	0.49
Sulphur levels									
S_0	3.88	3.8	3.84	7.17	6.96	7.07	7.96	7.71	7.84
S_{30}	4	4.13	4.07	7.38	7.09	7.23	8.13	7.75	7.94
S_{60}	4.09	4.13	4.11	7.21	7.00	7.11	8.17	7.75	7.96
SEm±	0.14	0.15	0.13	0.20	0.22	0.20	0.13	0.19	0.15
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

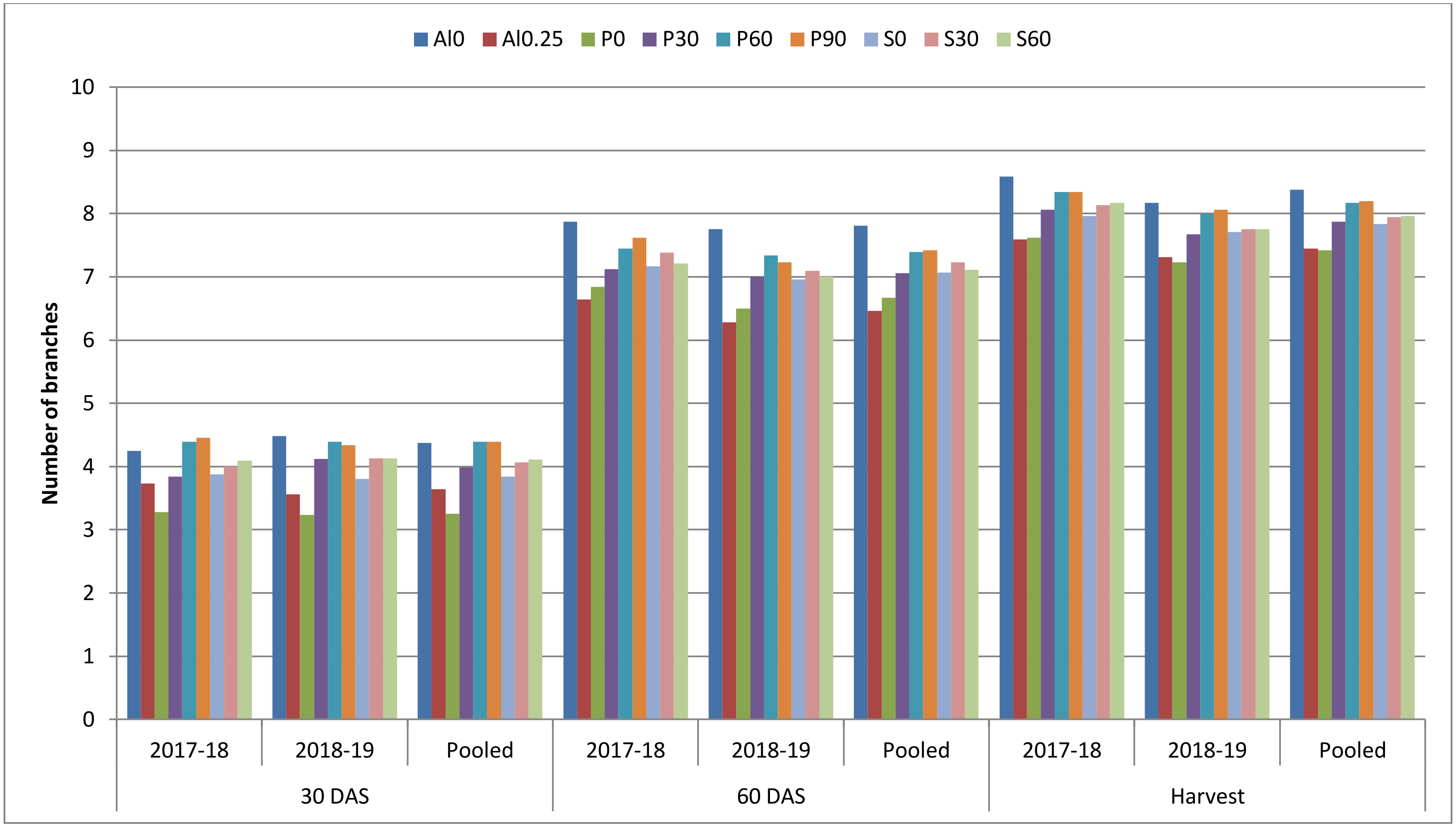

Figure 4.14: Effect of aluminium, phosphorus and sulphur levels on number of branches in french bean

The effect of phosphorus and sulphur on number of branches at 30, 60 DAS and at harvest is shown in table 4.20. Number of branches was significantly affected by phosphorus application only during 30 DAS stage whereas it did not show any significant effect during 60 DAS and at harvest. With every increase in phosphorus levels, the number of branches also increased significantly as compared to preceding lower level of phosphorus up to the level of P_{60} after which it did not increase significantly at 30 DAS. Significantly highest number of branches was recorded from 60 kg P_2O_5 ha^{-1} while lowest number of branches at 30 DAS (3.28 and 3.23 with pooled value of 3.25) was recorded from control.

The increment in number of branches per plant might because of importance of phosphorus for cell division activity, leading to the increase of plant height and number of branches and consequently increased the plant dry weight (Tesfaye *et al.*, 2007). Similar results have also been reported by Shubhashree (2007) and Zebire and Gelgelo (2019).

The data presented in table 4.20 also indicate that sulphur at increasing rates did not significantly influence the number of branches. The lowest number of branch was recorded in control at all the growth stages. (Tekseng, 2016)

4.2.1.4 Number of pods per plant

Data presented in table 4.21(a) revealed that, maximum number of pods per plant was recorded in Al_0, with 15.65 and 15.51 in 2017-18 and 2018-19, respectively with pooled value of 15.58 and the minimum as recorded from $Al_{0.25}$ with 10.42 and 11.29 during 2017-18 and 2018-19 respectively with pooled value of 10.85. On the basis of pooled values increase in aluminium levels decreased the number of pods by 30.35% from Al_0 to $Al_{0.25}$.

Thangavel (2002) also reported similar results on the number of pods per plant in green gram grown on alfisol generally showed a significant decreasing

Table 4.21(a): Effect of aluminium, phosphorus and sulphur levels on number of pods per plant, pod length, number of seeds per pod and test weight of french bean

Treatments	Number of pods per plant			Pod length (cm)			Number of seeds per pod			Test weight (g)		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	15.65	15.51	15.58	13.04	12.98	13.01	5.61	5.61	5.61	27.29	27.26	27.28
$Al_{0.25}$	10.42	11.29	10.85	10.22	9.66	9.94	4.55	4.63	4.59	29.60	29.43	29.52
SEm±	0.17	0.17	0.13	0.18	0.14	0.12	0.08	0.06	0.08	0.24	0.23	0.23
CD (p=0.05)	0.49	0.49	0.37	0.52	0.40	0.35	0.23	0.18	0.23	0.69	0.66	0.66
Phosphorus levels												
P_0	12.81	12.59	12.70	10.41	10.48	10.45	4.74	4.84	4.79	27.74	27.76	27.75
P_{30}	13.70	13.36	13.53	11.61	11.68	11.64	5.09	5.13	5.11	28.22	27.98	28.10
P_{60}	13.38	13.90	13.64	12.50	11.64	12.07	5.19	5.25	5.22	29.25	29.18	29.22
P_{90}	12.27	13.73	13.00	12.00	11.48	11.74	5.32	5.15	5.29	28.56	28.46	28.51
SEm±	0.24	0.24	0.19	0.25	0.19	0.17	0.11	0.09	0.11	0.33	0.32	0.32
CD (p=0.05)	0.69	0.69	0.54	0.71	0.54	0.49	0.32	0.26	0.26	0.33	0.32	0.32
Sulphur levels												
S_0	13.08	12.98	13.03	11.29	11.11	11.20	4.87	4.97	4.92	27.97	27.63	27.80
S_{30}	13.43	13.58	13.50	11.77	11.34	11.56	5.20	5.20	5.20	28.39	28.55	28.47
S_{60}	12.60	13.63	13.12	11.82	11.51	11.67	5.09	5.19	5.18	28.98	28.86	28.92
SEm±	0.21	0.21	0.16	0.22	0.17	0.15	0.10	0.08	0.1	0.29	0.28	0.28
CD (p=0.05)	0.60	NS	NS	NS	NS	NS	0.29	0.23	0.29	0.83	0.80	0.80

trend with increasing aluminium treatment concentration above 10 µg of Al g^{-1} of soil. The number of seeds per pod was significantly less than that of the control only above 20 µg of A1 g^{-1} of soil. The reason for decline in number of pods per plant with increase in aluminum levels might be due to poorely developed root system that limits nutrient and water uptake leading to decrease in growth and yield parameters. Similar results were recorded in cowpea by Kenechukwu *et al.* (2007) and Dong *et al.* (2018) in peanut.

The effect of phosphorus and sulphur on number of pods per plant is given in table 4.21(a) which indicated that significantly higher number of pods was obtained from P_{30} (13.70 and 13.36 during 2017-18, respectively with pooled value of 13.53) over control. The number of pods at P_{30} was at par with P_{60}. There was a significant decrease in number of pods from P_{60} to P_{90} level. The number of pods increased significantly with increase in doses of phosphorus, this may be attributed to the important role of phosphorus in flowering and fruiting including seed development. This result is in conformity With the findings of Okpara *et al.* (2007) and Shelke *et al.* (2014) and Zohmingliana *et al*. (2016).

Sulphur application at increasing levels showed significant effect on number of pods per plant during 2017-18 only. Significantly maximum number of pods (13.43) was recorded with sulphur dose of 30 kg ha^{-1} and lowest number of pods (12.60) was recorded from S_{60}. As apparent from the data there was a significant decrease in number of pods per plant from S_{30} to S_{60} level.

The increase in number of pods with increasing level of sulphur may be attributed to the fact that sulphur is mainly responsible for enhancing the reproductive growth and the proportion of the reproductive tissues (inflorescences and pods) (Mc Grath and Zhao, 1996). Similar results were reported by Osmar *et al*. (2019).

4.2.1.5 Pod length

The differences in pod length regarding the different treatment applications have been represented in the table 4.21(a). The given data clearly revealed that there was a significant difference among the pod lengths of different aluminium treatment applications. Longer pod length was recorded in control with 13.04 and 12.98 cm during 2017-18 and 2018-19, respectively with pooled value of 13.01 cm then with the aluminium treated ones. The shortest pod length was recorded in $Al_{0.25}$ level of aluminium with 10.22 and 9.66 cm during 2017-18 and 2018-19 with pooled value of 9.94 cm. The $Al_{0.25}$ level of aluminium reduced pod length by 23.59% over control in case of pooled data.

The reason for decline in pod length with increase in aluminum levels might be probably due to poorely developed root system that limits nutrient and water uptake leading to decrease in growth and yield parameters. Similar results were recorded in cowpea by Kenechukwu *et al.* (2007) and Dong *et al.* (2018) in peanut.

The effects of phosphorus and sulphur on pod length are given in table 4.21(a) which show that phosphorus application at increasing levels showed significant effect on pod length up to 60 kg P_2O_5 ha^{-1}. A decrease in pods length was found beyond 60 kg P_2O_5 ha^{-1}. Minimum pod length of 10.41 and 10.48 cm during 2017-18 and 2018-19, respectvely with pooled value of 10.45 cm was recorded in control. Maximum pod length of 12.50 and 11.64 cm during 2017-18 and 2018-19 respectively with pooled value of 12.07 cm was recorded from P_{60}.

The pod length increased significantly with increase in doses of phosphorus, this may be attributed to the important role of phosphorus on plant metabolism, cell division, cell development and seed formation. These results are in accordance with those of Rafat and Sharifi (2015) and Zohmingliana *et al*. (2016).

Sulphur application at increasing levels showed a non significant effect on pod length for both the year. Similar results of insignificant effect of sulphur on yield parameters were reported by Barlog *et al*. (2014) in broad bean and Sangwan *et al.* (2018) in wheat. Various authors reported that high yield effectiveness of sulphur fertilization can be achieved on soils characterized by a defecit of this element. (Głowacka *et al*.,2019)

The interaction effect between aluminium and phosphorus on pod length is given in table 4.21(b) which showed significant effect during the second year (2018-19) only. The maximum pod length was recorded from the treatment combination of Al_0P_{60} with 13.59 cm while the minimum pod length was recorded from the treatment combination of $Al_{0.25}P_{90}$ with 9.43 cm.

The interaction effect between aluminium and sulphur, phosphorus and sulphur and aluminium, phosphorus and sulphur showed non significant effect.

4.2.1.6 Number of seeds per pod

The data recorded on number of seeds per pod are presented in table 4.21(a). The data indicate that with increasing aluminium levels, there was a significant decrease in number of seeds per pod during both the year. The highest number of seeds per pod was recorded in control with 5.61 and 5.61 in 2017-18 and 2018-19 with pooled value of 5.61 while lower number of seeds was recorded from $Al_{0.25}$ with 4.55 and 4.63 during 2017-18 and 2018-19, respectively with pooled value of 4.59.

The decline in number of seeds per pod may be probably due to poorely developed root system that limits nutrient and water uptake leading to decrease in growth and yield parameters. Similar results were recorded in cowpea by Kenechukwu *et al.* (2007) and Dong *et al.* (2018) in peanut. Thangavel (2002) also reported similar results on the number of seeds per pod in green gram grown on alfisol.

Table 4.21(b): Interaction effect of aluminium and phosphorus levels on pod length of french bean

Aluminium levels	Pod length (cm)			
	Phosphorus levels			
	P_0	P_{30}	P_{60}	P_{90}
	2017-18			
Al_0	11.60	12.98	13.94	13.62
$Al_{0.25}$	9.22	10.22	11.05	10.37
SEm±	0.36			
CD (p=0.05)	NS			
	2018-2019			
Al_0	11.41	13.39	13.59	13.52
$Al_{0.25}$	9.53	9.96	9.69	9.43
SEm±	0.27			
CD (p=0.05)	0.77			
	Pooled			
Al_0	11.50	13.19	13.76	13.57
$Al_{0.25}$	9.38	10.09	10.37	9.90
SEm±	0.23			
CD (p=0.05)	0.64			

The effects of phosphorus and sulphur on number of seeds per pods are given in table 4.21(a) which show that phosphorus application showed significant effect on number of pods per plant. Significantly maximum number of pods was recorded with phosphorus dose of 90 kg ha^{-1} which was at par with $P_{60,}$ with 5.32 and 5.15 during 2017-18 and 2018-19, respectively with pooled value of 5.29. Minimum number of seeds per pod 4.74 and 4.84 during 2017-18 and 2018-19 respectively with pooled value of 4.79 was in control.

Application of phosphorus might have increased carbohydrate accumulation and their remobilization to reproductive parts of the plant, resulted in increased flowering, fruiting and seed formation.(Kumawat *et al.,* 2014). The number of seeds per pods increased significantly with increase in doses of phosphorus, this may be attributed to the important role of phosphorus on plant metabolism, cell division, cell development and seed formation. The results of the present study were in conformity with those of Nadal *et al*. (1987) and Rafat and Sharifi (2015).

Sulphur application at increasing levels showed significant effect on number of seeds per pod. Significantly maximum number of seeds was recorded with sulphur dose of 30 kg ha^{1} with 5.20 and 5.20 during 2017-18 and 2018-19, respectively with pooled value of 5.20 and lowest number of seeds per pods 4.87 and 4.97 during 2017-18 and 2018-19 respectively with pooled value of 4.92 was recorded no sulphur application.

The increase in number of seeds per pod with increasing level of sulphur may be attributed to the fact that sulphur is mainly responsible for enhancing the reproductive growth and the proportion of the reproductive tissues (inflorescences and pods) (Mc Grath and Zhao, 1996). Similar results were reported by and Singh *et al*. (2017) and Osmar *et al*. (2019).

There was no significant difference among the different treatment combination of aluminium, phosphorus and sulphur on seeds per pod of french bean.

4.2.1.7 Test weight

The data related to test weight is presented in table 4.21(a). It is clear from the data that a significant difference was observed in test weight with different aluminium levels. Between the two aluminium levels, the highest test weight was recorded in $Al_{0.25}$ with 29.60 and 29.43 g during 2017-18 and 2018-19, respectively with pooled value of 29.52. The minimum test weight was found in Al_0 with 27.29 and 27.26 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 27.28.

The 100 seed weight showed direct positive relation with seed size, these results are in consensus with the findings of Coimbra *et al*. (1998) in french bean. Untreated seeds produced the smallest size while aluminium treated produced the largest seed size. These may be due to the reason that the pods under treatment $Al_{0.25}$ have shorter pod length with lower number of seeds per pod which in turn produced bolder seed size as compared to the more number of seeds per pod with smaller seed size produced under control.

The effects of phosphorus and sulphur on test weight are given in table 4.21(a) which show that phosphorus application at increasing levels showed significant effect on test weight up to 60 kg P_2O_5 ha^{-1}. A decrease in test weight was found beyond 60 kg P_2O_5 ha^{-1}. Minimum test weight of 27.74 and 27.76 g during 2017-18 and 2018-19, respectively with pooled value of 27.75 g was recorded at harvest with no phosphorus application.

It might be also because of nutrient use efficiency by crop enhanced at optimum level of phosphorus since grain weight indicate the amount of resource utilized during critical growth periods (Tesfaye, 2015). These results are in accordance with Chatterjee and Som, (1991) who reported increased test weight up to 80 kg P_2O_5 ha^{-1} application and Baboo *et al.* (1998) up to 100 kg P_2O_5 ha^{-1}.

Sulphur application at increasing levels showed significant effect on test weight. Significantly maximum test weight was recorded with sulphur dose of 60 kg ha^{-1} with 28.98 and 28.86 g during 2017-18 and 2018-19, respectively with pooled value of 28.92 g and lowest test weight of 27.97 and 27.63 g during 2017-18 and 2018-19, respectively with pooled value of 27.80 g was recorded in control.

These results are in accordance with Kumawat *et al*. (2014) who stated that increase in different yield attributing characters might be due to more availability of sulphur during these vegetative and reproductive stages of the crop. Sulphur is a part of amino acid (cystine), which helps in chlorophyll formation, photosynthetic process, activation of enzymes and grain formation. Rise in different yield attributing characters like number of pods per plant and 100-grains weight also recorded by Singh and Yadav (2004) and Mitra *et al*. (2006), Serawat *et al*. (2018). Again, increased test weight with sulphur application in soybean was observed by Akter *et al*. (2013).

There was no significant difference among the different treatment combination of aluminium, phosphorus and sulphur on test weight.

4.2.1.8 Seed yield

The observation recorded on seed yield per pot of french bean after harvest as influenced by different aluminium, phosphorus and sulphur levels for both the year 2017-18 and 2018-19 and the pooled analysis has been presented in table 4.22(a) and depicted in figure 4.15.

From the concerned table it was cleared that higher seed yield was obtained from the control (Al_0) with the value of 23.95 and 23.90 g pot^{-1} during 2017-18

Table 4.22(a): Effect of aluminium, phosphorus and sulphur levels on yield and stover yield of french bean

Treatments	Seed yield (g pot^{-1})			Stover yield (g pot^{-1})		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels						
Al_0	23.95	23.9	23.92	33.14	32.63	32.89
$Al_{0.25}$	13.89	15.42	14.65	24.73	25.27	25.00
SEm±	0.35	0.31	0.29	0.23	0.31	0.19
CD (p=0.05)	1.00	0.88	0.83	0.66	0.88	0.54
Phosphorus levels						
P_0	16.75	17.07	16.91	26.67	26.94	26.80
P_{30}	19.74	19.26	19.50	28.26	28.54	28.40
P_{60}	20.46	21.6	21.03	30.33	30.01	30.17
P_{90}	18.72	20.7	19.71	30.50	30.3	30.40
SEm±	0.50	0.44	0.41	0.33	0.43	0.27
CD (p=0.05)	1.42	1.25	1.17	0.94	1.23	0.77
Sulphur levels						
S_0	17.91	18.24	18.08	28.36	28.18	28.27
S_{30}	19.96	20.26	20.11	29.19	29.16	29.17
S_{60}	18.88	20.48	19.68	29.27	29.51	29.19
SEm±	0.43	0.38	0.36	0.28	0.37	0.23
CD (p=0.05)	1.23	1.08	1.03	0.8	1.05	0.66

Table 4.22(b): Interaction effect of aluminium and phosphorus levels on test weight, seed yield and stover yield

Aluminium levels	Seed yield (g pot^{-1})				Stover yield (g pot^{-1})			
	Phosphorus levels				Phosphorus levels			
	P_0	P_{30}	P_{60}	P_{90}	P_0	P_{30}	P_{60}	P_{90}
	2017-18							
Al_0	20.59	25.41	26.13	23.64	31.27	32.88	33.72	34.68
$Al_{0.25}$	12.91	14.06	14.78	13.79	22.05	23.63	26.92	26.31
SEm±	0.73				0.47			
CD (p=0.05)	2.07				1.35			
	2018-19							
Al_0	20.43	22.84	26.89	25.44	30.68	32.40	33.69	33.73
$Al_{0.25}$	13.70	15.67	16.31	15.96	23.19	24.67	26.33	26.87
SEm±	0.37				0.63			
CD (p=0.05)	1.83				NS			
	Pooled							
Al_0	20.51	24.12	26.51	24.54	30.98	32.64	33.71	34.20
$Al_{0.25}$	13.30	14.87	15.54	14.87	22.62	24.15	26.62	26.59
SEm±	0.49				0.39			
CD (p=0.05)	1.37				NS			

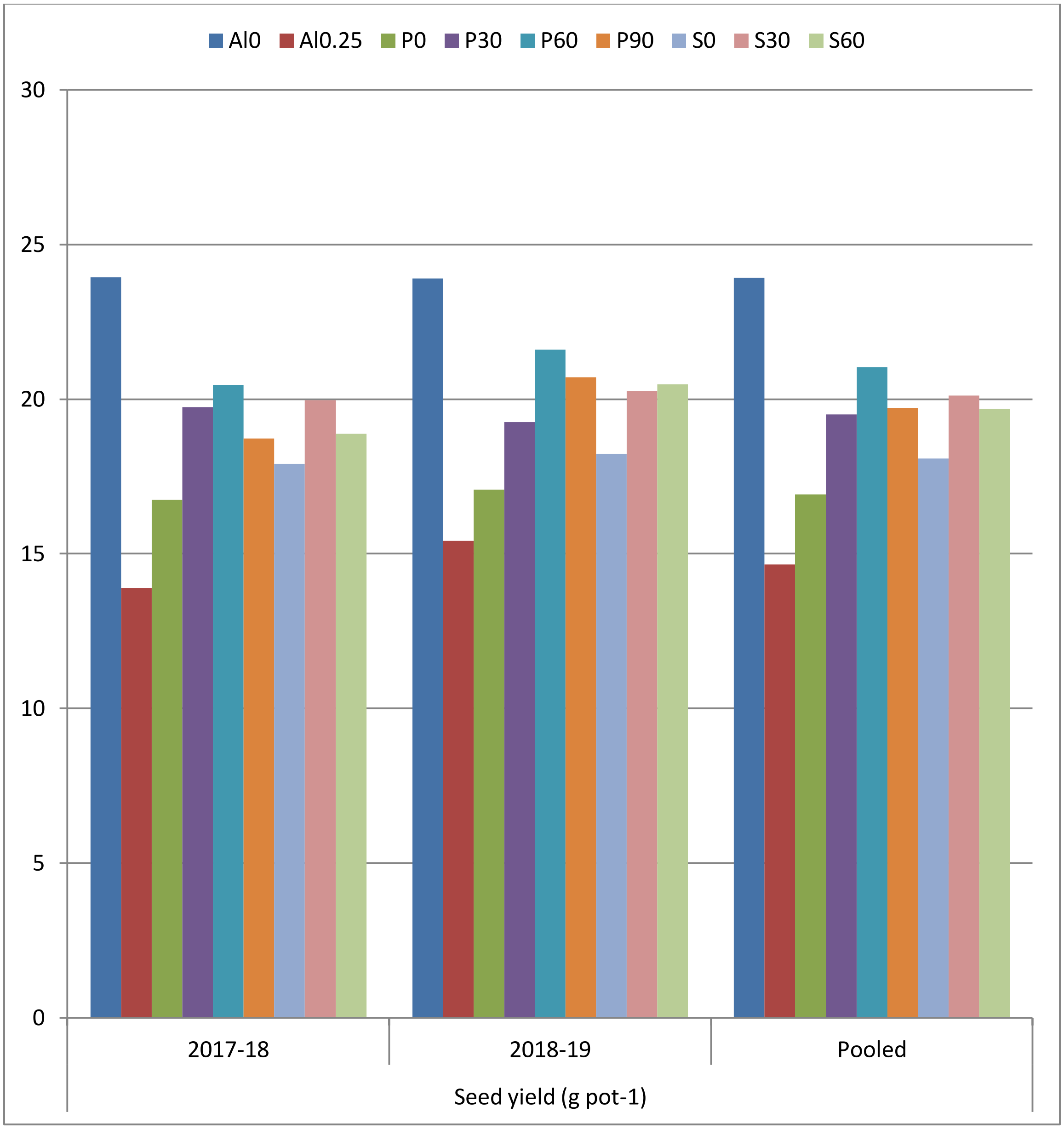

Figure 4.15: Effect of aluminium, phosphorus and sulphur levels on seed yield of french bean

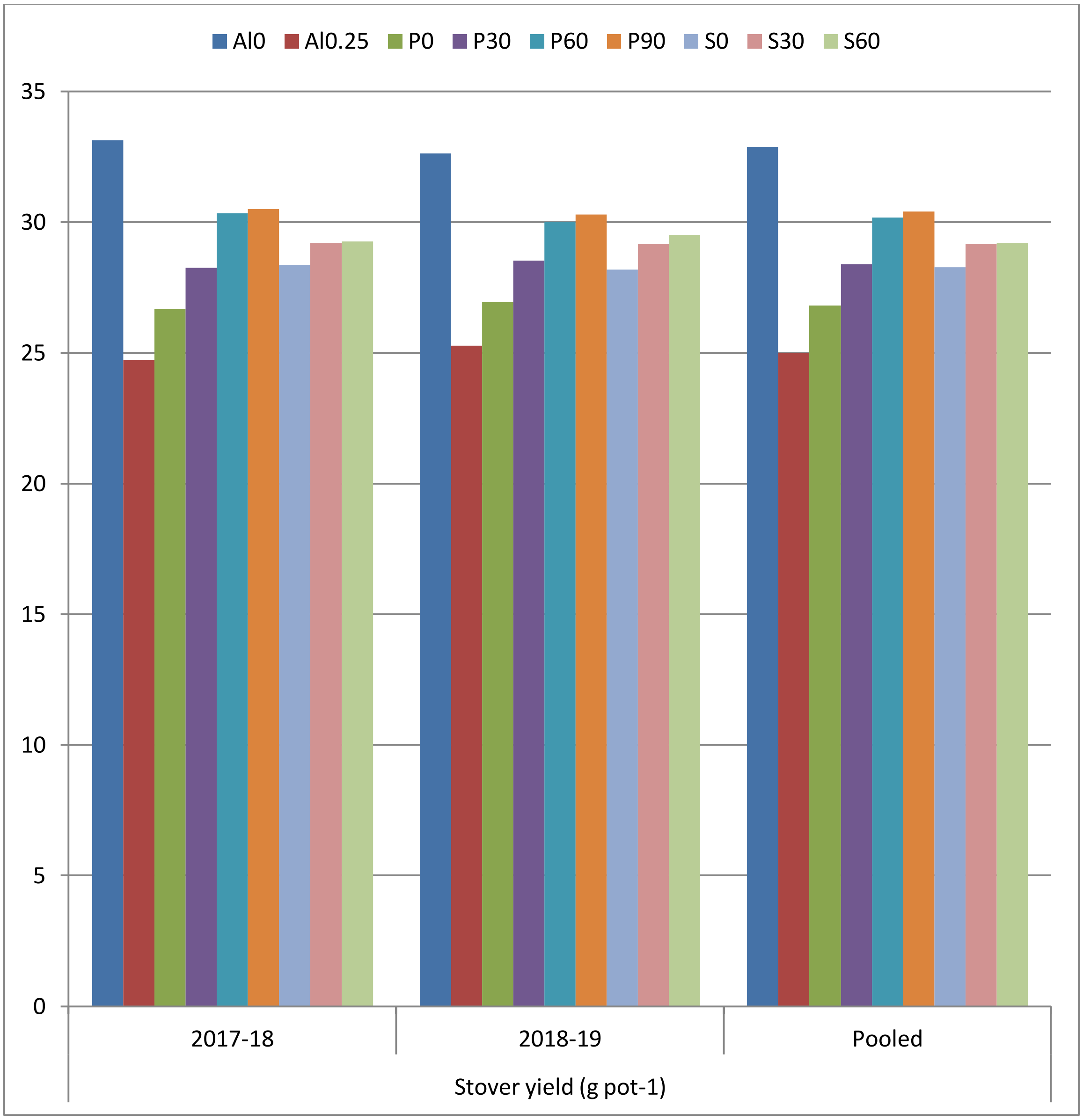

Figure 4.16: Effect of aluminium, phosphorus and sulphur levels on stover yield of french bean

and 2018-19, respectively with pooled value of 23.92 g pot^{-1} and the lower seed yield by $Al_{0.25}$ with 13.89 and 15.42 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 14.65 g pot^{-1}. Irrespective of treatments and years of experimentation the seed yield of french bean varied from 13.89 to 23.95 g pot^{-1}. A critical examination of data show that the increasing level of aluminium resulted significant decrease in seed yield of french bean. Application of aluminium at $Al_{0.25}$ decreased grain yield to the extent of 38.75% over control in case of pooled value.

Yield is a function of various yield contributing plant parameters, the reduction recorded in the yield attributes induced by aluminium may also be the consequence of the observed reduction in the seed yield. Similar results were reported by Thangavel (2002). These results are in accordance with the findings of Kenechukwu *et al.* (2007) and Dong *et al.* (2018).

The effects of phosphorus and sulphur on seed yield are given in table 4.22(a) which show that phosphorus application at increasing levels showed significant effect on seed yield up to 60 kg P_2O_5 ha^{-1}. A decrease in seed yield was found beyond 60 kg P_2O_5 ha^{-1}. Minimum seed yield of 16.75 and 17.07 g pot^{-1} during 2017-18 and 2018-19, respectively, with pooled value of 16.91 g pot^{-1} was recorded with no phosphorus application. On the basis of pooled value the P_{60} level (60 kg P_2O_5 ha^{-1}) of phosphorus proved optimum dose of phosphorus. This level enhanced seed yield significantly over other levels of phosphorus. Application of phosphorus at 60 kg P_2O_5 ha^{-1} enhanced grain yield to the extent of 24.36% over control and 7.8% over 30 kg P_2O_5 ha^{-1}.

Significantly higher grain and haulm yield was due to significantly higher performance of yield attributes viz., number of pods per plant, pod length, seeds per pod, pod length and test weight (Shubhashree, 2007). Tomar (2001) revealed that application of phosphorus influenced the seed yield significantly up to 60 kg

P_2O_5 ha^{-1}. Significantly higher grain yield (2006 kg ha^{-1}) of french bean was observed due to increased rate of phosphorus application up to 75 kg P_2O_5 ha^{-1} (Veeresh, 2003).

Sulphur application indicated significant effect on seed yield. Significantly maximum seed yield 19.96 g pot^{-1} during 2017-18 and 20.48 g pot^{-1} during 2018-19 was recorded with sulphur dose of 30 and 60 kg ha^{-1} respectively. Maximum pooled seed yield (20.11 g pot^{-1}) was obtained from 30 kg ha^{-1} sulphur application. The lowest seed yield of 17.91 and 18.24 g pot^{-1} during 2017-18 and 2018-19, respectively, with pooled value of 18.08 g pot^{-1} was recorded in control. On the basis of pooled seed yield, application of 30 kg S ha^{-1} (S_{30}) enhanced significantly the seed yield over control. Further application of sulphur at 60 kg ha^{-1} reduced seed yield as compared to 30 kg ha^{-1}. Hence, 30 kg S ha^{-1} proved to be the optimum dose of sulphur in present set of experimentation. The S_{30} level increased seed yield by 11.23% over control.

The improvement in yield due to increase in sulphur levels might be due to its important role in energy transformation, activation of enzymes and carbohydrate metabolism. Same results were obtained by Patel *et al*. (2018) who reported that application of 40 kg S ha^{-1} recorded highest yield components (number of pods per plant and number of seeds per pod) and yield (grain and haulm) of black gram. Deshbhratar *et al*. (2010) and Phogat (2016) also reported that sulphur levels application significantly influenced grain yield, in pigeon pea and black gram. The increase in these yield attributing characters might be due to the important role of sulphur in energy transformation, activation of number of enzymes and also in carbohydrate metabolism. (Singh *et al*., 2017).

The interaction effect of aluminium and sulphur on seed yield is presented in table 4.22(b) which showed that the maximum seed yield was recorded from Al_0P_{60} with 26.13 and 26.89 g pot^{-1} during 2017-18 and 2018-19 with pooled value of 26.51 g pot^{-1}. Minimum seed yield was obtained under $Al_{0.25}P_0$ with 12.91 and 13.70 g pot^{-1} with pooled value of 13.30 g pot^{-1}.

4.2.1.9 Stover yield

The data presented in table 4.22(a) and depicted in figure 4.16, also indicate that stover yield of french bean decreased significantly with increasing aluminium levels. The highest stover yield was recorded in control with 33.14 and 32.63 g pot^{-1} in 2017-18 and 2018-19, respectively with pooled value of 32.89 and the lower stover yield was recorded $Al_{0.25}$ with 24.73 and 25.27 g pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 25.00. On the basis of pooled stover yield, the $Al_{0.25}$ level reduced the stover yield by 23.98% over control.

Batista *et al*. (2012) reported that shoot dry matter, root dry matter and plant height decreased significantly with increasing aluminium concentrations. According to Farias *et al*. (2011), increasing aluminium levels in the nutrient solution led to a decline in the shoot and root dry matter production. The low dry matter accumulation in the shoot may be attributed to the significant effect of aluminium on nutrient absorption and translocation (Azevedo & Oliva, 1989).

The low translocated content of phosphorus to the plant shoots reduces the photosynthetic rate, which causes a lower accumulation of carbohydrates, thereby resulting in lighter leaves with less dry matter production (Rheinheimer *et al*., 1994).

The data presented in table 4.22 (a) also indicate that stover yield of french bean increased significantly with increasing phosphorus levels. Phosphorus at 90 kg P_2O_5 ha^{-1} resulted highest stover yield (30.50 and 30.30 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 30.14 g pot^{-1}) while the minimum yield (26.67 and 26.94 g pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 26.80 g pot^{-1}) was obtained from control. Application of 90 kg P_2O_5 ha^{-1} was at par with 60 kg ha^{-1}. Hence 60 kg ha^{-1} proved optimum dose with regard to stover yield of french bean. This level enhanced the stover yield by 12.57% on the basis of pooled stover yield. Lad *et al*. (2014) also reported similar results regarding phosphorus effect on stover yield.

The increase in above ground dry biomass yield at the highest rate of phosphorus might be attributed to the enhanced availability of phosphorus for vegetative growth of the plants. This result was in agreement with Shubhashree (2007) who reported that dry matter accumulation increase with application of phosphorus rates. Similarly, significant and linear increase in total dry matter production of common bean plant was observed due to increased phosphorus (Veeresh, 2003).

Sulphur application at increasing levels showed significant effect on stover yield. A critical examination of data revealed that the application of 30 kg S ha^{-1} increased the stover yield significantly over control. However, beyond this level effect of sulphur application was at par, indicated that 30 kg S ha^{-1} is the optimum dose of sulphur for french bean. The S_{30} level increased the stover yield by 3.18% over control with regard to pooled value.

The improvement in yield due to increase in sulphur levels might be due to its important role in energy transformation, activation of enzymes and carbohydrate metabolism. Sulphur application increased the plant height and other growth parameter of french bean which in turned to higher stover yield of french bean. These result are in agreement with Singh *et al*. (2017) and Phogat (2016).

A perusal of data presented in table 4.22(b) revealed that highest stover yield was recorded with application of 90 kg P_20_5 ha^{-1} under control level of aluminium. But under $Al_{0.25}$ level of aluminium application of 60 kg P_20_5 ha^{-1} gave highest stover yield while difference between P_{60} and P_{90} levels was at par under both levels of aluminium.

4.2.2 EFFECT ON NUTRIENT CONTENT

4.2.2.1. Nitrogen content

The data given in table 4.23 indicate that increased level of aluminium resulted in decrease nitrogen content in grains and stover of french bean. In grains, the highest nitrogen content was observed in Al_0 with 3.43 and 3.50% during 2017-18 and 2018-19, respectively with pooled value of 3.46%. whereas the lowest nitrogen content was observed in $Al_{0.25}$ with the value of 3.19 and 3.26% during 2017-18 and 2018-19, respectively with pooled value of 3.23%. Similarly in stover, the nitrogen content was highest in Al_0 with 1.25 and 1.26% during 2017-18 and 2018-19, respectively with pooled value of 1.26%. whereas the lowest N content was observed in $Al_{0.25}$ with the value of 1.14 and 1.15% during 2017-18 and 2018-19, respectively with pooled value of 1.15%.

The increased level of aluminium resulted in decreasing nitrogen content in seed and stover of french bean may be due to the reason that aluminium induces disturbances in the trans-membrane transport of ions (N, P, K, Ca and Mg) in plant roots (Kochian, 1995), becoming indirectly responsible for the impairment of root-shoot transport and metabolic processes in shoots. (Mihailovic *et al*., 2008). Root damage can reduce the nutrient uptake and eventually induce mineral deficiencies in shoots (Taylor, 1988). Pintro *et al*. (1996) reported that concentration of nitrogen in the shoot of the corn (*Zea mays*) decreased with the increase of aluminium levels in the soil solution. Ribeiro *et al*. (2013) reported that increasing aluminium levels in growth medium decreased nitrogen content in all plant organs of cacao. The data given in table 4.23 indicate that increased level of phosphorus resulted in increasing nitrogen content in grains and stover of french bean. In grains, the highest nitrogen content (3.35 and 3.45% during 2017-18 and 2018-19, respectively with pooled value of 3.40%) was observed where 60 kg P_2O_5 kg ha^{-1} was applied but it was at par with P_{90} (3.35 and 3.40% during 2017-18 and 2018-

Table 4.23: Effect of aluminium, phosphorus and sulphur levels on nitrogen and phosphorus content in grains and stover of french bean

Treatments	Nutrient content (%)											
	Nitrogen						Phosphorus					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	3.43	3.50	3.46	1.25	1.26	1.26	0.48	0.47	0.47	0.25	0.24	0.24
$Al_{0.25}$	3.19	3.26	3.23	1.14	1.15	1.15	0.43	0.43	0.43	0.15	0.14	0.14
SEm±	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (p=0.05)	0.06	0.09	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Phosphorus levels												
P_0	3.24	3.27	3.25	1.18	1.19	1.18	0.42	0.43	0.43	0.17	0.17	0.17
P_{30}	3.29	3.41	3.35	1.19	1.21	1.20	0.44	0.45	0.44	0.19	0.18	0.19
P_{60}	3.35	3.45	3.40	1.21	1.22	1.21	0.46	0.45	0.45	0.20	0.21	0.20
P_{90}	3.35	3.40	3.38	1.21	1.21	1.21	0.48	0.47	0.47	0.22	0.21	0.21
SEm±	0.03	0.04	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
CD (p=0.05)	0.09	0.12	0.09	0.03	0.03	0.03	0.03	NS	0.03	0.03	0.03	0.03
Sulphur levels												
S_0	3.27	3.32	3.29	1.18	1.19	1.19	0.44	0.44	0.44	0.19	0.19	0.20
S_{30}	3.33	3.42	3.37	1.20	1.21	1.21	0.45	0.45	0.45	0.20	0.19	0.19
S_{60}	3.33	3.41	3.37	1.20	1.21	1.21	0.46	0.45	0.46	0.20	0.19	0.20
SEm±	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (p=0.05)	0.03	0.03	0.03	0.03	0.03	0.03	NS	NS	NS	NS	NS	0.03

19, respectively with pooled value of 3.38%). Similarly in stover, the nitrogen content was increased significantly at P_{30} level over control. The nitrogen content at P_{60} and P_{90} level were at par with P_{30} level.

Yadav (2011) also reported that phosphorus application significantly increased nitrogen content in grain and stover of french bean. These results support the findings of Mathew *et al*. (2018), Dwivedi and Bapat (1998), who reported that nitrogen content in soybean increased significantly by phosphorus application up to 50 kg ha^{-1}. Moghaddam *et al*. (2015) also reported the same in case of green gram.

Nitrogen content in both seeds and stover increased up to S_{30} which it was at par with S_{60}. The nitrogen content in grain at S_{30} and S_{60} levels both showed similar values which were significantly higher than nitrogen content at control. Similarly nitrogen content in stover of french bean showed no difference among S_{30} and S_{60} levels but showed significantly higher values than that of control. These results support the findings of Sahaa *et al*. (2007), Singh *et al*. (2012) and Dharwe *et al*. (2019) in green gram.

The positive influence of sulphur fertilization on N content of the crop seems to be due to improved nutritional availability both in rhizosphere and the plant system (Serawat *et al*., 2018) .These findings are in accordance with the findings of Kumawat *et al*. (2007) and Bahadur *et al*. (2009) in mung bean.

There was no significant difference among the different treatment combination of aluminium, phosphorus and sulphur on nitrogen content in grains and stover of french bean.

4.2.2.2 Phosphorus content

The data in table 4.23 represent the phosphorus content in grain and stover of french bean. The data show that with each increasing level of aluminium, there was a significant decrease in phosphorus content as compared to lower level of aluminium in case of both grain and stover. The highest phosphorus content in grain was recorded in Al_0 with 0.48 and 0.47% with pooled value of 0.47%, whereas the lowest phosphorus content in grain was observed in $Al_{0.25}$ with 0.43 and 0.43% during 2017-18 and 2018-19, respectively with pooled value of 0.43%. Similarly in stover, the phosphorus content was highest in Al_0 with 0.25 and 0.24% during 2017-18 and 2018-19, respectively with pooled value of 0.24%. whereas the lowest phosphorus content was observed in $Al_{0.25}$ with the value of 0.15 and 0.14% during 2017-18 and 2018-19, respectively with pooled value of 0.14%.

The results in relation to the phophorus content are in agreement with those found for Al-treated Q. *glauca* (Akaya and Takenaka, 2001) and *Vigna unguiculata* Al-sensitive genotype, whose phosphorus accumulation was significantly reduced. Jemo *et al*. (2007). According to Macklon *et al*. (1994) in growth medium aluminium increases P fixation by precipitation as Al-P complexes thereby reducing P availability.

The data in table 4.23 represent the phosphorus content in grain and stover of french bean. The data show that increased levels of phosphorus had a significant effect on phosphorus content in grain and stover of french bean. The highest phosphorus content in grain (0.48 and 0.47% during 2017-18 and 2018-19, respectively with pooled value of 0.47%) and in stover (0.22 and 0.21% during 2017-18 and 2018-19 respectively with pooled value of 0.21%) were recorded with the application of 90 kg P_2O_5 ha^{-1}, whereas the lowest phosphorus content in grain (0.42 and 0.43% during 2017-18 and 2018-19 respectively with pooled value of 0.43%) and in stover (0.17 and 0.17% during 2017-18 and 2018-19 respectively with pooled value of 0.17%) were recorded in control.

Phosphorus application increased the phosphorus concentration in the soil solution resulted plants absorb more phosphorus and accumulated in the tissues as part of various compounds. These finding are in agreement with Yadav (2011), Phogat (2016) and Dharwe *et al*. (2019).

Different levels of sulphur failed to show any significant variation on the phosphorus content in both seeds as well as stover. These results are in conformity with Phogat (2016) and Tekseng (2016).

Even though there was variation with different treatment combinations the interaction of phosphorus and sulphur had no significant effect on phosphorus content in seeds as well as in stover.

4.2.2.3 Potassium content

The data regarding potassium content in grains and stover of french bean are presented in table 4.24. A critical examination of data show that potassium content in grains and stover decreased with increase in aluminium level. In grains, potassium content at Al_0 with 0.83 and 0.84% during 2017-18 and 2018-19, respectively with pooled value of 0.83 was significantly higher than the other which was treated with aluminium. Lowest potassium content was recorded in $Al_{0.25}$ with 0.76% for both the year and pooled. In stover, potassium content at Al_0 with 1.50 and 1.49% during 2017-18 and 2018-19 respectively with pooled value of 1.50% was significantly higher than that of $Al_{0.25}$. Lowest potassium content was recorded in $Al_{0.25}$ with 1.45 and 1.44% during 2017-18 and 2018-19, respectively with pooled value of 1.45%. Potassium content in grains was found lower than the potassium content in stover.

The decrease in potassium content with increase of aluminium level up to certain level might be due to the disturbances in trans membrane transport of ions induced by aluminium. Thronton *et al*. (1986) reported that the nutrient composition of aluminium treated plant parts were significantly lower than that of control plant parts in case of honey locust plants. Cristiane and

Table 4.24: Effect of aluminium, phosphorus and sulphur levels on phosphorus, potassium and sulphur content in grains and stover of french bean

Treatments	Nutrient content (%)											
	Potassium						Sulphur					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	0.83	0.84	0.83	1.50	1.49	1.50	0.32	0.34	0.33	0.15	0.13	0.14
$Al_{0.25}$	0.76	0.76	0.76	1.45	1.44	1.45	0.26	0.27	0.26	0.11	0.10	0.10
SEm±	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (p=0.05)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Phosphorus levels												
P_0	0.77	0.78	0.78	1.45	1.44	1.45	0.26	0.28	0.27	0.10	0.09	0.10
P_{30}	0.79	0.80	0.80	1.47	1.46	1.47	0.28	0.30	0.29	0.12	0.11	0.12
P_{60}	0.81	0.82	0.81	1.48	1.48	1.48	0.30	0.31	0.31	0.13	0.12	0.13
P_{90}	0.81	0.80	0.81	1.49	1.49	1.49	0.31	0.32	0.32	0.14	0.14	0.14
SEm±	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
CD (p=0.05)	0.03	NS	0.03	NS	0.03	0.03	0.03	0.06	0.03	0.03	0.03	0.03
Sulphur levels												
S_0	0.79	0.79	0.79	1.46	1.45	1.46	0.27	0.28	0.28	0.11	0.10	0.10
S_{30}	0.81	0.81	0.81	1.48	1.47	1.47	0.29	0.31	0.30	0.13	0.12	0.12
S_{60}	0.80	0.80	0.80	1.48	1.48	1.48	0.31	0.33	0.32	0.14	0.13	0.14
SEm±	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (p=0.05)	NS	NS	NS	NS	NS	NS	0.32	0.34	0.33	0.03	0.03	0.03

Veronique(2008) also reported that aluminium decreased Ca, P, K, Mg and Mn concentrations in shoots of rive cultivars.

A critical examination of data show that potassium content in grains and stover increased with increase in phosphorus level up to 60 kg P_2O_5 ha^{-1} but remain constant beyond this level. In grains, potassium content at P_{60} (0.81 and 0.82% during 2017-18 and 2018-19, respectively with pooled value of 0.81%) was significantly higher over control (0.77 and 0.78% during 2017-18 and 2018-19, respectively with pooled value of 0.78%). However, effect of phosphorus application on seed potassium content was non significant during second year of experimentation. In stover, potassium content at P_{60} (1.48% for both the year) was significantly higher than control (1.45 and 1.44% during 2017-18 and 2018-19, respectively with pooled value of 1.45%) and it was at par with P_{90}. Potassium content in grains was found lower than the potassium content in stover. The increase in potassium content with increase of phosphorus up to certain level might be due to the better root growth and higher nutrient uptake associated with increased phosphorus level. These results are in conformity with the findings of Taliman *et al*. (2019) who reported that total potassium concentration in seeds of soybean was higher in the higher levels of phosphorus application.

Different levels of sulphur failed to show any significant variation on the potassium content in both seeds as well as stover.

4.2.2.4 Sulphur content

The results obtained on the sulphur content in grain and stover of french bean in different treatment has been presented in table 4.24. As seen from the data, increased level of aluminium resulted in decreasing sulphur content in grains and stover of french bean. The maximum sulphur content in grain was recorded in Al_0 with 0.32 and 0.34% during 2017-18 and 2018-19, respectively with pooled value of 0.33%. The lowest sulphur content was observed in $Al_{0.25}$ with 0.26 and 0.27%

during 2017-18 and 2018-19, respectively with pooled value of 0.26%. Similarly in stover, the maximum sulphur content in was recorded from Al_0 with 0.15 and 0.13% during 2017-18 and 2018-19, respectively with pooled value of 0.14 while the lowest sulphur content was observed in $Al_{0.25}$ with 0.11 and 0.10 % during 2017-18 and 2018-19, respectively with pooled value of 0.10 %.

The Al-sulfate interaction occurs in acidic soils, whereby relatively high concentrations of trivalent toxic aluminum (Al^{3+}) may hamper root growth, limiting uptake of nutrients, including sulphur (Poblete *et al*. (2018). Similar results have also been reported by Guo *et al*. (2017).

A critical examination of data show that sulphur content in grains and stover increased with increase in phosphorus level up to 90 kg P_2O_5 ha^{-1} level. In grains, potassium content at P_{90} (0.31 and 0.32% during 2017-18 and 2018-19, respectively with pooled value of 0.32%) was significantly higher over control (0.26 and 0.28% during 2017-18 and 2018-19, respectively with pooled value of 0.27%). In stover, potassium content at P_{90} (0.14% for both the year) was significantly higher than control (0.10 and 0.09% during 2017-18 and 2018-19, respectively with pooled value of 0.11%).

Increasing sulphur levels significantly influenced sulphur content in seeds and stover. The significantly highest content in seeds (0.31 and 0.33% during 2017-18 and 2018-19, respectively with pooled value of 0.32%) and (0.14 and 0.13% during 2017-18 and 2018-19 respectively with pooled value of 0.13%) in stover was recorded with sulphur dose of 60 kg ha^{-1}whereas lowest content in seeds (0.27% for both the year 2017-18 and 2018-19) and stover (0.11 and 0.10% during 2017-18 and 2018-19 respectively with pooled value of 0.10%) was recorded in control.

The increased in sulphur concentration in seeds and stover with increased doses of phosphorus and sulphur may be attributed to proper root development and growth of plants thus enhancing the sulphur uptake in plants. These results are similar to the finding of Chaplot *et al.* (1991), Singh and Singh (2004) in black gram, Yadav (2011) in cluster bean, Teotia *et al*. (2000) and Islam *et al*. (2006) and Serawat *et al*. (2018) in moong bean.

4.2.2.5 Calcium content

The results obtained on calcium content in grain and stover of french bean in different treatment has been presented in table 4.25. From the data, increased level of aluminium resulted significant reduction in calcium content in grains and stover of french bean. The maximum calcium content in grain was recorded in Al_0 with 0.27 and 0.25% during 2017-18 and 2018-19, respectively with pooled value of 0.26%. The lowest calcium content was observed in $Al_{0.25}$ with 0.14 and 0.12% during 2017-18 and 2018-19 respectively with pooled value of 0.13%. Similarly in stover, the maximum calcium content was recorded under Al_0 with 0.73 and 0.76% during 2017-18 and 2018-19 respectively with pooled value of 0.75% while the lowest calcium content was observed in $Al_{0.25}$ with 0.45 and 0.45 % during 2017-18 and 2018-19 respectively with pooled value of 0.45%.

Decrease in calcium content in grains and stover with increase in aluminium level may be due to the reason that aluminium interacts antagonistically with calcium therefore, plants grown in external media with high concentration of aluminium may reduce the calcium content (Edwards *et al.*, 1976). Increasing levels of Al in the growth medium decreased calcium and magnesium contents in the roots, stems and leaves in both cacao genotypes. (Ribeiro *et al*., 2013).

A critical examination of data show that calcium content in grains and stover increased with increase in phosphorus level up to 60 kg P_2O_5 ha^{-1} level. In grains, calcium content at P_{60} (0.22 and 0.19% during 2017-18 and 2018-19 respectively, with pooled value of 0.20%) was significantly higher over control

Table 4.25: Effect of aluminium, phosphorus and sulphur levels on calcium and aluminium content in grains and stover of french bean

Treatments	Calcium (%)						Aluminium (mg kg^{-1})					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	0.27	0.25	0.26	0.73	0.76	0.75	196.52	199.12	197.82	741.80	742.81	742.31
$Al_{0.25}$	0.14	0.12	0.13	0.45	0.45	0.45	473.33	470.55	471.94	1013.61	1015.59	1014.60
SEm±	0.01	0.01	0.01	0.01	0.01	0.01	0.65	0.45	0.37	0.30	0.26	0.21
CD (p=0.05)	0.03	0.03	0.03	0.03	0.03	0.03	1.85	1.28	1.05	0.86	0.74	0.60
Phosphorus levels												
P_0	0.18	0.17	0.17	0.56	0.58	0.57	335.99	336.28	336.13	878.43	879.66	879.04
P_{30}	0.20	0.18	0.19	0.59	0.60	0.59	334.86	334.31	334.59	878.01	879.44	878.72
P_{60}	0.22	0.19	0.20	0.61	0.62	0.61	334.84	334.33	334.58	877.36	879.00	878.18
P_{90}	0.22	0.21	0.21	0.60	0.62	0.61	334.01	334.42	334.21	877.03	878.70	877.87
SEm±	0.01	0.02	0.01	0.01	0.01	0.01	0.91	0.64	0.52	0.42	0.37	0.30
CD (p=0.05)	0.03	NS	0.03	0.03	0.03	0.03	NS	NS	NS	NS	NS	NS
Sulphur levels												
S_0	0.19	0.18	0.19	0.58	0.60	0.59	335.24	335.48	335.36	877.84	879.47	878.65
S_{30}	0.21	0.19	0.20	0.59	0.61	0.60	334.53	334.43	334.48	877.79	879.25	878.52
S_{60}	0.21	0.19	0.20	0.60	0.60	0.60	335.01	334.59	334.80	877.50	878.88	878.19
SEm±	0.01	0.02	0.01	0.01	0.01	0.01	0.79	0.56	0.46	0.36	0.32	0.26
CD (p=0.05)	NS	NS	NS	NS	NS	0.03	NS	NS	NS	NS	NS	NS

(0.18 and 0.17% during 2017-18 and 2018-19, respectively with pooled value of 0.17%). In stover, calcium content at P_{60} (0.61 and 0.62% during 2017-18 and 2018-19, respectively with pooled value of 0.61%) was significantly higher than control (0.56 and 0.58% during 2017-18 and 2018-19, respectively with pooled value of 0.58%). The calcium content in grains was not affected significantly with phosphorus application during second year of experimentation. Calcium content in grains was found lower than the calcium content in stover. These results are in accordance with the findings of Kumar *et al*. (2017).

Different levels of sulphur failed to show any significant variation on the calcium content in both seeds and stover of french bean. But higher calcium content in seed and stover was recorded in sulphur treated pots as compared to compared to control. These results are in agreement with those of Yadav and Singh (1970).

4.2.2.6 Aluminium content

The results obtained on the aluminium content in grain and stover of french bean in different treatment has been presented in table 4.25. As evident from the data, increased level of aluminium resulted increased aluminium content in grains and stover of french bean. The maximum aluminium content in grain was recorded in $Al_{0.25}$ with 473.33 and 470.55 mg kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 471.94. The lowest aluminium content was observed in Al_0 with 196.52 and199.12 mg kg^{-1} during 2017-18 and 2018-19 respectively with pooled value of 197.82 mg kg^{-1}. Increase in aluminium level by $Al_{0.25}$ in grains of french bean increased the aluminium content by 138.57%. Similarly the maximum aluminium content in stover was recorded in $Al_{0.25}$ with 1013.61 and 1015.59 mg kg^{-1} during 2017-18 and 2018-19 respectively with pooled value of 1014.60 mg kg^{-1}. The lowest aluminium content was observed in Al_0 with 741.78 and 742.81 mg kg^{-1}during 2017-18 and 2018-19 respectively with pooled value of 742.31 mg kg^{-1}. Increase in aluminium level by $Al_{0.25}$ increased the aluminium content in stover by 36.68%.

It has been shown that aluminium content in stover was higher than that of grains, this is in accordance with the findings of Thangavel (2002) who reported that among the aboveground parts of the control green gram, the accumulation of aluminum was lowest in the grains as compared to leaves and stem and the aluminum content of stems recorded a significant increase with increasing treatment concentration of aluminum. Thronton *et al*. (1986) reported that aluminum concentration of leaves increased with increasing concentration of aluminum and length of exposure to aluminum in solution.

There was no significant effect found with phosphorus and sulphur application in influencing aluminium content in grains and stover of french bean.

4.2.2.7 Protein content

The data regarding protein content and protein yield are given in table 4.26(a). The data indicated that protein content of grains decreased significantly with increasing aluminium levels. The highest protein content was obtained in control Al_0 with 21.40 and 21.85% during 2017-18 and 2018-19, respectively with pooled value of 21.63 while the lowest protein content was obtained in $Al_{0.25}$ with 19.90 and 20.37% during 2017-18 and 2018-19 respectively with pooled value of 20.14. Application of $Al_{0.25}$ decreased the protein content upto the extent of 7.3% over control with regard to pooled value.

The decrease in protein content and protein yield with increase in aluminium level may be due to the reason that that the increase in Al concentration in growth medium decreased the nitrogen content as well as seed yield resulting reduction in protein content and yield. These results are in agreement with those of Thangavel (2002) and Ribeiro *et al*. (2013).

Table 4.26(a): Effect of aluminium, phosphorus and sulphur levels on protein content and protein yield in grains of french bean

Treatments	Protein content (%)			Protein yield (g pot^{-1})		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Aluminium levels						
Al_0	21.40	21.85	21.63	5.14	5.24	5.19
$Al_{0.25}$	19.90	20.37	20.14	2.77	3.15	2.96
SEm±	0.11	0.15	0.12	0.08	0.08	0.07
CD (p=0.05)	0.32	0.43	0.35	0.23	0.23	0.20
Phosphorus levels						
P_0	20.21	20.41	20.31	3.42	3.52	3.47
P_{30}	20.55	21.28	20.91	4.10	4.13	4.11
P_{60}	20.92	21.54	21.23	4.33	4.71	4.52
P_{90}	20.91	21.22	21.07	3.96	4.44	4.20
SEm±	0.15	0.21	0.17	0.11	0.11	0.10
CD (p=0.05)	0.43	0.60	0.49	0.32	0.32	0.29
Sulphur levels						
S_0	20.39	20.74	20.56	3.70	3.83	3.76
S_{30}	20.76	21.35	21.05	4.19	4.36	4.27
S_{60}	20.79	21.26	21.03	3.97	4.41	4.19
SEm±	0.13	0.18	0.15	0.10	0.10	0.09
CD (p=0.05)	0.37	0.52	0.43	0.29	0.29	0.26

Table 4.26(b): Interaction effect of aluminium and phosphorus on protein yield and protein yield

Aluminium levels	Protein yield (g pot^{-1})			
	Phosphorus levels			
	P_0	**P_{30}**	**P_{60}**	**P_{90}**
	2017-2018			
Al_0	4.30	5.40	5.69	5.13
$Al_{0.25}$	2.52	2.79	2.96	2.77
SEm±	0.16			
CD (p=0.05)	0.45			
	2018-2019			
Al_0	4.33	4.99	6.02	5.61
$Al_{0.25}$	2.70	3.25	3.38	3.25
SEm±	0.16			
CD (p=0.05)	0.46			
	Pooled			
Al_0	4.32	5.20	5.85	5.37
$Al_{0.25}$	2.61	3.02	3.17	3.01
SEm±	0.11			
CD (p=0.05)	0.32			

The data also indicated that protein content of french bean grains increased significantly with increasing phosphorus levels. The lowest protein content (20.21 and 20.41% during 2017-18 and 2018-19, respectively with pooled value of 20.31%) was recorded in control and the highest (20.92 and 21.54% during 2017-18 and 2018-19, respectively with pooled value of 21.23%) was obtained in P_{60}.

Girma *et al.* (2014) also reported that increased level of phosphorus resulted in higher protein content in french bean. Shubhashree (2007) also reported that there was linear and significant increase in protein content with P_2O_5 levels. This might also be due to enhanced nitrogen content of seeds.

A critical examination of data show that protein content in grains increased with increase in sulphur level up to 30 kg S ha^{-1} but remain at par beyond this level. In grains, protein content at S_{30} (20.76 and 21.35% during 2017-18 and 2018-19, respectively with pooled value of 21.05%) was significantly higher over control (20.39 and 20.74% during 2017-18 and 2018-19 respectively with pooled value of 20.56%). Difference between S_{30} and S_{60} level was non significant during both the years of experimentation with regard to protein content.

The protein content in grains increased with increase dose of sulphur which may be due to the reason that sulphur is the main component of amino acids like methionone and cysteine which plays a crucial role in protein structure and protein folding pathways. These results are in accordance with the findings of Deshbhratar *et al*. (2010) in pigeon pea and Rahman *et al*. (2007) in rice grains.

The interaction effect of aluminium, phosphorus and sulphur on protein content in grain showed non significant effect among all the treatment combination.

4.2.2.8 Protein yield

It is apparent from the data presented in table 4.26(a) that with the increase in aluminium levels, the protein yield decreased significantly. The highest protein yield was obtained in control Al_0 with 5.14 and 5.24 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.19 while the lowest protein yield was obtained in $Al_{0.25}$ with 2.77 and 3.15 g pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 2.96. Application of $Al_{0.25}$ decreased the pooled protein yield up to the extent of 42.97% over control. Decrease in protein yield with aluminium application might be due to decreased protein content and seed yield which ultimately reduced the protein yield. Similar results have also been reported by Ribeiro *et al*. (2013).

It is also apparent that with the increase in phosphorus levels, the protein yield increased significantly. Highest protein yield was observed with application of 60 kg P_2O_5 ha^{-1}. A sharp reduction in protein yield was recorded beyond P_{60} level of phosphorus. The P_{60} level enhanced pooled protein yield by 30.26% over control. Increase in protein content and seed yield resulted enhanced the protein yield.

A critical examination of data show that protein yield increased with increase in sulphur level up to 30 kg S ha^{-1} but remain at par beyond this level. Protein yield at S_{30} (4.19 and 4.36 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 4.27%) was significantly higher over control (3.70 and 3.83 g pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 3.76 g pot^{-1}). The S_{30} level of sulphur enhanced the pooled protein yield by 13.56% over control. Sulphur application enhanced protein content and seed yield resulted enhancement in protein yield of french bean. These results are in accordance with Deshbhratar *et al*. (2010).

The interaction effect between aluminium and phosphorus presented in table 4.26(b) showed significant effect on protein yield in grains of french bean. The highest protein yield was observed in the combination of Al_0P_{60} with 5.69 and 6.02 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.85 g pot^{-1} and the lowest was observed in the treatment combination of $Al_{0.25}$ P_0 with 2.52 and 2.70 g pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 2.61 g pot^{-1}.

4.2.3 Nutrient uptake

4.2.3.1 Nitrogen uptake

From the data presented in table 4.27(a) and depicted in figure 4.17, it is apparent that the highest nitrogen uptake by grains (821.02 and 838.18 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 829.60 mg pot^{-1}), stover (412.46 and 409.22 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 410.84) was found in Al_0 whereas the lowest uptake by grains (441.96 and 503.29 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 472.62 mg pot^{-1}), stover (282.63 and 290.55 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 286.59 mg pot^{-1}) was recorded in $Al_{0.25}$. The $Al_{0.25}$ level of aluminium reduced the pooled nitrogen uptake in seed and stover to the extent of 43.03 and 30.24%, respectively over control. The increase in aluminium level resulted in a drastic significant decrease in nitrogen uptake upto $Al_{0.25}$. Rufty *et al.* (1995) showed that NO^{3-} uptake by soybean decreased when Al concentration in solution increased from 10 to 50 µM. Calba and Jaillard (1997) reported that aluminium reduced Cl^- and NO^{3-} uptake in maize.

Decrease in nitrogen uptake up to $Al_{0.25}$ may be due to the reason that aluminum ions may bind to the cell surface and form a positively charged layer, thereby inhibiting the adsorption of positively charged cations to the cell surface but stimulating the adsorption of negatively charged anions (Zhao and Shen, 2018). Aluminium application decreased nitrogen content and yield of french bean resulting significant decrease in nitrogen uptake by plant.

Table 4.27(a): Effect of aluminium, phosphorus and sulphur levels on nitrogen and phosphorus uptake in grains and stover of french bean

Treatments	Nutrient uptake (mg pot^{-1})											
	Nitrogen						Phosphorus					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	821.02	838.18	829.60	412.46	409.22	410.84	113.10	111.45	112.28	79.86	78.13	79.00
$Al_{0.25}$	441.96	503.29	472.62	282.63	290.55	286.59	58.64	65.36	62	35.13	34.45	34.79
SEm±	12.05	12.38	10.86	3.38	3.61	2.64	2.04	1.89	1.64	0.89	0.78	0.60
CD (p=0.05)	34.20	35.14	30.82	9.60	10.25	7.50	5.79	5.37	4.66	2.53	2.22	1.71
Phosphorus levels												
P_0	545.95	562.59	554.27	315.65	320.67	318.16	71.39	74.14	72.77	47.33	46.08	46.71
P_{30}	655.59	659.38	657.49	338.45	345.54	341.99	88.10	85.94	87.02	54.68	52.47	53.58
P_{60}	692.11	752.09	722.10	368.62	366.78	367.70	94.24	97.37	95.8	61.06	62.95	62.00
P_{90}	632.30	708.87	670.59	367.44	366.56	367.00	89.74	96.17	92.95	66.91	63.67	65.29
SEm±	17.04	17.50	15.36	4.77	5.10	3.73	2.89	2.67	2.31	1.25	1.11	0.85
CD (p=0.05)	48.36	49.67	43.59	13.54	14.48	10.59	8.21	7.58	6.56	3.55	3.15	2.42
Sulphur levels												
S_0	590.46	611.27	600.86	342.42	337.62	340.02	79.02	80.47	79.74	54.70	53.74	54.22
S_{30}	669.36	696.92	683.14	350.09	353.97	352.03	90.91	92.02	91.47	58.65	57.36	58.00
S_{60}	634.65	704.01	669.33	350.12	358.08	354.10	87.67	92.73	90.2	59.15	57.77	58.46
SEm±	14.76	15.16	13.30	4.13	4.42	3.23	2.50	2.31	2.01	1.08	0.96	0.73
CD (p=0.05)	41.89	43.03	37.75	NS	12.55	9.17	7.10	6.56	5.71	3.07	2.73	2.08

Table 4.27 (b): Interaction effect of aluminium and phosphorus on nitrogen and phosphorus uptake in grains of french bean

Aluminium levels	Nutrient uptake							
	Nitrogen				Phosphorus			
	Phosphorus Levels							
	P_0	P_{30}	P_{60}	P_{90}	P_0	P_{30}	P_{60}	P_{90}
	2017-18							
Al_0	688.66	864.01	910.41	820.97	90.89	118.80	125.30	117.38
$Al_{0.25}$	403.24	447.17	473.80	443.62	51.88	57.40	63.17	62.08
SEm±	25.08				4.24			
CD (p=0.05)	71.30				NS			
	2018-2019							
Al_0	692.58	798.92	962.85	898.34	91.67	107.74	130.49	126.70
$Al_{0.25}$	432.59	519.83	541.31	519.40	53.45	63.87	69.42	71.46
SEm±	25.75				4.59			
CD (p=0.05)	73.23				13.06			
	Pooled							
Al_0	690.62	831.46	936.63	859.65	91.28	113.27	127.90	122.04
$Al_{0.25}$	417.91	483.50	507.56	481.51	52.67	60.63	66.29	66.77
SEm±	17.97				3.13			
CD (p=0.05)	50.45				8.78			

Table 4.27(c): Interaction effect of aluminium and phosphorus on phosphorus uptake in stover of french bean

Aluminium levels	Phosphorus uptake (mg pot^{-1})			
	Phosphorus levels			
	P_0	P_{30}	P_{60}	P_{90}
	2017-18			
Al_0	69.11	76.26	82.48	91.59
$Al_{0.25}$	25.55	33.10	39.64	42.22
SEm±	1.83			
CD (p=0.05)	NS			
	2018-2019			
Al_0	65.82	73.01	86.22	87.45
$Al_{0.25}$	26.33	31.91	39.66	39.87
SEm±	1.62			
CD (p=0.05)	4.61			
	Pooled			
Al_0	67.47	74.63	84.35	89.52
$Al_{0.25}$	25.94	32.51	39.65	41.04
SEm±	1.22			
CD (p=0.05)	NS			

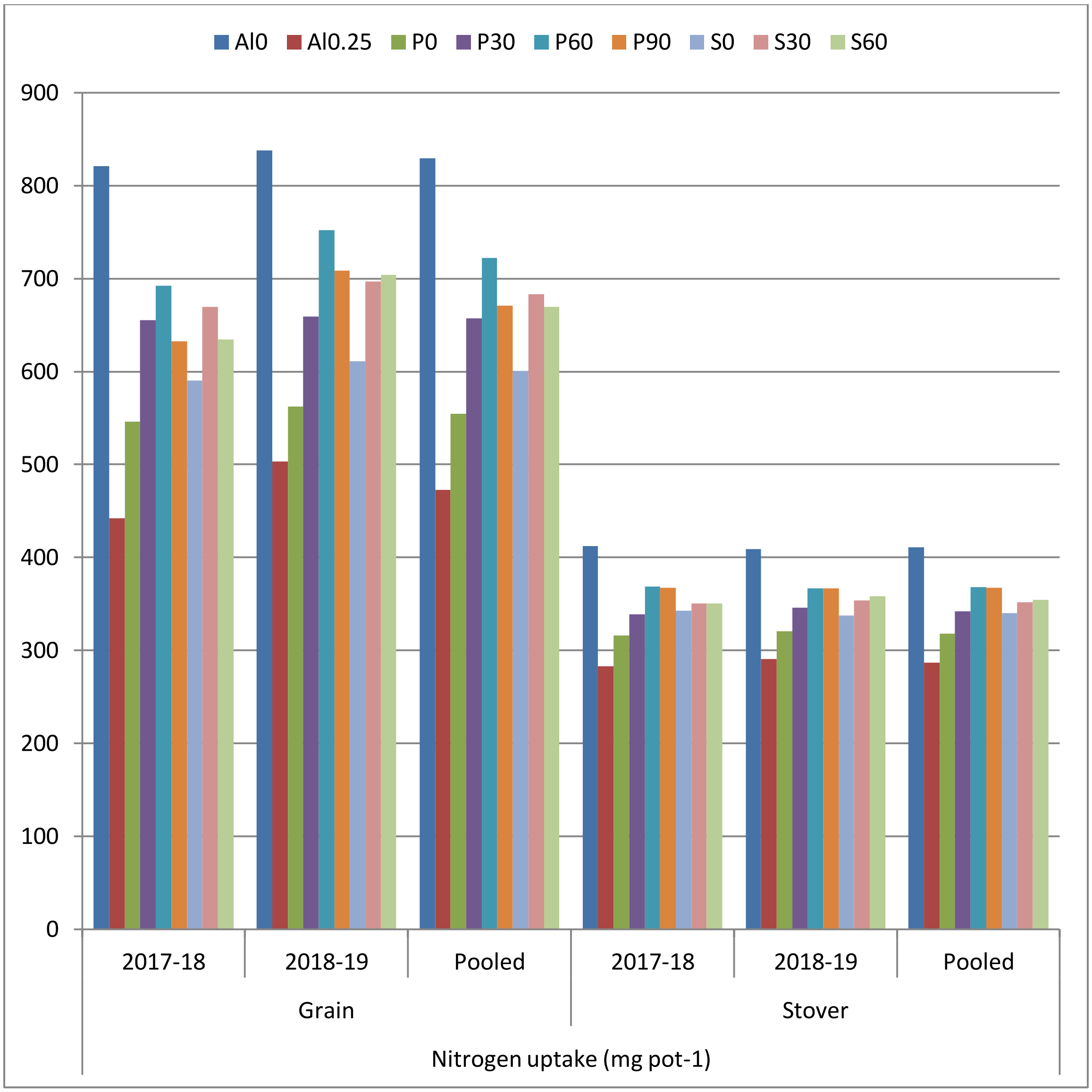

Figure 4.17: Effect of aluminium, phosphorus and sulphur levels on nitrogen uptake in grains and stover of french bean

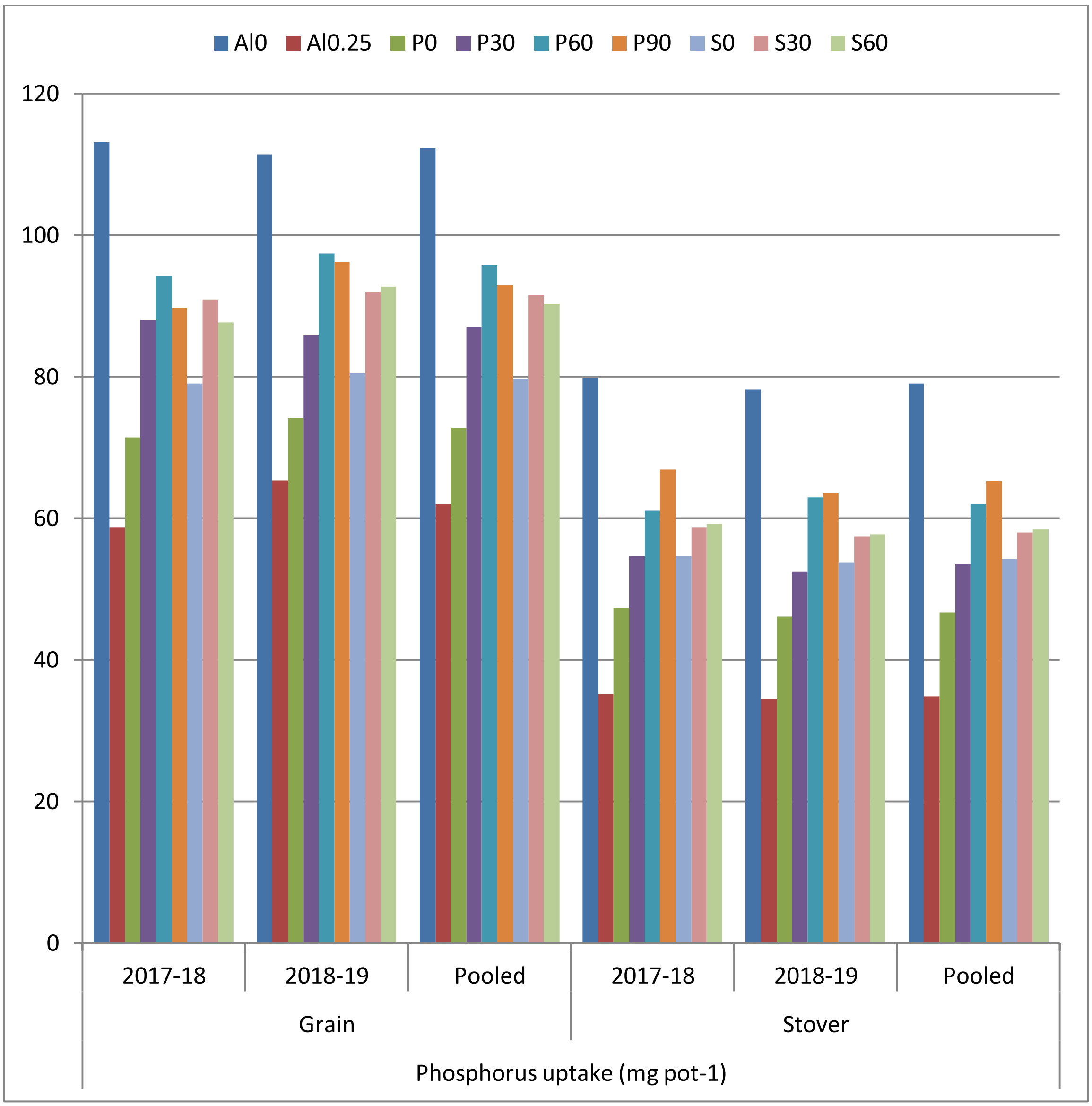

Figure 4.18: Effect of aluminium, phosphorus and sulphur levels on phosphorus uptake in grains and stover of french bean

From the data presented in table 4.27(a), it is apparent that the highest nitrogen uptake by grains (692.11 and 752.09 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 722.10 mg pot^{-1}), stover (368.62 and 366.78 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 367.70 mg pot^{-1}) was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains (545.95 and 562.59 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 554.27 mg pot^{-1}), stover (315.65 and 320.67 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 318.16 mg pot^{-1}) was found in control. The increase in each phosphorus level resulted in a drastic significant increase in nitrogen uptake up to 60 kg P_2O_5 ha^{-1}.

The reason behind the increase in nitrogen uptake by phosphorus application may be due to the reason that increase nitrogen fixation which in turn increased nitrogen content and increased the grains and stover yield. As nutrient uptake is the product of nutrient content and yield, with the increase in these attributes, the total nutrient uptake was also increased. Similar results were reported by Kumar *et al*. (2015) in case of urd bean, Shubhashree (2007) in french bean and Singh *et al*. (2017) in moong bean.

Increasing sulphur levels significantly influenced nitrogen uptake in seeds and stover. The significantly highest uptake in seeds (669.36 and 696.92 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 683.14 mg pot^{-1}) was recorded with sulphur dose of 30 kg ha^{-1} and (350.12 and 358.08 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 354.10 mg pot^{-1}) in stover was recorded with S dose of 60 kg ha^{-1}whereas lowest content in seeds (590.46 and 611.27 mg pot^{-1} for 2017-18 and 2018-19, respectively with pooled value of 600.86 mg pot^{-1}) and stover (342.42 and 337.62 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 340.02 mg pot^{-1}) was recorded in control. The similar kind of results was obtained by Singh *et al*. (2017).

The interaction effect of aluminium and phosphorus on nitrogen uptake in grains of french bean is given in table 4.27(b). The interaction effect between aluminium and phosphorus showed significant effect on nitrogen uptake in grains of french bean. The highest nitrogen uptake was observed in the combination of Al_0P_{60} (910.41 and 962.85 mg pot^{-1} for 2017-18 and 2018-19 respectively with pooled value of 936.63 mg pot^{-1}) and the lowest was observed in the treatment combination of $Al_{0.25}P_0$ (403.24 and 432.59 mg pot^{-1} for 201 7-18 and 2018-19, respectively with pooled value of 417.91 mg pot^{-1}).

4.2.3.2 Phosphorus uptake

The data regarding phosphorus uptake are presented in table 4.27(a) and depicted in figure 4.18. It is clear from the data that phosphorus uptake was greatly influenced by the increased level of applied aluminium. Phosphorus uptake by grains and stover decreased significantly with increasing aluminium levels. The highest phosphorus uptake by grain (113.10 and 111.45 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 112.28 mg pot^{-1}) and stover (79.86 and 78.13 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 79.00 mg pot^{-1}) was recorded in Al_0 whereas the minimum uptake (58.64 and 65.36 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 62.00 mg pot^{-1}) in grain and in stover (35.13 and 34.45 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 34.79 mg pot^{-1}) was recorded in treatment $Al_{0.25}$. Application of $Al_{0.25}$ decreased pooled phosphorus uptake to the extent of 44.78% in grain while 55.96 % in stover over control.

Jan and Pettersson (1989) reported that phosphorus uptake was decreased due to aluminium interference in upland rice. The decreased uptake of phosphorus induced by aluminum levels has been reported in cotton by Lance and Pearson (1969). Clarkson (1965) explained that the binding of phosphorus on root surfaced and cell walls of plant roots may be the cause for the decreased uptake of phosphorus. Aluminium interference with phosphorus uptake might result in phosphorus deficiency in plants grown on acid soils or in nutrient solutions (Jan and Pettersson, 1989).

It is clear from the data that phosphorus uptake was greatly influenced by the increased level of applied phosphorus. The highest phosphorus uptake by grains (94.24 and 97.37 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 95.80 mg pot^{-1}) was found in treatment of 60 kg P_2O_5 ha^{-1}, stover (66.91 and 63.67 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 65.29 mg pot^{-1}) was found in treatment of 90 kg P_2O_5 ha^{-1} whereas the lowest uptake by grains (71.39 and 74.14 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 46.71) was found in control. Application of 60 kg P_2O_5 ha^{-1} increased pooled phosphorus uptake of grain to the extent of 31.64% over control while application of 90 kg P_2O_5 increased phosphorus uptake of grain to the extent of 27.73% over control. Pooled phosphorus uptake in stover increased by 39.78% with application of 90 kg P_2O_5 ha^{-1} over control. Similar results were reported by Shubhashree (2007) in french bean and Dalai *et al*. (2019) in dolichos bean.

Increasing sulphur levels significantly influenced phosphorus uptake in seeds and stover of french bean. The significantly higher uptake in seeds (90.91 and 92.02 mg pot^{-1} during 2017-18 and 2018-19 respectively, with pooled value of 91.47 mg pot^{-1}) was recorded with sulphur dose of 30 kg ha^{-1} and (59.15 and 57.77 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 58.46 mg pot^{-1}) in stover was recorded with application of 60 kg S ha^{-1} whereas lowest uptake in seeds (79.02 and 80.47 mg pot^{-1} for 2017-18 and 2018-19 respectively with pooled value of 79.74 mg pot^{-1}) and stover (54.70 and 53.74 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 54.22 mg pot^{-1}) was recorded in control. Difference between S_{30} and S_{60} levels was non significant with regard to phosphorus uptake in seed and stover during during both the years of experimentation. Application of 30 kg S ha^{-1} enhanced the pooled phosphorus uptake to the extent of 14.71% in seed and 6.97% in stover over control.

The increase in phosphorus uptake with increase in sulphur levels might be due to the reason that phosphorus and sulphur has a synergistic relationship between. Sulphur application increased phosphorus content and yield which in resulted increased phosphorus uptake. The similar kinds of results were obtained by Singh *et al*. (2017) in moong bean and Yadav (2011) in cluster bean.

The interaction effect between aluminium and phosphorus presented in table 4.27(b) showed significant effect on phosphorus uptake in grains of french bean. The highest phosphorus uptake was observed in the combination of Al_0P_{60} (125.30 mg pot^{-1} and 130.49 mg pot^{-1} for 2017-18 and 2018-19, respectively with pooled value of 127.90 mg pot^{-1}) and the lowest was observed in the treatment combination of $Al_{0.25}P_0$ (51.88 and 53.45 for 2017-18 and 2018-19 respectively with pooled value of 52.67 mg pot^{-1}).

The interaction effect between aluminium and sulphur, phosphorus and sulphur and aluminium, phosphorus and sulphur did not show any significant effect on phosphorus uptake in grains of french bean.

The interaction effect between aluminium and phosphorus presented in table 4.27(c) showed significant effect on phosphorus uptake in stover of french bean. The highest nitrogen uptake was observed in the combination of Al_0P_{90} (90.02 and 87.45 mg pot^{-1} for 2017-18 and 2018-19, respectively with pooled value of 88.73 mg pot^{-1}) and the lowest was observed in the treatment combination of $Al_{0.25}P_0$ (24.18 and 26.33 mg pot^{-1} for 2017-18 and 2018-19 respectively with pooled value of 25.25 mg pot^{-1}).

The interaction effect between aluminium and sulphur, phosphorus and sulphur and aluminium, phosphorus and sulphur did not show any significant effect on phosphorus uptake in stover of french bean.

4.2.3.3 Potassium uptake

The data regarding potassium uptake are presented in table 4.28(a) and depicted in figure 4.19. It is clear from the data that potassium uptake was influenced significantly by the increased level of aluminium. Potassium uptake by grains and stover decreased significantly with increasing aluminium levels in comparison to control. The highest potassium uptake by grain (197.99 and 199.36 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 198.68 mg pot^{-1}) and stover (495.11 and 485.36 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 490.24 mg pot^{-1}) was recorded in treatment Al_0 (control) whereas the minimum uptake (105.66 and 116.84 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 111.25 mg pot^{-1}) in grain and in stover (357.69 and 363.77 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 360.73 mg pot^{-1}) was recorded in treatment $Al_{0.25}$. Application of $Al_{0.25}$ decreased pooled potassium uptake to the extent of 44.00% in grain and 26.42% in stover over control.

Narayanan and Syananda (1989) reported that the uptake of K decreased with increase in aluminium levels exceeding 10 ppm in pigeonpea (*Cajanus cajan L.*). Cumming *et al*. (1985) also reported similar results in case of red spruce seedlings. It is clear from the data that potassium uptake was positively influenced by increased levels of phosphorus. Pooled potassium uptake by seeds was enhanced significantly upto P_{60} level of phosphorus and beyond this it was decreased significantly. However, in case of stover, potassium uptake was increased upto highest level (P_{90}) of phosphorus, but difference between P_{60} and P_{90} was insignificant. The highest potassium uptake by grains (166.65 and 177.77

Table 4.28(a): Effect of aluminium, phosphorus and sulphur levels on potassium and sulphur uptake in grains and stover of french bean

Treatments	Nutrient uptake (mg pot^{-1})											
	Potassium						Sulphur					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	197.99	199.36	198.68	495.11	485.36	490.24	76.44	79.93	78.18	47.04	41.40	44.22
$Al_{0.25}$	105.66	116.84	111.25	357.69	363.77	360.73	35.31	37.98	36.65	25.31	24.91	25.11
SEm±	2.89	3.06	2.59	4.38	4.56	3.41	1.35	2.05	1.33	0.97	0.98	0.81
CD (p=0.05)	8.21	8.69	7.35	12.43	12.95	9.68	3.84	5.82	3.78	2.76	2.79	2.30
Phosphorus levels												
P_0	130.48	133.74	132.11	387.22	387.84	387.53	44.49	48.43	46.46	27.20	24.08	25.64
P_{30}	157.85	153.65	155.75	416.36	416.76	416.56	56.59	56.40	56.50	34.75	31.38	33.07
P_{60}	166.65	177.77	172.21	447.13	442.58	444.86	63.31	67.22	65.27	39.94	36.43	38.19
P_{90}	152.32	167.22	159.77	454.89	451.08	452.99	59.10	63.76	61.43	42.81	40.75	41.78
SEm±	4.09	4.33	3.66	6.20	6.44	4.82	1.91	2.90	1.88	1.38	1.39	1.14
CD (p=0.05)	11.61	12.29	10.39	17.60	18.28	13.68	5.43	8.23	5.34	3.92	3.95	3.24
Sulphur levels												
S_0	141.85	145.34	143.59	414.11	408.97	411.54	49.98	50.52	50.25	30.63	27.22	28.93
S_{30}	162.04	164.14	163.09	430.88	428.61	429.75	58.71	61.12	59.91	37.08	33.56	35.32
S_{60}	151.59	164.80	158.20	434.21	436.12	435.17	58.93	65.22	62.08	40.81	38.69	39.75
SEm±	3.54	3.75	3.17	5.37	5.58	4.17	1.65	2.51	1.63	1.19	1.20	0.99
CD (p=0.05)	10.05	10.65	9.00	15.24	15.84	11.84	4.69	7.13	4.63	3.38	3.41	2.81

Table 4.28(b): The interaction effect of aluminium and phosphorus on potassium uptake in grains of french bean

Aluminium levels	Potassium uptake			
	Phosphorus Levels			
	P_0	P_{30}	P_{60}	P_{90}
	2017-18			
Al_0	166.71	210.06	217.73	197.01
$Al_{0.25}$	95.58	105.62	115.57	107.63
SEm±	5.91			
CD (p=0.05)	16.79			
	2018-2019			
Al_0	165.42	189.76	227.75	212.95
$Al_{0.25}$	102.06	117.53	126.26	123.17
SEm±	6.40			
CD (p=0.05)	18.21			
	Pooled			
Al_0	166.07	199.91	222.74	204.98
$Al_{0.25}$	98.82	111.58	120.91	115.40
SEm±	4.36			
CD (p=0.05)	12.23			

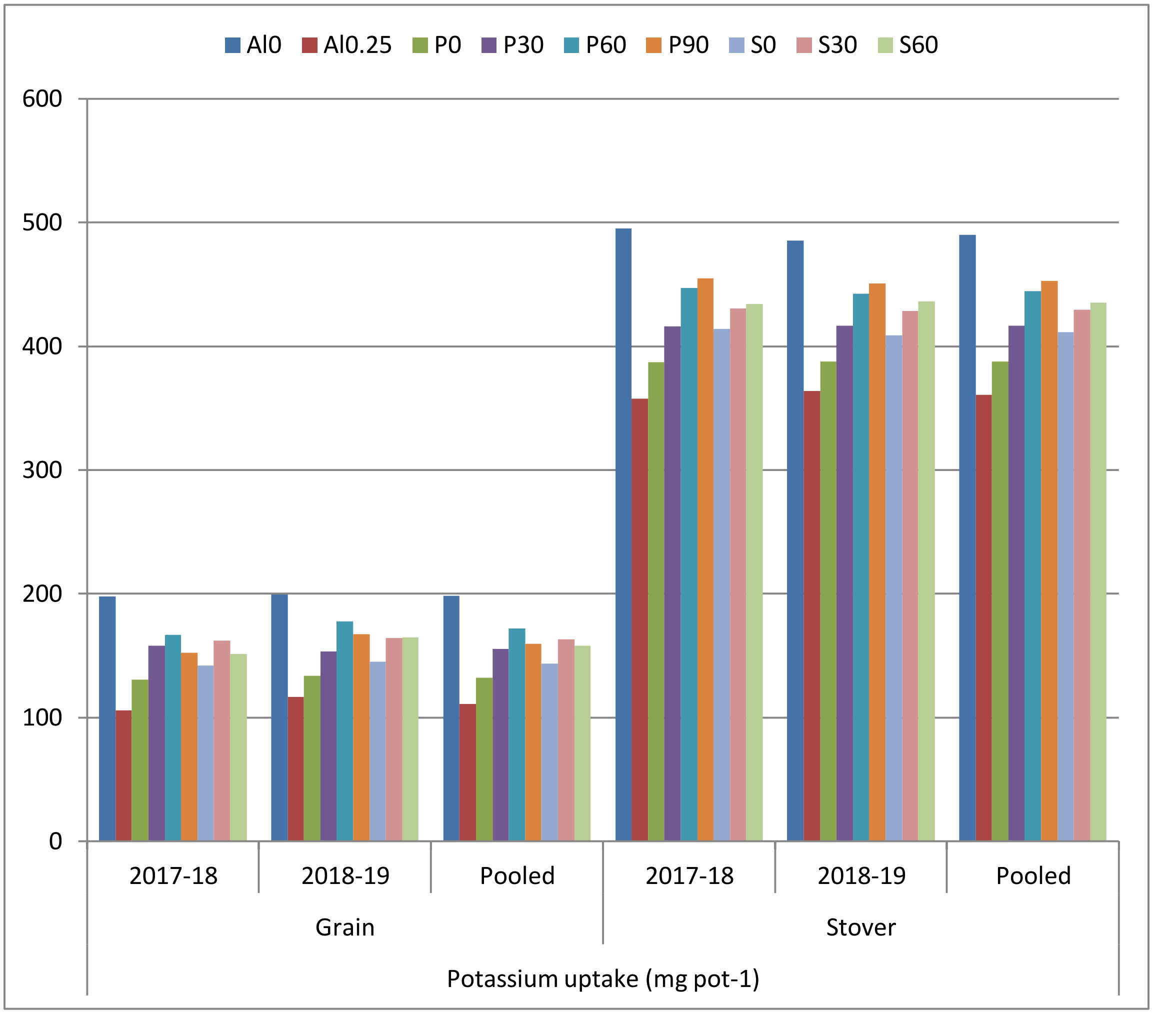

Figure 4.19: Effect of aluminium, phosphorus and sulphur levels on potassium uptake in grains and stover of french bean

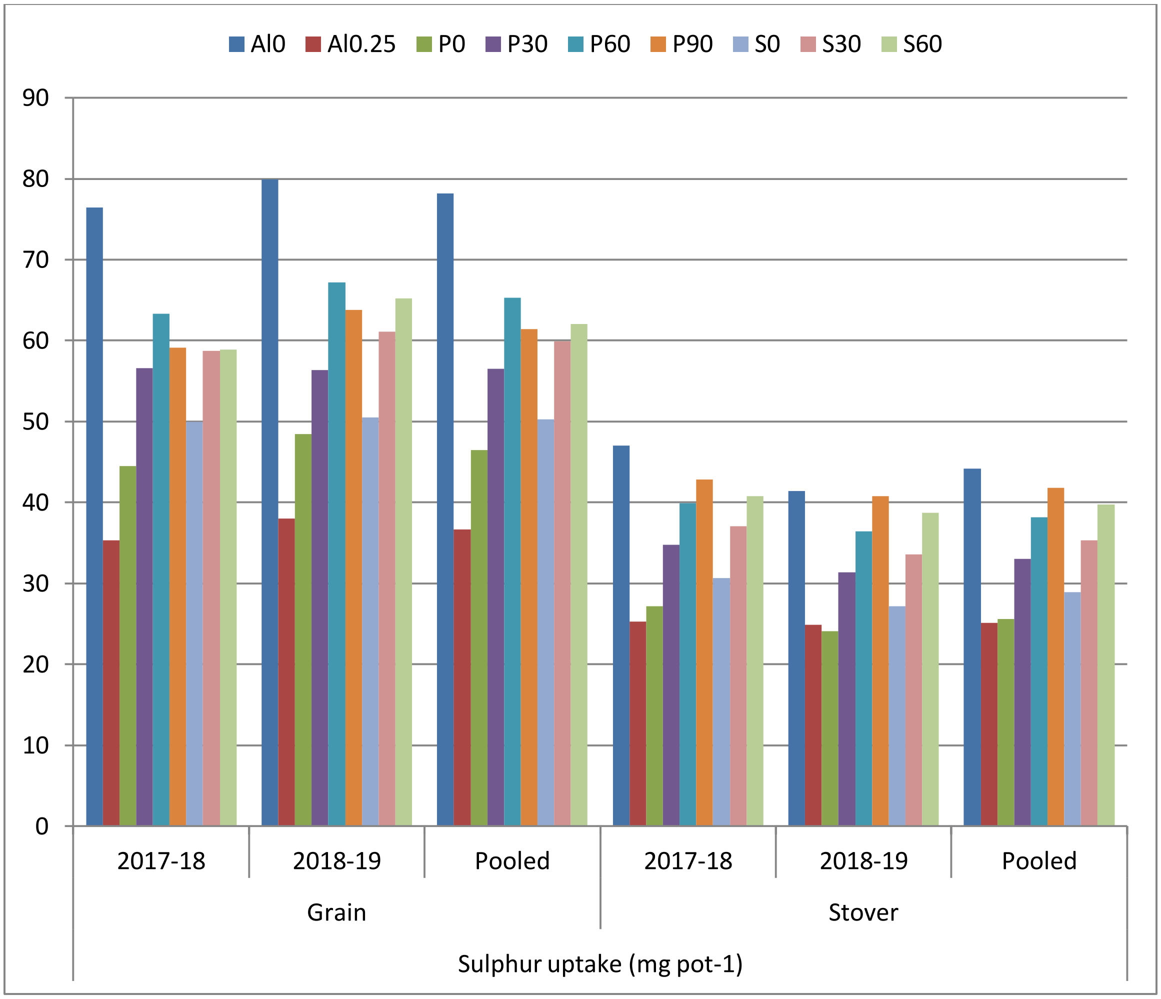

Figure 4.20: Effect of aluminium, phosphorus and sulphur levels on sulphur uptake in grains and stover of french bean

mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 172.21 mg pot^{-1}) was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}), stover (454.89 and 451.08 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 452.99 mg pot^{-1}) was found in treatment P_{90} (90 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in control. Application of 60 kg P_2O_5 ha^{-1} increased pooled potassium uptake of grain to the extent of 30.35% over control while application of 90 kg P_2O_5 increased pooled potassium uptake of stover to the extent of 16.89% over control. Fageria (1989) also reported beneficial effect of phosphorus application on potassium uptake.

Effect of sulphur nutrition was also significant on potassium uptake in seeds and stover. Significantly highest potassium uptake by grains (162.04 and 164.14 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 163.09 mg pot^{-1}) was recorded with application of 30 kg S ha^{-1} and highest uptake in stover (434.21 and 436.12 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 435.17 mg pot^{-1}) was recorded with S dose of 60 kg ha^{-1}. Lowest uptake (141.85 and 145.34 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 145.59 mg pot^{-1}) in grains and stover (414.11 and 408.97 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 411.54 mg pot^{-1}) was recorded with zero or no sulphur levels.

The reason of increased potassium uptake might be due to higher yield and potassium content which are enhanced by increasing phosphorus levels and sulphur levels. The similar kind of results was obtained by Singh *et al*. (2017) in moong bean and Dalai *et al*. (2019) in dolichos bean.

The interaction effect between aluminium and phosphorus presented in table 4.28(b) showed significant effect on potassium uptake in grains of french bean. The highest potassium uptake was observed in the combination of Al_0P_{60} (217.73 % and 227.75 % for 2017-18 and 2018-19 respectively with pooled value of 222.74 %) and the lowest was observed in the treatment combination of $Al_{0.25}P_0$.

The interaction effect between aluminium and sulphur, phosphorus and sulphur and aluminium, phosphorus and sulphur did not show any significant effect on potassium uptake in grains of french bean.

The interaction effect of aluminium and phosphorus, aluminium and sulphur, phosphorus and sulphur, aluminium, phosphorus and sulphur on potassium uptake in stover did not show any significant effect on potassium uptake in grains of french bean.

4.2.3.4 Sulphur uptake

The data regarding potassium uptake are presented in table 4.28(a) and depicted in figure 4.20. It is clear from the data that sulphur uptake was significantly influenced by the increased level of applied aluminium. Sulphur uptake by grains as well as stover decreased significantly with increasing aluminium levels. The highest sulphur uptake by grain (76.44 and 79.93 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 79.18 mg pot^{-1}) and stover (47.04 and 41.40 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 44.22 mg pot^{-1}) was recorded in treatment control whereas the minimum uptake (35.31 and 37.98 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 36.65 mg pot^{-1}) in grain and in stover (25.31 and 24.91 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 25.11 mg pot^{-1}) was recorded in treatment $Al_{0.25}$. Application of $Al_{0.25}$ decreased pooled sulphur uptake to the extent of 53.05% over control in grain while 10.85 % in stover. It might be due to reduction in yield as well as sulphur content with increasing concentration of aluminium in growth medium. Similar results have also been reported by Poblete *et al.* (2018).

It is clear from the data that sulphur uptake was greatly influenced by the increased level of phosphorus. Sulphur uptake by grains and stover increased significantly with each increasing phosphorus levels upto P_{60} level. Furthur application of phosphorus reduced the sulphur uptake by grain. But sulphur uptake by stover was increased upto P_{90} level. The highest sulphur uptake by grains (63.31 and 67.22 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 65.27 mg pot^{-1}) was found in treatment of 60 kg P_2O_5 ha^{-1}, stover (42.81 and 40.75 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 41.78 mg pot^{-1}) was found in treatment P_{90} (90 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in control. Application of 60 kg P_2O_5 ha^{-1} increased pooled sulphur uptake of grain to the extent of 40.49% over control while application of 90 kg P_2O_5 increased phosphorus uptake in stover to the extent of 62.95% over control. These results are in accordance with those of Phogat (2016). Increasing sulphur levels significantly influenced sulphur uptake in seeds and stover. The S_{30} and S_{60} levels of sulphur increased grain sulphur uptake significantly over control during both the years of experimentation. However, difference between S_{30} and S_{60} levels were non significant. Highest and lowest sulphur uptake in grain and stover was observed under S_{60} and control level of sulphur. The S_{30} level increased pooled sulphur uptake by 19.22% in grain and S_{60} level enhanced pooled sulphur uptake in stover by 37.40% over control.

Sulphur application increased the yield and sulphur content in french bean resulted in enhancement of sulpur uptake by the crop. The similar kind of results was obtained by Phogat (2016), Singh *et al*. (2017) and Yadav (2011). There was no significant difference among all the treatment combinations on sulphur uptake in stover of french bean.

4.2.3.6 Calcium uptake

From the data presented in table 4.29(a) and figure 4.21, it is apparent that the highest calcium uptake by grains (62.95 and 62.88 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 62.92 mg pot^{-1}), stover (241.40 and 246.72 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 244.06 mg pot^{-1}) was found control whereas the lowest uptake by grains (19.04 and 21.24 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 20.14 mg pot^{-1}), stover (109.54 and 112.68 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 111.11 mg pot^{-1}) was recorded in $Al_{0.25}$. The $Al_{0.25}$ level of aluminium reduced the pooled calcium uptake by seed and stover to the extent of 68.00% and 54.47%, respectively over control.

Nichol and Oliveira (1995) noted that Al^{3+} reduced Ca^{2+} influx in barley (*Hordeum vulgare*). It was reported that high aluminium concentrations in nutrient solution influenced the uptake of minerals; uptake of divalent cations particularly calcium and magnesium was often disturbed by Al (Delhaize and Ryan, 1995). Decrease in calcium concentrations in soybean tops and roots were associated with Al toxicity. (Foy *et al*.,1969).

From the data presented in table 4.29(a), it is apparent that the highest calcium uptake by grains (48.18 and 50.38 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 49.28 mg pot^{-1}) was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}), whereas in stover (188.05 and 192.21 mg pot^{-1} during 2017-18 and2018-19 respectively with pooled value of 190.13 mg pot^{-1}) was found in treatment P_{90} (90 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in control. Significant increase in calcium uptake in grains was observed upto P_{60} level, beyond this level; a non significant reduction was noted. But calcium uptake in stover was increased upto P_{90} level with non significant difference to P_{60} level. Similar results were also reported by Kumar *et al*. (2017).

Increasing sulphur levels showed significant effect on calcium uptake on seeds and stover for both the year and the highest uptake in seeds (43.98 and 44.28 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 44.13 mg

Table 4.29(a): Effect of aluminium, phosphorus and sulphur levels on calcium and aluminium uptake in grains and stover of french bean

Treatments	Calcium uptake (mg pot^{-1})						Aluminium uptake (mg pot^{-1})					
	Grain			Stover			Grain			Stover		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	62.95	62.88	62.92	241.40	246.72	244.06	4.70	4.75	4.72	24.51	24.23	24.37
$Al_{0.25}$	19.04	21.24	20.14	109.54	112.68	111.11	6.57	7.25	6.91	25.06	25.65	25.35
SEm±	1.57	1.51	1.49	1.58	1.94	1.30	0.12	0.11	0.10	0.19	0.29	0.16
CD (p=0.05)	4.46	4.29	4.23	4.49	5.51	3.69	0.33	0.32	0.29	0.53	0.82	0.46
Phosphorus levels												
P_0	31.50	31.60	31.55	155.90	161.45	158.68	5.09	5.28	5.19	22.78	23.18	22.98
P_{30}	41.87	39.50	40.68	170.83	175.47	173.15	5.82	5.94	5.88	24.12	24.56	24.34
P_{60}	48.18	50.38	49.28	187.12	189.68	188.40	6.05	6.50	6.27	26.12	25.87	26.00
P_{90}	42.44	46.77	44.60	188.05	192.21	190.13	5.57	6.27	5.92	26.12	26.15	26.14
SEm±	2.21	2.13	2.11	2.24	2.75	1.83	0.16	0.16	0.14	0.26	0.41	0.23
CD (p=0.05)	6.28	6.05	5.99	6.36	7.81	5.20	0.47	0.46	0.40	0.75	1.11	0.65
Sulphur levels												
S_0	37.00	37.29	37.15	170.28	173.88	172.08	5.36	5.59	5.48	24.29	24.25	24.27
S_{30}	43.98	44.28	44.13	177.66	183.16	180.41	5.98	6.19	6.08	24.96	25.12	25.04
S_{60}	42.01	44.61	43.31	178.48	182.07	180.28	5.56	6.21	5.89	25.11	25.45	25.28
SEm±	1.92	1.84	1.83	1.94	2.38	1.59	0.14	0.14	0.12	0.23	0.35	0.25
CD (p=0.05)	5.45	5.23	5.20	5.51	6.76	4.52	0.40	0.39	0.35	0.65	NS	0.56

Table 4.29 (b): Interaction effect of aluminium and phosphorus on aluminium uptake in stover of french bean

Aluminium levels	Aluminium uptake (mg pot^{-1})			
	Phosphorus levels			
	P_0	**P_{30}**	**P_{60}**	**P_{90}**
	2017-18			
Al_0	23.20	24.28	24.97	25.60
$Al_{0.25}$	22.36	23.95	27.28	26.64
SEm±	0.39			
CD (p=0.05)	1.11			
	2018-2019			
Al_0	22.80	24.07	25.02	25.04
$Al_{0.25}$	23.56	25.06	26.72	27.26
SEm±	0.60			
CD (p=0.05)	NS			
	Pooled			
Al_0	23.00	24.17	24.99	25.32
$Al_{0.25}$	22.96	24.50	27.00	26.95
SEm±	0.35			
CD (p=0.05)	1.01			

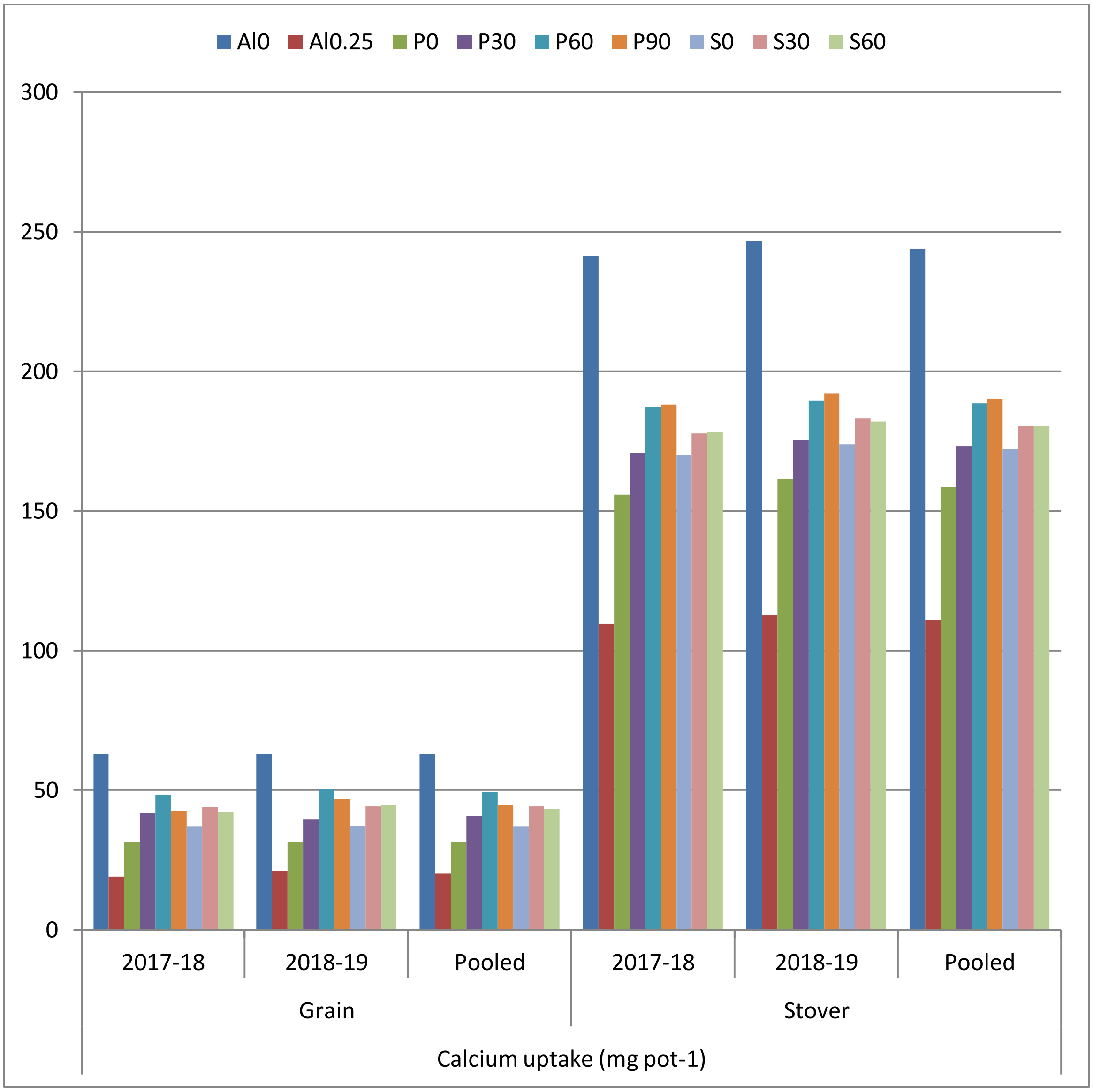

Figure 4.21: Effect of aluminium, phosphorus and sulphur levels on calcium uptake in grains and stover of french bean

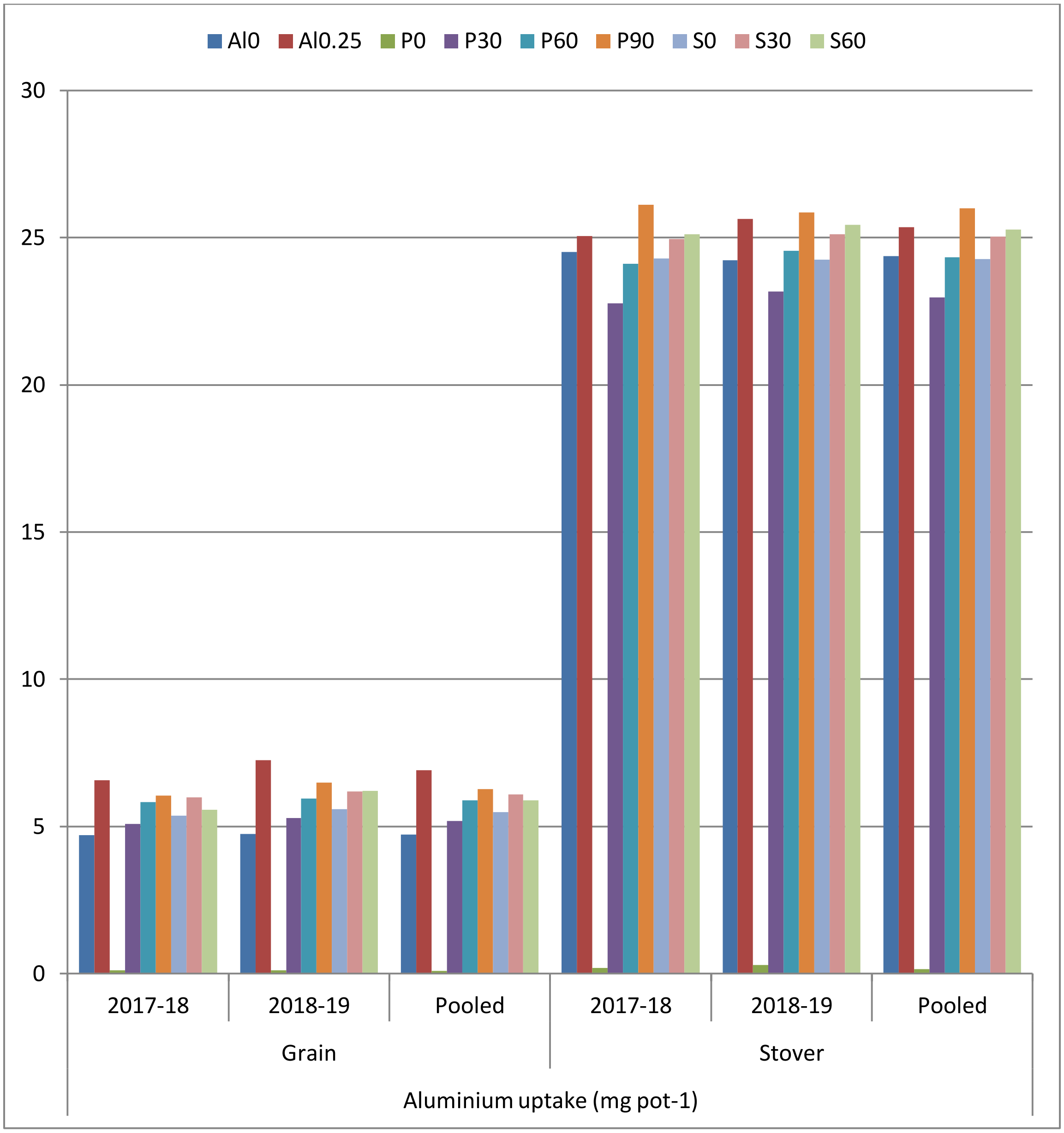

Figure 4.22: Effect of aluminium, phosphorus and sulphur levels on aluminium uptake in grains and stover of french bean

pot^{-1}) was recorded with sulphur dose of 30 kg ha^{-1} and (178.48 and 182.07 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 182.36 mg pot^{-1}) in stover was recorded with sulphur dose of 60 kg ha^{-1}whereas lowest uptake in seeds (37.00 and 37.29 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 37.15 mg pot^{-1}) and stover (170.28 and 173.88 mg pot^{-1} during 2017-18 and 2018-19 respectively with pooled value of 172.08 mg pot^{-1}) was recorded in control. These findings are in accordance with those of Ravikumar *et al.* (2016).

There was no significant difference among the different treatment combination of aluminium, phosphorus and sulphur on calcium uptake both in grain and stover of french bean.

4.2.3.7 Aluminium uptake

The results obtained on the aluminium uptake in grain and stover of french bean in different treatment has been presented in table 4.29(a) and depicted in figure 4.22. As seen from the data, increased level of aluminium resulted in increasing aluminium uptake in grains and stover of french bean. The maximum aluminium uptake in grain was recorded in $Al_{0.25}$ with 6.57 and 7.25 mg pot^{-1}during 2017-18 and 2018-19, respectively with pooled value of 6.91 mg pot^{-1}. The lowest aluminium uptake was observed in Al_0 with 4.70 and 4.75 mg pot^{-1}during 2017-18 and 2018-19, respectively with pooled value of 4.72 mg pot^{-1}. Aluminium level $Al_{0.25}$ increased the aluminium uptake in grain by 46.39%. Similarly the maximum aluminium uptake in stover was recorded in $Al_{0.25}$ with 25.06 and 25.65 mg pot^{-1}during 2017-18 and 2018-19, respectively with pooled value of 25.35 mg pot^{-1}. The lowest aluminium uptake was observed in Al_0 with 24.51 and 24.23 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 24.37 mg pot^{-1}. Aluminium level $Al_{0.25}$ increased the aluminium uptake in stover by 4.02% over control.

The increase in aluminium uptake with increase in aluminium levels is obvious as the concentration of aluminium in the soil was increased; more amount of aluminium was absorbed by the plant parts.

From the data presented in table 4.29(a), it is apparent that the highest aluminium uptake by grains (6.05 and 6.50 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 6.27 mg pot^{-1}) was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}), whereas in stover (26.12 and 25.87 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 26.00 mg pot^{-1}) was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in P_0 (control).

With increase in phosphorus level, still there was a significant increase in aluminium uptake which may be probably due to enhanced seed and stover yield.

Increasing sulphur levels showed significant effect on aluminium uptake on seeds and stover for both the year. The significantly highest uptake in seeds (5.98 and 6.19 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 6.08 mg pot^{-1}) and stover (24.96 and 25.12 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 25.04 mg pot^{-1}) was recorded with sulphur dose of 30 kg ha^{-1} whereas lowest uptake in seeds (5.36 and 5.59 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 5.48 mg pot^{-1}) and stover (24.29 and 24.25 mg pot^{-1} during 2017-18 and 2018-19, respectively with pooled value of 24.27 mg pot^{-1}) was recorded in control. Similar results were reported by Thronton *et al*. (1986).

The interaction effect between aluminium and phosphorus presented in table 4.29(b) showed significant effect on aluminium uptake in stover of french bean. The highest aluminium uptake was observed in the combination of $Al_{0.25}P_{60}$ (27.28 mg pot^{-1}) for 2017-18 and $Al_{0.25}P_{90}$ (27.26 mg pot^{-1}) for 2018-19, respectively, with pooled value of $Al_{0.25}P_{60}$ (27.00 mg pot^{-1}) and the lowest was observed in the treatment combination of $Al_{0.25}P_0$ (22.36 mg pot^{-1}) for 2017-18 and Al_0P_0 (22.80 mg pot^{-1}) for 2018-19 respectively with pooled value of $Al_{0.25}P_0$ (23.00 mg pot^{-1}).

There was no significant difference among the different treatment combination of aluminium, phosphorus and sulphur on aluminium uptake in seeds but showed significant effect in stover.

The interaction effect between aluminium and sulphur, phosphorus and sulphur and aluminium and phosphorus and sulphur did not show any significant effect on sulphur uptake in grains of french bean.

4.2.4 Effect on soil properties

4.2.4.1 Soil pH and organic carbon

The data pertaining to the effect of aluminium, phosphorus and sulphur levels on soil pH and organic carbon is projected in table 4.30. Treatment with aluminium ($Al_{0.25}$) significantly lowered the pH to 5.06 and 5.16 during 2017-18 and 2018-19, respectively with computed pooled value 5.11 as compared to that of control (Al_0) with a recorded pH of 5.37 during 2017-18 and 5.34 during 2018-19 along with pooled value of 5.35.

However, the effect of phosphorus as well as sulphur levels was found statistically non-significant on soil pH.

The presence of aluminium is one of the factors which contribute to soil acidity. The decrease in soil pH owing to the application of aluminium could possibly be due to solubility nature of aluminium where in aqueous solution, Al hydrolyzes the water molecules and forms soluble aluminium hydroxide, thereby lower soil pH. (Bojorquez-Quintal *et al*., 2017).

With regard to organic carbon content, the effect of levels of aluminium, phosphorus and sulphur was found statistically non-significant on soil organic carbon as shown in table 4.30.

Table 4.30: Effect of aluminium, phosphorous and sulphur levels on pH and organic carbon in post experimental soil

Treatments	**pH**			**Organic carbon (g kg^{-1})**		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Aluminium levels						
Al_0	5.37	5.34	5.35	17.6	18.2	17.9
$Al_{0.25}$	5.06	5.16	5.11	16.9	17.4	17.2
SEm±	0.04	0.03	0.03	0.3	0.3	0.3
CD (p=0.05)	0.12	0.09	0.09	NS	NS	NS
Phosphorus levels						
P_0	5.19	5.22	5.20	17.1	17.4	17.2
P_{30}	5.17	5.22	5.20	17.2	17.7	17.5
P_{60}	5.21	5.26	5.24	17.3	18.0	17.6
P_{90}	5.28	5.29	5.28	17.4	18.2	17.8
SEm±	0.05	0.04	0.04	0.5	0.5	0.5
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Sulphur levels						
S_0	5.27	5.29	5.28	17.1	17.7	17.4
S_{30}	5.21	5.26	5.24	17.3	17.8	17.6
S_{60}	5.15	5.20	5.18	17.4	17.9	17.6
SEm±	0.04	0.03	0.04	0.4	0.4	0.4
CD (p=0.05)	NS	NS	NS	NS	NS	NS

4.2.4.2 Soil available NPK and S

The data regarding the effect of different levels of aluminium, phosphorus and sulphur on soil available NPK and S is elaborated in table 4.31.

The effect of aluminium application significantly responded on the soil available nitrogen after crop harvest. Treatment with higher level of aluminium ($Al_{0.25}$) was found to decrease the available nitrogen in soil with a recorded data of 235.4 and 235.0 kg ha^{-1} during the experimental year 2017-18 and 2018-19, respectively with pooled value of 235.2 kg ha^{-1}. Maximum available nitrogen was recorded in control during both the years of experimentation. Application of higher dose of aluminium reduced the available nitrogen by 4.32% as compared to control.

Aluminium and nitrogen are known to have an antagonistic relationship, wherein the availability of one reduces the availability of the other. This was well documented by Zhao and Shen (2018) who reported that the presence of aluminium lowers the availability of nitrogen.

The treatment effect of different levels of phosphorus was found statistically significant on soil available nitrogen. Among all the given treatments, the highest response was observed in treatment with phosphorus level P_{90} for the available nitrogen of 243.9 kg ha^{-1} during 2017-18 and 242.9 kg ha^{-1} during 2018-19, along with pooled data of 243.4 kg ha^{-1} and an increment of 2.58 and 2.52% over that of control during the first and second year of experimentation, respectively. This was followed by treatment P_{60} with 242.5 kg ha^{-1} available N during 2017-18 and 241.1 kg ha^{-1} N during 2018-19 which yielded pooled value of 239.6 kg ha^{-1}. The increase in available nitrogen in the soil under phosphorus treated pots as compared to control indicated that phosphorus fertilization enhanced nitrogen fixation as well as nitrogen secretion by french bean which improved nitrogen status of the soil. These effects are in concordance with those

Table 4.31: Effect of aluminium, phosphorus and sulphur levels on available nutrients status of post harvest soil

Treatments	Available nutrients (kg ha^{-1})											
	Nitrogen			Phosphorus			Potassium			Sulphur		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Aluminium levels												
Al_0	246.8	244.8	245.8	14.9	15.0	15.0	179.7	180.1	179.9	17.72	16.36	17.04
$Al_{0.25}$	235.4	235.0	235.2	11.7	12.1	11.9	170.0	169.3	169.7	12.37	12.29	12.33
SEm±	0.18	0.18	0.12	0.1	0.12	0.08	0.20	0.23	0.16	0.25	0.25	0.18
CD (p=0.05)	0.52	0.52	0.35	0.29	0.35	0.23	0.57	0.66	0.46	0.72	0.72	0.52
Phosphorus levels												
P_0	237.7	236.9	237.3	11.1	11.0	11.0	175.4	175.3	175.3	14.49	13.91	14.20
P_{30}	240.4	238.7	239.6	13.1	12.8	12.9	174.7	175.0	174.9	15.05	13.94	14.50
P_{60}	242.5	241.1	241.8	13.8	14.5	14.1	174.5	174.3	174.4	15.29	14.66	14.97
P_{90}	243.9	242.9	243.4	15.3	15.9	15.6	174.8	174.2	174.5	15.36	14.80	15.08
SEm±	0.26	0.25	0.17	0.14	0.17	0.12	0.28	0.32	0.23	0.35	0.35	0.25
CD (p=0.05)	0.74	0.71	0.49	0.4	0.49	0.35	NS	NS	NS	NS	NS	NS
Sulphur levels												
S_0	239.5	238.2	238.8	13.3	13.3	13.3	174.4	174.2	174.3	14.65	13.92	14.29
S_{30}	241.0	239.8	240.4	13.3	13.5	13.4	175.1	174.9	175.0	15.21	14.44	14.83
S_{60}	242.9	241.7	242.3	13.4	13.8	13.6	175.0	175.1	175.1	15.28	14.61	14.95
SEm±	0.22	0.22	0.15	0.12	0.15	0.1	0.24	0.28	0.20	0.30	0.30	0.22
CD (p=0.05)	0.63	0.63	0.43	NS	NS	NS	NS	NS	NS	NS	NS	NS

of Yakubu *et al.* (2010).

The data on available nitrogen as affected by varying levels of sulphur showed a significant difference with increasing levels of sulphur. The treatment with S_{60} responded the best in maximizing the available N to 242.94 kg ha^{-1} during 2017-18 and 241.77 kg ha^{-1} during 2018-19 with pooled value of 242.36 kg ha^{-1} along with an increment of 1.43 and 1.48% over that of control (S_0).

In parallel with our findings, Sujata *et al*. (2007) also concluded that increased in soil available nitrogen content was observed with the addition of sulphur, which was probably be due to their synergistic effect. Jamal *et al*. (2010) also gave the same conclusion of appreciable increased available nitrogen when sulphur was applied to soil.

The effect of aluminium application on available phosphorus was observed statistically significant as shown in table 4.31. The data show that application of higher dose of aluminium led to a reduced content of available phosphorus as compared to that with control. Treatment with Al_0 obtained significantly higher soil available phosphorus of 14.9 kg ha^{-1} during 2017-18 and 15.0 kg ha^{-1} during 2018-19, the pooled value of which was worked out as 15.0 kg ha^{-1}. The antagonistic effect of added aluminium led to a deteriorating level of available phosphorus by 21.26 and 19.40% during the respective years of 2017-18 and 2018-19.

It is apparent that in acidic condition phosphorus gets fixed with aluminium to form Al-P bond, conclusively made the availability of phosphorus lower. These results are in agreement with (Zheng *et al*., 2005 and Iqbal, 2013).

With regard to effect of different phosphorus levels on soil available phosphorus significant response was observed across all the treatments as compared to that of control. The highest available phosphorus in soil was recorded in P_{90} with 15.3 and 15.9 kg ha^{-1}, respectively during the experimental years 2017-

18 and 2018-19 with pooled value of 15.6 kg ha^{-1}. This was followed by the treatment P_{60} with 13.8 and 14.50 kg ha^{-1} along with pooled value 14.1 kg ha^{-1}. Some portion of applied phosphorus through fertilizers might be accumulated in the soil resulted enhanced available phosphorus content of the soil after crop harvest. Similar results were reported by Nyekha *et al*. (2015).

The effect of sulphur levels was found statistically non-significant on the soil available phosphorus as depicted in table 4.31.

The data pertaining to the effect of aluminium levels on available potassium in soil indicate that there was a significant difference between the treatments. Maximum significant reduction in available potassium content was recorded at highest level of aluminium. The maximum available potassium was recorded in Al_0 with 179.7 and 180.1 kg ha^{-1} during 2017 and 2018, respectively with a pooled value of 179.9 kg ha^{-1} and the lowest was recorded in $Al_{0.25}$ with 170.0 and 169.3 kg ha^{-1} potassium during 2017-18 and 2018-19, respectively with pooled value of 169.7 kg ha^{-1}. It was observed that application of $Al_{0.25}$ decreased the soil available potassium by 5.36% and 6.01% over control, respectively during first and second year of experimentation. The increase in the concentration of hydrogen ions (though less in magnitude) and $Al(OH)_2$ naturally displace the macronutrients Na, K, Ca and Mg from their exchange sites thereby paving the way for their loss due to leaching (Clarkson and Sanderson, 1971; Schier, 1985; Ryan *et al*., 1986).

The effect of phosphorus as well as sulphur levels on soil available potassium was found statistically non-significant.

The soil available sulphur as shown in table 4.31 was found significantly higher in the soils of aluminium untreated pots with a recorded content of 17.72 and 16.36 kg ha^{-1} during 2017-18 and 2018-19, respectively with pooled value of 217.04 kg ha^{-1} as compared to $Al_{0.25}$ level of aluminium. It was observed that application of higher dose of aluminium ($Al_{0.25}$) reduced the available sulphur by 30.19 and 24.87% as compared to control during 2017-18 and 2018-19 respectively.

The effect of phosphorus application was found to be non significant with regard to available sulphur content of the soil.

The data in table 4.31 depict that with increased level of sulphur application there was no significant increase in the soil available sulphur.

4.2.4.3 Exchangeable calcium, aluminium and total potential acidity

The data in table 4.32 depicts the effect of different levels of aluminium, phosphorus and sulphur on exchangeable calcium, aluminium and total potential acidity of the soils after crop harvest. The effect of phosphorus and sulphur levels was found statistically non-significant on exchangeable calcium, exchangeable aluminium and total potential acidity.

However, the main effect of aluminium levels significantly responded on exchangeable calcium. The highest was recorded in treatment Al_0 with 3.26 and 3.29 cmol (p^+) kg^{-1} during 2017-18 and 2018-19, respectively and a computed pooled value 3.28 cmol(p^+) kg^{-1}. With higher level of aluminium the amount of exchangeable calcium was found to have decreased by 16.56 and 17.02 % as compared to that of control during first and second year respectively.

Exchangeable calcium generally competes with aluminium for exchange sites and replaces aluminium, thereby increasing their stand and availability. Studies have also reported that calcium amendments are commonly used to reduce aluminium in soil or ameliorate aluminium toxicity through the process of cation exchange or replacement (Mora *et al*. (2002), Rengel and Zhang (2003), Illera *et al*. (2004). This possibly explained why the higher dose of aluminium led to a decrease in exchangeable calcium.

Table 4.32: Effect of aluminium, phosphorus and sulphur levels on exchangeable calcium, exchangeable aluminium and total potential acidity of post harvest soil

Treatments	Exchangeable calcium cmol(p$^+$)kg^{-1}			Exchangeable aluminium cmol(p$^+$)kg^{-1}			Total potential acidity cmol(p$^+$)kg^{-1}		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Aluminium Levels									
Al_0	3.26	3.29	3.28	1.76	1.68	1.72	10.47	10.11	10.29
$Al_{0.25}$	2.72	2.73	2.72	2.62	2.40	2.51	13.45	13.32	13.38
SEm±	0.06	0.06	0.06	0.05	0.03	0.04	0.07	0.06	0.05
CD (p=0.05)	0.18	0.18	0.18	0.15	0.09	0.12	0.20	0.18	0.15
Phosphorus Levels									
P_0	2.97	2.96	2.97	2.21	2.09	2.15	12.06	11.87	11.97
P_{30}	3.00	3.01	3.01	2.19	2.05	2.12	11.97	11.61	11.79
P_{60}	2.99	3.03	3.01	2.19	2.01	2.10	12.02	11.61	11.81
P_{90}	2.99	3.03	3.01	2.17	2.01	2.09	11.77	11.78	11.78
SEm±	0.08	0.08	0.08	0.06	0.04	0.05	0.09	0.09	0.07
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sulphur Levels									
S_0	3.00	3.01	3.01	2.17	2.07	2.12	11.94	11.57	11.75
S_{30}	2.99	3.01	3	2.19	2.04	2.11	11.96	11.79	11.88
S_{60}	2.97	3.00	2.99	2.20	2.02	2.11	11.97	11.79	11.88
SEm±	0.07	0.07	0.07	0.05	0.03	0.04	0.08	0.08	0.06
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

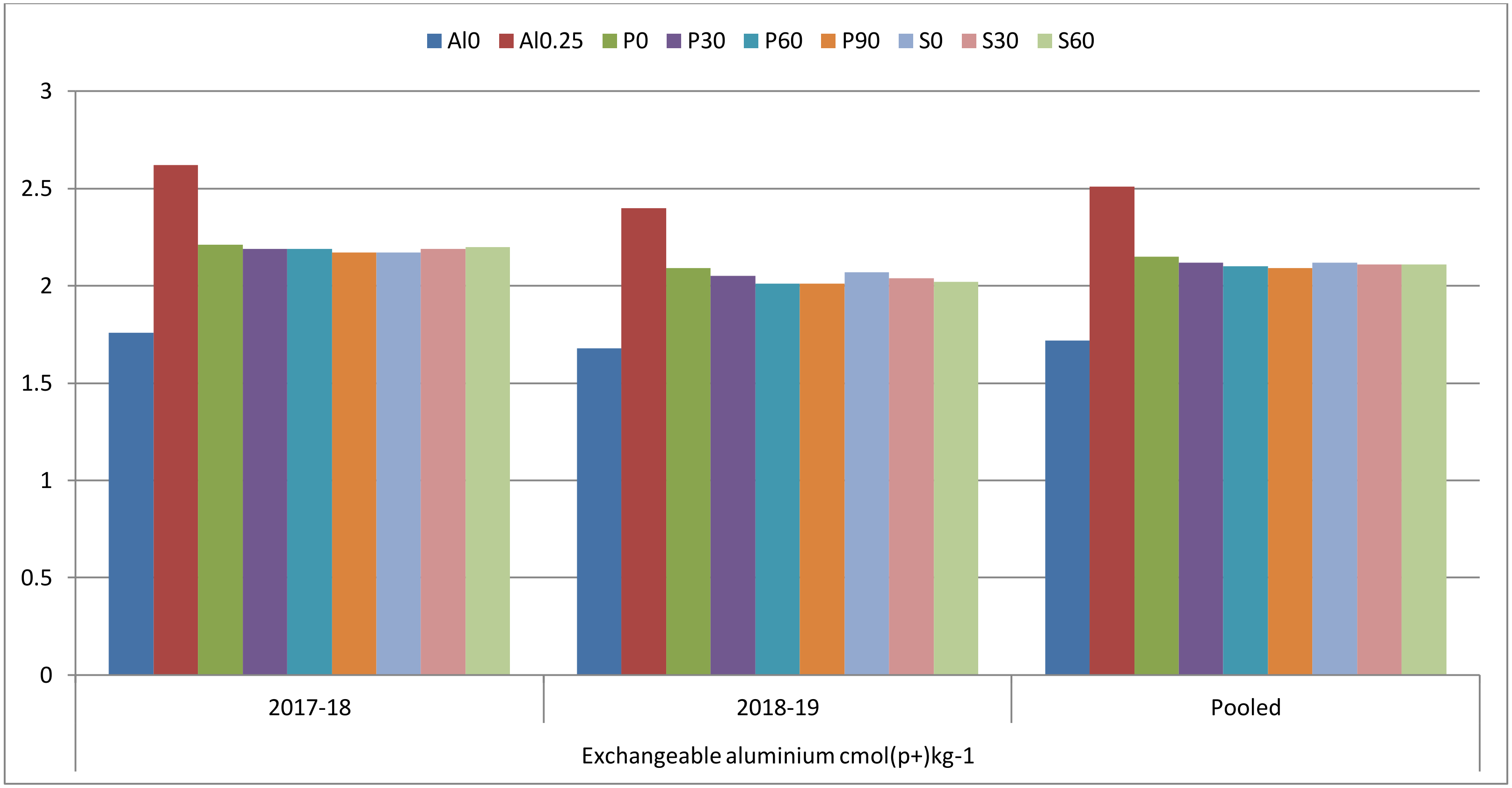

Fig 4.23: Effect of aluminium, phosphorus and sulphur levels on exchangeable aluminium

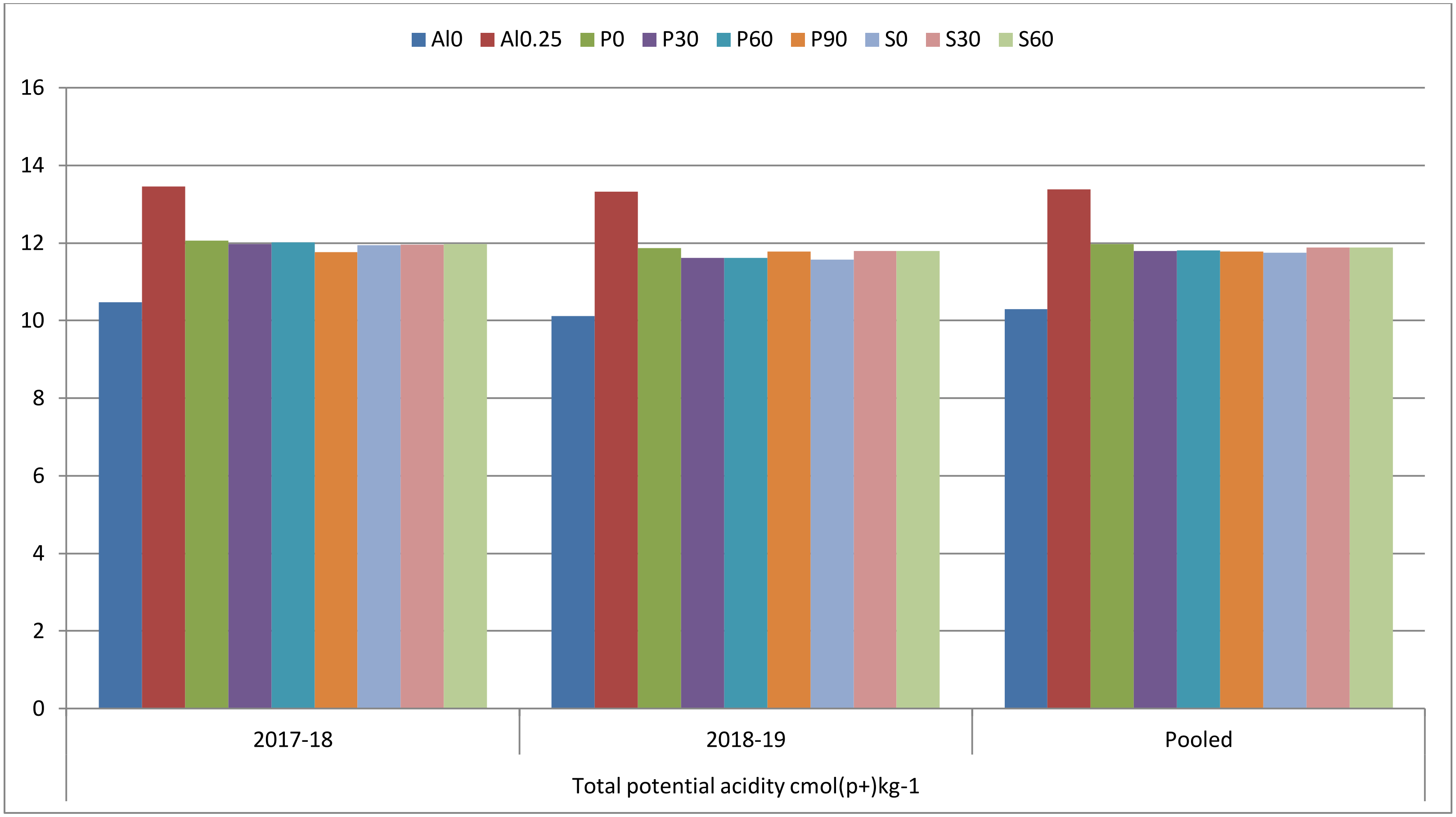

Fig 4.24: Effect of aluminium, phosphorus and sulphur levels on total potential acidity of post experimental soil

The data on the effect of aluminium on exchangeable aluminium show that with increased level of aluminium the content of exchangeable aluminium in soil increased (Fig. 4.23). The treatment $Al_{0.25}$ responded the maximum with exchangeable aluminium of 2.62 and 2.40 cmol(p^+)kg^{-1} during 2017-18 and 2018-19, respectively along with pooled value of 2.51 cmol (p^+) kg^{-1}. It is evidently clear that the increment in exchangeable aluminium could well be attributed to the addition of aluminium and thus their availability.

Similarly, the application of aluminium significantly responded in enhancing the total potential acidity of soil (Fig. 4.24). The highest response was obtained by treatment $Al_{0.25}$ with 13.45 and 13.32 cmol(p^+) kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 13.38 cmol(p^+) kg^{-1} and the lowest was recorded in Al_0 with 10.47 and 10.11 cmol(p^+)kg^{-1} during 2017-18 and 2018-19, respectively with pooled value of 10.29 cmol(p^+) kg^{-1}.

4.2.4.4 Interaction effect of aluminium, phosphorus and sulphur on soil properties

The data in table 4.33(a) presents the interaction effect of different levels of aluminium and phosphorus on nitrogen and phosphorus content of soil.

The interaction of Al_0P_{90} responded the highest in maximizing the nitrogen content of post harvest soil to 250.3 kg ha^{-1} during 2017-18 and 248.4 kg ha^{-1} during 2018-19 with pooled value of 249.3 kg ha^{-1}, respectively. This was followed by that of Al_0P_{60} for the nitrogen content of 248.6 and 246.3 kg ha^{-1}, respectively during 2017-18 and 2018-19 along with computed pooled data 247.4 kg ha^{-1}, respectively.

The interaction between aluminium and phosphorus levels significantly affected the available phosphorus content of soil. Increasing level of phosphorus increased available phosphorus under each level of aluminium. The highest

Table 4.33(a): Interaction effect of aluminium and phosphorus levels on available nutrients of post harvest soil

Aluminium levels	Nitrogen content (kg ha^{-1})				Phosphorus content (kg ha^{-1})			
	P_0	P_{30}	P_{60}	P_{90}	P_0	P_{30}	P_{60}	P_{90}
	2017-18							
Al_0	242.2	246.3	248.6	250.3	12.4	14.6	15.1	17.6
$Al_{0.25}$	233.2	234.6	236.4	237.4	9.7	11.7	12.6	13.0
SEm±	0.37				0.19			
CD (p=0.05)	1.05				0.55			
	2018-19							
Al_0	241.4	243.3	246.3	248.4	12.2	14.7	15.69	17.4
$Al_{0.25}$	232.4	234.2	236.0	237.4	9.8	10.9	13.2	14.4
SEm±	0.36				0.24			
CD (p=0.05)	1.03				0.69			
	Pooled							
Al_0	241.8	244.8	247.4	249.3	12.3	14.6	15.4	17.5
$Al_{0.25}$	232.8	234.4	236.2	237.4	9.7	11.3	12.9	13.7
SEm±	0.26				0.16			
CD (p=0.05)	0.73				0.44			

Table 4.33(b): Interaction effect of phosphorus and sulphur levels on available phosphorus content of post harvest soil

Phosphorus levels	Phosphorus content (kg ha^{-1})		
	S_0	**S_{30}**	**S_{60}**
	2017-18		
P_0	10.9	11.1	11.1
P_{30}	12.6	12.8	13.9
P_{60}	14.2	14.0	13.3
P_{90}	15.4	15.3	15.1
SEm±	0.24		
CD (p=0.05)	0.67		
	2018-19		
P_0	10.6	10.9	11.5
P_{30}	12.5	12.8	13.0
P_{60}	14.3	14.5	14.5
P_{90}	15.7	16.0	16.1
SEm±	0.30		
CD (p=0.05)	NS		
	Pooled		
P_0	10.8	11.0	11.3
P_{30}	12.5	12.8	13.5
P_{60}	14.3	14.2	13.9
P_{90}	15.6	15.7	15.6
SEm±	0.19		
CD (p=0.05)	0.53		

phosphorus content was recorded in Al_0P_{90} with 17.6 and 17.4 kg ha^{-1} during 2017-18 and 2018-19, the pooled data of which was 17.5 kg ha^{-1}, respectively.

The lowest response was obtained with $Al_{0.25}P_0$ for the available phosphorus content 9.7 and 9.8 kg ha^{-1} during 2017-18 and 2018-19, respectively.

However, the interaction effect between phosphorus and sulphur presented in table 4.33(b) on available phosphorus content significantly varied from 10.9 kg ha^{-1} with treatment combination P_0S_0 to 15.4 kg ha^{-1} with $P_{90}S_0$ during 2017-18 but in pooled value, the maximum available phosphorus was found in $P_{90}S_{30}$ treatment combination. These results are in accordance with Ali (2015) whose work also presented that higher level of sulphur resulted in low content of phosphorus and vice versa. This depicts their antagonistic effect with each, suggesting that addition of both in equal rate will give no additive effect. Aulakh and Pasricha (1977) also reported that application of sulphur reduced the uptake of phosphorus in grains, making their antagonistic interaction more conspicuous.

The interaction effect of aluminium and phosphorus, aluminium and sulphur, phosphorus and sulphur and aluminium, phosphorus and sulphur did not show any significant differences on exchangeable calcium, aluminium and total potential acidity.

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A research investigation entitled "Response of French Bean to Phosphorus and Sulphur at Different Levels of Aluminium" was conducted during *rabi* season, in the Department of Agricultural Chemistry and Soil Science; School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema. The main findings of the investigation are given below:

Experiment-1: To evaluate the aluminium tolerance of french bean varieties

Effect on growth and yield

1. The germination of french bean was delayed with increase in aluminium levels. The minimum number of days to germination was recorded in the control (3.33 days) for both the years and pooled, followed by $Al_{0.25}$ (4.00 days) for both the year and pooled and the maximum days to germination was recorded in $Al_{0.50}$ (5.00 and 4.67 days for 2017-18 and 2018-19, respectively with pooled value of 4.83 days). Varieties did not show positive effect on days to germination. The highest days to germinate was recorded from the treatment combination of $Al_{0.50}V_1$, $Al_{0.50}V_2$ and $Al_{0.50}V_3$ with 5 days each during the year 2017-18, $Al_{0.50}V_1$ and $Al_{0.50}V_2$ with 5 days each during 2018-19 while the pooled value of 5, 5 and 4 days were recorded in Al_0V_1 ,Al_0V_2 and Al_0V_3.
2. The plant height of french bean significantly decreased with every increase in aluminium level upto $Al_{0.50}$ cmol kg^{-1} at 30 DAS, 60 DAS and at harvest. The maximum plant height was recorded from Al_0 and the minimum plant height was recorded from $Al_{0.50}$ cmol kg^{-1}. Among the varieties the maximum plant height was recorded in the order of Selection-9 (20.96 and 19.38 cm, 27.79 and 26.78 cm and 29.47 and 28.16 cm for 30 DAS, 60

DAS and at harvest with pooled value of 20.17, 27.79 and 28.82 cm) followed by Nagaland Local (18.17 and 17.30 cm, 25.61 and 24.25 cm, 26.71 and 24.59 cm at 30 DAS, 60 DAS and at harvest with pooled data of 17.73, 24.93 and 25.65 cm respectively. The minimum plant height was observed in Anupam-R (17.38 and 16.79 cm, 24.04 and 23.57 cm and 25.88 and 24.62 cm during 2017-18 and 2018-19) with pooled value of 17.09, 23.81 and 25.25 cm at 30 DAS, 60 DAS and at harvest. Considering the interaction effect, the highest plant height was observed in Al_0V_1 at 30 DAS, 60 DAS and at harvest. The minimum plant height was seen to be different for different growth stages. At 30 DAS, the lowest plant height was in the treatment combination of $Al_{0.50}V_2$ (2017-18), $Al_{0.50}V_3$ (2018-19 and pooled), at 60 DAS lowest plant height was recorded in the treatment combination of $Al_{0.50}V_2$ during both the year and pooled. At harvest lowest plant height was recorded in the treatment combination of $Al_{0.50}V_2$ during both the year and pooled.

3. With every increase in aluminium levels, the number of branches per plant decreased significantly at all growth stages. At 30, 60 DAS and at harvest, highest number of branches was observed at Al_0 (3.78 and 3.33, 7.22 and 7.11, 9.67 and 9.33) with pooled value of 3.56, 7.17 and 9.50 at 30 DAS, 60 DAS and at harvest during 2017-18 and 2018-19. Minimum number of branches was recorded from $Al_{0.50}$ cmol kg^{-1} during both the year and pooled. The number of branches per plant at 30 and 60 DAS during 2017-18 and 2018-19 was not affected significantly by different varieties but at harvest V_1 (selection-9) produced higher number of branches in comparision to other varieties.
4. Maximum number of pods was recorded in Al_0 (14.00 and 13.56 with pooled value of 13.78) during 2017-18 and 2018-19. And the minimum

number of pods per plant was observed in $Al_{0.50}$ (8.11 and 7.78 with pooled value of 7.94) during 2017-18 and 2018-19. Among the three varieties, the number of pod per plant was highest in Selection-9 (11.67 and 11.78 with pooled value of 11.72) during 2017-18 and 2018-19 while minimum number of pods was recorded from Nagaland local (10.11 and 10.22 with the pooled value of 10.17) in the year 2017-18 and 2018-19. The V_1 variety produced significantly higher pods per plant under $Al_{0.25}$ level of aluminium in comparisions to other varieties. But under $Al_{0.50}$ level of aluminium, difference between V_1 and V_3 varieties was not significant under $Al_{0.50}$ levels in case of pods per plant.

5. Longer pod length was recorded in control (11.74 and 11.83 cm with pooled value of 11.79 cm) during 2017-18 and 2018-19 than the aluminium treated ones. The shortest pod length was recorded in $Al_{0.50}$ (7.16 and 7.64 cm with pooled value of 7.40 cm) during 2017-18 and 2018-19. The results of varietal performance represent that the significantly highest pod length was obtained from Selection-9 (9.91 and 10.06 cm with pooled value of 9.99 cm during 2017-18 and 2018-19.
6. The highest number of seeds per pod was recorded in Al_0 (4.92 and 4.96 with pooled value of 4.94) during 2017-18 and 2018-19. The lowest number of seeds per pod was observed in $Al_{0.50}$ (3.30 and 3.32 with pooled value of 3.31) during 2017-18 and 2018-19. The effect of varieties on seeds per pod was found to be non significant.
7. Among the three aluminium levels, the highest test weight was recorded in $Al_{0.50}$ (31.01 and 31.08 g with pooled value of 31.04) during 2017-18 and 2018-19. The minimum test weight was found in Al_0 (26.71 and 26.44 g pot^{-1} with pooled value of 26.58 g pot^{-1}) during 2017-18 and 2018-19. Test

weight of french bean was not affected significantly under different varieties.

8. A critical examination of the data showed that increasing level of aluminum significantly reduced the seed yield. Highest seed yield was obtained from the control Al_0 (18.77 and 17.89 g pot^{-1} with pooled value of 18.33 g pot^{-1}) during 2017-18 and 2018-19. The lowest seed yield was found in $Al_{0.50}$ (8.35 and 8.80 g pot^{-1} with pooled value of 8.58 g pot^{-1}) during 2017-18 and 2018-19. Reduction of seed yield was recorded 31.6% and 21.6% between Al_0 to $Al_{0.25}$ level and 34.8 and 33.4% between $Al_{0.25}$ to $Al_{0.50}$ level during first and second year, respectively. Among the varieties, the highest seed yield was recorded in Selection-9 (14.61 and 14.72 g pot^{-1} with pooled value of 14.66 g pot^{-1}) during 2017-18 and 2018-19. The lowest seed yield was obtained from Nagaland local (11.98 and 11.74 g pot^{-1} with pooled value of 11.86 g pot^{-1}) during 2017-18 and 2018-19. Considering the interaction effects which showed significant results, the highest seed yield was recorded in Al_0V_1 while the least seed yield was recorded in $Al_{0.50}V_3$ during both the year and pooled.
9. Stover yield of french bean decreased significantly with increasing aluminium levels. The highest stover yield was recorded in control (34.04 and 32.83 g pot^{-1} with pooled value of 33.44 g pot^{-1}) during 2017-18 and 2018-19 .The minimum stover yield was found in $Al_{0.50}$ (15.48 and 16.57 g pot^{-1} with pooled value of 16.02 during 2017-18 and 2018-19. Among the varieties Selection-9 showed the highest stover yield (25.50 and 26.17 g pot^{-1} with pooled value of 25.84 g pot^{-1}) during 2017-18 and 2018-19. The lowest stover yield was obtained from Nagaland local (21.95 and 22.64 g pot^{-1} with pooled value of 22.30 g pot^{-1}) during 2017-18 and 2018-19. The treatment combination showed non significant differences during first year

but highest stover yield was recorded in Al_0V_1 and the minimum stover yield was recorded in $Al_{0.50}V_3$ during the second year.

10. The highest root length was recorded under Al_0 (14.00 and 13.84 cm with pooled value of 13.92) cm during 2017-18 and 2018-19. The significantly shortest root length was observed in $Al_{0.50}$ (7.29 and 7.19 cm with pooled value of 7.24 cm) during 2017-18 and 2018-19. Among the three varieties the highest root length was observed in Selection-9 (11.75 and 10.80 cm with pooled value of 11.28 during 2017-18 and 2018-19. Among the different treatment combination, the highest root length was recorded in Al_0V_3 during 2017-18 and 2018-19 which was at par with Al_0V_1. The lowest root length was recorded in $Al_{0.50}$ V_2 for both the year and pooled which was at par with $Al_{0.50}V_1$.
11. The highest root mass was recorded in Al_0 (6.87 and 6.78 g pot^{-1} with pooled value of 6.83 g pot^{-1}) during 2017-18 and 2018-19. The minimum root mass was recorded in $Al_{0.50}$ (3.83 and 3.75 g pot^{-1} with pooled value of 3.79 g pot^{-1}) during 2017-18 and 2018-19. There were no significant differences between the varieties in case of root mass.

Effect on quality

1. Increased level of aluminium resulted in decrease in nitrogen, phosphorus, potassium, sulphur and calcium content in grains and stover of french bean. The highest nitrogen, phosphorus, potassium, sulphur and calcium content content in grains and stover was recorded from control (Al_0). The significant differences among the varieties in the nitrogen, phosphorus and potassium content were observed only in the stover. The highest nitrogen, phosphorus and potassium content were recorded from Selection-9 while the lowest was obtained from Nagaland local. There were no significant

differences observed among the varieties in case of sulphur and calcium content in grains and stover of french bean.

2. Increased level of aluminium resulted significant increase in aluminium content in grains and stover of french bean. The maximum aluminium content in both grain and stover was recorded in $Al_{0.50}$ while lowest was recorded from control. Among the varieties, the highest and lowest aluminium content in seeds was recorded in Nagaland local and Selection-9 but there was no significant effect found with variety in influencing aluminium content in stover of french bean.
3. The grain protein content and protein yield decreased significantly with increasing levels of aluminium. The highest protein content in grain was recorded from control while the lowest protein content was obtained in $Al_{0.50}$. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased the protein content to the extent of 4.6% and 12.09% over control and the protein yield by 31.97 and 58.62 % over control on the basis of pooled value. Varieties did not show significant effect on protein content while there was a significant variation among the varieties on protein yield. The highest protein yield was observed in Selection-9 followed by Anupam-R and the lowest protein yield was recorded in Nagaland local.
4. The nitrogen uptake by grain and stover decreased significantly with every increase in aluminium levels. The highest nitrogen uptake was recorded from Al_0 in grains (642.47 and 619.84 mg pot^{-1} with pooled value of 631.15 mg pot^{-1}) in 2017-18 and 2018-19 and in stover (419.75 and 408.21 mg pot^{-1} with pooled value of 413.98 mg pot^{-1}) while the lowest nitrogen uptake was recorded from $Al_{0.50}$ in both grain and stover. The three varieties showed significantly varied nitrogen uptake. The highest nitrogen uptake in grains (479.58 and 492.70 mg pot^{-1} with pooled value of

486.14mg pot^{-1}) in 2017-18 and 2018-19 and stover (296.90 and 306.26 mg pot^{-1} with pooled value of 301.58 mg pot^{-1}) was recorded from Selection-9 while the lowest was recorded from Nagaland local.

5. Phosphorus uptake by grain and stover decreased significantly with every increase in aluminium levels. The highest phosphorus uptake was recorded from Al_0 in seeds (100.38 and 97.04 mg pot^{-1} with pooled value of 98.71 mg pot^{-1}) in 2017-18 and 2018-19 and in stover (68.92 and 68.26 mg pot^{-1} with pooled value of 68.59 mg pot^{-1}) while the lowest phosphorus uptake was recorded from $Al_{0.50}$ in both grain and stover. The three varieties showed significantly varied phosphorus uptake. The highest phosphorus uptake by grains (72.41 and 73.34 mg pot^{-1} with pooled value of 72.87 mg pot^{-1}) in 2017-18 and 2018-19 and stover (47.03 and 45.56 mg pot^{-1} with pooled value of 46.30 mg pot^{-1}) was recorded from Selection-9 while the lowest phosphorus uptake in grains and stover was recorded from Nagaland local and Anupam-R respectively.

6. The potassium uptake by grain and stover decreased significantly with every increase in aluminium level. The highest potassium uptake was recorded from Al_0 in grains and stover while the lowest potassium uptake was recorded from $Al_{0.50}$ in both grain and stover during both the years. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased pooled potassium uptake to the extent of 32.51% and 57.99% over control in grain and 34.93% and 55.81% in stover. The tested varieties showed significant variation in potassium uptake. The highest potassium uptake by grains and stover was recorded from Selection-9 while the lowest potassium uptake in grains and stover was recorded from Nagaland local. The interaction effects indicated that there were no significant differences among the treatment combination in grain but in stover, it showed significant variation among the treatment

combination during the first year. The highest potassium uptake (535.82 mg pot^{-1}) was obtained from Al_0V_1. This treatment combination was significantly superior to all the others. The lowest (189.48 mg pot^{-1}) potassium uptake was recorded in $Al_{0.50}V_3$.

7. Sulphur uptake was significantly influenced by aluminium application. Uptake by grains as well as stover decreased significantly with each increasing aluminium levels in comparison to preceding lower level. The highest sulphur uptake by grain and stover were recorded in treatment Al_0 (control) whereas the minimum uptake in grain and in stover was recorded in treatment $Al_{0.50}$. Application of $Al_{0.25}$ and $Al_{0.50}$ decreased sulphur uptake to the extent of 44.91 % and 81.50 % over control in grain while 46.48 % and 75.88 % in stover on the basis of pooled values. The varieties showed significant difference in sulphur uptake in grain while it did not show any significant differences in stover. The highest sulphur uptake by grains and stover was found in Selection-9 whereas the lowest uptake by grain and stover was recorded in Nagaland local during both the years. The interaction effect indicated significant variation among the treatment combination for pooled value only in case of grains with the highest sulphur uptake in Al_0V_1 (66.34 mg pot^{-1}) and lowest in $Al_{0.50}V_2$ (8.41 mg pot^{-1}).
8. Calcium uptake by grains as well as stover decreased significantly with each increasing aluminium level in comparison to preceding lower level. The highest calcium uptake by grain and stover was recorded in treatment Al_0 (control) whereas the minimum uptake in grain and in stover were recorded in treatment $Al_{0.50}$. On the basis of pooled values, application of $Al_{0.25}$ and $Al_{0.50}$ decreased calcium uptake to the extent of 58.84% and 81.15% over control in grain while 46.31% and 68.74% in stover. Different

varieties of french bean showed significant differences in calcium uptake. The highest calcium uptake by grains as well as stover was found in Selection-9 whereas the lowest uptake by grains and stover was recorded in Nagaland local. The interaction effects showed significant variation among the treatment combination during the second year only, where it showed highest calcium uptake in grain (46.27 mg pot^{-1}) in the treatment combination of Al_0 V_1 and the lowest calcium uptake (7.30 mg pot^{-1}) was observed in the treatment combination of $Al_{0.50}V_3$ which was at par with $Al_{0.50}V_2$.

9. The highest aluminium uptake in grain was recorded in $Al_{0.25}$. The lowest aluminium uptake in grain was recorded in Al_0. Aluminium uptake in grain was increased to the extent of 40.37% by $Al_{0.25}$ while it was reduced by 37.37% at $Al_{0.50}$ over control. The aluminium uptake in stover showed non significant effect. Different varieties of french bean showed significant difference in aluminium uptake. The highest aluminium uptake by grains was recorded in Selection-9 whereas the lowest uptake was recorded in Anupam-R. The aluminium uptake in stover showed significant effect only during 2018-19. The highest aluminium uptake was recorded from Selection-9 (26128.36 µg pot^{-1}) and lowest was obtained in Anupam-R (22411.74 µg pot^{-1}). Interaction effect of aluminium levels and varieties on aluminium uptake by grain showed significant effect while aluminium uptake in stover showed non significant effect. $Al_{0.25}$ V_1 was recorded with highest aluminum uptake in grain while lowest aluminum uptake in grain was recorded in the treatment combination of Al_0V_3.

10. Increased level of aluminium resulted in increasing aluminium content in roots of french bean. The maximum aluminium content in root was recorded in $Al_{0.50}$ (15161.93 and 15160.95 mg kg^{-1} with pooled value of

15161.44 mg kg^{-1} during 2017-18 and 2018-19. The lowest aluminium content was observed in Al_0 (6060.13 and 6058.95 mg kg^{-1} with pooled value of 6059.54 mg kg^{-1}) during 2017-18 and 2018-19. The $Al_{0.25}$ and $Al_{0.50}$ levels of aluminium in roots of french bean increased the aluminium content by 45.70% and 60.03% over control respectively whereas the varieties showed non significant effect.

Effect on soil properties

1. The maximum pH of the soil after harvest was recorded under Al_0 (5.52 and 5.46 with pooled value of 5.49) during 2017-18 and 2018-19 and signnificantly lowest pH value was recorded under $Al_{0.50}$ (4.58 and 4.65 with pooled value of 4.61) during 2017-18 and 2018-19. The maximum organic carbon was recorded under Al_0 (20.8 and 22.50 with pooled value of 21.7 g kg^{-1}) during 2017-18 and 2018-19 and the lowest recorded under $Al_{0.50}$ (17.9 and 17.10 g kg^{-1} with pooled value of 17.10 g pot^{-1}) during 2017-18 and 2018-19 respectively. The varieties didn’t have any significant effect both on pH and organic carbon.
2. With increasing aluminium levels, there was a significant decrease in all the available nutrients (N, P, K and S). The highest available nitrogen, phosphorus, potassium and sulphur were recorded in Al_0 and the lowest were recorded in $Al_{0.50}$ during both the year of experimentation. Varieties showed significant effect on available nitrogen content in soil after harvest. The highest and lowest available nitrogen content in soil was recorded from Nagaland local and Selection-9, respectively. Varieties showed significant difference on available phosphorus and potassium content in soil after harvest only during the first year of experimentation. The highest and lowest available phosphorus content in soil was recorded from Nagaland local and Selection-9 respectively. There was a significant difference in

availale phosphorus content among the treatment combinations, the highest and lowest phosphorus content was observed in the combination treatment of Al_0 V_3 and $Al_{0.50}$ V_1 during 2017-18 and 2018-19. The highest and lowest available potassium content in soil was recorded from Anupam-R and Nagaland local respectively. Varieties didn't show significant difference on available sulphur content in soil after harvest.

3. The highest exchangeable ca was found in Al_0 and the lowest was recorded in $Al_{0.50}$ during both the year. There was no significant effect among the varieties on exchangeable calcium content of soil.
4. The highest exchangeable aluminium was found in $Al_{0.50}$ and the lowest was recorded in Al_0. There was no significant effect among the varieties on exchangeable aluminium content of soil. The highest total potential acidity was found in $Al_{0.50}$ (14.69 and 14.76 cmol (p^+) kg^{-1} with pooled value of 14.72 cmol (p^+) kg^{-1}) during 2017-18 and 2018-19 and the lowest was recorded in Al_0 (10.67 and 10.70 c mol (p^+) kg^{-1} with pooled value of 10.69 cmol (p^+) kg^{-1}) during 2017-18 and 2018-19 .

Experiment-2: To study the phosphorus and sulphur requirement of french bean under different levels of aluminium

Effect on growth and yield

1. The days to germination of french bean delayed with increase in aluminium levels. The minimum number of days to germination was recorded in the control (3.50 and 3.48 days with pooled value of 3.48) during 2017-18 and 2018-19. Maximum days to germination were recorded in $Al_{0.25}$ (3.87 and 3.89 days with pooled value 3.89) during 2017-18 and 2018-19. Phosphorus and sulphur application levels did not show any significant effect on days to germination.

2. The plant height of french bean significantly decreased with increase in aluminium level at 30 DAS, 60 DAS and at harvest. The maximum plant height was recorded from Al_0. The minimum plant height was recorded from $Al_{0.25}$ cmol kg^{-1}. The plant height of french bean significantly increased with every increase in phosphorus level upto 90 kg P_2O_5 ha^{-1} at 30 DAS, 60 DAS and at harvest. On the basis of plant height at harvest, 60 kg P_2O_5 ha^{-1} was proved optimum dose and this level increased plant height by 16.31% over control. Application of sulphur at increasing rates had significant effect on the plant height at all the growth stages. The highest plant height of 22.27 cm (2017-18) was obtained from S_{30}, 21.04 cm (2018-19) obtained from S_{60} and 21.62 cm (pooled) was obtained from S_{30} at 30 DAS and 31.54, 33.75 cm during 2017-18 and 2018-19 with pooled value of 32.65 cm at 60 DAS, at harvest, the highest plant height was obtained from S_{60} with 35.28 and 34.72 during 2017-18 and 2018-19 with pooled value of 35.00 cm. On the basis of plant height at harvest, S_{60} was proved optimimum dose and this level increased plant height by 13.48 % over control. The interaction effect between aluminium and phosphorus on plant height showed significant effect only during 30 DAS. The highest and lowest plant height was recorded from the treatment combination of Al_0 P_{60} and $Al_{0.25}$ P_0. The interaction effect between aluminium and sulphur showed significant effect only during 30 DAS for the year 2018-19 where it was observed that the highest plant height was recorded from Al_0 S_{60} while the lowest was recorded from $Al_{0.25}$ S_{30}.The interaction effect between phosphorus and sulphur showed significant effect only at 30 DAS where it was observed that the highest plant height was recorded from P_{90} S_{30} at 30 DAS while the lowest was recorded from P_0 S_0. The interaction effect of aluminium, phosphorus and sulphur on plant height showed significant

effect at 30 DAS during the year of 2017-18 only, the highest plant height was recorded from Al_0 P_{60} S_{60} and the lowest was recorded from $Al_{0.25}$ P_0 S_0.

3. With increase in aluminium levels, the number of branches per plant decreased significantly at all growth stages. At 30, 60 DAS and at harvest, highest number of branches was observed at Al_0. Minimum number of branches was recorded from $Al_{0.50}$ cmol kg^{-1} during both the year and pooled. Number of branches was significantly effected by phosphorus application only at 30 DAS stage whereas it did not show any significant effectd at 60 DAS and at harvest. At 30 DAS, the highest number of branches were observed at P_{90} (4.45) during 2017-18, P_{60} (4.39) during 2018-19 and pooled (4.39) from both the levels of P_{60} and P_{90}. Lowest number of branches at 30 DAS (3.28 and 3.23 with pooled value of 3.25) was recorded from control. Application of sulphur did not significantly influence the number of branches.
4. Maximum number of pods was recorded in Al_0 and the minimum number of pods per plant was observed in $Al_{0.25}$. On the basis of pooled values increase in aluminium levels decreased the number of pods by 30.35 % from Al_0 to $Al_{0.25}$. Significantly higher number of pods was obtained from P_{30} (13.70 and 13.36 during 2017-18, respectively with pooled value of 13.53). The numbers of pods at P_{30} were at par with P_{60}. There was a significant decrease in number of pods from P_{60} to P_{90} level. Sulphur application at increasing levels showed significant effect on number of pods per plant during 2017-18 only. Significantly maximum number of pods (13.43) was recorded with sulphur dose of 30 kg ha^{-1} and lowest number of pods (12.60) was recorded from control. As apparent from the data there was a significant decrease in number of pods per plant from S_{30} to S_{60} level.

5. Pod length was significantly highest in control while it was recorded to be shorter in the aluminium treated plants. The $Al_{0.25}$ level of aluminium reduced pooled pod length by 23.59% over control. Phosphorus application showed significant effect on pod length up to 60 kg P_2O_5 ha^{-1}. A decrease in pods length was found beyond 60 kg P_2O_5 ha^{-1}. Minimum pod length was recorded in control while maximum pod length was recorded from P_{60}. Sulphur application showed a non significant effect on pod length for both the year. The interaction effect of aluminium and phosphorus on pod length showed significant effect only during the second year (2018-19). The maximum pod length was recorded from the treatment combination of Al_0 P_{60} while the minimum pod length was recorded from the treatment combination of $Al_{0.25}$ P_0.
6. With increasing aluminium levels, there was a significant decrease in number of seeds per pod during both the year. The highest and lowest number of seeds per pod was recorded in control and $Al_{0.25}$. Significantly maximum number of pods was recorded with phosphorus dose of 90 kg ha^{-1}which was at par with 60 kg ha^{-1}, while minimum was obtained from control. Significantly maximum number of seeds was recorded with sulphur dose of 30 kg ha^{1} and lowest number of seeds per pods was recorded in control.
7. Among the two aluminium levels, the highest test weight was recorded in $Al_{0.25}$ (29.60 and 29.43 g with pooled value of 29.52g) during 2017-18 and 2018-19. The minimum test weight was found in control. Phosphorus application at increasing levels showed significant effect on test weight up to 60 kg P_2O_5 ha^{-1}. A decrease in test weight was found beyond 60 kg P_2O_5 ha^{-1}. Minimum test weight (27.74 and 27.76 g with pooled value of 27.75 g) during 2017-18 and 2018-19 was recorded at harvest with control. Sulphur

application at increasing levels showed significant effect on test weight. Significantly maximum test weight was recorded with sulphur dose of 60 kg ha^{-1} (28.98 and 28.86 g with pooled value of 28.92 g) during 2017-18 and 2018-19 and lowest test weight of 27.97 and 27.63 g during 2017-18 and 2018-19, respectively with pooled value of 27.80 g was recorded in control.

8. Higher seed yield was obtained from the control (Al_0) and the lower seed yield by $Al_{0.25}$. Irrespective of treatments and years of experimentation the seed yield of french bean varied from 13.89 to 23.95 g pot^{-1}. A critical examination of data show that the increasing level of aluminium resulted significant decrease in seed yield of french bean. Application of aluminium at $Al_{0.25}$ decreased grain yield to the extent of 38.75 % over control in case of pooled value. Phosphorus application at increasing levels showed significant effect on seed yield up to 60 kg P_2O_5 ha^{-1}. A decrease in seed yield was found beyond 60 kg P_2O_5 ha^{-1}. Minimum seed yield was recorded in control. On the basis of pooled value the P_{60} level (60 kg P_2O_5 ha^{-1}) of phosphorus proved optimum dose of phosphorus. This level enhanced seed yield significantly over other levels of phosphorus. Application of phosphorus at 60 kg P_2O_5 ha^{-1} enhanced grain yield to the extent of 24.36% over control and 7.8 % over 30 kg P_2O_5 ha^{-1}. Significantly maximum seed yield was recorded with sulphur dose of 30 kg $ha^{-1}$with 19.96 g pot^{-1} (2017-18) and 20.48 g pot^{-1} (2018-19) from S_{60} level, respectively with pooled value of 20.11 g pot^{-1} from S_{30} level. The lowest seed yield was recorded with control. On the basis of pooled seed yield, application of 30 kg S ha^{-1} (S_{30}) enhanced significantly the seed yield over control. Further application of sulphur (S_{60}) reduced seed yield as compared to S_{30} level. Hence, S_{30} (30 kg S ha^{-1}) proved optimum dose of sulphur in present set of

experimentation. The S_{30} level increased seed yield by 11.23% over control. The interaction effect of aluminium and sulphur on seed yield showed that the maximum and minimum seed yield was recorded from Al_0P_{60} and $Al_{0.25}$ P_0 during both the year.

9. The highest stover yield was recorded in control (Al_0) and the lower stover yield was recorded with $Al_{0.25}$. On the basis of pooled stover yield, the $Al_{0.25}$ level reduced the stover yield by 23.98% over control. Stover yield of french bean increased significantly with increasing phosphorus levels. Phosphorus at 90 kg P_2O_5 ha^{-1} resulted highest stover yield while the minimum yield was obtained from control. Application of 90 kg P_2O_5 ha^{-1} was at par with 60 kg ha^{-1}. Hence 60 kg ha^{-1} proved optimum dose with regard to stover yield of french bean. This level enhanced the stover yield by 12.57% on the basis of pooled stover yield. Sulphur application at increasing levels showed significant effect on stover yield. A critical examination of data revealed that the application of 30 kg S ha^{-1} increased the stover yield significantly over control. However, beyond this level effect of sulphur application was at par, indicated that 30 kg S ha^{-1} is the optimum dose of sulphur for french bean. The S_{30} level increased the stover yield by 3.18% over control with regard to pooled value.

Effect on quality

1. Increased level of aluminium resulted in decrease in nitrogen, phosphorus, potassium, sulphur and calcium content in grains and stover of french bean. The highest nitrogen, phosphorus, potassium, sulphur and calcium content content in grains and stover was recorded from control (Al_0).
2. In grains, the highest nitrogen content was recorded from 60 kg P_2O_5 kg ha^{-1} but it was at par with P_{90}. Similarly in stover, the nitrogen content was increased significantly at P_{30} level over control. The nitrogen content at P_{60}

and P_{90} level were at par with P_{30} level. Nitrogen content in both seeds and stover increased up to S_{30} which it was at par with S_{60}. The nitrogen content in grain at S_{30} and S_{60} levels both showed similar values which were significantly higher than nitrogen content in control. Similarly nitrogen content in stover of french bean showed no difference among S_{30} and S_{60} levels but showed significantly higher values than that of control.

3. Increased levels of phosphorus had a significant effect on phosphorus content in grain and stover of french bean. The highest phosphorus content in grain and in stover was recorded with the application of 90 kg P_2O_5 ha^{-1}, whereas the lowest phosphorus content in grain and in stover were recorded in control. Different levels of sulphur failed to show any significant variation on the phosphorus content in both seeds as well as stover.
4. Potassium content in grains and stover increased with increase in phosphorus level up to 60 kg P_2O_5 ha^{-1} but remain constant beyond this level. In grains, potassium content at P_{60} was significantly higher over control. However, effect of phosphorus application on seed potassium content was non significant during second year of experimentation. In stover, potassium content at P_{60} was significantly higher than control and it was at par with P_{90}. Potassium content in grains was found lower than the potassium content in stover. Different levels of sulphur failed to show any significant variation on the potassium content in both seeds as well as stover.
5. Sulphur content in grains and stover increased with increase in phosphorus level up to 90 kg P_2O_5 ha^{-1}. In grains, sulphur content at P_{90} was significantly higher over control. In stover, sulphur content at P_{90} was significantly higher than control. Increasing sulphur levels significantly influenced sulphur content in seeds and stover. The significantly highest

sulphur content in seeds and stover was recorded with sulphur dose of 60 kg ha^{-1}whereas lowest content in seeds and stover was recorded in control.

6. Calcium content in grains and stover increased with increase in phosphorus level up to 60 kg P_2O_5 ha^{-1} level. In grain and stover calcium content at P_{60} was significantly higher over control. Different levels of sulphur failed to show any significant variation on the calcium content in both seeds and stover of french bean.
7. Increased level of aluminium resulted in increasing aluminium content in grains and stover of french bean. The maximum and minimum aluminium content in grain and stover was recorded in $Al_{0.25}$ and Al_0 respectively. There was no significant effect found with phosphorus and sulphur application on aluminium content in grains and stover of french bean.
8. The grain protein content and protein yield decreased significantly with increasing levels of aluminium. The highest protein content in grain was recorded from control while the lowest protein content was obtained in $Al_{0.25}$. Application of $Al_{0.25}$ decreased the protein content upto the extent of 7.3% and protein yield up to the extent of 42.97% over control. Protein content and protein of french bean grains increased significantly with increasing phosphorus levels. The lowest protein content and protein yield was recorded in control and the highest was obtained in P_{60}. Application of 60 kg P_2O_5 increased the protein content up to the extent of 4.5% and protein yield upto 30.26% over control. Protein content and protein yield increased with increase in sulphur level up to 30 kg S ha^{-1} but remain at par beyond this level. The S_{30} level of sulphur enhanced the pooled protein yield by 13.56% over control. The interaction effect between aluminium and phosphorus showed significant effect on protein yield in grains of french bean. The highest protein yield was observed in the combination of

Al_0P_{60} and the lowest was observed in the treatment combination of $Al_{0.25}$ P_0.

9. The nitrogen, phosphorus, potassium, sulphur and calcium uptake by grain and stover decreased significantly with increase in aluminium levels. The highest nitrogen, phosphorus, potassium, sulphur and calcium uptake by grain and stover was recorded from Al_0 while the lowest uptake by grain and stover was recorded from $Al_{0.25}$. The $Al_{0.25}$ level of aluminium reduced the pooled nitrogen uptake in seed and stover to the extent of 43.03 and 30.24%, pooled phosphorus uptake to the extent of 44.78% in grain and 55.96 % in stover, pooled potassium uptake to the extent of 44.00% in grain and 26.42% in stover, pooled sulphur uptake to the extent of 53.05% in grain and 10.85% in stover, pooled calcium uptake by seed and stover to the extent of 68.00% and 54.47%, respectively over control.
10. The highest nitrogen uptake by grains and stover was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in control. The increase in each phosphorus level resulted in a drastic significant increase in nitrogen uptake up to 60 kg P_2O_5 ha^{-1}. Increasing sulphur levels significantly influenced nitrogen uptake in seeds and stover. The significantly highest uptake in seeds was recorded with sulphur dose of 30 kg ha^{-1} and in stover was recorded with S dose of 60 kg ha^{-1}whereas lowest uptake was recorded in control. The interaction effect between aluminium and phosphorus showed significant effect on nitrogen uptake in grains of french bean. The highest nitrogen uptake was observed in the combination of Al_0P_{60} and the lowest was observed in the treatment combination of $Al_{0.25}P_0$.
11. The highest phosphorus uptake by grains was found in treatment of 60 kg P_2O_5 ha^{-1}, stover was found in treatment of 90 kg P_2O_5 ha^{-1} whereas the

lowest uptake by grains and stover was found in control. Application of 60 kg P_2O_5 ha^{-1} increased phosphorus uptake of grain to the extent of 31.64% over control. Pooled phosphorus uptake in stover increased by 39.78% with application of 90 kg P_2O_5 ha^{-1} over control. Increasing sulphur levels significantly influenced phosphorus uptake in seeds and stover of french bean. The significantly higher uptake in seeds was recorded with sulphur dose of 30 kg ha^{-1} and in stover was recorded with application of 60 kg S ha^{-1} whereas lowest uptake in seeds and stover was recorded in control. Difference between S_{30} and S_{60} levels was non significant with regard to phosphorus uptake in seed and stover during both the years of experimentation. Application of 30 kg S ha^{-1} enhanced the pooled phosphorus uptake to the extent of 4.71% in seed and 6.97% in stover over control. The interaction effect between aluminium and phosphorus showed significant effect on phosphorus uptake in grains and stover of french bean. The highest phosphorus uptake in grain and stover of french bean was observed in the combination of Al_0 P_{60} and the lowest was observed in the treatment combination of $Al_{0.25}$ P_0.

12. Potassium uptake was positively influenced by increased level of phosphorus. Pooled potassium uptake by seeds was enhanced significantly upto P_{60} level of phosphorus and beyond this it was decreased significantly. However, in case of stover, potassium uptake was increased upto highest level (P_{90}) of phosphorus, but difference between P_{60} and P_{90} was insignificant. The highest potassium uptake by grains was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}) and in stover, was recorded in P_{90} (90 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was recorded from control. Application of 60 kg P_2O_5 ha^{-1} increased pooled potassium uptake of grain to the extent of 30.35% over control while application of 90

kg P_2O_5 increased pooled potassium uptake of stover to the extent of 16.89% over control. Effect of sulphur nutrition was also significant on potassium uptake in seeds and stover. Significantly highest potassium uptake by grains was recorded with application of 30 kg S $ha^{-1}$and highest uptake in stover was recorded with S dose of 60 kg ha^{-1}. Lowest uptake in grains and stover was recorded in control. The interaction effect between aluminium and phosphorus showed significant effect on potassium uptake in grains of french bean. The highest potassium uptake was observed in the combination of Al_0P_{60} and the lowest was observed in the treatment combination of $Al_{0.25}P_0$.

13. Sulphur uptake by grains and stover increased significantly with each increasing phosphorus levels upto P_{60} level. Furthur application of phosphorus reduced the sulphur uptake by grain. But sulphur uptake by stover was increased upto the highest level (P_{90}) of phosphorus. The highest sulphur uptake by grains was found in treatment of 60 kg P_2O_5 ha^{-1}, stover was found in treatment P_{90} (90 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in control. Application of 60 kg P_2O_5 ha^{-1} increased pooled sulphur uptake of grain to the extent of 62.95% over control while application of 90 kg P_2O_5 increased sulphur uptake in stover to the extent of 32.71% over control. The S_{30} and S_{60} levels of sulphur increased grain sulphur uptake significantly over control during both the years of experimentation. However, difference between S_{30} and S_{60} levels were non significant. Highest and lowest sulphur uptake in grain and stover was observed under S_{60} and control level of sulphur. The S_{30} level increased pooled sulphur uptake by 19.22% over control while S_{60} level enhanced pooled sulphur uptake in stover b 31.40% over control.

14. Highest calcium uptake by grains was recorded in treatment P_{60} (60 kg P_2O_5 ha^{-1}), whereas in stover was found in treatment P_{90} (90 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in P_0 (control). Significant increase in calcium uptake in grains was observed upto P_{60} level, beyond this level a non significant reduction was noted. But calcium uptake in stover was increased upto P_{90} level with non significant difference to P_{60} level. Increasing sulphur levels showed significant effect on calcium uptake on seeds and stover for both the year and the highest uptake in seeds was recorded with sulphur dose of 30 kg ha^{-1} and in stover was recorded with sulphur dose of 60 kg ha^{-1}whereas lowest uptake in seeds and stover was recorded in control.
15. Increased level of aluminium resulted in increasing aluminium uptake in grains and stover of french bean. The maximum aluminium uptake in grain and stover was recorded in $Al_{0.25}$ and the lowest aluminium uptake in grain and stover was observed in Al_0. The highest aluminium uptake by grains and stover was found in treatment P_{60} (60 kg P_2O_5 ha^{-1}) whereas the lowest uptake by grains and stover was found in P_0 (control). Increasing sulphur levels showed significant effect on aluminium uptake on seeds and stover for both the year. The significantly highest aluminium uptake in seeds and stover was recorded with S dose of 30 kg ha^{-1} while lowest uptake in seeds was recorded with control.

Effect on soil properties

1. Treatment with aluminium ($Al_{0.25}$) significantly reduced the pH to 5.06 and 5.16 during 2017-18 and 2018-19, respectively with pooled value 5.11 as compared to that of control (Al_0) with a recorded pH of 5.37 during 2017-18 and 5.34 during 2018-19 along with pooled value of 5.35. However, the effect of phosphorus as well as sulphur levels was found statistically non-

significant on soil pH. With increasing aluminium levels, there was a significant decrease in all the available nutrients (N, P, K and S). The highest available nitrogen, phosphorus, potassium and sulphur was recorded in Al_0 and the lowest were recorded in $Al_{0.25}$ during both the year of experimentation. Application of higher dose of aluminium reduced the pooled available nitrogen by 4.32% as compared to control. The antagonistic effect of added aluminium led to a deteriorating level of available phosphorus by 21.26 and 19.40% , soil available potassium by 5.36 % and 6.01% and available sulphur by 27.14 and 25.80% as compared to control during 2017-18 and 2018-19 respectively.

2. The treatment effect of different levels of phosphorus was found statistically significant on soil available nitrogen. Among all the given treatments, the highest response was observed in treatment with phosphorus level P_{90} for the available nitrogen and an increment of 2.58 and 2.52% over that of control (P_0) during the first and second year of experimentation respectively. The data on available nitrogen as affected by varying levels of sulphur showed a significant difference with increasing levels of sulphur. The treatment with S_{60} responded the best in maximizing the available N along with an increment of 1.43 and 1.48% over that of control (S_0).
3. With regard to effect of different phosphorus levels on soil available phosphorus significant response was observed across all the treatments as compared to that of control. The highest available phosphorus in soil was recorded in P_{90} which was followed by the treatment P_{60}. The effect of sulphur levels was found statistically non-significant on the soil available phosphorus.
4. The effect of phosphorus as well as sulphur levels on soil available potassium was found statistically non-significant.

5. The effect of phosphorus application was non significant during both the years with regard to available sulphur content of the soil. With increased level of sulphur application, the soil available sulphur increased. The highest available sulphur in soil was recorded under treatment S_{60} and the lowest was recorded in control.
6. The main effect of aluminium levels significantly responded on exchangeable calcium. The highest was recorded in treatment Al_0. With higher level of aluminium the amount of exchangeable calcium was found to have decreased by 16.56 and 17.02 % as compared to that of control during first and second year respectively. With increased level of aluminium, the content of exchangeable aluminium in soil increased. The treatment $Al_{0.25}$ responded the maximum as compared to control. Similarly, the application of different levels of aluminium significantly responded in enhancing the total potential acidity of soil. The highest response was obtained by treatment $Al_{0.25}$ as compared to control. The effect of different phosphorus and sulphur levels was found statistically non-significant on exchangeable calcium, aluminium and total potential acidity.

CONCLUSION

The following conclusions were drawn from the above summary:

1. Increasing concentration of aluminium in growth medium adversely affected the growth, yield attributes, seed, stover and protein yield, nutrient composition and nutrient uptake by french bean. Test weight, Al content and Al uptake were enhanced with aluminium application. Soil pH, organic carbon and available nutrient content of post harvest soil were decreased and exchangeable Al and total potential acidity was increased with aluminium application.
2. Better plant growth, yield attributes, grain, stover and protein yield and nutrient uptake were obtained from Selection-9 variety. On the basis of seed yield, superiority of variety was arrennged in the order of Selection-9> Anupam-R> Nagaland local. Post harvest soil properties were not affected by different varieties.
3. Growth, yield attributes, seed, stover and protein yield, nutrient composition and nutrient uptake by french bean improved with application of phosphorus and sulphur. Available nitrogen, phosphorus and sulphur status of post harvest soil was also improved with phosphorus and sulphur application.
4. Hence, cultivation of Selection-9 variety with 60 kg phosphorus ha^{-1} and 30 kg sulphur ha^{-1} as soil application may be recommended for better production of french bean in aluminium rich condition of Nagaland.

CHAPTER VI

REFERENCES

REFERENCES

Abdi, D., Cade-Menun, B. J., Ziadi, N. and Parent, L. E. 2014. Long-term impact of tillage practices and phosphorus fertilization on soil phosphorus forms as determined by 31p nuclear magnetic resonance spectroscopy. *Journal of Environmental Quality*. **43**(4): 1431-1441.

Ahlawat, I. P. S., and Sharma, R. P. 1989. Response of french bean genotypes to soil moisture regimes and phosphate fertilization. *Indian Journal of Argonomy*. **34**: 70-74.

Akaya, M. and Takenaka, C. 2001. Effects of aluminium stress on photosynthesis of *Quercus glauca* Thumb. *Plant and soil.* **237**(1): 137-146.

Akter, F., Islam, M. N., Shamsuddoha, A. T. M., Bhuiyan, M. S. I. and Shilpi, S. 2013. Effect of phosphorus and sulphur on growth and yield of soybean (*Glycine max* L.). *International Journal of Bio-resource and Stress Management.* **4**(4): 555-560.

Alamgir, A. N. M. and Akhter, S. 2009. Effects of aluminium (Al^{3+}) on seed germination and seedling growth of wheat (*Triticum aestivum* l.). *Bangladesh Journal of Botany*. **38**(1): 1-6.

Ali, M. 2015. Effect of phosphorus and sulphur on the yield and nutrient uptake of maize. *International Journal of Farming and Allied Sciences.* **3**(11): 1194-1200.

Amba, A. A., Agbo, E. B., Voncir, N. and Oyawoye, M. O. 2011. Effect of phosphorus fertilizer on some soil chemical properties and nitrogen fixation of legumes at Bauchi. *Continental Journal of Agricultural Sciences* **5**: 39-44.

Ambrosano, E. J., Tanaka, R. T., Mascarenhas, H. A. A., Raij, B. V., Quaggio, J. A. and Cantarella, H. 1996. Legumes and oilseeds. In: Raij B V, Cantarella H, Quaggio J A & Furlani A M C (Eds.) Recomendações de adubação e calagem para o Estado de São Paulo. 2ª ed. Campinas, IAC. pp.189-203. (Technical bulletien, 100).

Andrew, C. S., Johnson, A. D. and Sandland, R. D. 1973. Effect of aluminium on the growth chemical composition of some tropical and temperate pasture legumes. *Australian Journal of Agricultural Research*. **24**: 325-39.

Anonymous. 2018. *Statistical Handbook of Nagaland.* Directorate of Economics and Statistics, Govt. of Nagaland, Kohima.

Arunraj, M., Vasanthi, D. and Mansingh, D. M. I. 2018. Effect of sulphur on growth and yield of greengram (*Vigna radiate)*. *International Journal of Science, Environment and Technology*. **7**(5): 1861-1867.

Aulakh, M. S. and Pasricha, N. S. 1977. Interaction effect of sulphur and phosphorus on growth and nutrient content of moong (*Phaseolus aureus* L.). *Plant and Soil.* **47**: 341-350.

Azevedo, A. A. and Oliva, M. A. 1989. Effect of aluminium on productivity and mineral elements in soybean. *Pesquisa Agropecuaria Brasileira.* **24**:1537-1546.

Babaleshwar, S. B., Koppad, S. R., Math, K. K. and Dharmatti, R. 2017. Influence of sulphur on growth and yield of garlic (*Allium sativum* L.) *Journal of Pharmacognosy and Phytochemistry*. **6**(5): 450-452.

Baboo, R., Rana, N. S. and Pantola, P. 1998. Response of french bean (*Phaseolus vulgaris* L.) to nitrogen and phosphorus. *Annals of Agricultural Research.* **19**: 81-82.

Bache, B. W. and Crooke, W. M. 1981. Interactions between aluminium, phosphorus and pH in the response of barley to soil acidity. *Plant and Soil*. **61**(3): 365-375.

Bahadur, L., Tiwari, S. K. and Singh, D. 2009. Yield and quality of greengram improved by sulphur application and biofertilization. International Conference on grain legumes. Indian Society for Pulses Research and Development (Feb. 14-16), IIPR, Kanpur.

Balaguravaiah, D., Narasimha, R. Y., Adinarayana, V., Narasimha, R. P. and Subha, R. I. V. 1989. Phosphorus requirement of green gram. *Journal of the Indian Society of Soil Science*. **37**: 738-743.

Barlog, P., Niewiadomska, A. and Ambro˙zy-Dere gowska, K. 2014. Eff ect of sulphur fertilisation on seed yield and yield components of broad bean on the background of diff erent levels of potassium content in soil. *Fragmenta Agronomica*. **31** (2): 7-17.

Baruah, T. C. and Barthakur, H. P. 1997. Textbook of Soil Analysis. Vikas Publishing House Pvt. Ltd, New Delhi.

Batista, M. F., Moscheta, I. S., Bonato, C. M., Batista, M., Almeida, O. J. G. and Inoue, T. T . 2012. Aluminium in corn plants: influence on growth and morpho-anatomy of root and leaf. *RevistaBrasileira de Cienciado Solo*. **37**: 177-187.

Batista, M. A., Pintro, J. C., Costa, A. C. S., Tormena, C. A., Bonato, C. M. and Batista, M. F. 2009. Mineral composition and dry mass production of the corn plants in response to phosphorus sources and aluminium concentration. *Brazilian Archives of Biology and Technology*. **52**: 541-548.

Bennet, R. J., Breen, C. M. and Fey, M. V. 1985. Aluminium-induced changes in the morphology of the quiescent centre, proximal meristem and growth region of the root of *Zea mays*. *South African Journal of Plant Soil.* **51**: 355-62.

Black, C. A. 1965. Methods of soil chemical analysis and microbiological properties., Inc, Publisher, Madison, Wisconsin USA, *American Society of Agronomy*. pp. 771-1569.

Bojorquez-Quintal, E., Escalante-Magana, C., Echevarria-Machado, I. and Martinez-Estevez, M. 2017. Aluminium, a friend or foe of higher plants in acid soils. *Frontiers in Plant Science.* **8**: 1767.

Bona, F. D. and Monteiro, F. D. 2010. Marandu palisadegrass growth under nitrogen and sulphur for replacing signal grass in degraded tropical pasture. *Scientia Agricola.* **67**: 570-578.

Bothe, D. T., Sabale, R. N. and Raundal, P. U. 2000. Effect of phosphorus, plant population and P-Solubilizer on soybean-fenugreek cropping system. *Journal of Maharashtra Agricultural Universities.* **25**(3): 310-311.

Bożena Barczak, Knapowski, T., Kozera, W. and Ralcewicz, M. 2014. Effects of sulphur fertilization on the content and uptake of macroelements in narrow-leaf lupin. Romanian Agricultural Research, No. 31. Department of Agricultural Chemistry, University of Technology and Life Sciences, Bydgoszcz, Poland.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science.* **59**: 39-45.

Broughton, W. J., Hernandez. G., Blair, M. and Beebe, S. 2003. Bean *(Phaseolus vulgaris)* model food legume. *Plant and Soil.* **252**: 55-128.

Calba, H. and Jaillard, B. 1997. Effect of aluminium on ion uptake and H^+ release by maize. *New Phytologist.* **137**: 607-616.

Chandra, D. and Khaldelwal, R. B. 2009. Effect of phosphorus and sulphur nutrition on yield and quality of chick pea. *Journal of the Indian Society of Soil Science*. **57**(3): 352-356.

Chaplot, P. C., Jain, G. L. and Bansal, K. N. 1991. Effect of phosphorus and sulphur on the oil yield and uptake of N, P and S in sesame. *International Journal of Tropical Agriculture.* **9**(3): 190-193.

Chapman, H. D. and Pratt, P. F. 1962. Methods of analysis for soils, plants and water, University of California Division Agriculture Science, Barkley, pp 68.

Chatterjee, R. and Som, M. G. 1991. Response of french bean to different rates phosphorus, potassium and plant spacing. *Crop Research.* **4**: 214-217.

Chavan, M. G., Ramteke, J. R., Patil, B. P. and Shaikh, M. S. I. 2000. Studies on uptake of NPK and quality of french bean cultivars. *Journal of Maharashtra Agricultural Universities*. **25**: 95-96.

Chen, R. F., Zhang, F. L., Zhang, Q. M., Sun, Q. B., Dong, X. Y. and Shen, R. F. 2012. Aluminium-phosphorus interactions in plants growing on acid soils: Does phosphorus always alleviate aluminium toxicity. *Journal of Science, Food and Agriculture*. **92**: 995-1000.

Chenithung, T. S., Sharma, Y. K. and Sharma, S. K. 2014. Fertility status and soil acidity under different land use system in Wokha district of Nagaland. *Journal of Indian Society of Soil Science.* **62**: 414-418.

Chesnin, L. and Yien, C. H. 1951. Turbidimetric determination of available sulphate. *Soil Science Society. America Proceedings***.** **15**: 149-151.

Chotchutima, S., Tudsri, S., Kangvansaichol, K. and Sripichitta, P. 2016. Effects of sulphur and phosphorus application on the growth, biomass yield and fuel properties of leucaena (*Leucaena leucocephala*) as bioenergy crop on sandy infertile soil. *Agriculture and Natural Resources.* **50**: 54-59.

Clark, R. B., Pier, H. A., Knudsen, D. and Maranville, J. W. 1981. Effect of trace element deficiencies and excesses on mineral nutrients in sorghum. *Journal of Plant Nutrition.* **3:** 357–374.

Clarkson, D. T. 1965. The effect of aluminium and some other trivalent metal cations on cell division in root apices of *Allium cepa*. *Annals of Botany* **29**: 309-315.

Clarkson, D. T. and Sanderson J. 1971. Inhibition of the uptake and long distance transport of calcium by aluminium and other polyvalent cations. *Journal of Experimental Botany*. **22**: 837-51.

Cochran, W. G. and Cox, G. M. 1962. Experimental design (2^{nd} Edition). *Asian Publishing House, New Delhi.*

Coimbra, J. L. M., Guidolin, A. F., Carvalho, F. I. F. and Duarte, I. A. 1998. Quantitative analysis of genetic and phenotypic parameters in bean (*Phaseolus vulgaris* L.). *Pesquuisa Agropecuaria Gaucha* **4**(2): 157-165.

Costa, A., Muller, C. and Castoldi, G. 2020. Potential of calcium nitrate to mitigate the aluminium toxicity in *Phaseolus vulgaris*: effects on morphoanatomical traits, mineral nutrition and photosynthesis. *Ecotoxicology.* **29:** 203-216.

Cristiane, E. C. and Veronique, V. S. 2008. Effect of aluminium stress on mineral nutrition in rice cultivars differing in aluminium sensitivity. *Soil, Water and Plant Management.* **12**: 363-369.

Crusciol, C. A. C., Soratto, R. P., Silva, L. M. and Lemos, L. B. 2006. Covering sulphur application in common bean under no tillage system. *Bragantia*. **65**: 459-465.

Cui, Y., Dong, Y. T., Li, H. F. and Wang, Q. G. 2004. Effect of elemental sulphur on solubility of soil heavy metals and their uptake by maize. *Environment International* **30**(3): 323-328.

Cumming, J. R., Eckert, R. T. and Evans, L. S. 1985. Effect of aluminium on potassium uptake by red spruce seedlings. *Canadian Journal of Botany*. **63**: 1099-1103.

Dalai, S., Evoor, S., Hanchinamani, C. N., Mulge, R., Mastiholi, A. B., Kukanoor, L. and Kantharaju, V. 2019. Effect of different nutrient levels on yield components, nutrient uptake and post harvest soil fertility status of Dolichos beans. *International Journal of Current Microbiology and Applied Science.* **8**(2): 187-195.

Das, S. K. 2016. Effect of phosphorus and sulphur on yield attributes, yield, nodulation and nutrient uptake of green gram (*Vigna radiate* (L.) wilczek). *Legume Research.* ***40***: 138-143.

Das, S. K., Pareek, B. L., Kumawat, A. and Dhikwal, S. R. 2013. Effect of phosphorus and biofertilizers on productivity of chickpea (*Cicer arietinum* L.) in north western Rajasthan, India. *Legumes Research.* **36**: 511-514.

Das, R., Thapa, U., Debnath, S., Lyngdoh, Y. A. and Mallick, D. 2014. Evaluation of french bean (*Phaseolus vulgaris* L.) genotypes for seed production. *Journal of Applied and Natural Science.* **6**(2): 594-598.

Datnoff, L. E., Elmer, W. H. and Huber, D. M. 2007. *Mineral nutrition and plant disease*. APS Press, St. Paul, MN, USA: pp. 278.

Dawood, M., Cao, F., Jahangir, M. M., Zhang, G. and Wu, F. 2012. Alleviation of aluminium toxicity by hydrogen sulfide is related to elevated ATPase, and suppressed aluminium uptake and oxidative stress in barley. *Journal of Hazardous Materials.* **2**: 121-128.

Delhaize, E. and Ryan, P. R. 1995. Aluminium toxicity and tolerance in plants. *Plant Physiology*. **107**: 315-321.

Deshbhratar, P. B., Singh, P. K., Jambhulkar, A. P. and Ramteke, D. S. 2010. Effect of sulphur and phosphorus on yield, quality and nutrient status of pigeon pea (*Cajanus cajan*). *Journal of Environmental Biology.* **31**(6): 933-937.

Desta, B. 1988. Biological nitrogen fixation research on grain legumes in Ethiopia: An overview. pp., 73-78.

Dhage, J., Patil, V. D. and Patange, M. J. 2014. Effect of various levels of phosphorus and sulphur on yield, plant nutrient content, uptake and availability of nutrients at harvest stages of soybean (*Glycine max* L.). *International Journal of Current Microbiology*. **3**(12): 833-844.

Dharwe, D. S., Dixit, H. C., Dotaniya, C. K., Khandagle, A., Sandeep, M. and Doutaniya, R. K. 2019. Effect of phosphorus and sulphur on the yield and nutrient content of green gram. *International Journal of Chemical Studies* **7**(2): 1-5.

Dong, Z., Li, Y., Xiao, X., Chen, Y. and Shen, X. 2018. Silicon effect on growth, nutrient uptake, and yield of peanut (*Arachis hypogae* L.) under aluminium stress. *Journal of Plant Nutrition.* **41**(15): 2001-2008.

Dong, D., Peng, X. and Yan, X. 2004. Organic acid exudation induced by phosphorus deficiency and/or aluminium toxicity in two contrasting soybean genotypes. *Plant Physiology*. **122**: 190-199.

Dwivedi, A. K. and Bapat, P. N. 1998. Sulphur-phosphorus interaction on the synthesis of nitrogenous fraction and oil in soybean. *Journal of Indian Society of Soil Science.* **46**: 254-257.

Edwards, J. H., Horton, B. D. and Kirkpatrick, H. C. 1976. Aluminium toxicity symptoms in peach seedlings. *Journal of the American Society for Horticultural Science.* **101**(2): 139-142.

Fageria, N. K. 1989. Effects of phosphorus on growth, yield and nutrient accumulation in the common bean. *Journal of Tropical Agriculture.* **66**(3): 249-255.

Fagerias, N. K., Baligar, V. C. and Jones, C. A. 2010. Growth and mineral nutrition of field crops. 3rd edition. Boca Raton, CRC Press. pp 586.

Farias, E. S. T., Pintro, J. C., Silva, M. A. G., Muiniz, A. S., Marchetti, M. E., Nolla, A. and Noemi, P. 2011. Aluminium toxicity in corn plants cultivated with low and high ionic strength nutrient solutions. *Journal of Plant Nutrition.* **34**: 465-475.

Foy, C. D. 1992. Soil chemical factors limiting plant root growth, in: Hatfield J L, Stewart B A (Eds.), Advances in soil sciences: Limitation to plant root growth. New York: Springer- Verlag, 97-149.

Foy, C. D., Fleming, A. L. and Armiger, W. J. 1969. Aluminium tolerance of soybean varieties in relation to calcium nutrition. *Agronomy Journal.* **61**: 505-511.

Ganie, M. A., Farida, A., Bhat, M. A. and Najar, G. R. 2014. Growth, yield and quality of french bean (*Phaseolus vulgaris* L.) as influenced by sulphur and boron application on inceptisols of Kashmir. *The bioscan.* **9**: 513-518.

Gessa, C. E., Tanja, M., Salvatore, D. and Claudio, M. 2005. Effect of aluminium and pH on the mobility of phosphate through a soil-root interface model. *Plant and Soil.* **273**(1): 301-311.

Ghosh, M. K. and Joseph, S. B. (2006-07). Productivity and economics of summer green gram (*Vigna radiata*) as influenced by biofertilizers, phosphorus and sulphur application. *Fertilizer News.* **45** (8): 27-30.

Gidago, G., Beyene, S. and Worku, W. 2011. The response of haricot bean (*Phaseolus vulgaris L.*) to phosphorus application on Ultisols at Areka, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare.* **1**: 38-49.

Girma, A., Demelash, A. and Ayele, T. 2014. The response of haricot bean varieties to different rates of phosphorus at Arbaminch, Southern Ethiopia. *Journal of Agricultural and Biological Science.* **9**: 344-350.

Głowacka, A., Gruszecki, T., Szostak, B. and Michałek, S. 2019. The response of common bean to sulphur and molybdenum fertilization. *International Journal of Agronomy*. **2019**(2): 1-10.

Goransson, A. and Elduset, T. D. 1991. Effect of aluminium on growth and nutrient uptake of small picea abies and pinus sylvestres plants. *Trees*. **5**: 136-142.

Guo, P., Li, Q., Yi-Ping, Qi., Lin-Tong Yang, Xin Ye , Huan-Huan Chen, H. H. and Li-Song Chen. 2017. Sulfur-mediated-alleviation of aluminium-toxicity in *Citrus grandis* seedlings. *International journal of molecular sciences.* **18**: 1-19.

Hanlon, E. A. 1998. Elemental determination by AAS. **In**: Handbook of Reference Methods for Plant Analysis. (ed. Karla Y P). Published by CRC press Taylor and Francis group, pp 157-161.

Hanway, J. and Heidal, H. S. 1952. Soil testing laboratories procedures. *Jowa Agriculture.* **57:** 1-31.

Hendrix, J. E. 1967. The effect of pH on the uptake and accumulation of phosphate and sulphate ions by bean plants. *American Journal of Botany*. **54**: 500-564.

Hong, L., Wan, H., Shaff, J., Xiurong, J. S., Wang, Y. X. and Kochian, L. V. 2006. Phosphorus and aluminum interactions in soybean in relation to aluminum tolerance, exudation of specific organic acids from different regions of the intact root system. *Plant Physiology*. **141**: 674–684.

Horst, W. J., Rangel, A. F., Eticha, D., Manabu, I. and Rao, M. I. 2007. Aluminium toxicity and resistance in *Phaseolus vulgaris* - physiology drives molecular biology. Institute for Plant Nutrition, Leibniz University Hannover, Herrenhaeuser Str. 2, D30419 Hannover.

Huang, J. W., Grunes, D. L. and Kochian, L. V. 1992. Aluminium effects on the kinetics of calcium uptake into cells of the wheat root apex: Quantification of calcium fluxes using a calcium-selective vibrating microelectrode. *Planta.* **188**: 414-421.

Illera, V., Garrido, R., Vizcayno, C. and Garcia-Gonzalez, M. T. 2004. Field application of industrial by-products as Al-toxicity amendments: chemical and mineralogical implications. *European Journal of Soil Science.* **55**: 681-692.

Iqbal, M. T. 2013. Phosphorus enhances aluminium tolerance in both aluminium-tolerant and aluminium-sensitive wheat seedlings. *South African Journal of Plant and Soil.* **30**: 13–21.

Islam, M. N., Hoque, S. and Islam, A. 2006. Effect of P x S interactions on nutrient concentration and yield of wheat, rice and mungbean. *Journal of Indian Society of Soil Science.* **54**: 86-91.

Islam, M., Mohsan, S., Ali, S. 2012. Effect of different phosphorus and sulfur levels on nitrogen fixation and uptake by chickpea (*Cicer arietinum* L.). *Agrociencia*. **46**: 1-13.

Jackson, M. L. 1967 & 73. Soil Chemistry Analysis. *Pretince Hall of India Pvt. Ltd., New Delhi.*

Jadav, Padamani O. P., Polara, D. R., Parma, K. B. and Babaria, K. B. 2010. Effect of different level of sulphur and potassium on growth, yield and yield attributes of sesame (*Sesamum indicum* L.). *Asian Journal of Soil Science*. **5** : 106-108.

Jamal, A., Moon, Y. S. and Abdin, M. Z. 2010. Sulphur- a general overview and interaction with nitrogen. *Australian Journal of Crop Science.* **4**(7): 523-529.

Jan, F. and Pettersson, S. 1989. Varietal diversity of upland rice in sensitivity to aluminium. *Journal of Plant Nutrition.* **12**: 973-993.

Jat, B. L., Shaktwat, M. S. and Poona, T. C. 2005. Effect of S and P and biofertilizer on productivity and soil fertility of fenugreek and their residual effect on pearl millet. *Annals Agriculture Research.* **24**: 383-399.

Jemo, M., Abaidoo, R. C., Nolte, C. and Horst, W. J. 2007. Aluminium resistance of cowpea as affected by phosphorus-deficiency stress. *Journal of Plant Physiology*. **164**: 442-451.

Ji, F. S., Jing, C., Rong, F. C., Jian, F. M. and Fang, S. R .2015. Effect of in planta phosphorus on aluminium-induced inhibition of root elongation in wheat. *Plant and Soil.* **395**: 1104-1015.

Karimizarchi, M., Aminuddin, H., Khanif, M. Y. and Radziah, O. 2014. Elemental sulphur application effects on nutrient availability and sweet maize (*Zea mays L.*) response in a high pH soil of Malaysia. *Malaysian Journal of Soil Science.* **18**: 75-86.

Kenechukwu, N., Adewale, M. O. and Ezekiel, A. A. 2007. Aluminium influence on performance of some cowpea (*Vigna unguiculata*) varieties on a Nigerian alfisol. *World Journal of Agricultural Sciences.* **3**(4): 517-522.

Khatik, S. K., Mahajan, J. P., Vishwakarma, S. K. and Shukla, S. S. 1987. Concentration of macro nutrients (N & K) of soybean as affected by age, levels of sulphur and phosphorus in vertisol. *JNKVV Research Journal.* **21**(1-4): 187.

Kochian, L. V. 1995. Cellular mechanisms of aluminium toxicity and resistance in plants. *Annual Review of Plant Physiology and Molecular Biology.* **46**: 237-260.

Kokani, J. M., Shah, K. A., Tandel, B. M. and Bhiman, I. G. J. 2015. Effect of FYM, phosphorus and sulphur on yield of summer blackgram and post harvest nutrient status of soil. *The Bioscan.* **10**(1): 379-383.

Korcak, R. F. 1989. Aluminum relationships of highbush blueberries (*Vaccinium corymbosum* L.) *Acta Horticulturae.* **241**: 162-166.

Kothari, M. L. and Jethra, J. K. 2002. Response of wheat to sulphur application in loamy sand soil. *Annals of Arid Zone.* **41**: 191-194.

Kulhare, P. S. and Kauraw, D. L. 2000. Effect of regular residual and cumulative sulphur levels on phosphorus and sulphur uptake by soybean (*Glycine max*) in a wheat-soybean sequence and changes of physico-chemical soil properties of Vertisol. *Bhartiya Krishi Anusandhan Patrika.* **15**(1/2): 51-59.

Kulhare, P. S., Oswal, V. B., Kaurav, D. L. and Upadhyay, A. P. 2006. Effect of different levels and sources of sulphur on nutrient concentration and their uptake in different growth stages, crude protein and oil content of soybean. *Bhartiya Krishi Anusandhan Patrika.* **21**(2): 93-98.

Kumar, P., Pandey, S. K. and Kumar, A. P. 2015. Effect of different phosphorus levels on nutrient content, uptake and economics of urd bean under apple based agri-horti system. *Journal of Agricultural Research.* **2**: 88-93.

Kumar, A., Singh, P. K., Rai, N., Bhaskar, G. P. and Datta, D. 2014. Genetic diversity of french bean genotypes (*Phaseolus vulgaris L)* on the basis of morphological traits and molecular markers. *Indian Journal of Biotechnology.* **13**: 207-213.

Kumar, R. P., Singh, O. N, Singh, Y., Dwivedi, S. and Singh, J. P. 2009. Effect of integrated nutrient management on growth, yield, nutrient uptake and economics of french bean (*phaseolus vulgaris*). *Indian Journal of Agricultural Sciences.* **79**: 122-128.

Kumar, S., Wani, J. A., Lone, B. A., Singh, P., Dar, Z. A., Qayoom, S. and Fayaz, A. 2017. Effect of different levels of phosphorus and sulphur on seed & stover yield of soybean (*Glycine max* L. Merill) under 'Eutrochrepts' *Asian Research Journal of Agriculture.* **5**(1): 1-7

Kumawat, S. R., Khistriya, M. K., Yadav, S. L. and Kumar, M. 2014. Effect of sulphur and phosphorus on growth and yield attributes on summer green gram [*Vigna radiata* (L.) Wilczek]. *International Journal of Agricultural Sciences.* **10**(2): 770-773.

Kumawat, R. N., Rathore, P. S. and Kandal, B. K. 2007. Effect of sulphur and iron application on their concentration in mungbean grown on calcareous soil. *Annals of Arid Zone.* **46**: 205-208.

Lad, N. G., Patange, M. .J and Dhage, S. J. 2014. Effect of nitrogen and phosphorus levels on growth, yield attributing characters, yield and economics of french bean (*Phaseolus vulgaris* L.). *International Journal of Current Microbiology and Applied Sciences.* **3** (12): 822-827.

Lakshmi, T. B., Prakash, H. C. and Sudhir, K. 2010. Effect of different sources and levels of sulphur on the performance of rice and maize and properties of soils. *Mysore Journal of Agricultural Sciences.* **44**(1): 79-88.

Lal, K., Singh, B., Singh, R., Singh, C. M. and Singh, J. P. 2013. Effect of phosphorus on yield and biochemical composition of cowpea (*Vigna unguiculata* L.) pods. *A Journal of Multidisciplinary Advance Research.* **2**: 127-130.

Lance, J. C. and Pearson, R. W. 1969. Effect of low concentrations of aluminium on growth and water and nutrient uptake by cotton roots. *Soil Science Society of America Proceedings*. **33**: 95-98.

Lee, E. H. and Foy, C. D. 1986. Aluminium tolerances of two snap bean cultivars related to organic acid content evaluated by high-performance liquid chromatography. *Journal of Plant Nutrition* **9**: 1481-1498.

Lima, M. L. and Copeland, L. 1994. Changes in the ultra structure of the root tip of wheat following exposure to aluminium. *Journal of Plant Physiology* **21**: 85-94.

Lynch, Jonathan, Andre Lauchli. and Emanuel Epstein. 1991. Vegetative growth of the common bean in response to phosphorus nutrition. *Crop Science*. **31**: 380-387.

Macklon, A., Lumsdon, D. and Sim, A. 1994. Phosphate uptake and transport in *Agrostiscapillaris* L.: Effects of non-toxic levels of aluminium and the significance of P and Al speciation. *Journal of Experimental Botany* **45**: 887-894.

Macleod, L. B. and Jackson, L. P. 1964. Effect of concentration of the aluminium ion on root development and establishment of legume seedlings. *Canadian Journal of Soil Science*. **45**: 225-234.

Majumdar, B., Venkatesh, M. S., Lal, B. and Kumar, K. 2001. Response of soybean (*Glycine max*) to phosphorus and sulphur in acid alfisol of Meghalaya. *Indian Journal of Agronomy*. **46**(3): 500-505.

Marschner, H. 1997. Adaptation of plants to adverse chemical soil conditions. In: Mineral Nutrition of Higher Plants 2nd Ed. Academic Press, London. pp. 596-680.

Martin, R. B. 1988. Bio inorganic chemistry of aluminium. In Metal Ions in Biological Systems: Aluminium and its Role in Biology. Eds. H Sigel and A Sigel, pp. 1-57, Marcel Dekker, New York.

Mathew, E. E, Wafula, W. N., Korir, N. K. and Gweyi-Onyango, J. P. 2018. Effect of phosphorus levels on soil properties and plant tissues of two nerica varieties. *Asian Soil Research Journal.* **1**(3): 1-9.

McGrath, S. P. and Zhao, F. J. 1996. Sulphur uptake, yield responses and the interactions between nitrogen and sulphur in winter oilseed rape (*Brassica napus*). *The journal of Agricultural science.* **26**(1): 53-62

Mendel, R. R., Bittner, F. 2006. Cell biology of molybdenum. *Biochimica et Biophysica Acta.* **1763**(7): 621-635.

Miguel, A. Q. R., Alex, A. F. A., Marcelo, S. M., F´abio, P. G., Marcel, V. P., and Virupax, C. B. 2013. Aluminium effects on growth, photosynthesis, and mineral nutrition of cacao genotypes. *Journal of Plant Nutrition.* **36**: 1161–1179.

Mihailovic, N., Drazic, G. and Vucinic, Z. 2008. Effects of aluminium on photosynthetic performance in Al-sensitive and Al-tolerant maize inbred lines. *Photosynthetica.* **46**: 476-480.

Mitra, A. K., Banerjee, K. and Pal, A. K. 2006. Effect of different levels of phosphorus and sulphur on yield attributes, seed yield, protein content of seed and economics of summer green gram. *Research on Crops.* **7**(2): 404-405.

Moghaddam, F. R. and Aminpanah, H. 2015. Green bean (*Phaseolus vulgaris* L.) growth and yield as affected by chemical phosphorus fertilizer and phosphate bio-fertilizer. .*Idesia (Chile).* **33**(2): 77-85.

Mora, M. L., Cartes, P., Demanet, R. and Cornforth, I. S. 2002. Effects of lime and gypsum on pasture growth and composition on an acid Andisol in Chile, South America. *Communications in Soil Science and Plant Analysis.* **30**: 1251-1266.

Motsara, M. R. 2002. Available nitrogen, phosphorus and potassium status of Indian soil as depicted by soil fertility maps. *Fertilizer News.* **47**: 15-22.

Nadal, D. P., Mallik, D. S. and Singh, K. P. 1987. Effect of phosphorus on leave and dry matter accumulation of kharif pulse. *Legume Research.* **10**: 31-33.

Naik, K. R. 2000. Response of summer soybean to micronutrient sources, sulphur and nitrogen. *Annals of Plant and Soil Research.* **4**(22): 335-336.

Narayanan, A. and Syananda, R. 1989. Response of Pigeon pea (*Cajanus cajan L.*) Genotypes to aluminium toxicity. *Indian journal of Plant Physiology.* **32**(1): 17-24.

Nascente, A. S., Stone, L. F. and Melo, L. C. 2017. Common bean grain yield as affected by sulphur fertilization and cultivar. *Revista Ceres.* **64**(5): 548-552.

Nasr, N. 2013. Germination and seedling growth of maize (*Zea mays* L.) seeds in toxicity of aluminium and nickel. Merit Research Journal of Environmental Science and Toxicology. **1**: 110-113.

Negi, A., Pareek, N., Raverkar, K. P. and Chandra, R. 2017. Effect of two sulphur sources on growth, yield and nutrient use effeiciency of brassica. *International Journal of Science, Environment and Technology*. **6**(1): 236-247.

Neupane, R. K., Shrestha, R., Vaidya, M. L., Bhattarai, E. M. and Darai, R. 2008. Agromorphological diversity in common bean (*Phaseolus vulgaris L.*) landraces of Jumla, Nepal.pp 639-648. *In*:KharkwalM C (ed.) Proceedings of the Fourth International Food Legumes Research Conference. New Delhi, India.

Nichol, B. E. and Oliveira, L. A. 1995. Effects of aluminium on the growth and distribution of calcium in roots of an aluminium-sensitive cultivar of barley *(Hordeumvulgare*). *Canadian Journal of Botany.* **73**: 1849-1858.

Nkaa, F. A., Nwokeocha, O. W. and Ihuoma, O. 2014. Effect of phosphorus fertilizer on growth and yield of cowpea (*Vigna unguiculata*) . International organization of scientific research. *Journal of Pharmacy and Biological Sciences.* **9**: 74- 82.

Nosko, P., Brassard, P., Kramer, J. R. and Kershaw, K. A. 1988. The effect of aluminum on seed germination and early seedling establishment, growth and respiration f white spruce (Picea glauca). *Canadian Journal of Botany*. **66**(11): 2305-2310.

Nyekha, N., Sharma, Y. K., Sharma, S. K. and Gupta, R. C. 2015. Influence of phosphorus and PSB on performance of green gram and soil properties. *Annals of Plant and Soil Research.* **17**: 323-325.

Okpara, D. A., Muoneke, C. O. and Ojikpong, T. O. 2007. Effects of nitrogen and phosphorus fertilizers rates on the growth and yield of sesame (*Sesamum indicum* L.) in the south eastern rainforest belt of Nigeria. *Niger Agriculture Journal.* **38**: 1-11.

Osmar, H. C. P., Tales, Tiecher, M. R. C., Michael, M. and Cimélio, B. 2019. Crop yield responses to sulphur fertilization in Brazilian no-till soils: a systematic review. *Revista Brasileira Cienciado Solo.* **43**: e0180078.

Pacyna, S., Schulz, M. and Scherer, H. W. 2007. Influence of sulphur supply on glucose and ATP concentrations of inoculated broad beans (*Vicia faba minor* L.). *Biology and Fertility of Soils.* **42**(1): 324-329.

Paliwal, A. K., Vajpai, S. K. and Vajpai, K. 2009. Interaction effect of sulphur and phosphorus application on yield and major nutrient composition of soybean (*Glycine max* L. Merrill) grown on alfisol. *An Asian Journal of Soil Science.* **4**(1): 113- 117.

Pandey, R. Y., Gautam, D. M., Thapa, R. B., Sharma, M. D. and Prakash, P. K. 2012. Response of pole type french bean (*Phaseolus vulgaris* L.) genotypes to sowing dates in the mid hills of western Nepal. *Nepal Journal of Science and Technology*. **13**(2): 15-20.

Parakhia, D. V., Parmar, K. B., Vekaria, L. C. and Sisodiya, R. R. 2018. Effect of various sulphur levels on concentration and uptake of nitrogen, phosphorus and potash of soybean (*Glycine max* L.) varieties. *International Journal of Chemical Studies*. **6**(3): 2962-2966.

Parischa, N. S. and Sparks, D. L. 1990. Kinetics of adsorption of phosphate and desorption of sulphate in soils at two pH values. *Soil Science*. **150** :714-717.

Parthasharathy, V. A. 1993. French bean. In "Vegetable Crops in India" (T. K. Bose, M. G. Som, and J. Kabir, Eds.), Nayaprokash, Calcutta. pp. 591-602.

Patel, A. K., Nath, T., Prajapati, A., Singh, V. K. and Pandey, S. K. 2018. Effect of doses and sources of sulphur on growth and yield of black gram (*Vigna mungo* L. Hepper) under rainfed condition of Vindhyan Soil. *Journal of Pharmacognosy and Phytochemistry* **1**: 91-94.

Pellet, D. M., Papernik, L. A. and Kochian, L.V. 1996. Multiple aluminium resistance mechanisms in wheat: roles of root apical phosphate and malate exudation. *Plant Physiology*. **112**: 591-597.

Petra, S. K. and John Proctor. 2000. Effects of aluminium on the growth and mineral composition of *Betula pendula* Roth. *Journal of Experimental Botany*. **51**: 1057-1066.

Phogat, M. 2016. Effects of phosphorus and sulphur interaction on nutrient uptake and yield of black gram (*Vigna mungo* L. Hepper). M.Sc. Thesis submitted to Sher-e Kashmir University of Agricultural Sciences and Technology of Jammu in partial fulfilment for the degree of Master of Science (Agriculture) in Agricultural Chemistry and Soil Science.

Phogat, M. and Abidi, A. B. 2008. Response of sulphur and phosphorus application on protein and amino acid composition of groundnut *(Arachis hypogaea* L.*). New Botanist.* **35**(1/4): 135-140.

Phogat, M., Rai, A. and Padma, A. 2019. Effect of phosphorus and sulphur application on their dynamics and nodulation in soil under black gram (*Vigna mungo* L. Kepper) crop. *Legume research.* **43**(2): 1-7.

Pina, R. and Cervantes, C. 1996. Microbial interactions with aluminium. *Biometals: an international journal on the role of etal ions in biology, biochemistry and medicine.* **9**:311-16.

Pintro, J., Barloy, J. and Fallavier, P. 1996. Aluminium effects on the growth and mineral composition of corn plants cultivated in nutrient solution at low aluminium activity. *Journal of Plant Nutrition*. **19**: 729-741.

Pintro, J. C, Inoue, T. T, Tormena, C. A, Costa, A. C. S. and Silva, M. G. 2004. Mineral composition and dry mass production of corn plants affected by different phosphate sources and different soil aluminum saturation levels. *Journal of Plant Nutrition.* **27**: 2149-2158.

Poblete, A., Blancheteau, I. C., Alberdi, M., Rengel, Z. and Reyes-Díaz, M. 2018. Molecular regulation of aluminium resistance and sulphur nutrition during root growth. *Planta.* **247**(1):27-39.

Qian, P., Sun, R. A. B., Gill, R. A., Xu, L. and Zhou, W. 2014. Effects of hydrogen sulfide on growth, antioxidative capacity, and ultra structural changes in oil seed rape seedlings under aluminium toxicity. *Journal of Plant Growth Regulation.* **33**: 526-538.

Rafat, M. and Sharifi, P. 2015. The effect of phosphorus on yield and yield components of green bean. *Journals of Soil and Nature.* **8**: 9-13.

Rahman, A. M., Lee, S. H., Chung, J. H., Kabir, A. H., Jones, C. S. and Lee, K. W. 2018. Importance of Mineral Nutrition for Mitigating Aluminum

Toxicity in Plants on Acidic Soils: Current Status and Opportunities. *International Journal of molecular science.* **19**: 1-28.

Rahman, M. N, Sayem, S. M., Alam, M. K., Islam, M. S. and Mondol, A. T. M. A. 2007. Influence of sulphur on nutrient content and uptake by rice and its balance in old Brahmaputra floodplain soil. *Journal of Soil and Nature.* **1**: 5-10.

Rangel, A. F., Rao, I. M. and Horst, W. J. 2007. Spatial aluminium sensitivity of root apices of two common bean (*Phaseolus vulgaris* L.) genotypes with contrasting aluminium resistance. *Journal of Experimental Botany.* **58**: 3895-3904.

Rangel, A. F., Rao, I. M. and Horst, W. J. 2009. Intracellular distribution and binding state of aluminium in root apices of two common bean (*Phaseolus vulgaris*) genotypes in relation to Al toxicity. *Physiology of Plant.* **135**: 162-173.

Rengel, Z. and Zhang, W. H. 2003. Role of dynamics of intracellular calcium in aluminium-toxicity syndrome. *New Phytopathology.* **159**: 295-314.

Rao, I. M. 2001. Role of physiology in improving crop adaptation to abiotic stresses in the tropics: The case of common bean and tropical forages. Handbook of Plant and Crop Physiology. Chapter 29 pp. 583-613.

Rao, S., Singh, K. K. and Ali, M. 2001. Sulphur: A key nutrient for higher pulse production. *Fertilizer News*. **46**: 31-48.

Ravikumar, C., Ganapathy, M. and Vaiyapuri, V. 2016. Effect of sulphur fertilization on growth, yield and nutrient uptake of sunflower in north Cauvery deltaic region. *International Journal of Current Research.* **8**(22):13-17.

Rheinheimer, D. S., Petry, C., Kaminski, J. and Bartz, H. R. 1994. Aluminium stress in tobacco plants: I. Effects on phosphorus and calcium uptake, root system and dry matter production. *RevistaBrasileira de Cienciado Solo.* **18**: 63-68.

Ribeiro, M. A. Q., Almeida, A. F., Mielke, M. S., Gomes, F. P., Pires, M. V. and Baligar, V. C. 2013. Aluminium effects on growth, photosynthesis, and mineral nutrition of cacao genotypes. *Journal of Plant Nutrition.* **36**(8): 1161-1179.

Ritchie, G. S. P. 1989. The chemical behaviour of aluminium, hydrogen and manganese. In Soil Acidity and Plant Growth. Ed. A D Robson pp. 1-60. Academic Press, New York, USA.

Rufty, T. W., Mackown, C. T., Lazof, D. B. and Carter, T. E. 1995. Effects of aluminium on nitrate uptake and assimilation. *Plant, Cell and Environment.* **18**: 1325-1331.

Ryan, P. J., Gessel, S. P. and Zasoski, R. J. 1986. Acid tolerance of specific northwest conifers in solution culture. I. Effect of high aluminium concentration and solution acidity. *Plant and Soil.* **96**: 239-257.

Sahaa, P. K., Ishaqueb, M., Salequeb, M. A., Miahb, M. A. M., G., Panaullahb, Mand Bhuiyanb, N. I. 2007. Long-term integrated nutrient management for rice-based cropping pattern: Effect on growth, yield, nutrient uptake, nutrient balance sheet and soil fertility. *Comm unications in Soil Science and Plant Analysis.* **38**(5&6): 579-610.

Salvador, J. O., Moreira, A., Malavolta, E., Cabral, C. P. 2000. Influence of aluminium on growth and nutrient and nutrient accumulation in guava seedlings. *Revista Brasilia de Ciencia*. **24**: 787-796.

Samad, R., Rashid, P. and Karmoker, J. 2017. Effects of aluminium toxicity on germination of seeds and its correlation with K^+, Cl^- And Al^{3+} accumulation in radicle and plumule of *Oryza Sativa* L. and *Cicer aeriatinum* L. *Bangladesh Journal of Botany*. **46**(3): 979-986.

Sangwan, A., Duhan, B. S., Sangwan, P. S. 2018. Effect of different sources of sulphur on yield and nutrient uptake of wheat. *Journal of Pharmacognosy and Phytochemistry.* **7**(6): 2686-2691.

Scheel, T., Jensen, B., Wijk, A. J. V. and Verstraten, J. M. 2008. Stabilization of dissolved organic atter by aluminium: A toxic effect or stabilization through precipitation. *European Journal of soil science*. **59**(6): 1122-1132.

Scherer, H., Lange, A. 1996. Nitrogen fixation and growth of legumes as affected by sulphur fertilization. *Biology of Fertile Soils.* **23**: 449-453.

Schier, G. A. 1985. Response of red spruce and balsam fir seedlings to aluminium toxicity in nutrient solutions. *The Canadian Journal of Forest Res*earch. **15**: 29-33.

Schulze, J., Temple, G., Temple, S. J., Beschow, H. and Vance, C. P. 2006. Nitrogen fixation by white lupin under phosphorus deficiency. *Annals of Botany*. **98**(4): 731-740.

Serawat, A., Sharma, Y., Serawat, M., Kapoor, A. and Jakhar, R. K. 2018. Effect of phosphorus and sulphur on growth attributes and yield of mungbean (*Vigna radiate* L.) in sandy soils of hyper arid western plains of Rajasthan. *International Journal of Current Microbiology and Applied Sciences.* **7**(8): 2674-2683.

Sharma, S. N. and Prasad, R. 2009. Effect of different sources of phosphorus on summer mungbean (*Vigna radiata*) in alkaline soil of Delhi. *Indian Journal of Agricultural Sciences.* **79**(10): 782–789.

Shelke, Kalegore, R. I. and Wayase, N. K. 2014. Effect of levels of phosphorus and sulphur on growth, yield and quality of sesamum. *World Journal of Agricultural Sciences.* **10**(3): 108-111.

Shen, F. S. and Zhao, X. Q.2012. Strategies for increasing the ability of plants to adapt to acid soils based on the interactions between aluminium and other elements. 8th International Symposium on Plant Soil Interactions at Low pH. Bengalaru, India. pp 178-179.

Shrivastava, U. K., Rajput, R. L. and Diwivedi, M. L. 2000. Response of soybean-mustard cropping system to sulphur and bio-fertilizers on farmer's field. *Legume Research.* **23**: 277-278.

Shubhashree, K. S. 2007. Response of rajmash (*Phaseolus vulgaris* L.) to the levels of nitrogen, phosphorus and potassium during rabi in the northern transition zone. M.Sc Thesis submitted to Department of Agronomy, University of Agricultural Sciences, Dharwad, Karnataka.

Siddiqui, Md. and Noor- E- Alam. 2010. Response of bush bean to applied nitrogen and phosphorus. Ph.D. Thesis, Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur.

Singh, Y. P. 1993. Role of sulphur and phosphorus in blackgram production. *Fertilizer News.* **49**(2): 33-36.

Singh, O., Kumar, S., Dwivedi, S., Dhyani, B. P. and Naresh, R. K. 2013. Effect of sulphur and iron fertilization on performance and production potential of urd bean (*Vigna Mungo* L.) Hepper and nutrients removal under Inceptisols. Department of Soil Science, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, India.

Singh, A. K., Manibhushan, Meena, M. K. and Upadhyaya, A. 2012. Effect of sulphur and zinc on rice performance and nutrient dynamics in plants and soil of Indo Gangetic Plains. *Journal of Agricultural Science.* **4**(1)1: 161-171.

Singh, Y. P. and Singh, R. 2004. Interaction effect of sulphur and phosphorus on growth and nutrient content of black gram (*Phaseolus mungo* L.). *Journal of Indian Society of Soil Science.* **52**: 266-269.

Singh, V. and Yadav, D. S. 2004. Response of green gram to sulphur and zinc. *Annals of Agricultural Research.* **25**(3): 463-464.

Singh, P., Yadav, K. K., Meena, F. S., Singh, B. and Singh, R. 2017. Effect of phosphorus and sulphur on yield attributes, yield and nutrient uptake of mungbean (*Vignaradiata* l.) in central plain zone of Punjab, India. *Plant Archives.* **17**(2): 1756-1760.

Sipai, A. H., Jat, J. S., Rathore, B. S. and Singh, J.S. 2015. Effect of phosphorus, sulphur and biofertilizer on productivity and soil fertility after harvest of moongbean grown on light textured soil of Kachchh. *An Asian Journal of Soil Science.* **10**(2): 228-236.

Sivasubramaniam, S. and Talibudeen, O. 1971 Effect of aluminium on growth of tea (*Camellia sinensis*) and its uptake of potassium and phosphorus. *Journal of Science and Food Agriculture*. **22**: 325-329.

Skwierawska, M., Zawartka, L. and Zawadzki B. 2008. The effect of different rates and forms of applied sulphur on nutrient composition of planted crops. *Plant, Soil and Environment*. **54**:179-189.

Sriramachandrasekharan, M. V. and Muthukkaruppan, S. M. 2004. Effect of sulphur and *Rhizobium* on biological nitrogen fixation, nutrient uptake and seed yield of soybean. *Journal of Ecobiology*. **16**(3): 235-236.

Subbiah, B. V. and Asija, G. L. 1956. Rapid procedure for the estimation of available nitrogen in soils. *Current Science.* **25**: 259-260.

Sujata, P., Rathod, P. K., Ravankar, H. N., Patil, Y. G., Yewale, A. C. and Pothare, D. 2007. Effect of long term fertilization in vertisols on soil properties and yield of sorghum wheat sequence. *The Asian Journal of Soil Science.* **2**(1): 74-78.

Taliman, N. A., Dong, Q., Echigo, K., Raboy, V. and Saneoka, H. 2019. Effect of phosphorus fertilization on the growth, photosynthesis, nitrogen fixation, mineral accumulation, seed yield and seed quality of a soybean low-phytate line. *Plants.* **8**: 2-18.

Tan, K. and Keltjens, W. G. 1990. Interaction between aluminium and phosphorus in sorghum plants. *Plant and Soil.* **124**: 15-23.

Tandon, H. L. S. 1993. Methods of analysis of soils, plant, waters and fertilizers. FertilizerDevelopment and Consultation Organization, New Delhi, Pp.143.

Taylor, G. J. 1988. The physiology of aluminium tolerance in higher plants. *Soil Science and Plant Analysis.* **19**: 1179-1194.

Taylor, G. J. 1995: Overcoming barriers to understanding the cellular basis of aluminium resistance. *Plant and Soil* **171**: 89-103.

Tekseng, O. 2016. Effect of phosphorus and sulphur nutrition on the performance of Sesamum (*Sesamum indicum* L.) under acidic condition of Nagaland. Thesis submitted to Nagaland University in partial fulfilment for the degree of Master of Science (Agriculture) in Agricultural Chemistry and Soil Science.

Teotia, U. S., Mehta, V. S., Ghosh, D. and Srivastava, P. C. 2001. Phosphorus-sulphur interaction in moongbean (*Vigna radiata* L. Wilczek) yield, nitrogen, potassium, calcium and magnesium contents. *Legume Research.* **24** (4): 272-274.

Tesfaye, Dejene. 2015. Response of common bean (*Phaseolus vulgaris* L.) to application of lime and phosphorus on acidic soil of Areka, Southern Ethiopia Haramaya University, Haramaya.

Tesfaye, M. J., Liu, D. L., Allan and Vance, C. P. 2007. Genomic and genetic control of phosphate stress in legumes. *Plant Physiology* **144**: 594-603.

Tewari, J. K. and Singh, S. S. 2000. Effect of nitrogen and phosphorus on the growth and seed yield of french bean (*Phaseolus vulgaris* L.). *Vegetable Science* **27**: 172-175.

Thangavel. 2002. Aluminium effects on soil quality and on the growth and yield of green gram (*Vigna radiata* L. Wilczek cv. KM 2). Ph.D Thesis. Department Environmental Sciences. Bharathiar University.Coimbatore-641 046. Tamil Nadu. India.

Thronton, F. C., Schaedle, M. and Raynal, D. J. 1986. Effects of aluminium on growth, development, and nutrient composition of honeylocust (*Gleditsiatriacanthos* L.) seedlings. *Tree Physiology* **2**: 307-316.

Thung, M. and Rao, I. M. 1999. Integrated management of abiotic stresses. In: Common Bean Improvement in the Twenty-First Century. S. P. Singh (Ed.). Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 331-370.

Tomar, S. S. 2001. Response of french bean (*Phaseolus vulgaris*) to irrigation schedule and phosphorus levels in vertisols. *Indian Journal of Agronomy* **46**: 496-499.

Tomar, S. S., Singh, R. and Singh, S. P. 2004. Response of phosphorus, sulphur and *Rhizobium* inoculation on growth, yield and quality of soybean (*Glycine max* L.). *Progressive Agriculture* **4**(1): 72-73.

Van, S. A. and Voysests, O. 1991. “Common Bean: Research for Crop Improvement”. CAB International, Oxon. pp 980.

Veeresh, N. K. 2003. Response of french bean (*Phaseolus vulgaris* L.) to fertilizer levels in northern transitional zone of Karnataka. M.Sc. (Agri.) Thesis, University of Agriculture Science, Dharwad, Karnataka. pp. 37-79.

Wagatsuma, T., Kyuuda, T. and Sakuraba, A. 1987. Aluminium accumulation characteristics of aluminium tolerant plants. Bulletien of the Yamagata University of Agriculture Science. **10**: 355-359.

Walkley, A. and Black, C.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science.* **37**: 29-38.

Wang, J., Raman, H., Zhang, G., Mendham, N. and Zou, M. 2006. Aluminium tolerance in barely (*Horidium vulgarie* L.): Physiological mechanisms, genetic and screening methods. *Journal of Zhejiang University Science.* **7**: 769-787.

Yadav, B. K. 2011. Interaction of phosphorus and sulphur on yield and quality of cluster bean in typic Haplustept. *World Journal of Agricultural Sciences.* **7**(5): 556-660.

Yadav, B. V. S. 2015. Performance of vegetable frenchbean (*Phaseolus vulgaris* L.) as influenced by varieties and sowing dates under southern zone of Andhra Pradesh. M.Sc. Thesis. Dr. Y. S. R. Agricultural University, Y. S. R. District, Andhra Pradesh.

Yadav, R. and Singh, S. 1970. Effect of gypsum on the chemical competition, nutrient uptake and yield of groundnut. *Journal of Indian Society of Soil Science.* **18**: 183-186.

Yadav, H. K., Thomas, T. and Khajuria, V. 2010. Effect of different levels of sulphur and biofertilizer on the yield of Indian mustard (*Brassica juncea* L.) and soil properties. *Journal of Agricultural Physics.* **10**: 61-65.

Yakubu, H., Kwari, J. D. and Sandabe, M. K. 2010. Effect of phosphorus fertilizer on nitrogen fixation by some grain legume varieties in Sudano – Sahelian zone of North Eastern Nigeria. *Nigerian Journal of Basic and Applied Science.* **18**: 19-26.

Yang, Z. B., Eticha, D., Albacete, A., Rao, I. M., Roitsch, T., and Horst, W. J. 2012. Physiological and molecular analysis of the interaction between aluminium toxicity and drought stress in common bean (*Phaseolus vulgaris*). *Journal of Experimental Botany*. **63**: 3109-3125.

Zebire1, D. G. and Gelgelo, S. 2019. Effect of phosphorus fertilizer levels on growth and yield of haricot bean (*Phaseolus vulgaris* .L.) in South Ommo Zone, Ethiopia. *Agricultural Science Digest* **39**(1): 55-58.

Zhang, H., Tan, Z. Q., Hu, L. Y., Wang, S. H., Luo, J. P. and Jones, R. L. 2010. Hydrogen sulfide alleviates aluminum toxicity in germinating wheat seedlings. *Journal of Integrative Plant Biology*. **52**: 556–567.

Zhao, X. Q. and Shen, F. R. 2018. Aluminium- Nitrogen interactions in the soil plant system. *Frontiers in Plant Science.* **9**: 807.

Zhao, F., Wood, A. and McGrath, S.1999. Effects of sulphur nutrition on growth and nitrogen fixation of pea (*Pisum sativum* L.). *Plant and Soil.* **212**(4): 209-219.

Zheng, S. J., Yang, J. L., He, Y. F., Yu, X. H., Zhang, L., You, J. F., Shen, R. F. and Matsumoto, H. 2005. Immobilization of aluminium with phosphorus in roots is associated with high aluminium resistance in buckwheat. *Plant Physiology.* **138**: 297-303.

Zohmingliana, M., Sharma, Y. K. and Gupta, R. C. 2016. Influence of phosphorus and bio-inoculants on performance of french bean (*Phaseolus Vulgaris* L.). *Legume Research*. **41**: 1-5.

Appendix I: Effect of aluminium and varieties on days to germination

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	12.67	6.33	57.00*	8.00	4.00	18.00*	20.67	5.17	31.00*	3.55
Variety (V)	2	0.67	0.33	3.00	0.00	0.00	0.00	0.67	0.17	1.00	3.55
Al x V	4	1.33	0.33	3.00	4.00	1.00	4.50*	5.33	0.67	4.00*	2.93
ERR	18	2.00	0.11		4.00	0.22		6.00	0.17		
TSS	26	16.67			16.00			32.83			

* Significant at 5%

Appendix II: Effect of aluminium and varieties on plant height of french bean at 30 days

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	297.17	148.59	1122.91*	231.79	115.90	265.51*	528.97	132.24	464.96*	3.55
Variety (V)	2	63.43	31.72	239.68*	34.00	17.00	38.94*	97.43	24.36	85.64*	3.55
Al x V	4	1.63	0.41	3.09*	13.33	3.33	7.63*	14.96	1.87	6.58*	2.93
ERR	18	2.38	0.13		7.86	0.44		10.24	0.28		
TSS	26	364.62			286.98			665.44			

* Significant at 5%

Appendix III: Effect of aluminium and varieties on plant height of french bean at 60 days

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	409.24	204.62	216.00*	307.41	153.70	245.91	716.64	179.16	227.89*	3.55
Variety (V)	2	63.85	31.93	33.70*	51.54	25.77	41.23	115.39	28.85	36.69*	3.55
Al x V	4	14.02	3.50	3.70*	7.39	1.85	2.96	21.41	2.68	3.40*	2.93
ERR	18	17.05	0.95		11.25	0.63		28.30	0.79		
TSS	26	504.15			377.59			893.94			

* Significant at 5%

Appendix IV: Effect of aluminium and varieties on plant height of french bean at harvest

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	384.99	192.49	230.67*	362.17	181.08	242.60*	747.16	186.79	236.30*	3.55
Variety (V)	2	63.79	31.89	38.22*	75.64	37.82	50.67*	139.43	34.86	44.10*	3.55
Al x V	4	12.40	3.10	3.72*	8.87	2.22	2.97*	21.27	2.66	3.36*	2.93
ERR	18	15.02	0.83		13.44	0.75		28.46	0.79		
TSS	26	476.20			460.11			969.29			

* Significant at 5%

Appendix V: Effect of aluminium and varieties on number of branches of french bean at 30 days

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	8.07	4.04	10.90*	5.56	2.78	6.25*	13.63	3.41	8.36*	3.55
Variety (V)	2	0.52	0.26	0.70	0.89	0.44	1.00	1.41	0.35	0.86	3.55
Al x V	4	0.15	0.04	0.10	0.22	0.06	0.13	0.37	0.05	0.11	2.93
ERR	18	6.67	0.37		8.00	0.44		14.67	0.41		
TSS	26	15.41			14.67			31.93			

* Significant at 5%

Appendix VI: Effect of aluminium and varieties on number of branches of french bean at 60 days

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	8.07	4.04	3.76*	8.07	4.04	3.76*	16.15	4.04	3.76*	3.55
Variety (V)	2	1.85	0.93	0.86	0.96	0.48	0.45	2.81	0.70	0.66	3.55
Al x V	4	1.48	0.37	0.34	0.15	0.04	0.03	1.63	0.20	0.19	2.93
ERR	18	19.33	1.07		19.33	1.07		38.67	1.07		
TSS	26	30.74			28.52			59.43			

* Significant at 5%

Appendix VII: Effect of aluminium and varieties on number of branches of french bean at harvest

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	24.22	12.11	13.63*	7.19	3.59	3.59*	31.41	7.85	8.31*	3.55
Variety (V)	2	1.56	0.78	0.87	0.52	0.26	0.26	2.07	0.52	0.55	3.55
Al x V	4	0.89	0.22	0.25	0.37	0.09	0.09	1.26	0.16	0.17	2.93
ERR	18	16.00	0.89		18.00	1.00		34.00	0.94		
TSS	26	42.67			26.07			68.81			

* Significant at 5%

Appendix VIII: Effect of aluminium and varieties on number of pods per plant

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	156.07	78.04	175.58*	152.07	76.04	342.17	308.15	77.04	231.11*	3.55
Variety (V)	2	12.74	6.37	14.33*	12.07	6.04	27.17	24.81	6.20	18.61*	3.55
Al x V	4	5.04	1.26	2.83	3.26	0.81	3.67	8.30	1.04	3.11	2.93
ERR	18	8.00	0.44		4.00	0.22		12.00	0.33		
TSS	26	181.85			171.41			353.93			

* Significant at 5%

Appendix IX: Effect of aluminium and varieties on pod length

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	94.49	47.25	77.83*	79.06	39.53	85.67*	173.55	43.39	81.22*	3.55
Variety (V)	2	4.99	2.49	4.11*	3.80	1.90	4.11*	8.79	2.20	4.11*	3.55
Al x V	4	0.13	0.03	0.05	0.22	0.06	0.12	0.35	0.04	0.08	2.93
ERR	18	10.93	0.61		8.31	0.46		19.23	0.53		
TSS	26	110.54			91.38			202.81			

* Significant at 5%

Appendix X: Effect of aluminium and varieties on number of seeds per pod

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	11.99	5.99	17.90*	12.03	6.01	22.90*	24.01	6.00	20.10*	3.55
Variety (V)	2	0.64	0.32	0.96	0.64	0.32	1.21	1.28	0.32	1.07	3.55
Al x V	4	0.11	0.03	0.08	0.03	0.01	0.03	0.14	0.02	0.06	2.93
ERR	18	6.03	0.33		4.73	0.26		10.75	0.30		
TSS	26	18.77			17.42			36.23			

* Significant at 5%

Appendix XI: Effect of aluminium and varieties on test weight

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	83.55	41.78	7.70*	105.07	52.54	12.42*	4	188.62	47.16*	3.55
Variety (V)	2	20.69	10.34	1.91*	21.60	10.80	2.55	4	42.29	10.57*	3.55
Al x V	4	7.31	1.83	0.34	1.76	0.44	0.10	8	9.06	1.13	2.93
ERR	18	97.66	5.43		76.14	4.23		36	173.79	4.83	
TSS	26	209.20			204.57			53	415.68		

* Significant at 5%

Appendix XII: Effect of aluminium and varieties on seed yield (g pot^{-1})

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	491.97	245.98	333.43*	372.22	186.11	685.89*	864.19	216.05	428.20*	3.55
Variety (V)	2	31.21	15.61	21.15*	40.31	20.15	74.28*	71.52	17.88	35.44*	3.55
Al x V	4	5.45	1.36	1.85	3.75	0.94	3.45*	9.20	1.15	2.28	2.93
ERR	18	13.28	0.74		4.88	0.27		18.16	0.50		
TSS	26	541.91			421.16			963.08			

* Significant at 5%

Appendix XIII: Effect of aluminium and varieties on stover yield (g pot^{-1})

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	1606.44	803.22	1840.43*	1193.12	596.56	1115.36*	2799.56	699.89	1441.16*	3.55
Variety (V)	2	56.79	28.40	65.06*	56.28	28.14	52.61*	113.07	28.27	58.21*	3.55
Al x V	4	5.35	1.34	3.07*	0.17	0.04	0.08	5.53	0.69	1.42*	2.93
ERR	18	7.86	0.44		9.63	0.53		17.48	0.49		
TSS	26	1676.44			1259.20			2942.84			

* Significant at 5%

Appendix XIV: Effect of aluminium and on root length (cm)

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	212.45	106.23	171.04*	201.76	100.88	673.54*	414.21	103.55	268.68*	3.55
Variety (V)	2	17.27	8.63	13.90*	4.53	2.27	15.13*	21.80	5.45	14.14*	3.55
Al x V	4	7.45	1.86	3.00*	1.93	0.48	3.22*	9.38	1.17	3.04*	2.93
ERR	18	11.18	0.62		2.70	0.15		13.87	0.39		
TSS	26	248.35			210.91			460.62			

* Significant at 5%

Appendix XV: Effect of aluminium and varieties on root mass (g)

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	42.29	21.15	103.57*	42.62	21.31	92.34*	84.91	21.23	97.61*	3.55
Variety (V)	2	0.77	0.38	1.88	0.44	0.22	0.95	1.21	0.30	1.39	3.55
Al x V	4	0.23	0.06	0.28	0.23	0.06	0.25	0.45	0.06	0.26	2.93
ERR	18	3.68	0.20		4.15	0.23		7.83	0.22		
TSS	26	46.96			47.44			94.44			

* Significant at 5%

Appendix XVI: Effect of aluminium and varieties on available nitrogen of post harvest soil

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	1688.31	844.16	560.28*	1746.10	873.05	27.25*	3434.41	858.60	51.19*	3.55
Variety (V)	2	510.52	255.26	169.42*	423.27	211.63	6.61*	933.79	233.45	13.92*	3.55
Al x V	4	18.38	4.60	3.05*	17.07	4.27	0.13	35.45	4.43	0.26	2.93
ERR	18	27.12	1.51		576.74	32.04		603.86	16.77		
TSS	26	2244.33			2763.17			5195.51			

* Significant at 5%

Appendix XVII: Effect of aluminium and varieties on available phosphorus of post harvest soil

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	75.02	37.51	122.95*	68.45	34.22	7.39*	143.46	35.87	14.54*	3.55
Variety (V)	2	3.96	1.98	6.49*	5.50	2.75	0.59	9.46	2.36	0.96	3.55
Al x V	4	16.69	4.17	13.67*	1.34	0.33	0.07	18.02	2.25	0.91	2.93
ERR	18	5.49	0.31		83.33	4.63		88.82	2.47		
TSS	26	101.15			158.62			287.92			

* Significant at 5%

Appendix XVIII: Effect of aluminium and varieties on available potassium of post harvest soil

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	1490.91	745.45	1009.76*	1490.91	745.45	1009.76*	127.85	127.85	53.54*	3.55
Variety (V)	2	126.02	63.01	85.35*	126.02	63.01	85.35*	2918.88	729.72	46.09*	3.55
Al x V	4	14.64	3.66	4.96*	14.64	3.66	4.96*	132.18	33.05	2.09	2.93
ERR	18	13.29	0.74		13.29	0.74		19.10	2.39	0.15	
TSS	26	1644.85			1644.85			570.03	15.83		

* Significant at 5%

Appendix XIX: Effect of aluminium and varieties on available sulphur of post harvest soil

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	204.91	102.45	15.36*	185.23	92.62	4.77*	390.14	97.54	7.48*	3.55
Variety (V)	2	1.96	0.98	0.15	0.81	0.41	0.02	2.77	0.69	0.05	3.55
Al x V	4	1.18	0.29	0.04	3.17	0.79	0.04	4.35	0.54	0.04	2.93
ERR	18	120.07	6.67		349.58	19.42		469.65	13.05		
TSS	26	328.11			538.80			913.82			

* Significant at 5%

Appendix XX: Effect of aluminium and varieties on exchangeable calcium of post harvest soil

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	3.61	1.80	13.59*	3.36	1.68	19.18*	6.96	1.74	15.81*	3.55
Variety (V)	2	0.04	0.02	0.14	0.04	0.02	0.24	0.08	0.02	0.18	3.55
Al x V	4	0.11	0.03	0.22	0.09	0.02	0.25	0.20	0.03	0.23	2.93
ERR	18	2.39	0.13		1.57	0.09		3.96	0.11		
TSS	26	6.15			5.06			11.26			

* Significant at 5%

Appendix XXI: Effect of aluminium and varieties on exchangeable aluminium of post harvest soil

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	10.07	5.04	19.68*	8.76	4.38	4.05*	18.83	4.71	7.03*	3.55
Variety (V)	2	0.45	0.22	0.88	0.77	0.39	0.36	1.22	0.31	0.46	3.55
Al x V	4	0.03	0.01	0.03	0.31	0.08	0.07	0.34	0.04	0.06	2.93
ERR	18	4.61	0.26		19.48	1.08		24.09	0.67		
TSS	26	15.15			29.32			49.91			

* Significant at 5%

Appendix XXII: Effect of aluminium and varieties on total potential acidity

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	73.24	36.62	51.59*	74.42	37.21	51.70*	147.66	36.92	51.64*	3.55
Variety (V)	2	0.26	0.13	0.18	0.17	0.09	0.12	0.43	0.11	0.15	3.55
Al x V	4	0.04	0.01	0.01	0.04	0.01	0.02	0.08	0.01	0.01	2.93
ERR	18	12.78	0.71		12.96	0.72		25.73	0.71		
TSS	26	86.32			87.59			173.96			

* Significant at 5%

Appendix XXIII: Effect of aluminium and varieties on nitrogen content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	42.29	21.15	103.57*	0.65	0.32	15.62*	1.47	0.37	16.94*	3.55
Variety (V)	2	0.77	0.38	1.88	0.06	0.03	1.45	0.13	0.03	1.46	3.55
Al x V	4	0.23	0.06	0.28	0.01	0.00	0.13	0.04	0.00	0.22	2.93
ERR	18	3.68	0.20		0.37	0.02		0.78	0.02		
TSS	26	46.96			1.09			2.45			

* Significant at 5%

Appendix XXIV: Effect of aluminium and varieties on phosphorus content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.07	0.04	52.35*	0.07	0.04	70.15*	0.15	0.04	60.16*	3.55
Variety (V)	2	0.00	0.00	2.41	0.00	0.00	1.58	0.00	0.00	2.05	3.55
Al x V	4	0.00	0.00	0.20	0.00	0.00	0.32	0.00	0.00	0.26	2.93
ERR	18	0.01	0.00		0.01	0.00		0.02	0.00		
TSS	26	0.09			0.09			0.18			

* Significant at 5%

Appendix XXV: Effect of aluminium and varieties on potassium content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.03	0.02	23.74*	0.04	0.02	42.72*	0.07	0.02	31.42*	3.55
Variety (V)	2	0.00	0.00	2.04	0.00	0.00	1.41	0.00	0.00	1.79	3.55
Al x V	4	0.00	0.00	0.09	0.00	0.00	0.47	0.00	0.00	0.24	2.93
ERR	18	0.01	0.00		0.01	0.00		0.02	0.00		
TSS	26	0.05			0.05			0.10			

* Significant at 5%

Appendix XXVI: Effect of aluminium and varieties on sulphur content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.15	0.08	249.12*	0.12	0.06	14.15*	0.27	0.07	29.83*	3.55
Variety (V)	2	0.01	0.01	18.60*	0.01	0.00	0.96	0.02	0.00	2.14	3.55
Al x V	4	0.00	0.00	2.63	0.01	0.00	0.47	0.01	0.00	0.61	2.93
ERR	18	0.01	0.00		0.08	0.00		0.08	0.00		
TSS	26	0.17			0.21			0.39			

* Significant at 5%

Appendix XXVII: Effect of aluminium and varieties on calcium content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.09	0.04	235.61*	0.08	0.04	63.10*	0.17	0.04	102.45*	3.55
Variety (V)	2	0.00	0.00	2.61	0.00	0.00	0.74	0.00	0.00	1.17	3.55
Al x V	4	0.00	0.00	0.52	0.00	0.00	1.10	0.00	0.00	0.97	2.93
ERR	18	0.00	0.00		0.01	0.00		0.01	0.00		
TSS	26	0.09			0.10			0.19			

* Significant at 5%

Appendix XXVIII: Effect of aluminium and varieties on aluminium content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	1053902.93	526951.47	116503.90*	1053267.96	526633.98	90695.64*	2107170.90	526792.72	101996.29*	3.55
Variety (V)	2	31.05	15.53	3.43	33.40	16.70	2.88	64.45	16.11	3.12	3.55
Al x V	4	15.09	3.77	0.83	1.32	0.33	0.06	16.41	2.05	0.40	2.93
ERR	18	81.41	4.52		104.52	5.81		185.93	5.16		
TSS	26	1054030.49			1053407.20			2107438.39			

* Significant at 5%

Appendix XXIX: Effect of aluminium and varieties on protein content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	32.07	16.04	18.21*	29.99	14.99	18.75*	62.06	15.52	18.47*	3.55
Variety (V)	2	2.52	1.26	1.43	1.77	0.88	1.10	4.28	1.07	1.27	3.55
Al x V	4	1.06	0.27	0.30	0.30	0.07	0.09	1.36	0.17	0.20	2.93
ERR	18	15.85	0.88		14.39	0.80		30.24	0.84		
TSS	26	51.50			46.44			99.16			

* Significant at 5%

Appendix XXX: Effect of aluminium and varieties on protein yield in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	27.14	13.57	283.63*	21.31	10.66	467.80*	48.46	12.11	343.03*	3.55
Variety (V)	2	1.10	0.55	11.46*	1.67	0.84	36.76*	2.77	0.69	19.62*	3.55
Al x V	4	0.33	0.08	1.71	0.13	0.03	1.48	0.46	0.06	1.64	2.93
ERR	18	0.86	0.05		0.41	0.02		1.27	0.04		
TSS	26	29.43			23.53			52.97			

* Significant at 5%

Appendix XXXI: Effect of aluminium and varieties on nitrogen content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.23	0.12	60.68*	0.24	0.12	119.68*	0.47	0.12	80.92*	3.55
Variety (V)	2	0.02	0.01	4.77*	0.01	0.00	4.48*	0.03	0.01	4.67*	3.55
Al x V	4	0.00	0.00	0.65	0.00	0.00	1.19	0.01	0.00	0.83	2.93
ERR	18	0.03	0.00		0.02	0.00		0.05	0.00		
TSS	26	0.29			0.27			0.56			

* Significant at 5%

Appendix XXXII: Effect of aluminium and varieties on phosphorus content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.04	0.02	116.41*	0.03	0.02	24.63*	0.07	0.02	42.71*	3.55
Variety (V)	2	0.01	0.00	17.22*	0.00	0.00	1.46	0.01	0.00	4.56*	3.55
Al x V	4	0.00	0.00	5.58*	0.00	0.00	0.21	0.00	0.00	1.27	2.93
ERR	18	0.00	0.00		0.01	0.00		0.01	0.00		
TSS	26	0.05			0.04			0.09			

* Significant at 5%

Appendix XXXIII: Effect of aluminium and varieties on potassium content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.06	0.03	201.04*	0.05	0.03	115.61*	0.12	0.03	150.22*	3.55
Variety (V)	2	0.00	0.00	11.85*	0.00	0.00	8.69*	0.01	0.00	9.97*	3.55
Al x V	4	0.00	0.00	1.67	0.00	0.00	0.67	0.00	0.00	1.08	2.93
ERR	18	0.00	0.00		0.00	0.00		0.01	0.00		
TSS	26	0.07			0.06			0.14			

* Significant at 5%

Appendix XXXIV: Effect of aluminium and varieties on sulphur content in in stover french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.02	0.01	16.12*	0.03	0.02	47.81*	0.05	0.01	27.02*	3.55
Variety (V)	2	0.00	0.00	2.30	0.00	0.00	1.72	0.00	0.00	2.10	3.55
Al x V	4	0.00	0.00	0.05	0.00	0.00	0.32	0.00	0.00	0.14	2.93
ERR	18	0.01	0.00		0.01	0.00		0.02	0.00		
TSS	26	0.03			0.04			0.07			

* Significant at 5%

Appendix XXXV: Effect of aluminium and varieties on calcium content in in stover french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.29	0.14	102.85*	0.29	0.15	266.30*	0.58	0.15	148.96*	3.55
Variety (V)	2	0.00	0.00	1.72	0.00	0.00	2.70	0.01	0.00	2.00	3.55
Al x V	4	0.00	0.00	0.07	0.00	0.00	0.35	0.00	0.00	0.15	2.93
ERR	18	0.03	0.00		0.01	0.00		0.04	0.00		
TSS	26	0.32			0.31			0.63			

* Significant at 5%

Appendix XXXVI: Effect of aluminium and varieties on aluminiul content in stover french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	2396530.80	1198265.40	55725.96*	2388981.60	1194490.80	59375.87*	4785512.39	1196378.10	57490.17*	3.55
Variety (V)	2	34.74	17.37	0.81	31.76	15.88	0.79	66.50	16.63	0.80	3.55
Al x V	4	1.76	0.44	0.02	0.85	0.21	0.01	2.61	0.33	0.02	2.93
ERR	18	387.05	21.50		362.11	20.12		749.16	20.81		
TSS	26	2396954.35			2389376.32			4786330.69			

* Significant at 5%

Appendix XXXVII: Effect of aluminium and varieties on aluminium content in stover root of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	374612562.65	187306281.32	164316.04*	374620965.31	187310482.65	164316.04*	749233527.96	187308381.99	164649.61*	3.55
Variety (V)	2	43.64	21.82	0.02	43.64	21.82	0.02	80.89	20.22	0.02	3.55
Al x V	4	1.60	0.40	0.00	1.60	0.40	0.00	5.13	0.64	0.00	2.93
ERR	18	20518.47	1139.91		20518.47	1139.91		40954.25	1137.62		
TSS	26	374633126.36			20435.79			749274597.93			

* Significant at 5%

Appendix XXXVIII: Effect of aluminium and varieties on nitrogen uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	694882.83	347441.42	283.63*	545661.55	272830.78	467.80*	1240544.39	310136.10	343.03*	3.55
Variety (V)	2	28069.63	14034.82	11.46*	42874.32	21437.16	36.76*	70943.95	17735.99	19.62*	3.55
Al x V	4	8384.04	2096.01	1.71	3454.79	863.70	1.48	11838.83	1479.85	1.64	2.93
ERR	18	22049.47	1224.97		10497.96	583.22		32547.43	904.10		
TSS	26	753385.98			602488.62			1356146.96			

* Significant at 5%

Appendix XXXIX: Effect of aluminium and varieties on phosphorus uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	19947.14	9973.57	277.12*	16669.23	8334.61	581.54*	36616.37	9154.09	363.82*	3.55
Variety (V)	2	735.05	367.53	10.21*	1016.84	508.42	35.47*	1751.89	437.97	17.41*	3.55
Al x V	4	164.10	41.02	1.14	145.13	36.28	2.53	309.23	38.65	1.54	2.93
ERR	18	647.83	35.99		257.98	14.33		905.80	25.16		
TSS	26	21494.11			18089.18			39583.91			

* Significant at 5%

Appendix XL: Effect of aluminium and varieties on potassium uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	40668.38	20334.19	249.62*	32653.39	16326.69	544.63*	73321.76	18330.44	328.98*	3.55
Variety (V)	2	1687.36	843.68	10.36*	2421.15	1210.58	40.38*	4108.52	1027.13	18.43*	3.55
Al x V	4	377.70	94.43	1.16	247.52	61.88	2.06	625.22	78.15	1.40	2.93
ERR	18	1466.31	81.46		539.59	29.98		2005.90	55.72		
TSS	26	44199.75			35861.65			80064.10			

* Significant at 5%

Appendix XLI: Effect of aluminium and varieties on sulphur uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	9245.67	4622.83	318.68*	8803.70	4401.85	327.55*	18049.37	4512.34	322.94*	3.55
Variety (V)	2	904.40	452.20	31.17*	604.84	302.42	22.50*	1509.25	377.31	27.00*	3.55
Al x V	4	843.33	210.83	14.53*	84.93	21.23	1.58	928.26	116.03	8.30*	2.93
ERR	18	261.11	14.51		241.90	13.44		503.01	13.97		
TSS	26	11254.52			9735.37			21042.21			

* Significant at 5%

Appendix XLII: Effect of aluminium and Varieties on calcium uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	6152.59	3076.30	263.40*	5455.82	2727.91	1425.74*	11608.41	2902.10	427.02*	3.55
Variety (V)	2	98.34	49.17	4.21*	114.47	57.24	29.91*	212.82	53.20	7.83*	3.55
Al x V	4	30.74	7.69	0.66	27.85	6.96	3.64*	58.59	7.32	1.08	2.93
ERR	18	210.22	11.68		34.44	1.91		244.66	6.80		
TSS	26	6491.90			5632.59			12124.92			

* Significant at 5%

Appendix XLIII: Effect of aluminium and varieties on alumninium uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	27728189.97	13864094.98	180.18*	38997455.98	19498727.99	253.84*	66725645.95	16681411.49	216.98*	3.55
Variety (V)	2	5047441.43	2523720.72	32.80*	7566502.29	3783251.15	49.25*	12613943.73	3153485.93	41.02*	3.55
Al x V	4	1497429.25	374357.31	4.87	1811654.07	452913.52	5.90*	3309083.32	413635.42	5.38*	2.93
ERR	18	1385041.29	76946.74		1382675.80	76815.32		2767717.09	76881.03		
TSS	26	35658101.94			49758288.15			85567754.88			

* Significant at 5%

Appendix XLIV: Effect of aluminium and varieties on nitrogen uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	320255.54	160127.77	1653.47*	258916.78	129458.39	766.41*	579172.32	144793.08	1089.66*	3.55
Variety (V)	2	6086.51	3043.26	31.42*	6365.51	3182.75	18.84*	12452.02	3113.01	23.43*	3.55
Al x V	4	724.69	181.17	1.87	199.73	49.93	0.30	924.42	115.55	0.87	2.93
ERR	18	1743.18	96.84		3040.46	168.91		4783.65	132.88		
TSS	26	328809.92			268522.49			598663.58			

* Significant at 5%

Appendix XLV: Effect of aluminium and varieties on phosphorus uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	12472.92	6236.46	291.08*	11596.65	5798.32	274.81*	24069.56	6017.39	283.00*	3.55
Variety (V)	2	695.75	347.87	16.24*	250.42	125.21	5.93*	946.17	236.54	11.12*	3.55
Al x V	4	131.31	32.83	1.53	54.08	13.52	0.64	185.38	23.17	1.09	2.93
ERR	18	385.66	21.43		379.80	21.10		765.45	21.26		
TSS	26	13685.63			12280.93			25993.38			

* Significant at 5%

Appendix XLVI: Effect of aluminium and varieties on potassium uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	0.29	0.14	102.85*	0.29	0.15	266.30*	754216.25	188554.06	1420.47*	3.55
Variety (V)	2	0.00	0.00	1.72	0.00	0.00	2.70	18249.10	4562.27	34.37*	3.55
Al x V	4	0.00	0.00	0.07	0.00	0.00	0.35	1371.74	171.47	1.29	2.93
ERR	18	0.03	0.00		0.01	0.00		4778.66	132.74		
TSS	26	0.32			0.31			779509.80			

* Significant at 5%

Appendix XLVII: Effect of aluminium and varieties on sulphur uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	5923.64	2961.82	80.54*	5566.95	2783.48	102.29*	11490.60	2872.65	89.79*	3.55
Variety (V)	2	217.06	108.53	2.95	82.73	41.37	1.52	299.79	74.95	2.34	3.55
Al x V	4	51.96	12.99	0.35	28.38	7.09	0.26	80.34	10.04	0.31	2.93
ERR	18	661.95	36.77		489.80	27.21		1151.75	31.99		
TSS	26	6854.62			6167.87			13076.34			

* Significant at 5%

Appendix XLVIII: Effect of aluminium and varieties on calcium uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	139146.09	69573.05	283.83*	121275.74	60637.87	703.30*	260421.83	65105.46	392.98*	3.55
Variety (V)	2	2451.41	1225.70	5.00*	2177.93	1088.96	12.63*	4629.33	1157.33	6.99*	3.55
Al x V	4	815.94	203.99	0.83	54.26	13.56	0.16	870.20	108.77	0.66	2.93
ERR	18	4412.26	245.13		1551.95	86.22		5964.21	165.67		
TSS	26	146825.70			125059.87			272136.70			

* Significant at 5%

Appendix XLIX: Effect of aluminium and varieties on Al uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			FTABLE
		SS	MSS	FCAL	SS	MSS	FCAL	SS	MSS	FCAL	
Aluminium (Al)	2	51906279.08	25953139.54	91.90*	103122.44	51561.22	0.09	52009401.52	13002350.38	30.69*	3.55
Variety (V)	2	72667835.61	36333917.81	128.65*	62418752.43	31209376.22	55.26*	135086588.05	33771647.01	79.72*	3.55
Al x V	4	20046927.23	5011731.81	17.75*	5328429.16	1332107.29	2.36	25375356.39	3171919.55	7.49*	2.93
ERR	18	5083463.27	282414.63		10166705.09	564816.95		15250168.36	423615.79		
TSS	26	149704505.19			78017009.13			241734802.29			

* Significant at 5%

Appendix L: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on days to germination

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	2.00	2.00	5.33*	3.13	3.13	8.65*	2.53	2.53	7.15*	4.04
P levels	3	1.17	0.39	1.04*	0.71	0.24	0.65	0.90	0.30	0.85	2.80
S levels	2	0.53	0.26	0.70	0.86	0.43	1.19*	0.65	0.32	0.91	3.19
Al x P	3	1.44	0.48	1.28*	1.38	0.46	1.27*	1.29	0.43	1.21*	2.80
P x S	6	1.58	0.26	0.70	1.25	0.21	0.58	1.22	0.20	0.57	2.29
Al x S	2	1.08	0.54	1.44*	1.08	0.54	1.50*	1.02	0.51	1.44*	3.19
Al x P x S	6	1.47	0.25	0.65	1.92	0.32	0.88	1.62	0.27	0.76	2.29
Error	48	18.00	0.38		17.33	0.36		17.00	0.35		
TSS	71	27.28	0.38		27.65	0.39		26.22	0.37		

* Significant at 5%

Appendix LI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on plant height of french bean at 30 DAS

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	374.10	374.10	64.00*	487.17	487.17	2492.66*	428.77	428.77	284.31*	4.04
P levels	3	206.81	68.94	11.79*	33.77	11.26	57.60*	91.06	30.35	20.13*	2.80
S levels	2	4.95	2.47	0.42	1.43	0.72	3.66*	2.56	1.28	0.85	3.19
Al x P	3	66.86	22.29	3.81*	16.69	5.56	28.47*	33.25	11.08	7.35*	2.80
P x S	6	33.84	5.64	0.96	3.03	0.51	2.59*	8.68	1.45	0.96	2.29
Al x S	2	2.81	1.40	0.24	1.67	0.83	4.26*	2.17	1.08	0.72	3.19
Al x P x S	6	4.72	0.79	0.13	3.59	0.60	3.06*	2.52	0.42	0.28	2.29
Error	48	280.58	5.85		9.38	0.20		72.39	1.51		
TSS	71	974.68	13.73		556.73	7.84		641.40	9.03		

* Significant at 5%

Appendix LII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on plant height of french bean at 60 DAS

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	379.78	379.78	85.02*	528.67	528.67	17.62*	451.15	451.15	63.88*	4.04
P levels	3	216.49	72.16	16.15*	380.85	126.95	4.23*	291.11	97.04	13.74*	2.80
S levels	2	40.08	20.04	4.49*	217.11	108.56	3.62*	110.93	55.47	7.85*	3.19
Al x P	3	1.81	0.60	0.14	4.26	1.42	0.05	1.92	0.64	0.09	2.80
P x S	6	11.71	1.95	0.44	9.66	1.61	0.05	5.14	0.86	0.12	2.29
Al x S	2	2.80	1.40	0.31	0.23	0.11	0.00	0.36	0.18	0.03	3.19
Al x P x S	6	3.82	0.64	0.14	1.06	0.18	0.01	1.16	0.19	0.03	2.29
Error	48	214.41	4.47		1440.51	30.01		339.01	7.06		
TSS	71	870.90	12.27		2582.34	36.37		1200.78	16.91		

* Significant at 5%

Appendix LIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on plant height of french bean at harvest

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1079.81	1079.81	29.66*	370.11	370.11	76.83*	678.57	678.57	80.19*	4.04
P levels	3	477.26	159.09	4.37*	375.82	125.27	26.00*	422.45	140.82	16.64*	2.80
S levels	2	293.69	146.84	4.03*	137.87	68.93	14.31*	208.42	104.21	12.32*	3.19
Al x P	3	4.54	1.51	0.04	12.49	4.16	0.86	4.45	1.48	0.18	2.80
P x S	6	1.07	0.18	0.00	0.59	0.10	0.02	0.69	0.12	0.01	2.29
Al x S	2	0.01	0.01	0.00	8.79	4.40	0.91	2.28	1.14	0.13	3.19
Al x P x S	6	2.56	0.43	0.01	9.26	1.54	0.32	4.23	0.71	0.08	2.29
Error	48	1747.42	36.40		231.23	4.82		406.17	8.46		
TSS	71	3606.36	50.79		370.11	370.11		1727.26	24.33		

* Significant at 5%

Appendix LIV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on number of branch of french bean at 30 DAS

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	5.01	5.01	10.62*	15.13	15.13	26.56*	9.39	9.39	21.81*	4.04
P levels	3	16.15	5.38	11.40*	15.82	5.27	9.26*	15.58	5.19	12.06*	2.80
S levels	2	0.53	0.26	0.56	1.78	0.89	1.56	1.02	0.51	1.19	3.19
Al x P	3	1.15	0.38	0.81	4.71	1.57	2.76	2.03	0.68	1.57	2.80
P x S	6	0.81	0.13	0.28	0.22	0.04	0.07	0.40	0.07	0.15	2.29
Al x S	2	0.03	0.01	0.03	0.00	0.00	0.00	0.01	0.00	0.01	3.19
Al x P x S	6	0.64	0.11	0.23	2.00	0.33	0.59	0.91	0.15	0.35	2.29
Error	48	22.67	0.47		27.33	0.57		20.67	0.43		
TSS	71	46.99	0.66		66.99	0.94		50.00	0.70		

* Significant at 5%

Appendix LV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on number of branches of french bean at 60 DAS

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	26.89	26.89	28.47*	32.67	32.67	32.78*	32.67	32.67	32.78*	4.04
P levels	3	6.50	2.17	2.29	6.65	2.22	2.22	6.65	2.22	2.22	2.80
S levels	2	0.58	0.29	0.31	0.36	0.18	0.18	0.36	0.18	0.18	3.19
Al x P	3	2.78	0.93	0.98	4.79	1.60	1.60	4.79	1.60	1.60	2.80
P x S	6	0.42	0.07	0.07	0.36	0.06	0.06	0.36	0.06	0.06	2.29
Al x S	2	0.36	0.18	0.19	0.69	0.35	0.35	0.69	0.35	0.35	3.19
Al x P x S	6	0.64	0.11	0.11	0.64	0.11	0.11	0.64	0.11	0.11	2.29
Error	48	45.33	0.94		47.83	1.00		47.83	1.00		
TSS	71	83.50	1.18		94.00	1.32		94.00	1.32		

* Significant at 5%

Appendix LVI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on number of branches of french bean at harvest

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	18.00	18.00	43.20*	13.35	13.35	15.50*	15.59	15.59	29.73*	4.04
P levels	3	6.28	2.09	5.02*	7.93	2.64	3.07*	7.07	2.36	4.49*	2.80
S levels	2	0.58	0.29	0.70	0.03	0.01	0.02	0.22	0.11	0.21	3.19
Al x P	3	0.33	0.11	0.27	2.49	0.83	0.96	1.12	0.37	0.71	2.80
P x S	6	1.31	0.22	0.52	0.53	0.09	0.10	0.42	0.07	0.13	2.29
Al x S	2	0.25	0.13	0.30	0.19	0.10	0.11	0.01	0.00	0.01	3.19
Al x P x S	6	0.75	0.12	0.30	2.14	0.36	0.41	0.58	0.10	0.18	2.29
Error	48	20.00	0.42		41.33	0.86		25.17	0.52		
TSS	71	47.50	0.67		67.99	0.96		50.16	0.71		

* Significant at 5%

Appendix LVII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on pods per plant of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	492.09	492.09	458.90*	320.59	320.59	288.52*	401.77	401.77	610.18*	4.04
P levels	3	21.57	7.19	6.71*	18.48	6.16	5.54*	10.70	3.57	5.42*	2.80
S levels	2	8.27	4.14	3.86*	6.36	3.18	2.86	3.05	1.53	2.32	3.19
Al x P	3	5.52	1.84	1.72	3.14	1.05	0.94	2.89	0.96	1.46	2.80
P x S	6	12.40	2.07	1.93	4.62	0.77	0.69	5.25	0.88	1.33	2.29
Al x S	2	1.85	0.93	0.86	1.28	0.64	0.58	0.84	0.42	0.64	3.19
Al x P x S	6	10.20	1.70	1.59	1.42	0.24	0.21	4.32	0.72	1.09	2.29
Error	48	51.47	1.07		53.34	1.11		31.61	0.66		
TSS	71	603.39	8.50		409.23	5.76		460.44	6.49		

* Significant at 5%

Appendix LVIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on pod length of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	142.86	142.86	121.38*	198.80	198.80	297.49*	169.68	169.68	306.67*	4.04
P levels	3	42.51	14.17	12.04*	17.45	5.82	8.70*	27.19	9.06	16.38*	2.80
S levels	2	4.19	2.10	1.78	1.90	0.95	1.42	2.85	1.43	2.58	3.19
Al x P	3	1.77	0.59	0.50	13.56	4.52	6.76*	6.11	2.04	3.68*	2.80
P x S	6	4.10	0.68	0.58	3.86	0.64	0.96	3.65	0.61	1.10	2.29
Al x S	2	0.15	0.07	0.06	0.27	0.13	0.20	0.01	0.00	0.00	3.19
Al x P x S	6	1.55	0.26	0.22	0.59	0.10	0.15	0.51	0.08	0.15	2.29
Error	48	56.50	1.18		32.08	0.67		26.56	0.55		
TSS	71	253.63	3.57		268.50	3.78		236.54	3.33		

* Significant at 5%

Appendix LIX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on seed per pod of french bean.

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	20.27	20.27	95.63*	17.29	17.29	128.59*	18.75	18.75	124.51*	4.04
P levels	3	3.32	1.11	5.22*	2.04	0.68	5.07*	2.61	0.87	5.79*	2.80
S levels	2	1.67	0.84	3.94*	0.79	0.40	2.94	1.19	0.59	3.95*	3.19
Al x P	3	0.18	0.06	0.29	0.18	0.06	0.45	0.02	0.01	0.04	2.80
P x S	6	0.15	0.02	0.12	0.25	0.04	0.31	0.16	0.03	0.18	2.29
Al x S	2	0.50	0.25	1.19	0.02	0.01	0.06	0.17	0.08	0.56	3.19
Al x P x S	6	0.48	0.08	0.38	0.01	0.00	0.02	0.14	0.02	0.16	2.29
Error	48	10.17	0.21		6.45	0.13		7.23	0.15		
TSS	71	36.74	0.52		27.03	0.38		30.27	0.43		

* Significant at 5%

Appendix LX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on test weight of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	96.63	96.63	46.21*	84.39	84.39	42.62*	90.41	90.41	47.43*	4.04
P levels	3	21.70	7.23	3.46*	21.51	7.17	3.62*	21.45	7.15	3.75*	2.80
S levels	2	12.29	6.15	2.94	19.55	9.77	4.94*	15.19	7.59	3.98*	3.19
Al x P	3	6.39	2.13	1.02	5.51	1.84	0.93	5.92	1.97	1.04	2.80
P x S	6	2.76	0.46	0.22	1.81	0.30	0.15	1.81	0.30	0.16	2.29
Al x S	2	0.84	0.42	0.20	0.14	0.07	0.03	0.41	0.20	0.11	3.19
Al x P x S	6	1.49	0.25	0.12	0.29	0.05	0.02	0.57	0.10	0.05	2.29
Error	48	100.38	2.09		95.04	1.98		91.49	1.91		
TSS	71	242.47	3.42		228.23	3.21		227.24	3.20		

* Significant at 5%

Appendix LXI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on seed yield of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1820.77	1820.77	381.39*	1296.04	1296.04	346.69*	1547.28	1547.28	482.64*	4.04
P levels	3	139.93	46.64	9.77*	211.07	70.36	18.82*	160.27	53.42	16.66*	2.80
S levels	2	50.51	25.25	5.29*	72.83	36.41	9.74*	55.10	27.55	8.59*	3.19
Al x P	3	40.46	13.49	2.83*	45.82	15.27	4.09*	32.76	10.92	3.41*	2.80
P x S	6	39.92	6.65	1.39	19.20	3.20	0.86	21.00	3.50	1.09	2.29
Al x S	2	10.07	5.03	1.05	8.96	4.48	1.20	9.51	4.75	1.48	3.19
Al x P x S	6	25.03	4.17	0.87	3.25	0.54	0.14	10.14	1.69	0.53	2.29
Error	48	229.15	4.77		179.44	3.74		153.88	3.21		
TSS	71	2355.84	33.18		1836.61	25.87		1989.94	28.03		

* Significant at 5%

Appendix LXII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on stover yield of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1273.44	1273.44	629.22*	975.86	975.86	277.14*	1119.71	1119.71	841.21*	4.04
P levels	3	179.73	59.91	29.60*	129.16	43.05	12.23*	153.15	51.05	38.35*	2.80
S levels	2	12.05	6.03	2.98	22.88	11.44	3.25*	16.91	8.46	6.35*	3.19
Al x P	3	17.74	5.91	2.92	1.88	0.63	0.18	5.88	1.96	1.47	2.80
P x S	6	1.94	0.32	0.16	7.92	1.32	0.37	2.08	0.35	0.26	2.29
Al x S	2	0.42	0.21	0.10	1.51	0.75	0.21	0.84	0.42	0.31	3.19
Al x P x S	6	5.47	0.91	0.45	2.21	0.37	0.10	1.56	0.26	0.20	2.29
Error	48	97.14	2.02		169.02	3.52		63.89	1.33		
TSS	71	1587.94	22.37		1310.44	18.46		1364.02	19.21		

* Significant at 5%

Appendix LXIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on nitrogen content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1.04	1.04	108.07*	1.01	1.01	54.23*	1.03	1.03	83.25*	4.03
P levels	3	0.16	0.05	5.53*	0.33	0.11	5.88*	0.22	0.07	6.04*	2.78
S levels	2	0.06	0.03	3.19*	0.13	0.07	3.60*	0.09	0.05	3.78*	3.18
Al x P	3	0.01	0.00	0.48	0.02	0.01	0.38	0.02	0.01	0.42	2.78
P x S	6	0.05	0.01	0.94	0.04	0.01	0.33	0.04	0.01	0.59	2.28
Al x S	2	0.00	0.00	0.25	0.01	0.01	0.35	0.00	0.00	0.11	3.18
Al x P x S	6	0.02	0.00	0.32	0.01	0.00	0.08	0.00	0.00	0.05	2.28
Error	52	0.50	0.01		0.97	0.02		0.64	0.01		
TSS	71	1.86	0.03		2.52	0.04		2.05	0.03		

* Significant at 5%

Appendix LXIV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on phosphorus content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.04	0.04	25.58*	0.03	0.03	16.08*	0.04	0.04	46.98*	4.03
P levels	3	0.03	0.01	5.59*	0.01	0.00	2.01	0.02	0.01	8.01*	2.78
S levels	2	0.00	0.00	1.20	0.00	0.00	0.46	0.00	0.00	1.72	3.18
Al x P	3	0.00	0.00	0.15	0.01	0.00	1.24	0.00	0.00	0.89	2.78
P x S	6	0.00	0.00	0.11	0.00	0.00	0.30	0.00	0.00	0.25	2.28
Al x S	2	0.01	0.00	1.74	0.00	0.00	0.05	0.00	0.00	1.24	3.18
Al x P x S	6	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.17	2.28
Error	52	0.09	0.00		0.11	0.00		0.04	0.00		
TSS	71	0.17	0.00		0.17	0.00		0.11	0.00		

* Significant at 5%

Appendix LXV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on potassium content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.08	0.08	86.67*	0.10	0.10	33.16*	0.09	0.09	85.08*	4.03
P levels	3	0.02	0.01	6.78*	0.01	0.00	1.33	0.01	0.00	4.67*	2.78
S levels	2	0.01	0.00	2.77	0.00	0.00	0.51	0.00	0.00	1.88	3.18
Al x P	3	0.00	0.00	1.44	0.00	0.00	0.03	0.00	0.00	0.21	2.78
P x S	6	0.00	0.00	0.27	0.00	0.00	0.05	0.00	0.00	0.12	2.28
Al x S	2	0.00	0.00	0.20	0.00	0.00	0.01	0.00	0.00	0.05	3.18
Al x P x S	6	0.00	0.00	0.48	0.00	0.00	0.05	0.00	0.00	0.22	2.28
Error	52	0.05	0.00		0.16	0.00		0.06	0.00		
TSS	71	0.16	0.00		0.29	0.00		0.17	0.00		

* Significant at 5%

Appendix LXVI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on calcium content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.28	0.28	204.85*	0.27	0.27	87.44*	0.27	0.27	208.67*	4.03
P levels	3	0.02	0.01	5.51*	0.02	0.01	1.95	0.02	0.01	4.57*	2.78
S levels	2	0.00	0.00	1.18	0.00	0.00	0.16	0.00	0.00	0.74	3.18
Al x P	3	0.00	0.00	0.30	0.01	0.00	0.65	0.00	0.00	0.40	2.78
P x S	6	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.04	2.28
Al x S	2	0.00	0.00	0.08	0.00	0.00	0.18	0.00	0.00	0.17	3.18
Al x P x S	6	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.08	2.28
Error	52	0.07	0.00		0.16	0.00		0.07	0.00		
TSS	71	0.38	0.01		0.45	0.01		0.36	0.01		

* Significant at 5%

Appendix LXVII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on sulphur content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.07	0.07	136.02*	0.11	0.11	59.56*	0.09	0.09	163.42*	4.03
P levels	3	0.03	0.01	15.88*	0.02	0.01	3.15*	0.02	0.01	12.74*	2.78
S levels	2	0.01	0.01	10.48*	0.02	0.01	6.81*	0.02	0.01	15.74*	3.18
Al x P	3	0.00	0.00	1.72	0.00	0.00	0.26	0.00	0.00	1.23	2.78
P x S	6	0.00	0.00	0.21	0.00	0.00	0.11	0.00	0.00	0.15	2.28
Al x S	2	0.00	0.00	0.71	0.00	0.00	0.10	0.00	0.00	0.47	3.18
Al x P x S	6	0.00	0.00	0.33	0.00	0.00	0.07	0.00	0.00	0.22	2.28
Error	52	0.03	0.00		0.10	0.00		0.03	0.00		
TSS	71	0.15	0.00		0.25	0.00		0.16	0.00		

* Significant at 5%

Appendix LXVIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on aluminium content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1379322.09	1379322.09	93183.88*	1326179.84	1326179.84	181964.55*	1352620.47	1352620.47	277993.22*	4.03
P levels	3	35.70	11.90	0.80	50.14	16.71	2.29	39.40	13.13	2.70	2.78
S levels	2	6.31	3.16	0.21	15.57	7.78	1.07	9.58	4.79	0.98	3.18
Al x P	3	38.98	12.99	0.88	19.18	6.39	0.88	21.62	7.21	1.48	2.78
P x S	6	9.75	1.63	0.11	6.75	1.13	0.15	3.03	0.51	0.10	2.28
Al x S	2	18.24	9.12	0.62	7.03	3.52	0.48	11.96	5.98	1.23	3.18
Al x P x S	6	2.59	0.43	0.03	13.85	2.31	0.32	3.25	0.54	0.11	2.28
Error	52	769.71	14.80		378.98	7.29		253.01	4.87		
TSS	71	1380203.37	19439.48		1326671.35	18685.51		1352962.33	19055.81		

* Significant at 5%

Appendix LXIX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on protein content in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	40.78	40.78	108.07*	39.38	39.38	54.23*	40.08	40.08	83.25*	4.03
P levels	3	6.27	2.09	5.53*	12.81	4.27	5.88*	8.72	2.91	6.04*	2.78
S levels	2	2.41	1.20	3.19*	5.22	2.61	3.60*	3.64	1.82	3.78*	3.18
Al x P	3	0.54	0.18	0.48	0.83	0.28	0.38	0.61	0.20	0.42	2.78
P x S	6	2.13	0.35	0.94	1.44	0.24	0.33	1.70	0.28	0.59	2.28
Al x S	2	0.19	0.09	0.25	0.50	0.25	0.35	0.11	0.05	0.11	3.18
Al x P x S	6	0.73	0.12	0.32	0.33	0.05	0.08	0.16	0.03	0.05	2.28
Error	52	19.62	0.38		37.76	0.73		25.03	0.48		
TSS	71	72.66	1.02		98.27	1.38		80.05	1.13		

* Significant at 5%

Appendix LXX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on protein yield in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	101.03	101.03	495.11*	78.86	78.86	366.39*	89.60	89.60	540.70*	4.03
P levels	3	8.14	2.71	13.29*	13.99	4.66	21.67*	10.43	3.48	20.99*	2.78
S levels	2	2.93	1.47	7.19*	5.00	2.50	11.61*	3.64	1.82	10.98*	3.18
Al x P	3	2.37	0.79	3.88*	3.19	1.06	4.95*	2.25	0.75	4.54*	2.78
P x S	6	2.12	0.35	1.73	1.11	0.19	0.86	1.22	0.20	1.23	2.28
Al x S	2	0.62	0.31	1.51	0.64	0.32	1.49	0.62	0.31	1.87	3.18
Al x P x S	6	1.30	0.22	1.06	0.20	0.03	0.16	0.55	0.09	0.56	2.28
Error	52	10.61	0.20		11.19	0.22		8.62	0.17		
TSS	71	129.11	1.82		114.18	1.61		116.94	1.65		

* Significant at 5%

Appendix LXXI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on nitrogen content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.23	0.23	281.85*	0.19	0.19	523.23*	0.21	0.21	836.52*	4.03
P levels	3	0.01	0.00	4.34*	0.01	0.00	8.32*	0.01	0.00	12.34*	2.78
S levels	2	0.01	0.00	3.20*	0.00	0.00	6.56*	0.01	0.00	9.95*	3.18
Al x P	3	0.00	0.00	0.82	0.00	0.00	3.59*	0.00	0.00	3.83*	2.78
P x S	6	0.00	0.00	0.59	0.00	0.00	1.20	0.00	0.00	1.69	2.28
Al x S	2	0.00	0.00	0.69	0.00	0.00	0.04	0.00	0.00	0.40	3.18
Al x P x S	6	0.00	0.00	0.30	0.00	0.00	0.61	0.00	0.00	0.44	2.28
Error	52	0.04	0.00		0.02	0.00		0.01	0.00		
TSS	71	0.30	0.00		0.23	0.00		0.25	0.00		

* Significant at 5%

Appendix LXXII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on phosphorus content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.18	0.18	642.98*	0.19	0.19	1666.70*	0.19	0.19	1666.62*	4.03
P levels	3	0.02	0.01	21.91*	0.02	0.01	61.93*	0.02	0.01	57.18*	2.78
S levels	2	0.00	0.00	2.72	0.00	0.00	3.14	0.00	0.00	4.84*	3.18
Al x P	3	0.00	0.00	0.57	0.00	0.00	1.65	0.00	0.00	1.27	2.78
P x S	6	0.00	0.00	0.86	0.00	0.00	2.15	0.00	0.00	2.05	2.28
Al x S	2	0.00	0.00	0.33	0.00	0.00	0.03	0.00	0.00	0.23	3.18
Al x P x S	6	0.00	0.00	0.45	0.00	0.00	0.92	0.00	0.00	0.83	2.28
Error	52	0.01	0.00		0.01	0.00		0.01	0.00		
TSS	71	0.22	0.00		0.22	0.00		0.21	0.00		

* Significant at 5%

Appendix LXXIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on potassium content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.04	0.04	18.97*	0.04	0.04	26.31*	0.04	0.04	25.26*	4.03
P levels	3	0.01	0.00	2.26	0.02	0.01	5.16*	0.02	0.01	3.88*	2.78
S levels	2	0.01	0.00	1.54	0.01	0.00	2.76	0.01	0.00	2.34	3.18
Al x P	3	0.00	0.00	0.11	0.00	0.00	0.08	0.00	0.00	0.10	2.78
P x S	6	0.00	0.00	0.14	0.00	0.00	0.22	0.00	0.00	0.19	2.28
Al x S	2	0.00	0.00	0.15	0.00	0.00	0.40	0.00	0.00	0.28	3.18
Al x P x S	6	0.00	0.00	0.25	0.00	0.00	0.37	0.00	0.00	0.33	2.28
Error	52	0.11	0.00		0.08	0.00		0.09	0.00		
TSS	71	0.18	0.00		0.17	0.00		0.16	0.00		

* Significant at 5%

Appendix LXXIV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on calcium content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1.48	1.48	3443.28*	1.74	1.74	4790.49*	1.61	1.61	7846.66*	4.03
P levels	3	0.02	0.01	15.38*	0.02	0.01	15.65*	0.02	0.01	29.62*	2.78
S levels	2	0.00	0.00	2.78	0.00	0.00	2.97	0.00	0.00	4.30*	3.18
Al x P	3	0.00	0.00	2.75	0.00	0.00	0.59	0.00	0.00	2.02	2.78
P x S	6	0.00	0.00	0.09	0.00	0.00	0.19	0.00	0.00	0.15	2.28
Al x S	2	0.00	0.00	3.88	0.00	0.00	0.69	0.00	0.00	3.86	3.18
Al x P x S	6	0.00	0.00	0.37	0.00	0.00	0.35	0.00	0.00	0.52	2.28
Error	52	0.02	0.00		0.02	0.00		0.01	0.00		
TSS	71	1.54	0.02		1.78	0.03		1.64	0.02		

* Significant at 5%

Appendix LXXV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on sulphur content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.03	0.03	74.25*	0.02	0.02	49.35*	0.02	0.02	100.07*	4.03
P levels	3	0.02	0.01	13.11*	0.02	0.01	21.72*	0.02	0.01	27.21*	2.78
S levels	2	0.01	0.01	15.31*	0.02	0.01	24.31*	0.01	0.01	31.09*	3.18
Al x P	3	0.00	0.00	0.34	0.00	0.00	0.41	0.00	0.00	0.41	2.78
P x S	6	0.00	0.00	0.39	0.00	0.00	0.22	0.00	0.00	0.24	2.28
Al x S	2	0.00	0.00	0.18	0.00	0.00	0.04	0.00	0.00	0.08	3.18
Al x P x S	6	0.00	0.00	0.26	0.00	0.00	0.41	0.00	0.00	0.23	2.28
Error	52	0.02	0.00		0.02	0.00		0.01	0.00		
TSS	71	0.08	0.00		0.07	0.00		0.07	0.00		

* Significant at 5%

Appendix LXXVI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on aluminium content in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1329841.30	1329841.30	433332.85*	1339297.97	1339297.97	555330.32*	1334565.45	1334565.45	850351.38*	4.03
P levels	3	21.35	7.12	2.32	10.01	3.34	1.38	15.12	5.04	3.21*	2.78
S levels	2	1.62	0.81	0.26	4.18	2.09	0.87	2.71	1.35	0.86	3.18
Al x P	3	2.01	0.67	0.22	2.64	0.88	0.36	0.18	0.06	0.04	2.78
P x S	6	1.09	0.18	0.06	2.43	0.41	0.17	1.20	0.20	0.13	2.28
Al x S	2	0.06	0.03	0.01	2.75	1.37	0.57	0.88	0.44	0.28	3.18
Al x P x S	6	2.14	0.36	0.12	4.52	0.75	0.31	1.73	0.29	0.18	2.28
Error	52	159.58	3.07		125.41	2.41		81.61	1.57		
TSS	71	1330029.15	18732.80		1339449.92	18865.49		1334668.88	18798.15		

* Significant at 5%

Appendix LXXVII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on nitrogen uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	2586306.35	2586306.35	457.02*	2018730.83	2018730.83	338.21*	2293740.85	2293740.85	499.10*	4.04
P levels	3	208312.65	69437.55	12.27*	358146.08	119382.03	20.00*	267068.46	89022.82	19.37*	2.80
S levels	2	75069.17	37534.59	6.63*	127904.76	63952.38	10.71*	93188.42	46594.21	10.14*	3.19
Al x P	3	60793.44	20264.48	3.58*	81768.94	27256.31	4.57*	57726.47	19242.16	4.19*	2.80
P x S	6	54166.26	9027.71	1.60	28479.25	4746.54	0.80	31305.51	5217.58	1.14	2.29
Al x S	2	15745.85	7872.92	1.39	16439.27	8219.63	1.38	15875.33	7937.66	1.73	3.19
Al x P x S	6	33301.59	5550.27	0.98	5142.56	857.09	0.14	14202.87	2367.15	0.52	2.29
Error	48	271634.35	5659.05		286509.57	5968.95		220594.48	4595.72		
TSS	71	3305329.67	46553.94		2923121.26	41170.72		2993702.39	42164.82		

* Significant at 5%

Appendix LXXVIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on phosphorus uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	53389.39	53389.39	329.30*	38241.05	38241.05	275.72*	45500.01	45500.01	437.38*	4.04
P levels	3	5393.36	1797.79	11.09*	6302.24	2100.75	15.15*	5678.05	1892.68	18.19*	2.80
S levels	2	1814.83	907.42	5.60*	2274.93	1137.47	8.20*	1987.31	993.66	9.55*	3.19
Al x P	3	1558.87	519.62	3.20*	671.28	223.76	1.61	887.03	295.68	2.84*	2.80
P x S	6	845.65	140.94	0.87	462.13	77.02	0.56	534.41	89.07	0.86	2.29
Al x S	2	993.44	496.72	3.06	444.41	222.20	1.60	687.97	343.98	3.31	3.19
Al x P x S	6	541.89	90.32	0.56	46.17	7.69	0.06	216.42	36.07	0.35	2.29
Error	48	7782.24	162.13		6657.49	138.70		4993.42	104.03		
TSS	71	72319.68	1018.59		55099.70	776.05		60484.63	851.90		

* Significant at 5%

Appendix LXXIX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on potassium uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	153474.85	153474.85	471.32*	122572.56	122572.56	335.96*	137589.92	137589.92	527.51*	4.04
P levels	3	12819.69	4273.23	13.12*	19497.38	6499.13	17.81*	15184.41	5061.47	19.41*	2.80
S levels	2	4894.06	2447.03	7.51*	5859.59	2929.80	8.03*	4938.05	2469.03	9.47*	3.19
Al x P	3	2752.43	917.48	2.82*	4378.83	1459.61	4.00*	2713.78	904.59	3.47*	2.80
P x S	6	2296.26	382.71	1.18	1035.08	172.51	0.47	1215.68	202.61	0.78	2.29
Al x S	2	945.16	472.58	1.45	730.64	365.32	1.00	834.40	417.20	1.60	3.19
Al x P x S	6	1656.64	276.11	0.85	273.13	45.52	0.12	711.90	118.65	0.45	2.29
Error	48	15630.25	325.63		17512.57	364.85		12519.81	260.83		
TSS	71	194469.34	2739.00		171859.79	2420.56		175707.95	2474.76		

* Significant at 5%

Appendix LXXX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on calcium uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	34705.85	34705.85	365.57*	31212.84	31212.84	355.46*	32936.19	32936.19	382.34*	4.04
P levels	3	2601.84	867.28	9.14*	3732.05	1244.02	14.17*	3055.67	1018.56	11.82*	2.80
S levels	2	621.15	310.58	3.27*	820.09	410.04	4.67*	699.42	349.71	4.06*	3.19
Al x P	3	818.59	272.86	2.87*	935.86	311.95	3.55*	810.38	270.13	3.14*	2.80
P x S	6	160.15	26.69	0.28	99.38	16.56	0.19	90.35	15.06	0.17	2.29
Al x S	2	127.69	63.85	0.67	212.44	106.22	1.21	166.62	83.31	0.97	3.19
Al x P x S	6	102.25	17.04	0.18	26.59	4.43	0.05	42.02	7.00	0.08	2.29
Error	48	4556.99	94.94		4214.86	87.81		4134.94	86.14		
TSS	71	43694.50	615.42		41254.11	581.04		41935.58	590.64		

*Significant at 5%

Appendix LXXXI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on sulphur uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	30446.34	30446.34	430.35*	31669.25	31669.25	193.65*	31054.78	31054.78	454.74*	4.04
P levels	3	3525.65	1175.22	16.61*	3757.85	1252.62	7.66*	3576.23	1192.08	17.46*	2.80
S levels	2	1249.71	624.85	8.83*	2763.24	1381.62	8.45*	1902.77	951.38	13.93*	3.19
Al x P	3	821.91	273.97	3.87*	1042.31	347.44	2.12	871.33	290.44	4.25*	2.80
P x S	6	271.40	45.23	0.64	224.71	37.45	0.23	191.68	31.95	0.47	2.29
Al x S	2	373.67	186.84	2.64	566.38	283.19	1.73	463.85	231.93	3.40	3.19
Al x P x S	6	340.24	56.71	0.80	84.79	14.13	0.09	149.17	24.86	0.36	2.29
Error	48	3395.87	70.75		7849.85	163.54		3277.95	68.29		
TSS	71	40424.79	569.36		47958.38	675.47		41487.76	584.33		

*Significant at 5%

Appendix LXXXII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on aluminium uptake in grains of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	62851742.65	62851742.65	118.90*	112215964.93	112215964.93	218.68*	85757904.95	85757904.95	216.58*	4.04
P levels	3	9068365.17	3022788.39	5.72*	15135148.71	5045049.57	9.83*	11156926.78	3718975.59	9.39*	2.80
S levels	2	4732279.16	2366139.58	4.48*	5882566.46	2941283.23	5.73*	4573739.80	2286869.90	5.78*	3.19
Al x P	3	292371.62	97457.21	0.18	739951.11	246650.37	0.48	39660.99	13220.33	0.03	2.80
P x S	6	3212861.13	535476.86	1.01	1962548.19	327091.36	0.64	1680166.83	280027.81	0.71	2.29
Al x S	2	1345175.68	672587.84	1.27	269530.58	134765.29	0.26	646715.55	323357.78	0.82	3.19
Al x P x S	6	1739532.64	289922.11	0.55	280309.16	46718.19	0.09	550248.07	91708.01	0.23	2.29
Error	48	25372432.97	528592.35		24631797.56	513162.45		19006349.19	395965.61		
TSS	71	108614761.04	1529785.37		161117816.70	2269265.02		123411712.15	1738193.13		

*Significant at 5%

Appendix LXXXIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on nitrogen uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	303397.13	303397.13	742.02*	253477.27	253477.27	542.49*	277876.70	277876.70	1113.71*	4.03
P levels	3	34922.16	11640.72	28.47*	25845.80	8615.27	18.44*	30124.86	10041.62	40.25*	2.78
S levels	2	944.19	472.10	1.15	5623.24	2811.62	6.02	2773.74	1386.87	5.56*	3.18
Al x P	3	1944.11	648.04	1.58	196.77	65.59	0.14	324.13	108.04	0.43	2.78
P x S	6	568.31	94.72	0.23	1998.43	333.07	0.71	903.41	150.57	0.60	2.28
Al x S	2	11.28	5.64	0.01	154.43	77.22	0.17	54.25	27.12	0.11	3.18
Al x P x S	6	759.21	126.54	0.31	338.52	56.42	0.12	324.12	54.02	0.22	2.28
Error	52	21261.84	408.88		24297.01	467.25		12974.28	249.51		
TSS	71	363808.24	5124.06		311931.48	4393.40		325355.48	4582.47		

* Significant at 5%

Appendix LXXXIV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on phosphorus uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	36016.16	36016.16	1287.55*	34350.42	34350.42	1571.01*	35178.36	35178.36	2751.92*	4.03
P levels	3	3825.18	1275.06	45.58*	3916.15	1305.38	59.70*	3804.45	1268.15	99.20*	2.78
S levels	2	285.40	142.70	5.10*	235.44	117.72	5.38*	259.82	129.91	10.16*	3.18
Al x P	3	130.46	43.49	1.55	214.58	71.53	3.27*	134.86	44.95	3.52*	2.78
P x S	6	167.78	27.96	1.00	205.63	34.27	1.57	152.69	25.45	1.99	2.28
Al x S	2	12.82	6.41	0.23	5.39	2.69	0.12	3.27	1.63	0.13	3.18
Al x P x S	6	142.92	23.82	0.85	70.53	11.76	0.54	63.14	10.52	0.82	2.28
Error	52	1454.57	27.97		1136.99	21.87		664.73	12.78		
TSS	71	42035.29	592.05		40135.14	565.28		40261.32	567.06		

* Significant at 5%

Appendix LXXXV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on potassium uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	339912.89	339912.89	492.31*	266112.69	266112.69	356.81*	301885.19	301885.19	723.61*	4.03
P levels	3	51799.57	17266.52	25.01*	43864.52	14621.51	19.60*	47731.36	15910.45	38.14*	2.78
S levels	2	5569.93	2784.97	4.03*	9435.13	4717.57	6.33*	7351.34	3675.67	8.81*	3.18
Al x P	3	3532.46	1177.49	1.71	137.20	45.73	0.06	957.85	319.28	0.77	2.78
P x S	6	162.68	27.11	0.04	1699.96	283.33	0.38	333.26	55.54	0.13	2.28
Al x S	2	9.35	4.67	0.01	19.63	9.82	0.01	1.04	0.52	0.00	3.18
Al x P x S	6	994.04	165.67	0.24	969.92	161.65	0.22	501.08	83.51	0.20	2.28
Error	52	35902.78	690.44		38782.42	745.82		21693.91	417.19		
TSS	71	437883.69	6167.38		361021.48	5084.81		380455.04	5358.52		

* Significant at 5%

Appendix LXXXVI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on calcium uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	312958.75	312958.75	3485.21*	323379.76	323379.76	2387.76*	318147.92	318147.92	5290.34*	4.03
P levels	3	12567.89	4189.30	46.65*	10929.54	3643.18	26.90*	11727.64	3909.21	65.00*	2.78
S levels	2	979.97	489.99	5.46*	1236.31	618.16	4.56*	1093.66	546.83	9.09*	3.18
Al x P	3	11.34	3.78	0.04	596.03	198.68	1.47	172.36	57.45	0.96	2.78
P x S	6	49.70	8.28	0.09	267.09	44.52	0.33	65.99	11.00	0.18	2.28
Al x S	2	215.45	107.72	1.20	63.10	31.55	0.23	123.87	61.94	1.03	3.18
Al x P x S	6	176.99	29.50	0.33	135.25	22.54	0.17	71.07	11.84	0.20	2.28
Error	52	4669.40	89.80		7042.49	135.43		3127.15	60.14		
TSS	71	331629.50	4670.84		343649.56	4840.13		334529.67	4711.69		

* Significant at 5%

Appendix LXXXVII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on sulphur uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	8505.60	8505.60	251.76*	4894.66	4894.66	142.51*	6576.21	6576.21	281.50*	4.03
P levels	3	2533.15	844.38	24.99*	2769.16	923.05	26.87*	2645.33	881.78	37.75*	2.78
S levels	2	1272.89	636.45	18.84*	1584.62	792.31	23.07*	1421.44	710.72	30.42*	3.18
Al x P	3	81.62	27.21	0.81	17.23	5.74	0.17	33.02	11.01	0.47	2.78
P x S	6	68.81	11.47	0.34	44.28	7.38	0.21	29.35	4.89	0.21	2.28
Al x S	2	56.77	28.39	0.84	6.57	3.28	0.10	25.13	12.56	0.54	3.18
Al x P x S	6	62.67	10.45	0.31	92.43	15.40	0.45	53.63	8.94	0.38	2.28
Error	52	1756.80	33.78		1786.02	34.35		1214.78	23.36		
TSS	71	14338.32	201.95		11194.96	157.68		11998.88	169.00		

* Significant at 5%

Appendix LXXXVIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on aluminium uptake in stover of french bean

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	5327509.58	5327509.58	4.18*	36320859.96	36320859.96	11.99*	17367301.39	17367301.39	18.02*	4.03
P levels	3	144902447.92	48300815.97	37.92*	100576455.13	33525485.04	11.07*	121283505.55	40427835.18	41.95*	2.78
S levels	2	9200798.65	4600399.32	3.61*	18399166.47	9199583.24	3.04*	13377893.79	6688946.90	6.94*	3.18
Al x P	3	27265208.52	9088402.84	7.14*	6065206.32	2021735.44	0.67	13267769.80	4422589.93	4.59*	2.78
P x S	6	1928259.60	321376.60	0.25	5868480.98	978080.16	0.32	1641575.49	273595.91	0.28	2.28
Al x S	2	1287823.62	643911.81	0.51	2976180.37	1488090.18	0.49	1860749.39	930374.70	0.97	3.18
Al x P x S	6	4794479.64	799079.94	0.63	1401791.48	233631.91	0.08	1069489.99	178248.33	0.18	2.28
Error	52	66231725.95	1273687.04		157509999.98	3029038.46		50116171.79	963772.53		
TSS	71	260938253.48	3675186.67		329118140.69	4635466.77		219984457.19	3098372.64		

* Significant at 5%

Appendix LXXXIX: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on available nitrogen content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	2348.41	2348.41	1916.01*	1744.83	1744.83	1468.11*	2035.43	2035.43	3772.26*	4.04
P levels	3	384.72	128.24	104.63*	373.78	124.59	104.83*	377.02	125.67	232.91*	2.80
S levels	2	141.17	70.59	57.59*	150.07	75.03	63.13*	145.58	72.79	134.90*	3.19
Al x P	3	38.02	12.67	10.34*	11.81	3.94	3.31*	20.72	6.91	12.80*	2.80
P x S	6	2.79	0.47	0.38	5.01	0.83	0.70	2.04	0.34	0.63	2.29
Al x S	2	0.13	0.07	0.05	0.11	0.05	0.04	0.10	0.05	0.09	3.19
Al x P x S	6	1.88	0.31	0.26	5.15	0.86	0.72	2.09	0.35	0.64	2.29
Error	48	58.83	1.23		57.05	1.19		25.90	0.54		
TSS	71	2975.95	41.91					2608.88	36.74		

* Significant at 5%

Appendix XC: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on phosphorus content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	181.93	181.93	541.25*	153.80	153.80	288.65*	167.57	167.57	674.51*	4.04
P levels	3	169.08	56.36	167.68*	243.49	81.16	152.33*	203.13	67.71	272.56*	2.80
S levels	2	0.17	0.08	0.25	2.88	1.44	2.70	1.11	0.56	2.23	3.19
Al x P	3	11.06	3.69	10.96	5.74	1.91	3.59*	5.12	1.71	6.87*	2.80
P x S	6	9.40	1.57	4.66	1.07	0.18	0.34	3.15	0.52	2.11	2.29
Al x S	2	0.82	0.41	1.22	1.36	0.68	1.27	0.19	0.09	0.38	3.19
Al x P x S	6	0.81	0.14	0.40	0.96	0.16	0.30	0.44	0.07	0.29	2.29
Error	48	16.13	0.34		25.58	0.53		11.92	0.25		
TSS	71	389.40	5.48		434.86	6.12		392.63	5.53		

* Significant at 5%

Appendix XCI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on potassium content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1671.58	1671.58	1131.27*	2109.68	2109.68	1060.58*	1884.26	1884.26	1887.48*	4.04
P levels	3	7.74	2.58	1.75	14.04	4.68	2.35	9.34	3.11	3.12*	2.80
S levels	2	8.59	4.30	2.91*	11.00	5.50	2.76	9.46	4.73	4.74*	3.19
Al x P	3	1.83	0.61	0.41	9.46	3.15	1.59	3.74	1.25	1.25*	2.80
P x S	6	11.01	1.83	1.24	6.98	1.16	0.59	7.33	1.22	1.22	2.29
Al x S	2	7.97	3.99	2.70	12.13	6.07	3.05	9.90	4.95	4.96*	3.19
Al x P x S	6	5.91	0.98	0.67	4.61	0.77	0.39	2.37	0.40	0.40	2.29
Error	48	70.93	1.48		95.48	1.99		47.92	1.00		
TSS	71	1785.55	25.15		2263.40	31.88		1974.32	27.81		

* Significant at 5%

Appendix XCII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on sulphur content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	445.96	445.96	135.71*	387.39	387.39	105.80*	416.16	416.16	185.75*	4.04
P levels	3	12.60	4.20	1.28	26.27	8.76	2.39	15.76	5.25	2.35	2.80
S levels	2	75.11	37.55	11.43*	86.81	43.40	11.85*	80.83	40.42	18.04*	3.19
Al x P	3	16.52	5.51	1.68	8.81	2.94	0.80	11.89	3.96	1.77	2.80
P x S	6	4.22	0.70	0.21	7.20	1.20	0.33	4.47	0.74	0.33	2.29
Al x S	2	3.95	1.97	0.60	2.95	1.47	0.40	3.35	1.68	0.75	3.19
Al x P x S	6	4.35	0.73	0.22	4.15	0.69	0.19	2.26	0.38	0.17	2.29
Error	48	157.73	3.29		175.75	3.66		107.54	2.24		
TSS	71	720.44	10.15		699.34	9.85		642.26	9.05		

*Significant at 5%

Appendix XCIII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on calcium content in post harvest l soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	5.27	5.27	43.78*	5.81	5.81	58.89*	5.53	5.53	52.95*	4.04
P levels	3	0.01	0.00	0.02	0.06	0.02	0.19	0.02	0.01	0.08	2.80
S levels	2	0.02	0.01	0.07	0.00	0.00	0.01	0.01	0.00	0.03	3.19
Al x P	3	0.03	0.01	0.08	0.01	0.00	0.02	0.00	0.00	0.01	2.80
P x S	6	0.05	0.01	0.07	0.01	0.00	0.02	0.02	0.00	0.04	2.29
Al x S	2	0.01	0.01	0.05	0.00	0.00	0.01	0.01	0.00	0.03	3.19
Al x P x S	6	0.06	0.01	0.09	0.00	0.00	0.01	0.02	0.00	0.03	2.29
Error	48	5.77	0.12		4.73	0.10		5.02	0.10		
TSS	71	11.22	0.16		10.62	0.15		10.63	0.15		

*Significant at 5%

Appendix XCIV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on aluminium content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	13.40	13.40	206.20*	9.21	9.21	412.40*	11.21	11.21	302.80*	4.04
P levels	3	0.02	0.01	0.11	0.07	0.02	1.09	0.04	0.01	0.37	2.80
S levels	2	0.01	0.00	0.07	0.04	0.02	0.82	0.00	0.00	0.03	3.19
Al x P	3	0.01	0.00	0.03	0.04	0.01	0.54	0.02	0.01	0.15	2.80
P x S	6	0.01	0.00	0.02	0.01	0.00	0.05	0.00	0.00	0.01	2.29
Al x S	2	0.00	0.00	0.01	0.02	0.01	0.50	0.00	0.00	0.05	3.19
Al x P x S	6	0.00	0.00	0.01	0.01	0.00	0.05	0.00	0.00	0.01	2.29
Error	48	3.12	0.06		1.07	0.02		1.78	0.04		
TSS	71	16.57	0.23		10.46	0.15		13.05	0.18		

*Significant at 5%

Appendix XCV: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on TPA content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	159.70	159.70	1044.84*	184.90	184.90	1360.99*	172.07	172.07	1980.12*	4.04
P levels	3	0.91	0.30	1.98	0.95	0.32	2.33	0.43	0.14	1.66	2.80
S levels	2	0.01	0.01	0.03	0.80	0.40	2.93	0.24	0.12	1.40	3.19
Al x P	3	0.49	0.16	1.07	0.39	0.13	0.95	0.39	0.13	1.51	2.80
P x S	6	0.18	0.03	0.20	0.20	0.03	0.25	0.13	0.02	0.25	2.29
Al x S	2	0.08	0.04	0.27	0.28	0.14	1.03	0.13	0.07	0.77	3.19
Al x P x S	6	0.07	0.01	0.08	0.15	0.03	0.19	0.05	0.01	0.09	2.29
Error	48	7.34	0.15		6.52	0.14		4.17	0.09		
TSS	71	168.78	2.38		194.19	2.74		177.61	2.50		

* Significant at 5%

Appendix XCVI: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on pH content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	1.73	1.73	41.61*	0.29	0.29	12.21*	0.86	0.86	30.37*	4.04
P levels	3	0.11	0.04	0.91	0.10	0.03	1.42	0.10	0.03	1.23	2.80
S levels	2	0.18	0.09	2.13	0.27	0.14	5.71	0.22	0.11	3.93	3.19
Al x P	3	0.09	0.03	0.75	0.05	0.02	0.72	0.02	0.01	0.21	2.80
P x S	6	0.18	0.03	0.71	0.06	0.01	0.43	0.08	0.01	0.48	2.29
Al x S	2	0.00	0.00	0.04	0.04	0.02	0.92	0.02	0.01	0.32	3.19
Al x P x S	6	0.18	0.03	0.72	0.03	0.01	0.24	0.07	0.01	0.43	2.29
Error	48	1.99	0.04		1.16	0.02		1.36	0.03		
TSS	71	4.46	0.06		2.02	0.03		2.74	0.04		

* Significant at 5%

Appendix XCVII: Analysis of variance showing effect of aluminium, phosphorus and sulphur levels on organic carbon content in post harvest soil

SOV	DF	2017-18			2018-19			Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal	SS	MSS	F cal	
Al levels	1	0.09	0.09	2.62	0.12	0.12	3.71	0.10	0.10	3.22	4.04
P levels	3	0.01	0.00	0.09	0.07	0.02	0.75	0.03	0.01	0.33	2.80
S levels	2	0.01	0.00	0.09	0.01	0.00	0.08	0.01	0.00	0.09	3.19
Al x P	3	0.00	0.00	0.02	0.02	0.01	0.18	0.01	0.00	0.06	2.80
P x S	6	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	2.29
Al x S	2	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	3.19
Al x P x S	6	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	2.29
Error	48	1.68	0.03		1.52	0.03		1.56	0.03		
TSS	71	1.79	0.03		1.74	0.02		1.71	0.02		

* Significant at 5%