

**MANAGEMENT OF PHOSPHORUS IN AN
ALFISOL WITH MAIZE – COWPEA CROPPING
SEQUENCE**

SYED WALI JALALZAI

PALB 2098

**DEPARTMENT OF SOIL SCIENCE AND
AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICUTURAL SCIENCES
BANGALORE**

2015

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Thesis submitted to the

UNIVERSITY OF AGRICULTURAL SCIENCES, BANGALORE

in partial fulfillment of the requirements

for the award of the degree of

Doctor of Philosophy

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

BANGALORE

AUGUST, 2015



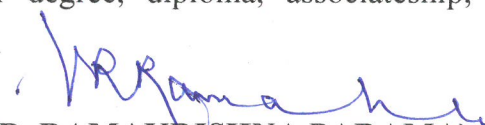
*Affectionately
Dedicated to
My Beloved Parents,
Uncles, Brothers,
Sisters, Wife, Children
and Afghan nation*

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE - 560 065

CERTIFICATE

This is to certify that the thesis entitled “Management of phosphorus in an Alfisol with maize – cowpea cropping sequence” submitted by Mr. Syed Wali Jalalzai, ID. No. PALB 2098, in partial fulfillment of the requirement for the award of degree of DOCTOR OF PHILOSOPHY in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY to the University of Agricultural Sciences, Bangalore, is a record of research work done by him during the period of his study in this university under my guidance and supervision and no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

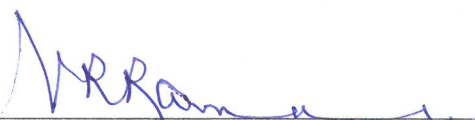
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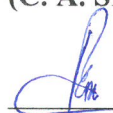
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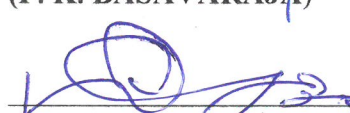
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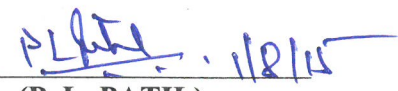

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External Examiner

ACKNOWLEDGEMENT

*First and foremost I earnestly praise the **Almighty Allah** (J) the most gracious and merciful who enabled me to complete my Ph. D thesis.*

The beatitude and euphoria that accompanies successful completion of any task would be incomplete without expression of simple certitude to the people who made it possible to achieve the goal by their encouraging, guidance and proper steering. It is still great at this juncture to recall all the faces and spirit in the form of teachers, friends, near and dear ones.

*I cannot but consider myself lucky to have worked under the guidance of knowledge hungry, excellence pursuing and ever helpful personality **Prof. V. R. Ramakrishna Parama**, a personality worth emulating. His dedication to the subject and teaching profession has always been a model for me to look upto. The valuable suggestions and the encouragement given to me for my research work and career advancement will always remain in my heart with great respect. His creative criticism and comments inculcated a strong sense of positive thinking in me.*

*No less do I regard **Dr. C.A. Srinivasamurthy** Professor SS & AC and University Head, UAS, Bengaluru, and member of my advisory committee, for his constant encouragement, suggestions and valuable guidance during the course of my study and investigation.*

*I sincerely owe my deep sense of gratitude to **Dr. P.K. Basavaraja**, Professor, Dept. of Soil Science & Agril. Chemistry and Head of STCR Dept. SS & AC College of Agriculture, GKVK, UAS, Bengaluru and the member of my advisory committee for his invaluable and expert guidance, encouragement and help provided during my investigation.*

*It gives me immense pleasure to express my heartfelt thanks to **Dr. A. Manjunath**, Professor, Dept. of Agril. Microbiology, College of Agriculture, GKVK, UAS, Bengaluru and member of my advisory committee for his support and precious remarks during my degree programme. I shall ever remember him as one of the*

best teacher in my life. I am gratefully indebted to him both personally and academically.

*I am extremely grateful to **Dr. Nagraju**, Professor, Chief Scientist, Agro-forestry, Agriculture Project, UAS, GKVK, Bengaluru and member of my advisory committee for his invaluable guidance and suggestions during my investigation.*

*I whole heartedly thank **Dr. Aftab Hussain**, Professor, Dept. of Crop Physiology, UAS, Bangalore, for his support and precious remarks during my degree programme. I shall ever remember him as one of the best teacher in my life. I am gratefully indebted to him both personally and academically.*

*I would like to extend my sincere gratitude to all my teachers **Dr. H. C. Prakash**, **Dr. Subbarayappa**, **Dr. R. C. Gowda**, **Dr. N. B. Prakash**, **Dr. Saralakumari**, **Dr. Chikkramappa**, **Dr. Chamegowda** and **Dr. Sathish** for their valuable guidance during my postgraduate degree programme which generated great interest in the subject matter.*

*I sincerely thank **Dr. Veernagappa**, **Dr. Atheefa Munawery**, **Dr. Vijay Kumar**, **Dr. Karthika K. S.**, **Mr. Narendra**, **Mrs. Prathibha** and **Ms. Hemalatha** for their support and precious remarks especially during the laboratory and research work.*

*I am highly indebted and owe all my success to my beloved parents **Kind father Mohammad Ghani Jalalzai**, **Kind mother**, my uncles **Mr. Ahmad Jan Jalalzai**, **Mr. Gul Mohammad Jalalzai**, **My brothers**, **wife**, **children** and **relatives** without whose affection, encouragement and support, it would not have been possible for me to complete my Doctor of Philosophy degree.*

*I am extremely grateful to the non teaching staff of Department of Soil Science and Agricultural Chemistry **Mr. D. Srinivasamurthy**, **Mr. Manjunath**, **Mr. Prasanna**, **Mrs. Shardamma**, **Mrs. Leelavathi**, **Mrs. Channamma** for their help and encouragement throughout my study.*

*I am thankful to all the staff members of **Department of Soil Science and Agril. Chemistry**, U.A.S., GKVK, Bangalore, for their kind support during the course of this investigation.*

I thank the University of Agricultural Sciences, Bangalore for giving me an opportunity to pursue my Ph. D degree programme.

I avail this opportunity to express my deep and profound sense of gratitude to the Ministry of Higher Education, Islamic Republic of Afghanistan and my lovely people of Afghanistan which provided the opportunity and financial assistance for me to undergo post-graduation study in India.

I take this opportunity to thank Dr. Noor Mohammad Niaz previous Chancellor, Sayed Mohammad Mal, Dr. Ghousdin Ghous, and Engineer Fida Mohammad Fida deputy chancellor, Mohammad Nazeer Mohammadi, Mohammad Gul Arabzai, Mohammad Gulab Sajad, Noor Ahmad, Atheef, Abdulzahir Mohseen, Pakteen, Hekmat, all teachers and staff members of Paktia University, Gardiz, Kabul, Afghanistan, for providing me the opportunity to pursue post-graduation.

I whole heartedly thank my classmates Mrs. Gangamrutha, Mr. Shivanna, Ms. Punitha, Mrs. Savitha, Mrs. Shilpashree and Ms. Anitha for their help and support during the course period and research work.

I would like to place on record my most gratifying acknowledgement to Mr. Fazily, Mr. Faize, Mr. Gulab Omary, Mr. Sherzad, Mr. Emran, Mr. Ahamad Walid Qadri, Mr. Sayfie, Mr. Najeeb Rahmanzai, Mr. Abdulhadi Salihzai, Mr. Serat, Mr. Majaheed, Mr. Chikkaraju, Mr. Sandeep, Ms. Prabha, Mr. Sidhram Patil, Dr. Yogendra, Ms. Shruthi, Ms. Mamtha, Ms. Vidya C. S. and Mrs. Gayathri who have been a sources of encouragement and inspiration throughout.

I issue a blanket of thanks for those who helped me directly or indirectly during the course of study and any omission in this brief acknowledgment does not mean lack of gratitude.

*Bengaluru
August, 2015*

(Syed Wali Jalalzai)

MANAGEMENT OF PHOSPHORUS IN AN ALFISOL WITH MAIZE - COWPEA CROPPING SEQUENCE

SYED WALI JALALZAI

THESIS ABSTRACT

A study was conducted during 2013-14 at UAS, Bangalore on “*Management of Phosphorus in an Alfisol with maize - cowpea cropping sequence*” using a soil low available P (20.81 kg ha⁻¹) and other high in available P (63.94 kg ha⁻¹). In total there were fourteen treatments replicated thrice. The P levels varied from recommended, 50 per cent and no P tried with combinations of FMY, PSB and VAM. The treatment, organic matter, phosphorus solubilizing bacteria and vesicular arbuscular mycorrhiza + recommended dose of P (75 kg ha⁻¹) treatment (T₆) applied to high P soil recorded higher maize grain and stover (85 and 97.70 q ha⁻¹) yield. At harvest of maize the treatment T₆ recorded higher available NPK (167.66, 93.29 and 316 kg ha⁻¹), S (11.20 mg kg⁻¹), Ca and Mg (3.28 and 2.32 meq/100 g soil⁻¹) and phosphatase activity (65.85 µg of PNP g⁻¹ soil hr⁻¹). The residual cowpea also recorded higher seed and haulm yield (13.73 and 19.23 q ha⁻¹) due to treatment (T₆). In soil low in available P (20.81 kg ha⁻¹) as well, the treatment (T₆) recorded higher maize grain and stover yield (36.45 and 49.33 g pot⁻¹) and higher soil NPK (186.81, 36.70 and 270.99 kg ha⁻¹), S (16.49 mg kg⁻¹), secondary and micronutrients and phosphatase activity (45.18 µg PNP g⁻¹soil hr⁻¹) at harvest. This treatment (T₆) recorded higher residual cowpea seed and haulm (21.60 and 29.73 g pot⁻¹). The phosphate adsorption gave good fit for Langmuir and Freundlich isotherms for low and high P soil. The dominant P fractions in soil with high available P were in the order Al-P>Fe-P>RS-P>Org-P>Occl-P>Ca-P>Sal-P whereas in low available P soil the order was Al-P>Fe-P>RS-P>Occl-P>Org-P>Ca-P>Sal-P. Studies clearly indicated that application of only 50% of recommended P along with OM, PSB and VAM to maize (first crop) in a soil high in available P was enough to record higher maize yield followed by cowpea thus saving 50 % of P.

August, 2015

Department of Soil Science and Agricultural Chemistry
UAS, GKVK, Bengaluru – 65

Signature of Major Advisor
(V. R. Ramakrishna Parama)

ಕೆಂಪು ಮಣ್ಣಿನಲ್ಲಿ ಬೆಳೆದ ಮೆಕ್ಕೆಜೋಳ - ಅಲಸಂದೆ ಬೆಳೆ ಪದ್ಧತಿಯಲ್ಲಿ ರಂಜಕದ ನಿರ್ವಹಣೆ

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಸೈಯದ್ ವಾಲಿ ಜಲಾಲ್ ಜಾಯ್

ಮೆಕ್ಕೆಜೋಳ - ಅಲಸಂದೆ ಬೆಳೆಪದ್ಧತಿಯಲ್ಲಿ ರಂಜಕದ ನಿರ್ವಹಣೆ ಬಗ್ಗೆ ಕ್ಷೇತ್ರ ಪ್ರಯೋಗಗಳನ್ನು ಜಿ.ಕೆ.ವಿ.ಕೆ ಆವರಣದಲ್ಲಿನ ಕಡಿಮೆ ರಂಜಕ (20.81 ಕಿ.ಗ್ರಾಂ ಹೆ⁻¹) ಮತ್ತು ಹೆಚ್ಚು ರಂಜಕ (63.94 ಕಿ.ಗ್ರಾಂ ಹೆ⁻¹) ಲಭ್ಯವಿರುವ ಎರಡು ತಾಕುಗಳ ಮಣ್ಣಿನಲ್ಲಿ ನಡೆಸಲಾಯಿತು. ಒಟ್ಟು ಹದಿನಾಲ್ಕು ಉಪಚಾರಗಳನ್ನು ಮೂರು ಬಾರಿ ಪುನರಾವರ್ತಿತವಾಯಿತು. ಸಾವಯವ ಗೊಬ್ಬರ, ರಂಜಕ ಕರಗಿಸುವ ದುಂಡಾಣು ಹಾಗೂ ಸೂಕ್ಷ್ಮಜೀವಿಯನ್ನು (ವಿ.ಎ.ಎಮ್.) ಶಿಫಾರಸ್ಸಿದ ರಂಜಕ, ಶೇ.50% ರಷ್ಟು ರಂಜಕ ಮತ್ತು ರಂಜಕವಿಲ್ಲದ ಉಪಚಾರಗಳ ವಿವಿಧ ಸಂಯೋಜನೆಗಳೊಂದಿಗೆ ಪರೀಕ್ಷೆಗೆ ಒಳಪಡಿಸಲಾಗಿತ್ತು. ಶಿಫಾರಸ್ಸಿನ ರಂಜಕದ ಪ್ರಮಾಣದ (75 ಕಿ.ಗ್ರಾಂ.ಹೆ⁻¹) ಜೊತೆಗೆ ಸಾವಯವ ಗೊಬ್ಬರ, ರಂಜಕ ಕರಗಿಸುವ ದುಂಡಾಣು ಹಾಗೂ ಸೂಕ್ಷ್ಮ ಜೀವಿ (ವಿ.ಎ.ಎಮ್) ಒಳಗೊಂಡ (85 ಮತ್ತು 95.70 ಕ್ವಿಂಟಾಲ್ ಹೆ⁻¹) ಉಪಚಾರವು (ಟಿ.6) ಹೆಚ್ಚು ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನಲ್ಲಿ ಅತ್ಯಂತ ಹೆಚ್ಚು ಮೆಕ್ಕೆಜೋಳದ ಕಾಳು ಮತ್ತು ಸ್ಟೋವರ್‌ನ ಇಳುವರಿಯನ್ನು ನೀಡಿರುತ್ತದೆ. ಈ ಬೆಳೆಯ ಕೊಯ್ಲಿನೊತ್ತರ ಮಣ್ಣಿನಲ್ಲಿ ಲಭಿಸುವ ಸಾರಜನಕ, ರಂಜಕ, ಪೊಟ್ಯಾಷ್, ಗಂಧಕ, ಕ್ಯಾಲ್ಸಿಯಂ, ಮೆಗ್ನೀಷಿಯಂ ಹಾಗೂ ಫಾಸ್ಫೇಟ್ ಕಿಣ್ವದ ಚಟುವಟಿಕೆಯು ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡು ಬಂದಿರುತ್ತದೆ. ಹಾಗೂ ಈ ಪ್ರಯೋಗಗಳಲ್ಲಿ ಉಳಿಕೆ ಗೊಬ್ಬರದಲ್ಲಿ ಬೆಳೆದ ಅಲಸಂದೆ ಬೆಳೆಯು ಹೆಚ್ಚಿನ ಇಳುವರಿಯನ್ನು ನೀಡಿರುತ್ತದೆ. ಲಭಿಸುವ ರಂಜಕ ಕಡಿಮೆ ಇರುವ ಮಣ್ಣಿನಲ್ಲಿ (ಟಿ.6) ಉಪಚಾರದಲ್ಲಿ ನೀಡಿರುವ ಮೆಕ್ಕೆಜೋಳದ ಇಳುವರಿಯು ಹೆಚ್ಚು ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನಲ್ಲಿ ನೀಡಿರುವ ಇಳುವರಿಗೆ ಸರಿಸಮವಾಗಿರುತ್ತದೆ, ಹಾಗೂ ಲಭಿಸುವ ಸಾರಜನಕ, ರಂಜಕ, ಪೊಟ್ಯಾಷ್, ಗಂಧಕ, ಕ್ಯಾಲ್ಸಿಯಂ, ಮೆಗ್ನೀಷಿಯಂ, ಲಘುಪೋಷಕಾಂಶಗಳು ಮತ್ತು ಫಾಸ್ಫೇಟ್ ಕಿಣ್ವದ ಚಟುವಟಿಕೆಯು ಸಹ ಲಭಿಸುವ ರಂಜಕ ಹೆಚ್ಚು ಇರುವ ಮಣ್ಣಿಗೆ ಸರಿಸಮವಾಗಿರುತ್ತದೆ. ಕಡಿಮೆ ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನ ಉಳಿಕೆ ಫಲವತ್ತತೆಯಲ್ಲಿ ಬೆಳೆದ ಅಲಸಂದೆ ಇಳುವರಿಯು ಹೆಚ್ಚು ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನಲ್ಲಿ ನೀಡಿ ಇಳುವರಿಗೆ ಸರಿಸಮವಾಗಿರುವುದು ಕಂಡು ಬಂದಿರುತ್ತದೆ. ಕಡಿಮೆ ಮತ್ತು ಹೆಚ್ಚು ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನಲ್ಲಿ ಲಾಂಗ್‌ಮಿಯರ್ ಮತ್ತು ಫ್ರೆಂಡ್‌ಜ್ ಸಮೀಕರಣಗಳೆರಡರಲ್ಲೂ ಫಾಸ್ಫೇಟ್ ಅಂಟಿಕೊಳ್ಳುವ ಮಟ್ಟವು ಉತ್ತಮವಾಗಿರುವುದು ಕಂಡು ಬಂದಿದೆ. ಒಟ್ಟಾರೆ ಹೆಚ್ಚು ರಂಜಕ, ರಂಜಕದ ಭಿನ್ನರಾಶಿಗಳು ಮಣ್ಣಿನಲ್ಲಿ ಕ್ರಮವಾಗಿ Al-P>Fe-P>RS-P>Org-P>Occl-P>Ca-P>Sal-P ಹಾಗೂ ಕಡಿಮೆ ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನಲ್ಲಿ ರಂಜಕದ ಭಿನ್ನರಾಶಿಗಳು ಕ್ರಮವಾಗಿ Al-P>Fe-P>RS-P>Occl-P>Org-P>Ca-P>Sal-P ಇರುವುದು ಕಂಡುಬಂದಿದೆ. ಈ ಅಧ್ಯಯನದಿಂದ ತಿಳಿದುಬಂದಿರುವುದೇನೆಂದರೆ ಹೆಚ್ಚು ರಂಜಕ ಲಭಿಸುವ ಮಣ್ಣಿನಲ್ಲಿ ಶಿಫಾರಸ್ಸಿನ ಕೇವಲ ಶೇ.50 ರಂಜಕದ ಜೊತೆಗೆ ಸಾರಜನಕ ಗೊಬ್ಬರ, ರಂಜಕ ಕರಗಿಸುವ ದುಂಡಾಣು ಹಾಗೂ ಸೂಕ್ಷ್ಮ ಜೀವಿ (ವಿ.ಎ.ಎಮ್) ಬಳಸುವುದರಿಂದ ಮೆಕ್ಕೆಜೋಳ ಹಾಗೂ ಉಳಿಕೆ ಬೆಳೆಯಾದ ಅಲಸಂದೆಯಲ್ಲಿ ಹೆಚ್ಚಿನ ಇಳುವರಿ ಪಡೆಯಬಹುದಾಗಿದೆ. ಹಾಗೂ ಶೇ.50ರಷ್ಟು ರಂಜಕವನ್ನು ಉಳಿತಾಯ ಮಾಡಿದಂತಾಗುತ್ತದೆ.

ಆಗಸ್ಟ್, 2015

ಮಣ್ಣು ವಿಜ್ಞಾನ ಮತ್ತು ಕೃಷಿ ರಾಸಾಯನ ಶಾಸ್ತ್ರ ವಿಭಾಗ
ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯ, ಗಾ.ಕೃ.ವಿ.ಕೇ,
ಬೆಂಗಳೂರು - 560 065

ಮುಖ್ಯ ಸಲಹೆಗಾರರು
(ಡಾ|| ವಿ. ಆರ್. ರಾಮಕೃಷ್ಣ ಪರಮ)

CONTENTS

CHAPTER	TITLE	PAGE No.
I	INTRODUCTION	1-3
II	REVIEW OF LITERATURE	4-29
III	MATERIAL AND METHODS	30-38
IV	RESULTS AND DISCUSSION	39-171
V	SUMMARY	172-178
VI	REFERENCES	179-195
	PUBLICATIONS	196-200

LIST OF TABLES

Table No.	Title	Page No.
1	Methods used to determine soil physical and chemical properties	32
2	Initial soil physico-chemical properties, forms of P in soils used for field and pot experiment	33
3	Treatment details for pot culture and field experiment	35
4	Methods used for analysis of plant samples	37
5	Influence of P, PSB and VAM application on soil pH, EC and nutrient status of soil at tasseling stage and at harvest of maize in soil with high available phosphorus	41
6	Influence of P, PSB and VAM application on soil Ca, Mg and micronutrients status at tasseling stage and at harvest of maize in soil with high available phosphorus	44
7	Influence of P, PSB and VAM application on soil nutrient ratios and phosphatase activity at tasseling stage and at harvest of maize in soil with high available phosphorus	46
8	Influence of phosphorus, PSB and VAM application on different fractions of phosphorus (mg kg^{-1}) in soil at harvest of maize in soil high in available P	48
9	Influence of phosphorus, PSB and VAM application on growth parameters of maize at tasseling (60 DAS) and at harvest in high available phosphorus soil	51
10	Influence of phosphorus, PSB and VAM application on fresh and dry biomass of maize at tasseling and at harvest in high available phosphorus soil	53
11	Influence of phosphorus, PSB and VAM application on growth and yield parameters of maize at harvest in high available phosphorus soil	56
12	Influence of phosphorus, PSB and VAM application on major nutrients content (%) of maize at tasseling stage in high available phosphorus soil	58
13	Influence of phosphorus, PSB and VAM application on secondary nutrients content (%) of maize at tasseling stage in high available phosphorus soil	60

Table No.	Title	Page No.
14	Influence of phosphorus, PSB and VAM application on micronutrients content (mg kg^{-1}) of maize at tasseling stage in high available phosphorus soil	62
15	Influence of phosphorus, PSB and VAM application on major nutrients uptake by maize crop (kg ha^{-1}) at harvest in high available phosphorus soil	64
16	Influence of phosphorus, PSB and VAM application on secondary nutrients uptake by maize crop (kg ha^{-1}) at harvest in high available phosphorus soil	66
17	Influence of phosphorus, PSB and VAM application on Fe and Mn uptake (g ha^{-1}) by maize crop at harvest in high available phosphorus soil	68
18	Influence of phosphorus, PSB and VAM application on uptake of Zn and Cu (g ha^{-1}) by maize crop at harvest in high available phosphorus soil	69
19	Correlation of available P, nitrogen, potassium, fractions of soil P with maize yield in high available phosphorus soil	71
20	Residual effect of P, PSB and VAM on soil pH, EC, nutrient status after 60 days of sowing and at harvest of cowpea in soil with high available phosphorus	72
21	Residual effect of P, PSB and VAM on soil Ca, Mg and micronutrients status after 60 days of sowing and at harvest of cowpea in soil with high available phosphorus	75
22	Residual effect of P, PSB and VAM on nutrient ratios in soil and phosphatase activity after 60 days of sowing and at harvest of cowpea in soil with high available phosphorus	78
23	Residual effect of phosphorus, PSB and VAM on different fractions of phosphorus (mg kg^{-1}) in cowpea at harvest in high available phosphorus soil	80
24	Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea after 60 days of sowing (60 DAS) and at harvest in high available phosphorus soil	83
25	Residual effect of phosphorus, PSB and VAM on fresh and dry biomass of cowpea after 60 days of sowing (60 DAS) and at harvest in high available phosphorus soil	86

Table No.	Title	Page No.
26	Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea at harvest in high available phosphorus soil	88
27	Residual effect of phosphorus, PSB and VAM on major nutrients content (%) of cowpea at 60 DAS in high available phosphorus soil	90
28	Residual effect of phosphorus, PSB and VAM on secondary nutrients content (%) of cowpea at 60 DAS in high available phosphorus soil	92
29	Residual effect of phosphorus, PSB and VAM on micronutrients content (mg kg ⁻¹) of cowpea at 60 DAS in high available phosphorus soil	94
30	Residual effect of phosphorus, PSB and VAM on major nutrients uptake by cowpea (kg ha ⁻¹) at harvest in high available phosphorus soil	97
31	Residual effect of phosphorus, PSB and VAM on secondary nutrients uptake by cowpea (kg ha ⁻¹) at harvest in high available phosphorus soil	99
32	Residual effect of phosphorus, PSB and VAM on Fe and Mn uptake (g ha ⁻¹) by cowpea at harvest in high available phosphorus soil	100
33	Residual effect of phosphorus, PSB and VAM on Zn and Cu uptake (g ha ⁻¹) by cowpea at harvest in high available phosphorus soil	101
34	Correlation between soil phosphorus, nitrogen, potassium, different fractions of phosphorus and yield of cowpea as a residual crop in high available phosphorus soil	103
35	Influence of P, PSB and VAM application on soil pH, EC and nutrient status of soil at tasseling stage and at harvest of maize in soil with low available phosphorus	106
36	Influence of P, PSB and VAM application on soil Ca, Mg and micronutrients status at tasseling stage and at harvest of maize in soil with low available phosphorus	109
37	Influence of P, PSB and VAM application on soil nutrient ratios and phosphatase activity at tasseling stage and at harvest of maize in soil with low available phosphorus	111
38	Influence of phosphorus, PSB and VAM application on different fractions of phosphorus (mg kg ⁻¹) in maize at harvest low available phosphorus soil	114

Table No.	Title	Page No.
39	Influence of phosphorus, PSB and VAM application on growth and yield parameters of maize at tasseling stage and at harvest in low available phosphorus soil	116
40	Influence of phosphorus, PSB and VAM application on fresh and dry biomass of maize at tasseling stage and at harvest in low available phosphorus soil	118
41	Influence of phosphorus, PSB and VAM application on growth and yield parameters of maize at harvest in low available phosphorus soil	120
42	Influence of phosphorus, PSB and VAM application on major nutrients content (%) of maize at tasseling stage in low available phosphorus soil	122
43	Influence of phosphorus, PSB and VAM application on secondary nutrients content (%) of maize at tasseling stage in low available phosphorus soil	124
44	Influence of phosphorus, PSB and VAM application on micronutrient content (mg kg ⁻¹) of maize at tasseling stage in low available phosphorus soil	126
45	Influence of phosphorus, PSB and VAM application on major nutrients uptake by maize (kg ha ⁻¹) at harvest in low available phosphorus soil	128
46	Influence of phosphorus, PSB and VAM application on secondary nutrients uptake by maize crop (kg ha ⁻¹) at harvest in low available phosphorus soil	130
47	Influence of phosphorus, PSB and VAM application on Fe and Mn uptake (g ha ⁻¹) by maize crop at harvest in low available phosphorus soil	132
48	Influence of phosphorus, PSB and VAM application on Zn and Cu uptake (g ha ⁻¹) by maize crop at harvest in low available phosphorus soil	133
49	Correlation between soil phosphorus, nitrogen, potassium, different fractions of phosphorus and yield of maize crop in low available and high total phosphorus soil.	135
50	Residual effect of P, PSB and VAM on soil pH, EC, nutrient status after 60 days of sowing and at harvest of cowpea in soil with low available phosphorus	136

Table No.	Title	Page No.
51	Residual effect of P, PSB and VAM on soil Ca, Mg and micronutrients status after 60 days of sowing and at harvest of cowpea in soil with low available phosphorus	139
52	Residual effect of P, PSB and VAM on soil nutrient ratios and phosphatase activity after 60 days of sowing and at harvest of cowpea in soil with low available phosphorus	141
53	Residual effect of phosphorus, PSB and VAM on different fractions of phosphorus (mg kg^{-1}) in cowpea at harvest in low available phosphorus soil	144
54	Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea 60 days after sowing (60 DAS) and at harvest in low available phosphorus soil	147
55	Residual effect of phosphorus, PSB and VAM on fresh and dry biomass of cowpea 60 days after sowing (60 DAS) and at harvest in low available phosphorus soil	150
56	Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea at harvest in low available phosphorus soil	152
57	Residual effect of phosphorus, PSB and VAM on major nutrients content (%) of cowpea at 60 DAS in low available phosphorus soil	154
58	Residual effect of phosphorus, PSB and VAM on secondary nutrients content (%) of cowpea at 60 DAS in low available phosphorus soil	156
59	Residual effect of phosphorus, PSB and VAM on micronutrient content (mg kg^{-1}) of cowpea at 60 DAS in low available phosphorus soil	158
60	Residual effect of phosphorus, PSB and VAM on major nutrients uptake by cowpea (kg ha^{-1}) at harvest in low available phosphorus soil	160
61	Residual effect of phosphorus, PSB and VAM on secondary nutrients uptake by cowpea (kg ha^{-1}) at harvest in low available phosphorus soil	162
62	Residual effect of phosphorus, PSB and VAM on Fe and Mn uptake (g ha^{-1}) by cowpea at harvest in low available phosphorus soil	164
63	Residual effect of phosphorus, PSB and VAM on Zn and Cu uptake (g ha^{-1}) by cowpea at harvest in low available phosphorus soil	166

Table No.	Title	Page No.
64	Correlation between soil phosphorus, nitrogen, potassium, different fractions of phosphorus and yield of cowpea as a residual crop in low available and high total phosphorus soil	167
65a	Equilibrium P concentration, adsorption of P per unit soil in two type of soil by Langmuir isotherm	171
65b	Equilibrium soil solution, adsorbed P derived from Freundlich isotherm in two soils	171
65c	Equilibrium soil solution, adsorbed P derived from Freundlich isotherm in two soils	171

LIST OF FIGURES

Figure No.	Particulars	Between Pages
1	Plan and layout of the field experiment	37-38
2	Influence of P, PSB and VAM application on yield of maize (kg ha^{-1}) in soil high in available phosphorus	56-57
3	Residual effect of phosphorus, PSB and VAM on yield of cowpea (kg ha^{-1}) in high available phosphorus soil	90-91
4	Influence of phosphorus, PSB and VAM application on yield of maize (g pot^{-1}) in low available phosphorus soil	122-123
5	Residual effect of phosphorus, PSB and VAM on yield of cowpea (g pot^{-1}) in low available phosphorus soil	152-153

LIST OF PLATES

Plate No.	Particulars	Between Pages
1	General view of field experiment plot	37-38
2	General view of the field experiment on maize	37-38
3	Dr. V.R. Ramakrishna Parama major advisor and Dr. Veeranagappa during the field visit	40-41
4	Maize crop at tasseling stage	40-41
5	Cowpea at maturity stage	72-73
6	Tagging five plants in each plots of cowpea	72-73
7	Dr. V. R. Ramakrishna, Major advisor, Dr. A. Manjunath and I. S. Aftab Hussain, Advisory members during selection of low available P soil for pot culture experiment	104-105
8	Pot culture experiment on maize at tasseling stage	104-105
9	Cowpea in pot experiment at 20 days after sowing	136-137
10	Cowpea in pot culture experiment at maturity stage	136-137

I INTRODUCTION

“Without phosphorus there will be no agriculture, nor biofuels, nor life. Humanity will end” (Euripedes Malavolta, a veteran agronomist). To feed the projected population of 1.41 billion by 2025 India needs to produce 350 million tonnes of food grains (Rao *et al.*, 2008). The expanding food needs of future must be met through intensive agriculture using the available land and limited natural resources. With dwindling phosphorus (P) resources and reports of phosphorus build up in soils; strategies to utilize the phosphorus built up in soil should be aimed at. A contingency plan to face P shortage is of importance hence the relevance of the research.

Phosphorus is an important plant macronutrient which is a component of key molecules such as nucleic acids, phospholipids and ATP. Consequently plants cannot grow without a reliable supply of this nutrient. Phosphorus is also involved in controlling key enzyme reactions and in the regulation of the metabolic pathways. Soils are known to vary widely in their capacities to supply P to crops because only a small fraction (> 1 – 3 %) of the total P in any soil is in a form which is available to plants (Tarafdar, 2013).

Phosphorus plays a pivotal role in photosynthesis, root development, energy conservation and transformations, carbon metabolism, redox reactions, enzyme activation or inactivation, signaling and nucleic acid synthesis (Vance *et al.*, 2003). As unit of the DNA molecule, the carriers of genetic information and as units of RNA are the structures responsible for the translation of the genetic information (Marschner, 1997). It also has a significant role in sustaining and building up soil fertility, particularly under intensive systems of agriculture. But is one of the most inaccessible plant nutrients present in the soil. Phosphorus is the backbone of balanced fertilization in Indian agriculture. Phosphorus deficiency in soil is corrected by application of P fertilizer, which undergoes fixation by oxides, hydroxides and oxyhydroxides of Fe and Al and clay minerals in acidic soil, which makes it less available or effectively unavailable to plants (Shen *et al.*, 2004). India stands among top world economies along with China and US in world P consumption (Liu *et al.*, 2008). China and India are being the largest consumers of phosphorus fertilizers demanding 34 % and 19 % of global consumption, respectively (Tirado and Allsopp, 2012).

Phosphorus is an indispensable plant nutrient and no plant on the planet earth can complete its life cycle without adequate supply of P. The only economic source of P in the world is rock phosphate. However, very meager rock phosphate resources (310 Mt) are present in India; much of it is low-grade. Hence, almost 90 per cent of the P needs of the country are met through imports. Although P is abundant in the lithosphere, limited Pi availability is a general phenomenon in agriculture. Imbalanced and inadequate fertilizer application, organic and inorganic fixation and fear of exhaust of world's reserves of rock phosphate (Plaxton, 2004) coupled with high phosphate fertilizer prices, point out the need for recycling and exploitation of native plant unavailable phosphorus to improve crop production. It looks feasible by developing strategies to monitor soil phosphorus.

Major part of water-soluble phosphorus of added P fertilizers soon becomes unavailable due to its chemical fixation in soils. Hence, solubilization of fixed soil P through use of mobilizing/solubilizing microorganisms is a viable option to augment the availability of P in easily assimilable form by the crops. Vesicular arbuscular mycorrhizal fungi and rhizosphere microorganisms within the rhizosphere can influence their mutual development due to synergistic interactions (Singh *et al.*, 2011a). It is a well known fact that the introduced saprophytic bacteria with VAM fungi stimulate the growth and development of VAM spores (Johansson *et al.*, 2004). Root colonized VAM fungi increased bacterial growth (Andrade *et al.*, 1997).

Phosphatic fertilizers and organic manures have a carryover effect on the succeeding crops. The utilization efficiency of applied phosphatic fertilizers seldom exceeds 15 % by the first crop, but a substantial amount of them is left as residue for the next crop (Roy *et al.*, 1978). Out of the total utilizable nutrient content of FYM, only one-third N and two-thirds P are available to the current-season crop, leaving the rest to the succeeding crops (Yawalkar *et al.*, 1992).

Due to scarcity of phosphorus resources, every country has initiated steps to gradually restrict its export. Due to soaring demand for phosphorus fertilizer, the price of one ton of diammonium phosphate has increased from \$ 39 to \$ 1102 in the year 2009 according to a 2010 report. The alternatives are to use P in the organic form such as organic manures, green leaf manures, provide organic inputs to enhance organic P mineralization by soil microorganisms. Application of phosphorus solubilizing bacteria (PSB) such as *Bacillus megaterium* to enhance the solubilization of fixed forms of phosphorus, use of *Vesicular Arbuscular Mycorrhizae* (VAM) to enhance phosphorus mobilization to roots so that the efficiency of root system will be increased and most importantly rely on soil tests, phosphorus index guidelines and other nutrient management practices when applying fertilizers.

Amending soils with organic residues or green manures helps in increasing the phosphorus concentration in soil solution through mineralization of organic P compounds. Several decomposition products of organic materials in the soil are known to form chelates with multivalent metallic cations (Fe^{2+} , Al^{3+} , Mn^{2+} , etc.) in acidic soils and release the P bound to them. The effect of added organic manures in regulating the release of P and enriching the labile pool is more pronounced in strongly acidic soils than normal soils.

Biofertilizers have an important role in crop production in improving the nutrient supply to crop growth. Among these, *Bacillus sp.* and *Pseudomonas sp.* are the most studied phosphate-solubilizers (Rodriguez and Fraga, 1999). *Arbuscular Mycorrhizae* fungi have the ability to access much of soil P and make it more available to plants. Besides, biofertilizers increases the uptake of Zn, Cu, Fe, and Mn by plants.

However, information on the combined use of P mobilizing/solubilizing microorganisms along with P levels and FYM in maize and their residual effect on cowpea under high and low available P of Alfisol; of Karnataka are not studied. Keeping

in view of the above facts, the present investigation entitled “*Management of Phosphorus in an Alfisol with maize – cowpea cropping sequence*” was carried out with the following objectives.

- i. To study transformation of phosphorus fractions, P uptake and phosphatase activity during maize – cowpea cropping sequence.
- ii. To study crop growth and yield of maize and cowpea as influenced by P management.
- iii. To determine the best P management practices in an Alfisol.

II REVIEW OF LITERATURE

Phosphorus is one of the major nutrients, which limits the crop growth and productivity and has been the subject of intense research because of its chemical transformation in soil which limit its availability to plants researchable aspects viz. the native P compounds are mostly unavailable for plant uptake, some being highly insoluble and when soluble sources of P are added, they are readily converted to unavailable forms and with time may react further to become highly insoluble.

The amount of P in soil solutions and the capacity of the soil to supply P to the soil solution are very important with respect to phosphorus nutrition to crops. These are greatly influenced by the physical and chemical properties of soil. To make available the fixed phosphorus and to reduce the application of chemical fertilizers which is very costly, an attempt was made through this research to recycle phosphorus from fixed pool of soil to the plant.

Literature available on status, availability of phosphorus, growth and yield, nutrient uptake, phosphatase enzymes activity, different forms of phosphorus, P transformation and phosphorus adsorption under maize cowpea cropping sequence are arranged under the following sections:

- 2.1. Transformation of applied phosphorus in soil.
- 2.2. Effect of organic matter addition on P transformation in soil.
- 2.3. P adsorption studies.
- 2.4. P- solubilization by soil micro-organisms.
- 2.5. Phosphatase activity in soil.
- 2.6. Strategies for phosphorus management in soil.
- 2.7. Different forms of phosphorus as influenced by phosphorus application and PSM.
- 2.8. Relationship of P with other properties, yield and nutrients uptake by crops.
- 2.9. Nutrient uptake by maize and cowpea.
- 2.10. Changes in soil physico-chemical properties on P application, phosphorus build up and availability.
- 2.11. Growth and yield of crops as influenced by phosphorus levels, PSB, VAM and FYM.

2.1 Transformation of applied phosphorus in soil

When a phosphate fertilizer such as superphosphate is applied to a soil, all its phosphorus being water-soluble, immediately enters the soil solution and readily form new compounds with calcium, aluminium, iron and manganese, *etc.* and gets out of the solution as soon as the newly formed compounds are precipitated. These sparingly soluble compounds are called initial reaction products. All these reactions takes place

within close proximity of the site of placement of a phosphatic fertilizer and are fairly rapid.

Kelly *et al.* (2001) reported that application of P fertilizer is not necessary for sugarcane when acid-extractable P present in soil is 30 mg kg⁻¹ and if sufficient VAM propagules are present.

Devi and Reddy (2002) reported that mycorrhiza and rhizobium inoculation resulted in a significant increase in the quantities of phenolic compounds in roots and shoots of groundnut (cv. TMV2) plants compared to uninoculated plants. The production of some new compounds and the increase in the activity of peroxidase and polyphenol oxidase (catechol oxidase), following inoculation was observed. The accumulation of phenolics and the activation of oxidative enzymes were more pronounced in the dual-inoculated plants.

Uptake of phosphate into plant cells occurs against a steep concentration gradient, as the concentration within plant cells (1 to 10 mM) is 10,000-fold higher than that of the soil solution (Rausch and Bucher, 2002). The two important mechanisms for phosphate uptake in higher plant roots are the activity of high affinity phosphate transporters and the symbiotic association with arbuscular mycorrhizal (AM) fungi. AM fungi have the ability to access much of soil P and make it more available to plants.

Yang *et al.* (2002) investigated the effects of P fertilizer application and soil incubation time on soil inorganic P fractions (Pi) and Olsen P concentrations. Results showed that Resin-P, Water-P, bic-P, their summation (Av-P), and Olsen P were significantly correlated with the amount of P added. During the incubation, Resin-P decreased most of the three available fractions, yet Olsen P was relatively constant. Combined results suggest that available Pi fractions, especially the Resin-P fraction, may be better indicator than Olsen P at predicting P availability and P responses in calcareous soils.

Feng *et al.* (2003) compared uptake of P by AMF, associated with red clover, from three organic sources (lecithin, RNA and sodium phytate) and one inorganic P

Medina *et al.* (2003) investigated the effects of two *Bacillus* strains in single or dual inoculation with three AMF and compared to P-fertilization. For most of the plant parameters determined, the effectiveness of AMF species was influenced by the bacterial strain associated, particularly when colonized by *G. mosseae*.

Mohammed *et al.* (2003) reported that phosphorus concentration in plants inoculated with VAM was higher compared to that of plants that were not inoculated. Iron and zinc uptake increased with VAM inoculation.

Evaluation of soil phosphorus transformations by sequential fractionation and phosphatase hydrolysis were done by He *et al.* (2004). Added inorganic P from either chemical fertilizer or animal manure amendments was found mainly in the NaHCO₃ and

NaOH fractions. Changes in H₂O, NaHCO₃, and NaOH-extractable P were similar for P fertilizer-amended soils and unamended soils, indicating that soil properties played a major role in controlling P dynamics. In the H₂O fraction, inorganic P attained a low and stable level after an initial rapid decrease.

In mycorrhizal inoculated soil, P depletion extended up to 20 mm from the root surface. In non-VAM inoculated soil P depletion extended upto 10 mm from the root surface and remained unchanged at greater distances. In the mycorrhizal inoculated soils, the contribution of the 0-5 mm soil zone to P uptake was greater than the core soil, which reflects the hyphal contribution to P supply (Ortas *et al.*, 2004).

Saini *et al.* (2004) reported that microbial biomass C, N and P under sorghum (*Sorghum bicolor* L. and chickpea (*Cicer arietinum* L.) were significantly higher ($r = 0.641-0.735$, $P = 0.01$) when a combination of *Azospirillum brasilense* or *Rhizobium*, *Bacillus megaterium* and *Glomus fasciculatum* were used, and was maximum with 50 per cent of recommended fertilizers. VAM infectivity was also improved significantly with combined inoculants and FYM compared to sole application of FYM or fertilizers (N and P). The results suggested that for maximum crop yield only 50 per cent of the required fertilizer might be supplied along with bioinoculants.

Shen *et al.* (2004) evaluated the long term effect of continuous rice cropping and fertilization on crop yield, soil fertility and phosphorus fractions. The results showed that available soil P significantly decreased in the P-omitted treatments, but remained at a stable level in the P-applied treatments with time. Of the total inorganic P (Pi), Ca phosphates (Ca-P) were the dominant Pi forms (accounting for 69-71 %) followed by Fe phosphates (Fe-P), P occluded within Fe oxides (O-P) and then Al phosphates (Al-P). The NK treatment had significant Ca₂-P depletion with time compared with the NPK treatment, and a similar trend was observed for Ca₈-P despite decreasing Ca₈-P with time for the two treatments. In the NK treatment, Ca₂-P and Ca₈-P had a good correlation with Olsen-P. The significant changes with time were not observed for Fe-P, O-P and Ca₁₀-P.

Clark *et al.* (2005) analysed different fractions of P in each soil to assess their importance to plant acquisition by AM and non-AM plants. Total and organic P fractions in soil were relatively high compared with other extractable P fractions that are considered available to plants. Concentrations of mineral nutrients in shoot generally increased in plants associated with AM, which enhanced growth. Extractable P fractions appeared to be more readily available to AM plants than nonextractable fractions.

Green *et al.* (2006) conducted an incubation study on the aggregates of the no-till system and quantified the bioactive P changes over time. Water-extractable P and complexed inorganic P concentrations did not change significantly during the incubation. However, complexed organic P concentrations increased upto two fold during the 56 day incubation.

The transformation of added P in fifteen acid upland soils was studied by Hartono *et al.* (2006). The transformation of added P (300 mg P kg⁻¹) into other fractions was

studied by the recovery of P fractions after 1, 7, 30, and 90 days after incubation. After 90 days incubation, most of the added P was transformed into NaOH-Pi fraction. Soils developed from andesite and volcanic ash exhibited significantly higher NaOH-Pi than soils developed from granite, volcanic sediments and sedimentary rocks. Soil properties summarized as oxides-related factor, parent material, and clay mineralogy were concluded very important in assessing P transformation and P accumulation in acid upland soils in Indonesia.

Cardoso and Kuyper (2006) reported that mycorrhizal associations enable a better use of sparingly soluble phosphorus pools, thereby increasing the efficiency of added phosphorus fertilizer and of the large relatively immobile phosphorus pools.

Phosphate solubilization was related to pH decrease caused by growth of fungus in medium containing glucose as carbon source. *Aspergillus* spp. solubilized 480 $\mu\text{g ml}^{-1}$ of phosphorus, while *Penicillium* spp. solubilized 275 $\mu\text{g ml}^{-1}$ of phosphorus from tricalcium phosphate (0.5 %) after 4 and 3 days of growth respectively. Drop in pH during growth was more prominent in presence of TCP in the liquid medium. This indicates that absence of soluble P in media induces the acid production (Pradhan and Sukla, 2006).

Raiesi and Ghollarata (2006) reported that activities of alkaline phosphatase and acid phosphatase enzymes responded negatively to P addition, but positively to AM fungus inoculation and AM fungus inoculation led to an improvement of P and N uptake.

Reynolds *et al.* (2006) estimated variable responses of old-field perennials to arbuscular mycorrhizal fungi and phosphorus source. The results suggest that the degree of AMF benefit to a plant host depends not only on AMF species, plant species, and soil phosphorus availability, but also depend on the form of soil phosphorus.

Smith *et al.* (2006) quantified the contribution of AM fungi (*Glomus intraradices*) to P uptake by wheat. Results showed that 50 per cent of P uptake by plants was absorbed via AM fungi, even when P was added and it was also observed that application of P decreased both colonization and hyphal length density in soil.

In general it can be concluded from the above literatures that on phosphorus application, it immediately transforms to fixed form such as Fe-P, Al-P, reductant soluble-P, occluded-P and Ca-P.

2.2 Effect of organic matter addition on P transformation in soil

During decomposition of organic matter various organic acids are produced which solubilize phosphates and other phosphate-bearing minerals and thereby lower phosphate fixation. The decrease in phosphate fixation is due to the formation of phosphohumic complexes that are easily assimilated by plants. The replacement of the phosphate by the humate ion, and formation of a coating on sesquioxide particles by humus as a protective cover results in reducing the phosphate fixing capacity of the soil.

Szott and Melendez (2001) investigated the P availability under annual cropping, alley cropping and multistrata agroforestry systems. Greater resin P was associated with greater amounts and percentages of P in bicarbonate fractions and less P in residual fractions. With P fertilizer application, resin P increased. However, resin P increased even more when inorganic P fertilizers were combined with organic residue additions.

Guppy *et al.* (2005) reported that the incorporation of organic matter, which rapidly sorb applied phosphorus, increases P availability to plants. It was noticed that incubation of organic matter in soil, reduced phosphorus. However, the decrease in phosphorus sorption was not related to competition from the decomposition products of organic matter, but was the result of phosphorus release from the organic matter.

Reddy *et al.* (2005) conducted sequential fraction of soil P at the end of 16 weeks which were treated with and without fertilizer P in combination with crop residues. In the study it was observed that a major part of added fertilizer P transformed into moderately labile and stable P fractions as evident from the increased NaOH-Pi and HCl-P in the FP treatment. In contrast, the addition of soyabean residue and wheat residue alone or in combination with FP favoured a build-up in NaHCO_3 -Pi and -Po and NaOH-Po fractions while causing a decrease in NaOH-Pi and HCl-P fractions.

Sheeba and Kumaraswamy (2005) revealed that amongst manures, application of urban compost at 12.5 t ha^{-1} improved the maximum status of total P (895 ppm) and organic (143 ppm) and inorganic P (743 ppm) followed by FYM application at 12.5 t ha^{-1} . However, available P was the highest (78 kg ha^{-1}) in plots receiving FYM followed by urban compost (72 kg ha^{-1}). Amongst fertilizers, the maximum values of total P (874 ppm), inorganic P (709 ppm) and available P (85 kg ha^{-1}) were found in NPK at 120:60:60 with almost on par value in the fertilizer treatments receiving 60 kg P ha^{-1} . Organic P content was almost similar in fertilizer treatments.

Sangeeta *et al.* (2006) studied the uptake of P from organic manures in groundnut-corn sequence using radio tracer technique. It was observed that in both the crops, organic manure had a significant effect on the uptake of P as compared to SSP and control. Poultry manure and sewage sludge applications showed higher P uptake from soil. In case of residual corn, the per cent of P was more from organic manures than for SSP, obviously due to greater residual availability and P release from organic sources. The highest A value was associated with SSP and lowest with FYM. The highest P uptake and therefore the highest P use efficiency, was due to FYM.

It can be concluded that the addition of organic manures decreases the fixation of added P in soil through the decomposition products like organic acids, which chelate with multivalent metallic cations. Addition of organic manures also enhances soil microbial growth and phosphatase enzyme activity in soil and thus brings about P solubilization.

2.3 P adsorption

Iyamuremye and Dick, (1996) revealed that the phosphorous retention (sorption) capacity of soils refers to the capacity of the soil to precipitate P with minerals or adsorb

P onto AEC sites. Adsorption is the main mechanism that leads to P retention in soils, and is influenced by many factors such as the nature and amount of soil minerals, soil pH, cation and anion effects, the extent of soil saturation with P, organic matter, reaction time and temperature, flooding, and fertilizer P management. Aluminum (Al) and iron (Fe) oxides are abundant in acidic and weathered solution (Fox and Kamprath, 1970). Soils with higher clay content, and higher Al and Fe content, will have higher P retention capacities. In calcareous soils, P is adsorbed to calcium carbonate (CaCO_3) surfaces. Calcium carbonate has a large surface area for P binding and this leads to enhanced P adsorption and precipitation to Ca minerals (Parfitt, 1978).

Total P in agricultural soils has been reported to range from 300-1200 mg P kg⁻¹ (Havlin *et al.*, 1999). The total P pool in soils consists of inorganic P (orthoP) and organic P compounds. Solution P concentrations of 0.1 to 1 mg P L⁻¹ are common in soils. When ortho-P ions are added to soils, they are adsorbed quickly on mineral particles and are subsequently "fixed" in less soluble states (Bohn *et al.*, 1979). In acidic soils, most of the solid phase P is associated with aluminum (Al) and iron (Fe), while basic soils contain more calcium (Ca) associated P.

Hooda *et al.* (2000) observed that the amount of P desorbed using a successive dilution procedure had no relationship with either total soil P content or P sorption capacity. The most significant property was the extent of P saturation. There was little desorption for DSSP values below 10 %; above this point, the amount of P desorbed increased linearly with the DSSP. Five STP methods (Olsen, Mehlich-3, acidified ammonium oxalate-oxalic acid, Fe_2O_3 -coated paper strip, and distilled water) were compared to predict their effectiveness in predicting potential P release to water. While STP values obtained using acidified ammonium oxalate proved to be least effective, those extracted with water correlated best with the amount of P desorbed, accounting for 96 % of the variability in differential P release from the soils.

Vasanthi *et al.*, (2000) conducted a lab incubation study to assess the P fixing capacity, the amount fixed increased with increased level of P added; however the fixation of added P was more in soils which were low in P content followed by medium content and sesquioxides sorbed P under coffee plantation.

Roberto and Paolo (2004) investigated the existence of a change point by evaluating the relationships between CaCl_2 -extractable P and Olsen-P test values in soils collected from two sites selected to have a similar wide range of soil extractable P (Olsen-P concentration was in the range of 4-171 mg P kg⁻¹ for both soil groups), but very contrasting P adsorption properties (the P sorption index, a P sorption capacity related soil parameter, ranged from 335 to 669 mg P kg⁻¹ in one group of soils, and from 1124 to 1482 mg P kg⁻¹ in the other one). A close linear correlation between CaCl_2 -P and Olsen-P was verified in samples from both the sites studied. However, a change point of 88 mg kg⁻¹ Olsen-P was evident for less P sorbing soils, whereas no change point could be determined in soils with the highest P retention, probably because the latter groups of soils were not sufficiently saturated with P, even if having high content of Olsen extractable phosphorus.

Heneriquez and Killorn (2005) observed that the initial P desorbed was related to labile-Pi. The forest soil had the higher rate of P desorption as compared with coffee and sugar cane soils even though this was defined under specific time conditions imposed by the methodology.

Zhang *et al.* (2005) Revealed that the $S_{\max}$ value ranged from 34 to 500 mg kg⁻¹ and was highly correlated with clay content ($r = 0.79$), organic C ($r = 0.80$), Al_{ox} ($r = 0.88$), and Fe_{ox} ($r = 0.83$). Soil pH was not correlated ($p > 0.05$) with $S_{\max}$. Path analysis showed significant direct effects ($p < 0.01$) between Al_{ox} and $S_{\max}$ and between Fe_{ox} and $S_{\max}$ but these relationships were highly influenced by indirect effects of Al_{ox} and Fe_{ox} . Multiple regression agreed well with path analysis and found that the combination of Al_{ox} and Fe_{ox} were the two most important soil properties related to $S_{\max}$ of the soils studied. Significant relationships existed between Al_{M3} ($r = 0.54$) and $S_{\max}$ and between Fe_{M3} ($r = 0.54$) and $S_{\max}$. Three P saturation indices studied were highly correlated ($p < 0.05$) with each other. Our results show that $S_{\max}$ of Oklahoma soils may be predicted with oxalate extractable Al and Fe or M_3 extractable Al, Fe, and Ca.

Pal *et al.* (2009) studied the effect of land use pattern on P adsorption desorption in Terai soils of West Bengal. The different land use pattern used for the study was forest, orchard, cultivated land and tea garden. The results indicated phosphorus adsorbed at 0.2 mg L⁻¹ equilibrium solution P concentration in these land uses was low (40.2 to 67.6 mg kg⁻¹). The adsorption behaviour of these soils could be significantly correlated with Freundlich, Langmuir and Tempkin equations. The study revealed that phosphorus adsorption at 0.2 mg L⁻¹ equilibrium solution P concentration was significantly correlated with organic carbon, CEC, free Fe_2O_3 and AEC, suggesting the role of these soil characteristics in P sorption process. Higher amount of added P was extracted during two successive desorption with 0.5 M $NaHCO_3$ (pH 8.5).

Egwu *et al.* (2010) initiated a study to determine the P sorption characteristics and derive parameter estimates relevant in the prediction and management of P in major soils of the Nigerian savanna. The adsorption isotherms for the soils were gentle to steep, covered a wide range of P sorption characteristics. The Langmuir plots gave gentle curves in most cases, indicating that the assumptions on which the model was based were not fully satisfied. The Langmuir parameter estimates varied widely for the soils. The energy coefficient (K) ranged from 0.015 to 11.593 ml μg^{-1} and was particularly high for soils of the Jos plateau with appreciable amounts of Fe oxides. The standard phosphate requirement (SRP) ranged from 2.87 - 1021 $\mu g g^{-1}$, which implied that P amendment (fertilization) would be necessary for good crop growth in a good number of soils. P sorption parameters appreciably influenced by dithionite extractable Fe (Fed). Generally, pH and CEC explained over 50 % of the variation in the sorption parameters in these savanna soils.

In a study conducted by Mozaed *et al.*, (2010) to determine P sorption characteristics of five soil samples of southeastern Iran in a cropping system illustrated that Langmuir adsorption isotherm was much accurate for P adsorption and had maximum r^2 . The adsorption of P was different for different soil due to the soil

parameters like soil organic carbon (SOC), pH, exchangeable calcium, aluminium (Al) etc. results also indicated that SOC, and exchangeable Al are the major predictors of P sorption in these soils.

Qingren Wang and Yuncong Li, (2010) observed that the sediments from the canal and lake had the greatest native adsorbed P and the highest zero equilibrium P concentration. Sediment from the estuary had the highest P adsorption and followed by those from wetland and marine origins, respectively. Phosphorus de-sorption from sediments by replacing exchangeable P with Cl^{-1} (20 mmol L^{-1} KCl) was obtained from an excellent fit of the data by an exponential growth model of desorption kinetics. The fractions of retained P ($P_{\text{ret}} = P_{\text{ads}} - P_{\text{des}}$) were as high as 85-98 % in the studied sediments, which displayed strong P retention capacities by all these sediments.

2.4 P- solubilization by soil micro-organisms

Available phosphorus status of most of the soils is less because of its immobile nature and the phenomenon of P fixation. Though soils usually contain high total phosphorus, the negligible quantity of plant available form of P becomes the major bottle neck for crop production. In this context, solubilization of fixed form of phosphorus to plant available form has great importance.

Microbial solubilization of hardly soluble mineral phosphate in soil is an important process in natural ecosystem and in agricultural soils because, in soil, both macro- and micronutrients undergo a complex dynamic equilibrium of solubilization and insolubilization that is greatly influenced by the soil pH and microflora which ultimately affects their accessibility to plant roots for absorption.

Khan *et al.* (2009) showed greater efficiency of P solubilizing bacteria through co-inoculation with other beneficial bacteria and mycorrhiza.

PGPR based products mostly contain strains of *Bacillus* that may have direct agricultural application because of long term viability of these sporogenous bacteria. Therefore, *Bacillus* spp. has the potential to be applied as booster inoculants to increase the efficacy of plant growth promotion and elicitation of systemic disease protection in the field (Kloepper *et al.*, 2004).

The stimulation of the microbial biomass by added organic carbon due to manure application, and its role in soil P solubility was reported by Leytem *et al.* (2005). The net P balance was slightly positive in soils treated with single super phosphate and Azophos with or without FYM.

Local farmers, living in South Kalimantan (Banjarese farmers), apply almost none of phosphatic (P) fertilizers to grow local rice varieties. This practice has been adopted for many years. P uptake by the rice crop was much higher than the sum of P released from soil, water and soil microbial biomass P. It was also observed that these soils harboured bacteria and fungi that have the capability of dissolving aluminium phosphate (AlPO_4) and tricalcium phosphate [$\text{Ca}_3(\text{PO}_4)_2$]. Based on the area of clear zone on plates,

it was concluded that there were variations of ability in dissolving Al-P or Ca-P, (Purnomo *et al.*, 2005).

Genes were involved in mineralization of organic P sources (by the action of enzymes - acid phosphatases and phytases), as well as mineral phosphate solubilization, were identified which improved agricultural production (Rodriguez *et al.*, 2006).

Kaleeswari *et al.* (2007) reported that the dissolution of P was significantly higher with P fertilizer + FYM + Phosphate solubilizing microorganisms irrespective of the P sources. Higher phosphatase activity was observed in FYM treated plots.

2.5 Phosphatase activity

Dick *et al.* (2000) investigated the influence of soil pH on phosphatase activity and showed that the ratio of alkaline phosphatase to acid phosphatase responded immediately to the changes in pH caused by CaCO₃ addition and an AlkP:AcidP ratio of approximately 0.5 divided soils into those with appropriate pH adjustment and those still needed additional lime treatment. For cropping systems that rely heavily on natural biological processes to maintain productivity, measuring the AlkP:AcidP ratio may be preferable to chemical approaches for evaluating effective soil pH and liming needs.

Experiments of Yadav and Tarafdar (2001) showed that an organic P concentration of 250 mg L⁻¹ and above, and an inorganic P concentration <50 mg L⁻¹ provided the most suitable conditions for plants to secrete a maximum amount of acid phosphatase.

As a result of histochemical procedure, developed to visualize the excretion of phosphatase by arbuscular mycorrhizal (AM) fungi (*Glomus mosseae*), Fen *et al.* (2002) reported that AM hyphae increased the activities of acid and alkaline phosphatase and decreased the concentration of soil organic phosphorus in the hyphal compartments and the acid phosphatase activity was observed around the hyphae.

Fox and Comerford (2002) examined the acid phosphatase activity in the rhizosphere of slash pine and reported that phosphorus fertilization decreased the phosphatase activity in the rhizosphere soil. Soluble organic P comprised of 15 - 25 per cent of the total soluble organic P in two A horizon soils and over 75 per cent in the Bh horizon soils and between 20 and 30 per cent of the water soluble organic P in the A and Bh horizons of the two soils which was hydrolyzed when an acid phosphor mono esterase was added.

Ekenler and Tabatabai (2003) investigated the long term influence of lime application and tillage systems on activities of acid and alkaline phosphatase. Acid phosphatase was significantly (P 0.01) but negatively correlated with soil pH. The Δ activity/ Δ pH values were calculated to determine the sensitivity to change in soil pH. Acid phosphatase was most sensitive and aryl sulphatase was least sensitive to changes in soil pH. Activities of enzymes were greater in the 0 - 5 cm depth sample than those in 0.15 cm samples.

Li *et al.* (2004) reported that soil acid phosphatase activity in the rhizosphere of chickpea was significantly higher than maize regardless of P sources.

Sarapatka *et al.* (2004) indicated that the acid phosphatase activity in the root system of various species and cereal cultivars was negatively correlated with increasing pH and available phosphorus level in the nutrient medium.

Zornoza *et al.* (2006) evaluated the effect of air-drying or air-drying followed by rewetting on acid phosphatase activity and the results showed that the phosphatase activities were hardly affected by air drying of soils, collected from two locations studied in all seasons.

The mineralization of organic P was mediated by phosphatases that hydrolyze carbon-oxygen-phosphorus ester bonds. Therefore these enzymes are very important in the P nutrition of plants (Kaleeswari, 2007).

Betty *et al.* (2008) showed that the kind of organic phosphorous of medium affect phosphatase activity of *Pseudomonas mallei*, *Bacillus subtilis*, *Aspergillus niger* and *Penicillium sp.* In general, all microbe grown on medium with organic P substrate of phytic acid (myo-inositol hexalphosphate) showed highest phosphatase activity compared to those grown on organic P substrate from glycerophosphate disodium salt, phenil phosphate or α -D-glucose 1-phosphate disodium salt. On the other hand, the highest dissolved P was obtained from the medium which contained glycerophosphate disodium salt.

Garg and Bahl (2008) observed that the overall, phosphatase activity, Paranitrophenyl phosphate (PNP $\text{h}^{-1}\text{g}^{-1}$), in the Ladhowal silt loam soil was higher than in the Samana sandy loam soil. As the level of inorganic P increased, the release of PNP $\text{h}^{-1}\text{g}^{-1}$ soil also increased. Among different organic manures, PM registered the highest enzyme activity followed by FYM, GM and CR. Compared to seven days incubation a slightly higher increase in PNP was noticed in samples from 90 days incubation in both soils. The deferential phosphatase activity in the organic manures was further reflected in dynamic P availability.

Saha *et al.* (2008) reported that both acid and alkaline phosphatase activities were negatively influenced by chemical fertilizer treatment. Almost all the enzymes studied were significantly correlated with soil C content. The results suggested that application of FYM directly or indirectly influenced the enzyme activity and in turn regulates nutrient transformation.

Alocious Anu (2009) opined that a large proportion of phosphorus in soil exists in organic form (50-80 % of total P). The cycling of organic P has a large effect on P availability and long term ecosystem productivity. The organic fraction of soil P received relatively little attention, because of its complex nature. In order to become available to plants, P compounds must be hydrolyzed by phosphatases, which are of plant and microbial origin. Measurement of specific enzyme activity is useful in determining soil

biological activity which might be used as an index of soil fertility. Phosphatase produced by microorganisms and plant roots have a major role in the hydrolysis of soil organic P thereby releasing inorganic P for plant uptake. Ester hydrolysis of P by phosphatase enzymes is a major factor in the P cycle in soil.

Jose *et al.* (2011) indicated that the acid phosphatase activity was greater when legumes achieved greater phytomass development, thus highlighting the root's stimulating effect on soil biological activity.

Lemanowicz (2011) observed that the lowest content of available phosphorus was found in soil without P fertilization (K, Mg, Ca, and S). A significant effect of nitrogen fertilization on the activity of alkaline and acid phosphatase was found. Increasing doses of nitrogen resulted in increased acid phosphatase activity while contributing to the reduction of alkaline phosphatase activity.

Banerjee *et al.* (2012) investigated the phosphatase activity of 10 soil samples, collected from the various agricultural lands, of the Burdwan district, West Bengal, India. The maximum unit of activity was 6.393 in standard assay conditions. The phosphatases present in a soil sample were heterogeneous and might be utilized as a major parameter to assess soil fertility in an agricultural land.

Adnane *et al.* (2012) observed that the variations of APase and phytase activities in nodules and seeds depend on genotype and can greatly influence the internal utilization of P, which might result in low P soil tolerance in N₂-fixing legumes.

Nath and Samanta (2012) indicated that the rice field soil showed more nitrate reductase activity (11.09 µg/ml/hr), while botanical garden soil showed higher alkaline phosphatase activity (26.40 µg/ml/hr). Isolation, characterization and identification of microbes from soil with higher alkaline phosphatase activity and their proper culture and implementation as a source of biofertilizer will open a new area in organic cultivation.

Onthong *et al.* (2014) found that the optimum pH for acid phosphatase activity was 3.5-4.5. The activity of acid phosphatase secreted from AR101 (3,690 nmol min⁻¹ mL⁻¹) was remarkably higher than that from AR 102 (956 nmol min⁻¹ mL⁻¹).

Ye *et al.* (2015) indicated that the acid phosphatase activities was enhanced by both swine manure application and rhizosphere processes.

2.6 Strategies for phosphorus management in soil.

Hocking (2001) reported that improved P use efficiency is critical to reduce the consumption of P fertilizer and to enable the withdrawal of some of the previously applied fertilizer P locked up in the soil P “bank”. Crops that can access reserves of P through exudation of organic acids in high P fixing soils in developing countries can help sustain agricultural production improve P fertilizer use efficiency and enable the use of cheaper and more readily available sources of P fertilizer such as rock phosphates.

Vasuki *et al.* (2002) opined at the end of 6th year that cured leaf yield of tobacco was not significantly affected either by reducing the level of application to 30 kg P₂O₅ ha⁻¹ or by omitting the P application. Application of 30 kg P₂O₅ ha⁻¹ once in three years recorded a cured leaf yield of 1161 kg ha⁻¹. Similarly the quality with respect to nicotine and reducing sugar content did not differ significantly. Based on the highest benefit: cost ratio and depletion of available P in soil, application of P @ 30 kg ha⁻¹ once in three years was sufficient to meet the P requirement.

Aulakh *et al.* (2003) revealed that (a) long-term applications of fertilizer P to both crops each year significantly increased residual fertilizer P accumulation in soil and accelerated its conversion to non-labile P forms. (b) While application of fertilizer P to winter crops was essential, P requirement of summer grown groundnut was met from soil derived and residual fertilizer P; this practice helped enhance fertilizer use efficiency (42-54 % as compared to 27-40 % in cumulative P treatment), saved costly fertilizer (50 %), and reduced P accumulation by 44-76 %. (c) The Olsen-P test alone was not adequate to reflect the depletion/accumulation of bio-available P.

Miller *et al.* (2003) proposed that adventitious rooting was a useful adaptation to low phosphorus availability, because adventitious roots explore top soil horizons more efficiently than other root types.

Singh and Pandey (2003) reasoned that both inter- and intra-species differences do exist among maize and green gram in terms of root exudation, P uptake, shoot and root P content. In general, green gram, a legume crop, had greater root exudation compared to maize. However, the amino acid content of the total root exudates in maize was two-fold as compared to green gram. The maize and green gram genotypes possessed genetic variability in root exudation. Irrespective of the species or genotypes, a positive relationship was found among P uptake rates, total root exudation, and shoot and root ³²P content. The amount of sugars and amino acid present in the root exudates of P-starved seedlings also add to the variation in P uptake efficiency of genotypes.

Ibrikci *et al.* (2005) reported that under irrigated conditions, corn was likely to respond to P fertilization, but buildup of available P can occur within a few years and adequate plant available P levels can be maintained in soil by modest P fertilizer application rates.

Zhu *et al.* (2005) demonstrated that genetic variation for root shallowness exists in maize and that P and AM can modulate root shallowness independently, shallower root system was beneficial for plant performance in maize at low P availability. They proposed that root architectural traits enhanced topsoil foraging which were important traits for improved P acquisition efficiency of annual grain crops such as maize in addition to legumes.

Kleinman *et al.* (2009) grew four genotypes of common bean (*Phaseolus vulgaris* L.) and two genotypes of soybean (*Glycine max*) of contrasting root architecture in a low P soil (Aquic Fragiudult, <20 mg kg⁻¹ Mehlich-3 P) and subjected it to rainfall run off

experiments with and without shoot removal. Plots with intact shoots had significantly lower run off volumes (1.3 - 7.6 mm) and total P loads in runoff (0.005 - 0.32 kg ha⁻¹) than plots with shoots removed (7.0 -16.8 mm; 0.025 - 1.95 kg ha⁻¹). Dissolved reactive P leached from plant material did not contribute significantly to P loss in runoff.

Jakkeral and Kajjidoni (2011) indicated that organic acid (root exudates) release and root production were enhanced in times of nutrient stress and responsive genotypes were found to be superior in both acquisition and utilization of phosphorus due to enhanced root production and shoot expansion, respectively. Hence increased release of citric acid and oxalic acid coupled with increased root volume may provide a mechanism by which P deficient plants can enhance availability of P in the rhizosphere.

Richardson *et al.* (2001) discussed that the rate of P accumulation in moderate to highly P-sorbing soils is a major contributor to inefficient P-fertiliser use. They discussed the causal edaphic, plant and microbial factors in the context of soil P management, P cycling and productivity goals of farms. Management interventions that can alter P-use efficiency are explored, including better targeted P-fertiliser use, organic amendments, removing other constraints to yield, zone management, use of plants with low critical-P requirements, and modified farming systems. Higher productivity in low-P soils, or lower P inputs in fertilized agricultural systems could be achieved by various interventions, but it is also critically important to understand the agroecology of plant P nutrition within farming systems for improvements in P-use efficiency to be realised.

Richardson and Simpson (2011) discussed that the soil microorganisms play an important role in the cycling of P in soil-plant systems and it is expected that better understanding of their contribution to the mobilization of soil P and plant P nutrition will provide opportunity for development of more P-efficient and sustainable agricultural systems and improved knowledge of ecosystem function.

Balemi and Negisho (2012) pointed out that the maintenance of soil P at a target value through either of the following ways: application of P fertilizers, periodic incorporation of crop residue, and application of organic manures would be very essential for sustainably higher crop yield. Under conditions where all these soil P management options might not be possible, the use of P-efficient crops or crop genotypes, having desirable traits that enable them to have better performance under P stress conditions, might serve as an alternate option for sustainable crop production.

From the literature it is clear that use of P efficient variety of crop, application of organic matter with PSM and VAM are good for mining P from soil fixed pool and mineralization of organic P. Arbuscular mycorrhiza help plant to reach place where P is available.

2.7 Different forms of phosphorus as influenced by phosphorus application and phosphorus solubilizing microorganisms

Soil P exists in various chemical forms including inorganic P (Pi) and organic P (Po). These P forms differ in their behavior and fate in soils (Hansen *et al.*, 2004).

Heneriquez and Killorn (2005) observed that the P fertilization impacted labile-Pi, NaOH-Pi, and HCl-Pi supporting the readily and reversible available nature of these soil P forms that occurred during the 120 days, of the study. NaOH-Pi and HCl-Pi seem to act as sinks of applied P when the labile-Pi is not able to hold high amounts of applied P. Residual-P could participate in replenishment of depleted available P forms under certain conditions, i.e. low amounts of labile-Pi even though the rate or replenishment may not meet the plant requirements over time. Plant P uptake was related to the amount of available labile-Pi.

Rocha *et al.* (2005) conducted a study on P fractionation in high P soils derived from volcanic parent materials. The results showed that high P content in the soil samples were derived mainly from the soil parent material. As a consequence, the organic P was less important than inorganic forms in contributing to the total P in such soils. Ca-P and Fe-P fractions were the most important chemical forms in the soil samples.

Fuleky (2006) studied the P supply of thirty six Hungarian soils, collected from the soil bank, by determining the inorganic phosphate fractions. The P fractions analysed were sorbed phosphates, easily soluble Ca phosphates, Al bound phosphates, Fe phosphates and hardly soluble Ca phosphates. The observations showed the accumulation of P in the form of easily soluble Ca-P and Fe-P as the main phosphorus source for the plants on both calcareous and non-calcareous soils. The Fe phosphates play greater roles in non-calcareous soils while the hardly soluble Ca phosphates in calcareous soils.

Schroeder and Kovar (2006) conducted a P fractionation study using soils of Tipton Creek in central Iowa, USA. Most of the extractable inorganic P (32 to 39 %), in the crop field was present in the calcium (Ca)-P fraction. Levels of the most labile P fractions were higher in the cropped area compared to non-cropped area.

Silveira *et al.* (2006) studied P distribution in different soil orders in the semi-arid states of Paraiba and Pernambuco in Brazil. The results showed that the largest proportions of total P were in the residual fraction and the smallest in the labile fractions (resin-P and NaHCO_3 -Pi). Mehlich extracted low proportions of P from Vertisols (1 %) and high proportion from Latosols (24 %), while the opposite was true for bicarbonate extraction (11 and 5 %, respectively).

Kolawole and Tian (2007) concluded that the amendment of the near-neutral soils of West Africa with PR combined with or without selected plant residues increased most of the P fractions after the four weeks incubation period. However, application of PR alone was not beneficial to the test crops. This indicated that other nutrients apart from P alone were responsible for the post incubation response of test crops to the combined application of PR with plant residues.

Olusegun and Yerokun (2008) reported the distribution of total P, organic P, inorganic P [aluminum plus iron P (Al+Fe-P) and calcium P (Ca-P)] and occluded P of twenty soils of Zambia belonging to several soil orders and originating from different agro-ecological zones. Total P in the soils were observed to be similar to those found in

more productive regions, ranging from 126 mg kg⁻¹ in the Bulozzi Inceptisol to 742 mg kg⁻¹ in the Malashi Alfisol. There was overlap in total P contents determined among soil orders, this is attributed to interruptions in the pedogenic process whereby new material was deposited on more weathered old basement complex. Soil organic P content was relatively low (3-175 mg kg⁻¹) and constituted an average 15 % total P. The ratio of organic carbon to organic P was generally less than 200, suggesting the potential for significant mineralization of organic P. The Al+Fe-P was the dominant inorganic P pool because of high Al and Fe oxides contents of these soils. The range of Al+Fe-P was 1-246 mg kg⁻¹ while Ca-P was 1-78 mg kg⁻¹. A disproportionately high fraction of total P (18-88 %) was tied up in the occluded P pool. It was observed that clay content and Fe plus Al oxides content of the soils explained 62 and 51 %, respectively of the variation in occluded P. Therefore the presence of high amounts of oxides and the rate of soil weathering due to high temperatures and moisture in part explain the low availability of P in Zambian soils.

Alocious Anu (2009) indicated that in soils P is present in both organic and inorganic forms. The inorganic P constitutes a dominant part of total P, it being 52 – 95 percent. The different forms of inorganic P in the soil are Al-P, Fe-P, Ca-P, reductant soluble Fe-P and occluded-Fe and Al phosphate. Phosphorus bound to aluminium (Al-P), iron (Fe-P) and calcium (Ca-P) constitutes the major active form of inorganic P. Reductant soluble forms are the highly fixed forms of P. All these forms exist in all soils but generally Al-P and Fe-P are more abundant in acid soils while Ca-P dominates in neutral-alkaline soils. Highly mobile-P in sodic soils is thought to be associated with sodium ions (Na⁺). Various forms of P are interrelated and contribute to the pool of plant-available P according to their physico-chemical properties such as composition, solubility, surface area, etc.

Halajnia *et al.* (2009) observed that the manure application had an appreciable and different impact on the chemical fractions of P in calcareous soils as P from manure gradually turned into available forms over the time.

Chatterjee *et al.* (2014) revealed that the calcium-P was the dominant fraction in Inceptisol used for the study. Phosphorus fixation was high in Alfisol (58.72 % for colloidal clay and 67.26 % for non colloidal clay) Phosphorus fixation was positively correlated with different pools of iron and aluminum compounds.

Annaheima *et al.* (2015) indicated that the presence of different forms of organic P in the organic fertilizers (dairy manure, compost and sewage sludge) characterized by ³¹P solution NMR spectroscopy and enzyme additions, corresponding soil organic P forms remained largely unaffected by 62 years of different fertilization treatments. Only changes in inorganic P in accordance with the P balance were observed, as well as an accumulation of non-hydrolyzed MUP after application of sewage sludge. The similar composition of soil organic P across the different fertilization treatments suggests that annual additions of specific organic P forms such as isomers of IP6 as determined by ³¹P NMR and phytate like P or nonhydrolyzed MUP as determined by enzyme additions in the order of 4 kg P ha⁻¹ yr⁻¹ were completely transformed in the slightly acidic top soil,

or else lost from it. The study also found no indirect effects of the contrasting fertilization treatments on the composition of soil organic P, which thus appears to be governed more by other factors such as climate, vegetation or mineralogy.

Shi *et al.* (2015) demonstrated that P in cultivated soils changed during winter as a result of changes in labile P fractions possibly due to the solubilization of residual fertilizer P combined with environmental factors.

Ye *et al.* (2015) indicated that the P accumulation in P. hydropiper was significantly higher at 100 g kg^{-1} compared to the control. Besides, P accumulation of the ME were higher than the NME's. Swine manure application increased the levels of various P fractions. H_2O , NaHCO_3 - and NaOH-Pi (Pi, inorganic P) could be utilized efficiently by both ecotypes. Significant depletions of NaHCO_3^- and NaOH-Po (Po, organic P) were observed in the rhizosphere of the ME compared to the NME. No statistical changes of HCl^- and residual-P were observed in the rhizosphere.

2.8 Relationship of P with other soil properties, yield and nutrients uptake by crops

Barroso and Nahas (2005) revealed that a significant negative correlation was found between titratable acidity and pH ($r = -0.30$, $p < 0.01$), and between titratable acidity and mycelium dry weight ($r = -0.12$, $p < 0.05$).

John (2006) reported that there was a highly significant and positive correlation between harvest index with total dry matter production (0.846^{**}). Grain yield showed highly significant and positive correlation with total dry matter production (0.585) and harvest index (0.595). Significant and positive regression coefficients were obtained between grain yield and dry matter production, ($r^2 = 0.3747$) harvest index ($r^2 = 0.4691$) and dry matter production with harvest index ($r^2 = 0.7416$).

Rossella *et al.* (2007) indicated that on the basis of a correlation analysis of soil properties, soil nitrate content and pH were inversely correlated. Total N was positively correlated with all forms of soil P, as well as with $\text{NH}_4\text{-N}$ and soil water content. Total P was correlated with available and organic P, as well as with $\text{NH}_4\text{-N}$ and soil water contents.

Halajnia *et al.* (2009) observed that the Olsen-P, in P-treated soils, showed a positive correlation with the NH_4OAc extractable Al and active CaCO_3 . Increases in recovery as CBD-P revealed that Fe oxides play an important role in P sorption during 0-30 days. The relative distribution of P fractions and Olsen-P followed the order of $\text{HCl-P} > \text{OAc-P} > \text{Organic-P} > \text{CBD-P} > \text{Olsen-P} > \text{NaCl-NaOH-P}$. The CB-P fraction was not measurable. Application of manure along with P increased the recovery of applied P and recovery as CBD-P compared with the P treatment.

Chatterjee *et al.* (2014) revealed that the phosphorus fixation was positively correlated with different pools of iron and aluminum compounds.

2.9 Nutrient uptake by maize and cowpea.

Nuruzzaman *et al.* (2004) demonstrated a residual benefit of the legumes on the growth of the subsequent wheat crop due to enhanced P uptake. Faba bean was the best of the species tested in promoting subsequent wheat growth, and therefore it appears to be a suitable P-mobilizing legume crop for use in rotations with wheat. The results of the second experiment, using one soil type, showed that the increased growth and P uptake of the subsequent wheat did not require the presence of the roots of the previous crops, suggesting that rhizosphere effects on soil P status were more important for P availability than mineralization of root residues.

The results obtained showed superiority of single super phosphate (SSP) application over either Sokoto or Ogun rock phosphates. However, complementary application of the Sokoto and Ogun rock phosphates with poultry manure increased P content in maize and cowpea. The leaf tissues increased respectively by 33 and 22, and 22 and 25 % in 2000, and by 25 and 6, and 16 and 18 %, respectively in 2001. Single super phosphate treated soil had the highest residual P values in all the three sampling periods (Akande *et al.* 2005).

Gupta *et al.* (2006) indicated the effect of bio-fertilizer inoculation and phosphorus fertilization on N and P uptake. The practice of seed inoculation with phosphorus solubilising bacteria showed a significant increase in N and P uptake over uninoculated treatment. Phosphorus application also resulted in significant increase of N and P uptake in seed and straw.

Jat and Ahlawat (2006) revealed that application of 3 t vermicompost ha⁻¹ to chickpea improved total N and P uptake by the cropping system over no vermicompost. Seed inoculation of chickpea with Rhizobium and PSB (phosphate solubilizing bacteria) increased total N and P uptake by the cropping system over no inoculation and inoculation with Rhizobium alone. Application of phosphorus up to 26 kg P ha⁻¹ to chickpea improved total N and P uptake by cropping system.

Garg and Bahl (2008) observed that the total P uptake by maize increased with increasing level of inorganic P in both soils. The highest uptake was obtained in PM treated soil and lowest in the CR amended soil.

Hussaini *et al.* (2008) revealed that the nutrient concentration either increased or decreased with increasing N and P application levels. However, increasing levels of nitrogen and phosphorus application either significantly enhanced the accumulation of nutrients in the grain and stover or failed to influence nutrient accumulation and in the same vein the uptake of nutrients by the maize plant. Irrigation in frequency influenced nutrient concentration and accumulation in maize very minimally but increase in frequency significantly increased concentration and accumulation for certain nutrients. Nitrogen x phosphorus interactions was significant for P concentration and N accumulation in maize grain.

Dutta and Bandyopadhyay (2009) revealed that the P and biofertilizers application significantly influenced the P uptake of chickpea. Seed inoculation with Rhizobium and phosphobacteria was significantly superior over no inoculation or phosphobacteria inoculation alone. Combined application of P at 26.2 kg ha⁻¹ and bio-fertilizers (Rhizobium and phosphobacteria) enhanced significantly P uptake compared to other levels of P with bio-fertilizer.

Jensen *et al.* (2009) investigated the content of six macro elements (N, P, K, S, Mg, Ca) at the tasseling stage and were found to be able to predict 83 % of variation in the grain yield at maturity whereas the inclusion of micronutrients only improved this prediction with an additional 3 %. N alone predicted 50 % of the variation in grain yield and the N supply of the maize crops in eastern and southern Africa must thus be the first priority before yields can be improved.

Adnane *et al.* (2012) reasoned out that low P decreased P uptake and N accumulation in all the genotypes, but to a greater extent in the sensitive recombinant inbred line 147. In addition, while seed P content was slightly reduced under low P soil; a higher P was noticed in the Flamingo and Contender large seeded-beans (6.15 to 7.11 mg g⁻¹).

Mehta *et al.* (2012) observed that the application of 20 kg N and 18 kg P ha⁻¹ significantly increased N, P and K content and uptake by seed and straw of fenugreek over their respective lower levels. Combined inoculation of seed with Rhizobium and phosphorus solubilizing bacteria resulted in the highest benefit cost ratio, N, P & K content and uptake by seed and straw followed by Rhizobium. Thus net return and nutrient uptake by fenugreek can be realized with the application of 20 kg nitrogen, 18 kg P ha⁻¹ with seed inoculation with Rhizobium and phosphorus solubilizing bacteria.

Kolawole *et al.* (2013) pointed out that the total N uptake was not significantly different among the treatments but P and K uptake was significantly higher in plants grown on Leucaena+PR, Leucaena, Flemingia, and Flemingia+PR incubated soils than those grown on the control, PR, and maize+PR incubated soils. These results suggest that plant residues can be selected and incubated in near neutral P-deficient soils to enhance P availability and increase crop yield and P uptake.

Nyoki and Ndakidemi (2014) observed a significant improvement in the uptake of micronutrients in the *B. japonicum* inoculated treatments over the control. Phosphorus supplementation (40 kg P ha⁻¹) also showed a significant increase in the uptake of some micronutrients while decreasing the uptake of Zn in some plant organs. There was also a significant interaction between *B. japonicum* inoculation and phosphorus in the root uptake of Zn for the field experiment.

2.10 Changes in soil physico-chemical properties and phosphorus build up and availability

Srinivas and Raju (1996) reported that on sandy loam soils of Andhra Pradesh, the crop sequences maize-groundnut, maize-green gram and maize-pigeon pea improved the

nutrient status of the soil after crop harvesting, whereas crop sequences maize-maize, maize-sunflower, maize-Indian mustard showed depletion of nutrients in the soil.

Amrani *et al.* (1999) observed significant response of corn to residual P in soils with initial $\text{NaHCO}_3\text{-P}$ test levels less than 6 mg P kg^{-1} . The response was inconsistent between 9 and 14 mg P kg^{-1} and there was no response above 14 mg P kg^{-1} . In general, soils with more than $14 \text{ mg kg}^{-1} \text{NaHCO}_3\text{-P}$ could provide adequate P for maximum yield for three succeeding crops under greenhouse conditions.

The chemical fractions of P, S, and Mo in differently used Oxisols were compared with similar properties in an on-farm experiment by Lilienfein *et al.* (2000). Soil samples (0-0.15 m) were collected from three replicate plots of each of conventional tillage (CT) and no-till (NT) maize-soyabean and conventional tillage sugarcane (SC) cropping systems, degraded (DP) and productive pastures (PP), Eucalyptus (EU) and Pinus reforestations (PI), and native savannah (CE). Among the P fractions, the most important fraction was the NaOH fraction (38-49 % of total P). The Pi:Po ratios in NT and CT were higher than in CE because fertilizer P mainly accumulated in inorganic P fractions. Thus, 12-20 years of land use had marked effects on P, smaller ones on S, and almost none on Mo concentrations and chemical fractions.

Daroub *et al.* (2001) compared soil P under conventional agriculture to an adjacent forest site. The results showed that the calcium phosphate pool and the residual P fraction increased under conventional agriculture compared with the forest site because of fertilizer application.

A field experiment was conducted by Nziguheba *et al.* (2002) on a P-fixing Acrisol to study the possibilities of replenishing soil P with seasonal additions of P fertilizers. Results showed that seasonal additions of 150 kg P ha^{-1} increased maize yields to a cumulative value of 39 t ha^{-1} at the end of the experiment and increased all soil inorganic P fractions. At the third season of residual phase, treatment with a cumulative addition of 750 kg P ha^{-1} gave the highest yields compared to treatments at the same residual stage, but these yields were considered less than the maximum yield of the season. This indicated that the large build up of soil P was not available for crop uptake.

Peltovuori *et al.* (2002) investigated the phosphorus reserves and apparent phosphorus saturation in four weakly developed cultivated pedons. The results showed that fertilizer P had accumulated in the Ap horizons, leading to an anthropic epipedon in one of the four soils. The result showed very low amounts of water-extractable P in the respective horizons.

Abekoe and Sahrawat (2003) investigated the long term cropping effect on phosphorus fractions in an Ultisols of the humid forest zone in West Africa. Five rates of P: 0(P 0), 45(P 45), 90(P 90), 135(P 135) and 180 (P 180) kg ha^{-1} in the form of triple superphosphate (TSP) were applied. It was observed that after five year of cropping the soil reduced labile Pi (resin-P + $\text{NaHCO}_3\text{-Pi}$) from $10.8 \text{ mg P kg}^{-1}$ in the uncultivated soil to $7.62 \text{ mg P kg}^{-1}$ in the control (P0) and to 9.71 mg kg^{-1} in the P45 treatment. The

NaOH-Pi and residual P fractions of lower availability increased with increasing rates of P application.

Conte *et al.* (2003) determined the preferential phosphorus accumulation forms and fractions under the application of soluble phosphate rates in a no-tillage system. During five and a half years, the following P_2O_5 rates: 0, 130, 180, 260, 360, 540, 720, 980, and 1.240 kg ha^{-1} of P_2O_5 , were applied in the winter and/or summer. The observed alterations in the total phosphorus content under phosphate addition were restricted to the inorganic fractions. The moderately labile fraction was the major sink for the applied phosphorus.

Ghosh *et al.* (2003) investigated optimization of fertilizer schedules in groundnut cropping system and reported that the P status of soil showed a significant build up due to continuous application of fertilizers.

Silva *et al.* (2003) investigated the influence of phosphorus application, mycorrhizal inoculation and cultivation with *Brachiaria decumbens* and soyabeans on P fractions in three Oxisols. The results showed that the Al-P, Fe-P and Ca-P were higher in the cultivated soils, and in the dystroferic red latosol (LVdf). P addition elevated mainly the labile inorganic (Pi-resin and Pi- $NaHCO_3$) and the moderately labile (Pi-NaOH) fractions. The effect of mycorrhizas was smaller and less consistent than the cultivation and P application.

Reddy *et al.* (2005) conducted sequential fractionation of P at the end of 16 weeks which were treated with and without fertilizer P in combination with crop residues. In the study it was observed that a major part of added fertilizer P transformed into moderately labile and stable P fractions as was evident from the increased NaOH-Pi and HCl-P in the fertilizer P treatment.

Sushma (2005) revealed that application of FYM @ 75 t ha^{-1} with 100 per cent RDF recorded significantly higher available macro (250: 10.93: $146.87 \text{ kg ha}^{-1}$ N: P: K, respectively) and secondary (20.27 c.mol kg⁻¹: 9.20 c.mol kg⁻¹: 58.8 mg kg^{-1} , Ca: Mg: S, respectively) nutrients with FYM plus 100 per cent RDF. However, there is an increase in available micronutrients and organic carbon with FYM plus 100 per cent RDF but did not differ significantly over RDF alone. Similarly, pH and EC also did not differ significantly. Further, significantly higher uptake of N (65.5 kg ha^{-1}), P (10.9 kg ha^{-1}), K (41.3 kg ha^{-1}), Ca (72.2 kg ha^{-1}), Mg (58.0 kg ha^{-1}), S (10.3 kg ha^{-1}), Fe (383.4 g ha^{-1}), Zn (388.1 g ha^{-1}), Cu (43.0 g ha^{-1}) and Mn (1749.2 g ha^{-1}) by ragi straw at harvest were recorded with the FYM plus 100 per cent RDF.

Qureshi *et al.* (2005) revealed that after soybean the $0.5M \text{ NaHCO}_3$ extractable P due to TSP application recorded high (19.0 P kg^{-1} soil) P followed by North Carolina, Udaipur and Mussoorie RP with 14.1, 12.0 and $11.7 \text{ mg P kg}^{-1}$ soil, respectively. Among the phosphate solubilizers, *Aspergillus awamori* showed significant effect in improving available P, which was followed by *Pseudomonas striata*. After mustard crop the available P in soil was highest in TSP treatment but decreased after wheat crop. Though,

a difference was recorded among the rock phosphates on soil available P after mustard, it was not noticed after wheat. Seed treatment of mustard and wheat with *Aspergillus awamori* improved the soil P status compared to *Bacillus polymyxa*.

Jat and Ahlawat (2006) revealed that application of 3 t vermicompost ha⁻¹ to chickpea improved soil N and P by cropping system compared to no vermicompost. Rhizobium with and without PSB also increased soil N content over no inoculation. However, soil P content remained unaffected by Rhizobium alone but improved with Rhizobium PSB over no inoculation. Application of 13 and 26 kg P/ha increased soil N and P content over no phosphorus.

Mahala *et al.* (2006) indicated that the application of URP + phosphate-solubilizing bacteria (PSB) recorded the highest available P after maize harvest, the available N and P status of the soil after maize harvest increased up to 80 kg P₂O₅ ha⁻¹. FYM also significantly improved the availability of N and P in the soil after maize harvest. Residual effect of URP+PSB recorded the highest available P in soil after mustard harvest. Residual effect of FYM also had a significant positive impact on mustard crop as well as on the available N and P in soil.

Zhang *et al.* (2006) conducted a study on changes in P fractions in a calcareous paddy soil under intensive rice cropping and found that in treatments with fertilizer-P addition, the P mass balance was positive (+8 - 10 kg P ha⁻¹ crop⁻¹) and it increased (+51%) in the residual-P fraction.

Saltali *et al.* (2007) studied the changes in soil organic and inorganic P fractions in the native grassland (Gr), 5-year (C5), and 20-year (C20) cultivated fields. The total P, Res-P, available and medium available P were higher ($p = 0.01$) in the grassland site than that in the C5 and C20 sites, where as these fractions were high in C20 than C5 which indicated that cultivation led to a marked increase in the proportion of the Res-P and HCl-P to P-total. It conversely resulted in a gradual decrease in the ratio of organic bound P.

Wang *et al.* (2007) studied the changes in P fractions at various soil depths following long-term fertilizer application on Vertisol. The results showed that P addition at 20 kg P ha⁻¹ per crop over 18 crops doubled the resin and bicarbonate inorganic P (NaHCO₃-Pi) pools in the surface 0.10 m. Hydroxide (NaOH-Pi) and acid extracted inorganic P increased by 25 per cent and 10 per cent, respectively. With P addition, labile pools acted as the main sink for P and the total P level was elevated. Below 0.30 m, no significant changes were detected for each fraction and total P. Thus from the literatures it can be concluded that P fixation or build up in soil is a complex process and is mediated by many soil factors such as pH, sesquioxides, bases and others.

Garg and Bahl (2008) reported that the highest amount of Olsen extractable P was in PM treated soil followed by FYM, GM and field pea crop residue. Organic manure addition along with inorganic P, irrespective of the source, increased the Olsen extractable P throughout the incubation period.

Hemalatha *et al.* (2013) reviewed inclusion of legumes in a cropping system it helped improving soil fertility resulting in higher yield of the succeeding crop (s) compared to preceding exhaustive cereal or other non-legume crops. There was build-up of N and P_2O_5 with the inclusion of legumes in cropping system. The superiority in building up of soil available nitrogen and phosphorus was in the order of cropping patterns having all legumes > legumes+cereals > all cereals.

Kolawole *et al.* (2013) generalized that the soil P availability increased with increasing length of incubation. Compared with the initial soil P value of 3.14 mg kg^{-1} , after 12 weeks of incubation Leucaena +PR had the highest soil P ($9.9 \text{ mg kg soil}^{-1}$), followed by Flemingia ($7.9 \text{ mg kg soil}^{-1}$) and Flemingia + PR ($7.3 \text{ mg kg soil}^{-1}$). Phosphorus availability following incubation of PR was $5.11 \text{ mg kg soil}^{-1}$, $4.2 \text{ mg kg soil}^{-1}$ for the control treatment, and $3.37 \text{ mg kg soil}^{-1}$ for maize stover, which rather immobilized P throughout the incubation period.

Pereira and Castro (2014) indicated that the inoculated PSB has great potential to be used as biofertilizers in P-deficient soils, especially strains *Pseudomonas sp.* EAV and *A. nicotinovorans* EAPAA increase P availability in soils.

2.11 Growth and yield of crops as influenced by phosphorus levels, PSB, VAM and FYM

Kahiluoto *et al.* (2001) resulted out that the soil with low initial P supply, cumulative P fertilization decreased AM contribution to crop growth. The higher AM effectiveness in soil with no added P compensated the cumulative P fertilization (soil P_{H_2O} 2.5 v. 9.5 mg kg^{-1}) for flax, but not completely for clover. In contrast, barley obtained no benefit from AM at harvest and only a slight benefit from cumulated P. In the soil with intermediate initial P supply, AM reduced growth of flax and barley, especially with no added P and no response to AM was obtained on clover due to retarded mycorrhization. Cumulative P fertilization reduced yield losses of flax by AM (P_{H_2O} 18.8 v. 5.4 mg kg^{-1}), because fertilization inhibited mycorrhization, in both soils, root colonization and spore density were decreased by cumulative P fertilization, but no change in AMF species composition were observed.

Manske *et al.* (2001) reported in acid Andisol under rainfed conditions and on a calcareous Aridisol with irrigation, without (- P) and with 35 kg P per ha fertilized (+ P). Without P fertilization, grain yield was range from 0.8 to 4.6 t ha^{-1} in the acid soil and from 2.4 to 5.2 t ha^{-1} in the calcareous soil. With P fertilization, this range was even larger. Under conditions of P deficiency, i.e. in the acid soil at - P and + P (high P adsorption) and calcareous soil at - P (P-depleted soil). P uptake explained 71 -100 % of the variation in grain yield, and was highly correlated with grain yield ($r = 0.79-0.95$). In contrast, at + P in the calcareous soil P utilization efficiency explained 60-63 % of the variation in grain yield. Here, low grain P concentration was related to high grain yield ($r = - 0.40$ to $- 0.59$). In the calcareous soil, the harvest index was correlated with grain yield, irrespective of the P level. In the acid soil post-anthesis P accumulation was important. It was positively correlated with grain yield, whereas in the calcareous soil, no

post-anthesis-P accumulation occurred. Here, grain P accumulation at maturity was completely determined by translocation of pre-anthesis shoot P.

Khalil *et al.* (2002) observed that rock phosphate with PSM inoculation along with FYM and green manure yielded more compared to any rock phosphate, while inorganic amendments showed a feeble response. Rock phosphate application along with green manure plus PSM increased paddy yield by 41 % closely followed by 39 % increase in the case of rock phosphate only with PSM inoculation. Rock phosphate with FYM produced 17 % more yield than that of control (without PSM). Sole application of rock phosphate with PSM performed better than that of gypsum and aluminum sulfate.

Kogbe and Adediran (2003) revealed that the hybrid maize gave higher yields and used N and P more efficiently than the open pollinated at both trial locations. The yield of maize was higher in the southern guinea savanna than in the derived savanna. The performance of the hybrid varieties followed in the ascending order of 8516-12, 8321-18 and 8329-15. The optimum rates of N and P for maize grown in the derived savanna were 100 and 40 kg ha⁻¹ respectively. In the southern guinea savanna the open pollinated and hybrid varieties responded up to 150 and 200 kg N ha⁻¹ respectively. The 8516-12 showed higher N and P use efficiency than other varieties. Consequently, planting such variety could be advantageous, using minimal dose of fertilizer most especially, where farmers have less access to fertilizer.

The results obtained showed superiority of single super phosphate (SSP) application over either Sokoto or Ogun rock phosphates. However, complementary application of the Sokoto and Ogun rock phosphates with poultry manure increased maize plant height by 12 and 6, and 19 and 8 %, respectively. Maize grain yield was increased by 33 and 26, and 18 and 25 %, respectively, while that of cowpea was increased by 25 and 32, and 49 and 38 % in 2000 and 2001, respectively when compared with application of rock phosphate alone. Single super phosphate treated soil had the highest residual P values in all the three sampling periods. The effectiveness of rock phosphate as a P sources for crop production was remarkably enhanced by solubilizing effect of poultry manure (Akande *et al.*, 2005).

Sushma (2005) observed the residual effect of organics and inorganics on nutrient concentration of ragi crop. There was an increase in N, P, K, Ca, Mg and S concentration (1.337: 0.249: 0.558: 0.867: 0.517 and 0.142 per cent, respectively) in ragi grain with the application of FYM plus 100 per cent RDF but did not differ significantly over RDF alone (1.294: 0.220: 0.543: 0.747: 0.467: 0.128 per cent N: P: K: Ca: Mg: S, respectively). Similarly in ragi straw, higher per cent N, P, K, Ca, Mg and S (0.93, 0.155, 0.582, 1.018, 0.818 and 0.146 per cent, respectively) concentration was recorded with FYM plus 100 per cent RDF over 100 per cent RDF alone (0.862, 0.129, 0.566, 0.893, 0.766 and 0.106 per cent N, P, K, Ca, Mg and S, respectively).

Jat and Ahlawat (2006) revealed principal findings that application of 3 t vermicompost ha⁻¹ to chickpea improved dry matter accumulation, grain yield and grain protein content in chickpea, dry fodder yield of succeeding maize, total N and P uptake

by the cropping system over no vermicompost. Seed inoculation of chickpea with *Rhizobium* PSB (phosphate solubilizing bacteria) increased dry matter accumulation, grain yield and dry fodder yield of succeeding maize by the cropping system over no inoculation and inoculation with *Rhizobium* alone. Application of phosphorus up to 26 kg P ha⁻¹ to chickpea improved dry matter accumulation and grain yield of chickpea and dry fodder yield of succeeding maize by cropping system.

Mahala *et al.* (2006) indicated that the phosphorus application through single superphosphate (SSP) recorded the maximum grain and stover yields of maize and were on a par with that of Udaipur rock phosphate (URP) +SSP (1:1). Grain and stover yields of maize significantly increased. FYM also significantly improved the grain and stover yields after maize harvest. Residual effect of P sources was found equally effective in improving the yield. Residual effect of URP+PSB recorded the highest available P in the soil after mustard harvest. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the seed and straw yields after mustard harvest. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop as well as on the available N and P in soil.

Gupta *et al.* (2006) studied the effect of bio-fertilizer inoculation and phosphorus fertilization on yield and quality of the cultivars of urdbean (*Vigna mungo* (L.) Hepper] 'UG 218' urdbean produced significantly higher pods/plants, 1,000-seed weight, seed yield as well as straw yield over other 2 varieties. The practice of seed inoculation with phosphorus solubilising bacteria showed a significant increase in seed yield and N and P uptake over uninoculated treatment. Response of crop to phosphorus fertilization was significant up to 60 kg P₂O₅ ha⁻¹ for seed and straw yields.

Das *et al.* (2007) revealed that the biomass yield in stevia have been recorded an increase significantly due to inorganic chemical and biofertilizers applications. The magnitude of such increase in biomass yield was recorded significantly higher with the application of biofertilizer, being further greater increase with combined applications of VAM, PSB and *Azospirillum*. The increase of biomass yield was 10.80 and 53.20 % higher with the combined applications of VAM+PSB+*Azospirillum* over that of PSB+VAM and chemical fertilizers (N, P and K), respectively.

Stamford *et al.* (2007) investigated that the TSP and biofertilizers plus S inoculated with *Acidithiobacillus* increased plant growth. They concluded that biofertilizers may be used as P source; however, long term use will reduce soil pH and potentially reduce crop growth.

Dutta and Bandyopadhyay (2009) reported that the P and biofertilizers application influenced significantly the growth attributes, nodulation, leghaemoglobin content, nitrogenase activity, yield components, seed and stover yields and harvest index of chickpea, except test weight. The highest seed yield (1085 kg ha⁻¹) obtained with 39.3 kg P ha⁻¹, producing 40.7, 27.4 and 4.0 % more yield, respectively, over control (no P input), 13.1 kg and 26.2 kg P/ha. The seed yield produced by 39.3 and 26.2 kg P ha⁻¹ had no significant difference. Seed inoculation with *Rhizobium* and phosphobacterin was

significantly superior over no inoculation or phosphobacterin inoculation alone. Combined application of P at 26.2 kg/ha and bio-fertilizers (Rhizobium and phosphobacterin) enhanced significantly all these characters compared to other levels of P with bio-fertilizer.

Yousefi *et al.* (2011) indicated that the highest shoot dry matter of wheat was observed in clay loam soil (21.5 g pot⁻¹). Combined application of PSB and AMF helped utilize fixed P and increased shoot dry matter yield, seed grain spike number and grain yield by 52.19 and 26 %, respectively compared to the control.

Bairva *et al.* (2012) indicated that superiority of dual inoculation of seed with Rhizobium+PSB recorded significantly higher plant height, no of branches/plant, number of nodules/plant and dry weight of nodules per plant at 45 DAS and harvest stage over rest of the treatment. Dual inoculation of seed with Rhizobium+PSB also recorded significantly higher yield components (viz.), number of pods/plant, pod length, pod weight, number of seeds/pod and shelling percentage) and consequently increase seed and biological yield (i.e., 18.02 and 63.96 q ha⁻¹) over control (15.62 and 57.55 q ha⁻¹), respectively. The growth parameters, yield components and seed yield showed positive response to foliar application of plant growth regulators.

Adnane *et al.* (2012) resulted out that low P decreased nodulation, growth in all the genotypes, but to a greater extent in the sensitive recombinant inbred line 147. In addition, while seed P content was slightly reduced under low P soil; a higher growth was noticed in the Flamingo and Contender large seeded-beans (6.15 to 7.11 mg g⁻¹).

Mehta *et al.* (2012) reported that the application of 20 kg N and 18 kg P ha⁻¹ significantly increased plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net return of fenugreek over their respective lower levels. Combined inoculation of seed with Rhizobium and phosphorus solubilizing bacteria resulted in higher plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net return followed by Rhizobium.

Kolawole *et al.* (2013) revealed that the cowpea plants grown on Flemingia and Leucaena incubated soils with and without PR produced higher number of pods, grain yield, and shoot dry matter than those grown on PR and maize+PR incubated soils.

Sharif *et al.* (2013) showed that composts significantly ($p \leq 0.05$) increased grain, total dry matter, straw yield and 1000 grains weight of wheat over control. Higher grain yield of 5274 kg ha⁻¹, total dry matter yield of 8533 kg ha⁻¹, straw yield of 3585 kg ha⁻¹ and thousand grain weight of 40.5 g of wheat were produced on addition of compost of organic waste and half dose of SSP. Residual effect of the prepared composts was determined on yield of mung bean (*Vigna radiate*). Maximum and significantly ($p \leq 0.05$) higher mung bean grain yield, total dry matter and straw yield of 858 kg ha⁻¹, 8167 kg ha⁻¹ and 7309 kg ha⁻¹, respectively were recorded due to the residual effect of RP treated dung compost with half dose of SSP.

Ghosal *et al.* (2014) indicated that the yield of paddy was significant on direct application of water soluble TSP (2.77 t ha^{-1}) followed by PARP (2.50 t ha^{-1}) of the first crop. The best residual effect on the yield of paddy was obtained by insoluble and slowly available rock phosphates, MORP (3.87 t ha^{-1}) followed by PARP (3.81 t ha^{-1}) and MRP (3.74 t ha^{-1}). The yield also increased with increase in dose of phosphate at 40 or 80 kg P ha^{-1} , applied once in three years and residual effect was better than the direct one. TSP and PARP gave linear response whereas MORP and MRP showed quadratic response to P application. MRP also resulted in higher P balance in soil, ($29.53 \text{ kg P ha}^{-1}$) and better economic benefit was realized in case of PARP and MORP in the three-crop system.

Nhamo *et al.* (2014) conducted field experiments on P application effects in maize-cowpea sequences. In the first season, 20 kg ha^{-1} of P_2O_5 increased both maize and cowpea yields significantly ($P < 0.05$) on P-deficient sandy soils. There was a decline in the kg grain/kg P applied with fertilizer P rates beyond 20 kg/ha P_2O_5 in the first and the second (residual) year on both maize and cowpea. The relative effect of each kg of P was higher on maize than on cowpea in the residual year. Yields in the second season were higher from plots where higher P levels were previously applied, with the residual treatments being statistically significant ($P < 0.05$). Total grain yields for the rotation were highest when the P fertilizer was applied to cowpea, followed by maize grown on the residual P and the incorporated cowpea residues.

Nsanzabaganwa *et al.* (2014) observed higher maize yield at 240 kg N ha^{-1} , but the yield obtained at 160 kg N ha^{-1} was comparable. Every kg N applied produced 44.34 kg grain, and the N-use efficiency was reduced with increased N dose (67.4, 38.4, and 27.2 kg grain kg^{-1} N for 80, 160, and 240 kg N ha^{-1} , respectively). Phosphorus application increased yield up to 26.4 kg ha^{-1} . A combination of 240 kg N ha^{-1} and 26.4 kg P ha^{-1} , providing highest gross returns, net returns and net benefit: cost, was most profitable. The economic optimum dose for N and P was 196 kg N ha^{-1} and 23.4 kg P ha^{-1} , respectively. This study shows that winter maize is responsive to higher levels of N up to 240 kg ha^{-1} compared to 120 kg N ha^{-1} recommended for rainy-season maize, but P application at 26.4 kg ha^{-1} remains same for both the seasons. Their study provided recommendation of N and P for winter maize based on economics. The data would be useful for fitting models and simulating yields across the doses of N and P.

Pereira and Castro (2014) indicated that PSB have great potential to be used as biofertilizers in P-deficient soils, especially strains of *Pseudomonas sp.* EAV and *A. nicotinovorans* EAPAA since both promoted maize growth, constituting an attractive alternative to the phosphatic fertilizers amendments.

Singh *et al.* (2011b) results showed significant response to applied P on cowpea pods per plant, grain and stover yield and 100-seed weight with highest response to the application of 60 kg P ha^{-1} . From this study it can be concluded that K VX303096G and TN 5-78 could both be sown under Sokoto condition to obtain reasonable yield of about 1 t ha^{-1} of grain and 1.6 t ha^{-1} of stover.

III MATERIAL AND METHODS

The main focus of this study was to utilize the native phosphorus present in the soil; and for comparison, a soil with low P was also used. The above soils varying in P status were identified at Zonal Agricultural Research Station (ZARS), GKVK. Soil which was low in available P was used for the pot culture experiment and field experiment was conducted in soil with high P at D-16 Block, (ZARS), Gandhi Krishi Vigyan Kendra, University of Agricultural Sciences, Bangalore, Karnataka which is located in Eastern Dry Zone of Karnataka at latitude of 12° 58' N and longitude of 75° 35' E at an altitude of 930 m above mean sea level. The details of material used and the methods followed during the course of investigation on “Management of phosphorus in an Alfisol with maize – cowpea cropping sequence” conducted during 2013-2014 are presented in this chapter.

3.1 General description of the study area

The study area is located within a kilometer radius in GKVK, UAS, Bangalore, Karnataka. The soils of the study area belong to Vijayapura soil series. The climate was cool summer and warm winter with a bimodal rainfall distribution pattern and a mean annual rainfall of 844 mm. The maximum average temperature was 30 °C. The GKVK campus represents typical lateritic area of Bangalore plateau. The plateau is gently sloping to undulating.

The experiments were planned for two types of soils with maize-cowpea cropping sequence. Maize was the first crop followed by cowpea.

The sequence of events planned were as listed below

- (a) Collection of soil with low in available phosphorus from different blocks of UAS, GKVK Bangalore campus, Bangalore, Karnataka to study the changes in phosphorus fractions, P uptake and phosphatase activity during maize – cowpea cropping sequence.
- (b) Field experiment was conducted on high available phosphorus soil found at agro-forestry block, D-16, UAS, GKVK, Bangalore, Karnataka, to study the changes in phosphorus fractions, P uptake and phosphatase activity during maize – cowpea cropping sequence.
- (c) To study crop growth and yield of maize and cowpea as influenced by P management.
- (d) Determine best management practices for P in Alfisol.

3.2 Collection of soil samples for choosing the experimental site

Seventy soil samples were collected at two depths (0-15 cm and 15-30 cm) from seven different locations near Bangalore namely, Virgin soil high with total and low available P was collected from horticulture Block No. 24 (GKVK), Ragi field (GKVK), Dry land Block No. 21 (GKVK), ZARS D-16 Block (GKVK), soybean plot (GKVK), Farmer's field near to Doddabelavangala and Shanthapura village. Available P status of

these soils are 20.81, 33.5, 27.24, 63.18, 42.5, 260 and 40.98 kg ha⁻¹ and total P was 1185.03, 1075.34, 985.9, 819.78, 1070.4, 920.2 and 810.45 mg kg⁻¹ respectively. Among these soils virgin soil from GKVK was selected for pot experiment which was low in available P and ZARS (GKVK) soil was selected to conduct the field experiment which was high in available P. The initial properties for both high and low available P soils are presented in Table 2.

3.3 Preparation of soil samples and analysis

The soil samples were air dried under shade, ground using wooden pestle and mortar and passed through 2 mm sieve for further analysis. The soil samples collected from the two sites of low and high available P were analyzed for soil pH, EC, available P and total P, fractions of P, macro and micronutrients, acid phosphatase activity, iron and aluminum oxides, soil buffering capacity, Q/I relation, CEC and P adsorption following the standard procedures as indicated in Table 2.

3.3.1 Soil physical and chemical properties

The soil samples were analyzed for physico-chemical parameters, different forms of phosphorus, phosphatase enzymes activity, P adsorption and P buffering capacity using standard procedures (Table 1) as described below:

3.3.2 Phosphorus adsorption studies:

Phosphorus adsorption studies were carried out in two soils by following the method as described by Fox and Kamprath (1970). Three grams of soil was equilibrated in 50ml centrifuge tubes in triplicate with 30ml of KH₂PO₄ containing 0, 5, 10, 25, 50, 75, 100 mg P kg⁻¹ in 0.01 M CaCl₂ (soil: solution ratio 1:10). Two drops of toluene was added to each tube to prevent microbial growth. The centrifuge tubes were capped and kept for shaking for six days at 25±5 °C. Samples were shaken for half an hour twice a day and three replicates of each concentration were taken. The soils were equilibrated with graded levels of phosphorus prepared in 0.01 M CaCl₂ so as to mimic soil solution composition and to control ionic strength. The tubes were shaken for 30 minutes on reciprocating shaker twice a day. After six days of shaking the tubes were centrifuged at 3500rpm (2700 x G) for 10 minutes and filtered. The filtrates were used to estimate soluble reactive P by ascorbic acid blue colour method (Watanabe and Olsen, 1965) at 880 nm. The amount of P adsorbed was calculated by depletion method (Olsen and Watanabe, 1957). The P sorption data was interpreted by using the following adsorption equation:

(i) Langmuir equation: $C/x/m = 1/kb + C/b$

C = equilibrium P concentration in soil solution (µg ml⁻¹)

x/m = amount of P adsorbed on soil colloids (µg g⁻¹)

b = Langmuir adsorption maxima (µg g⁻¹)

k = Langmuir bonding term i.e. the ratio of specific constants for adsorption and desorption

A plot of C/x/m versus C gives a straight line.

Table 1: Methods used to determine soil physical and chemical properties

Parameters	Method	Reference
Physical properties		
Bulk density	Keens cup method	Piper (1966)
Water holding capacity	Keens cup method	Piper (1966)
Mechanical composition	International pipette method	Piper (1966)
Physico-chemical properties		
Soil reaction (pH) (1:2.5 soil : water)	Potentiometry	Jackson (1973)
EC (1:2.5) (dS m ⁻¹)	Conductometry	Jackson (1973)
Organic carbon (g kg ⁻¹)	Wet oxidation method	Walkley and Black (1934)
Cation exchange capacity (CEC) (c mol P ⁺ /kg soil)	Neutral normal ammonium acetate	(Piper, 1966)
Al and Fe oxides (sesquioxides)	Oxalate extractable	McKeague and Day (1966)
Available nutrients (kg ha⁻¹)		
Available Nitrogen	Alkaline permanganate distillation method	Subbiah and Asija (1956)
Available Phosphorus	Spectrophotometry (Olsen method)	Jackson (1973)
Available Potassium	Flame photometry	Jackson (1973)
Exch. Calcium	Versenate titration method	Hesse (1994)
Exch. Magnesium	Versenate titration method	Hesse (1994)
Available Sulfur (mg kg ⁻¹)	Spectrophotometry	Hesse (1994)
DTPA (Fe, Mn, Zn and Cu) (mg/kg)	Atomic Absorption Spectrophotometry	Lindsay and Norwell 1978
Phosphorus fixing capacity	Spectrophotometry	Waugh and Fitts (1966).
Acid phosphatase (μ g of p- nitrophenol released g ⁻¹ of soil h ⁻¹)	p-nitrophenol extraction method	Tabatabai and Bremner (1972)
Phosphorus fractions (mg kg⁻¹)		
Saloid-P (Sal-P)	Chloromolybdic boric acid method	Peterson and Corey (1966)
Aluminium-P (Al-P)		
Iron-P (Fe-P)		
Reductant soluble-P (Red-P)		
Occluded-P (Occl-P)		
Calcium-P (Ca-P)		
Organic phosphorus		(Metha <i>et al.</i> , 1954).

Table 2: Initial soil physico-chemical properties, forms of P in soils used for field and pot experiment

Sl. No.	Properties	High P soil	Low P soil
Physical properties			
1.	Sand (%)	64.01	57.16
2.	Silt (%)	9.48	13.57
3.	Clay (%)	25.91	28.47
4.	Textural Class	Sandy Clay loam	
5.	Bulk density (Mg m^{-3})	1.48	1.37
6.	Particle density (Mg m^{-3})	2.56	2.69
7.	Water holding capacity (%)	26.44	31.10
8.	Pore space (%)	57.86	54.51
Chemical properties			
9.	pH (1: 2.5)	5.42	5.80
10.	EC (dS m^{-1})	0.10	0.09
11.	OC (%)	1.02	0.78
12.	OM (%)	1.77	1.34
13.	Av. N (kg ha^{-1})	178.22	201.32
14.	Av. P_2O_5 (kg ha^{-1})	63.94	20.81
15.	Av. K_2O (kg ha^{-1})	364.48	308.33
16.	Av. S (mg kg^{-1})	18.10	21.45
17.	Ex. Ca ($\text{meq}/100 \text{ g soil}$)	3.35	3.81
18.	Ex. Mg ($\text{meq}/100 \text{ g soil}$)	2.50	2.70
19.	CEC ($\text{cmol (p+)} \text{ kg}^{-1}$)	11.67	12.1
20.	Fe (mg kg^{-1})	49.21	38.31
21.	Mn (mg kg^{-1})	30.83	25.46
22.	Zn (mg kg^{-1})	2.59	1.93
23.	Cu (mg kg^{-1})	1.97	1.20
25.	Total P (mg kg^{-1})	819.78	1185.03
26.	Sal – P (mg kg^{-1})	19.86	15.77
27.	Al –P (mg kg^{-1})	261.85	363.77
28.	Fe –P (mg kg^{-1})	206.78	291.24
29.	Red –P (mg kg^{-1})	109.58	180.01
30.	Occl-P (mg kg^{-1})	36.14	81.52
31.	Ca-P (mg kg^{-1})	31.12	38.70
32.	Org-P (mg kg^{-1})	143.98	59.87
33.	Acid phosphatase (μg of PNP released $\text{g}^{-1} \text{ soil h}^{-1}$)	20.15	22.19
34.	P fixation	12.11	21.35
35.	Soil buffering capacity ($\text{meq } 100 \text{ g}^{-1} \text{ soil}$)	1.50	1.50
36.	Al oxide (%)	1.36	1.30
37.	Fe oxide (%)	0.59	0.55
Phosphorus buffering capacity (PBC)			
38.	Quantity parameters (Q_0) ($10^{-7} \text{ mol g}^{-1}$)	0.11	0.13
39.	Intensity parameters (I_e) ($10^{-7} \text{ mol g}^{-1}$)	6.93	7.56

(ii) Freundlich equation

$$X = kC^{1/n}$$

X = Amount of P adsorbed per unit gram of soil colloids ($\mu\text{g g}^{-1}$)

C = Equilibrium P concentration in soil solution ($\mu\text{g ml}^{-1}$)

k and C = Constants

A linear plot between log X versus log C leads to k and n from the intercept and slope respectively.

3.4 Experiments

3.4.1 Pot culture experiment

A pot culture experiment by using maize-cowpea cropping sequence was carried out using a soil low in available P. The study focused on P solubilization and P transformation during the growing period. The experimental details are as follows.

Design: Complete randomized design: (CRD)

No. of treatments	: 14
No. of Replications	: 4
Crop	: Maize
Variety	: Hema
Date of sowing	: 29-08-2013 (<i>Kharif</i>)
Date of harvesting	: 22-01-2014
Capacity of pots	: 10 kg
Quantity of soil used	: 8 kg pot ⁻¹
FYM	: @ 10 t ha ⁻¹
Recommended dose of fertilizer	: 150: 75: 40 NPK kg ha ⁻¹ + ZnSO ₄ 10 kg ha ⁻¹
Microbial inoculants	: PSB @ 4 kg ha ⁻¹ VAM @ 5 kg ha ⁻¹
Type of fertilizers used	: N - Urea, P - SSP and K MOP

Eight kg of soil was taken in each pot, the treatments involved different combinations of organic manures, fertilizers and microbial inoculants (Table 3). Calculated quantities of FYM was applied to the pots as per the treatment and thoroughly mixed with soil and allowed to stand for two weeks. After two weeks fertilizers were applied and maize seeds were sown. A gap of ten days was allowed between fertilizer application and biofertilizer application. Protective irrigations were provided up to harvest of crops. Cowpea was grown as residual crop without any addition of fertilizers or FYM.

Table 3: Treatment details for pot culture and field experiment

T₁	RD (NPK - 150: 75: 40 kg ha ⁻¹)
T₂	FYM (10 t ha ⁻¹)
T₃	RD (NPK) + FYM
T₄	RD (NPK) + FYM + PSB (4 kg ha ⁻¹)
T₅	RD (NPK) + FYM + VAM (5 kg ha ⁻¹)
T₆	RD (NPK) + FYM + PSB + VAM
T₇	50 % P + RD (NK) and FYM
T₈	0 % P + RD (NK) and FYM
T₉	50 % P + PSB + RD (NK) and FYM
T₁₀	0 % P + PSB + RD (NK) and FYM
T₁₁	50 % P + VAM + RD (NK) and FYM
T₁₂	0 % P + VAM + RD (NK) and FYM
T₁₃	50 % P + PSB + VAM + RD (NK) and FYM
T₁₄	0 % P + PSB + VAM + RD (NK) and FYM

3.4.1.1 Soil analysis

The soil samples were drawn at tasseling stage of maize and at harvest. The samples were analyzed for acid phosphatase enzyme activity, macro and micro nutrients status. The different P fractions such as saloid-P, Fe-P, Al-P, Ca-P, reductant soluble P, occluded P and organic phosphorus were analyzed only in soil samples which were drawn after harvest of the crop. The plant samples were collected at tasseling and at harvest of crops. The plant samples were dried in an oven at 70 °C. The dried samples were powdered and used for the further analysis following the standard procedures as given in Table 4. Nutrient ratio namely N:P, P:K, P:S, P:Ca and P:Zn and correlation studies were also done for soil physico-chemical properties, physicals, macro and micro nutrients, P fractions and phosphatase enzyme activity

3.4.1.2 Plant analysis

At tasseling stage maize plant was uprooted and plant parameters were recorded. They were analyzed for macro and micronutrient content following the standard procedures as listed in Table 4.

3.4.2 Field experiment

A field experiment was carried out at ZARS, GKVK, Bangalore in soils which had total P content of 819.78 mg kg⁻¹ and available P₂O₅ content of 63.94 kg ha⁻¹.

3.4.2.1 Preparation of field, layout and after care

The selected experimental site was ploughed, harrowed, leveled and representative soil sample was collected to determine the soil properties. The plots were prepared uniformly. Calculated quantities of organic manures were applied to each plot as per treatments and thoroughly mixed with the soil and allowed to decompose for two weeks. Fertilizers were applied as per treatment prior to sowing. The same treatment combinations as in the pot culture experiment were imposed in the field. The plan of layout of the experimental plot is indicated in Fig. 1. and plate 1 and 2. The crop was provided protective irrigation up to harvest. Growth parameters were recorded at tasseling stage of maize and cowpea at 50 DAS. The maize plants were harvested at 150 DAS and cob yield and stover yield were recorded separately from each plot.

3.4.2.2 Details of field experiment

Design	: Randomized complete block design (RCBD)
No. of treatments	: 14
No. of replications	: 3
Crops	: maize - cowpea sequence
Variety	: Hema.
Spacing	: 60 cm X 30 cm.
Date of sowing	: 21-08-2013 (<i>Kharif</i>)
Date of harvesting	: 18/01/2014
Recommended fertilizer dosage	: 150: 75: 40 kg ha ⁻¹ NPK FYM @ 10 t ha ⁻¹ , ZnSO ₄ · 2H ₂ O @ 10 kg ha ⁻¹
Microbial inoculants	: PSB @ 4 kg ha ⁻¹ VAM @ 5 kg ha ⁻¹

Treatment details for field experiment are same as in pot culture experiment which is mentioned in Table 3.

3.4.2.3 Growth and yield parameters

The parameters recorded during tasseling and harvest of maize are plant height, number of leaves per plant, leaf area, leaf area index, stover fresh weight per plant, stover dry weight per plant, leaves fresh weight per plant, root fresh weight per plant and root dry weight per plant. After 150 DAS crop was harvested, whole plant was uprooted and separated into leaves, stover and root. Plant samples were oven dried at 60 °C and processed for nutrient analysis.

3.4.3 Chemical analysis of plant samples

Total phosphorus and potassium content of leaves, shoot, roots and grains were extracted using di acid digestion method and total P content was estimated by vanadomolybdate phosphoric acid yellow colour method at 430 nm (Piper, 1966) expressed in percentage.

3.4.4 Nutrient uptake by crops

Total P uptake was calculated using the following formula:

1. $\text{Macronutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Per cent of nutrient concentration}}{100} \times \text{Biomass (kg ha}^{-1}\text{)}$
2. $\text{Micronutrient uptake (mg ha}^{-1}\text{)} = \frac{\text{mg kg}^{-1} \text{ of nutrient concentration}}{10000} \times \text{Biomass (kg ha}^{-1}\text{)}$

Table 4: Methods used for analysis of plant samples

Sl. No.	Parameter	Method	Reference
1	Total nitrogen	Kjeldahl digestion and distillation method	Piper (1966)
2	Total phosphorus	Diacid digestion method and Spectrophotometry	Piper (1966)
3	Total potassium	Diacid digestion method and Flame photometry	Piper (1966)
4	Total calcium	Diacid digestion method and Versenate titrimetry	Jackson (1973)
5	Total magnesium	Diacid digestion method and Versenate titrimetry	Jackson (1973)
6	Total sulphur	Diacid digestion method and Turbidimetry	Jackson (1973)
7	Micronutrients Fe, Cu, Mn, Zn	Diacid digestion method and Atomic absorption Spectrophotometry	Lindsay & Norwell (1978)

3.4.5 Field experiment after maize using cowpea as residual crop

Cowpea was grown as a residual crop after maize crop in the same plots without any addition of nutrients. Details of cowpea variety and the date of sowing and other experimental details are given below.

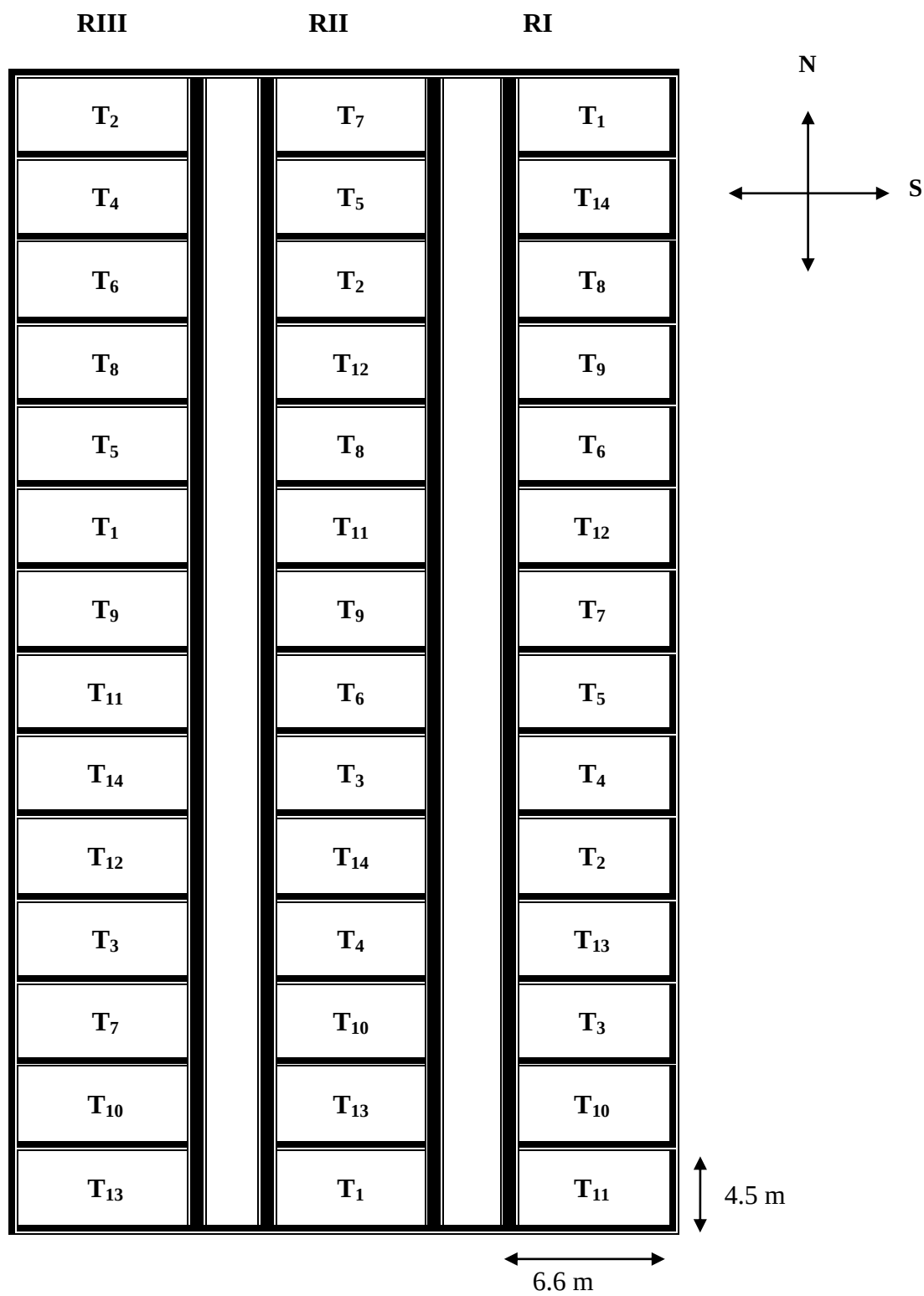


Fig. 1. Layout plan of the field experiment



Plate 1. General view of field experiment plot



Plate 2. General view of the field experiment on maize

Experiments on cowpea

Field experiment

Crop: Cowpea

Variety: AV-5

Season: Summer

Spacing: 60 cm x10 cm

Date of sowing: 22-02-2014

Date of harvesting: 26-06-2014

Observation recorded

Five plants from net plot area were randomly selected and observations on following growth parameters were recorded at 50 DAS and at harvest. plant height (cm), number of leaves plant⁻¹, number of branches plant⁻¹, leaf area per plant (cm²), leaf area index (LAI), dry matter production g⁻¹, harvesting and threshing, observations on yield and yield components, , number of pods plant⁻¹, number of seeds pod⁻¹, thousand seed weight (g), seed yield per plant (g), seed yield (kg ha⁻¹). The same variety of cowpea as a residual crop was used for pot culture sown during 24-02-2014 and harvested 29-06-2014.

3.5 Statistical analysis of the data

Fisher's method of analysis of variance was adopted for statistical analysis and interpretation of the data. Level of significance used in was $p = 0.05$ (Sundararaj *et al.*, 1977).

3.6 Correlation between various parameters:

The values obtained from soil for various parameters like physico-chemical properties, nutrient status and P fractions were subjected to correlation test.

IV RESULTS AND DISCUSSION

The study was carried out with a specific objective of managing P in soils and it was conducted on two types of soils one with high available P and the other with low available P using maize-cowpea cropping sequence. The experiments were conducted in the field and pot. The field experiment was conducted using soil high in available and total phosphorus. The test crops used were maize followed by cowpea as residual crop. The pot experiment was conducted using soil low in available P and high in total P and same cropping sequence as in field experiment was adopted. Four experiments were conducted to fulfill the objectives. The results of the experiments are presented, described and discussed in this chapter.

4.1 Field experiment: Studies on the effect of application of different levels of phosphorus, phosphorus solubilizers and FYM to the soils high in available P and total P under maize - cowpea cropping system

4.1.1 Changes in chemical properties of soil at tasseling stage and at harvest of maize

4.1.1.1 Soil pH, EC, NPK in high available P soil

Data on the effect of PSB, AM, FYM and levels of phosphorus on soil pH, EC, major nutrients and sulphur content at tasseling stage of maize and at harvest (Plate 3 and 4) are presented in Table 5.

There was a significant difference in soil pH at tasseling stage and at harvest of maize. Compared to initial value, the pH has declined in all treatments except in T₁ (RD NPK @150: 75: 40 kg ha⁻¹), T₂ (FYM @ 10 t ha⁻¹), T₅ (RD NPK + FYM + VAM @ 5 kg ha⁻¹), T₈ (0 % P + RD NK + FYM) and T₁₂ (0 % P + VAM + RD NK + FYM) at tasseling stage and at harvest of maize. The pH was slightly higher at tasseling stage compared to harvest of maize crop. Among the treatments decrease in pH was seen in those treatments where PSB and VAM were added. The pH value ranged from 5.55 in T₁₀ (0 % P + PSB + RD NK + FYM) to 6.62 in T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹). There was significant difference among the treatments with respect to pH. At tasseling stage high pH was recorded in treatment T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) 6.62 compared to other treatment and lower pH values (5.55, 5.56 and 6.62) were recorded in T₁₀ (0 % P + PSB + RD NK + FYM) and T₃ (RD NPK + FYM) and T₁ (RD NPK @150: 75: 40 kg ha⁻¹) treatments respectively.

At harvest the soil pH has significantly decreased. Higher pH (6.58) was observed in treatment T₅ (RD NPK + FYM + VAM @ 5 kg ha⁻¹) and lower pH of 5.55 was recorded in treatment T₁₀ (0 % P + PSB + RD NK + FYM) (Table 5). A slight decrease in pH may be due to the production of organic acid by P solubilizers into the rhizosphere. Organic acids were released by PSB with an associated fall in pH (Sperber, 1957). Hussain *et al.* (2013) also reported a decrease in soil pH by phosphate solubilizing bacteria through production of organic acids.

There was no significant difference in EC of soil among the treatments at tasseling stage of maize but after harvest there was significant difference among the treatments (Table 5). Treatment T₉ (50 % P + PSB + RD NK + FYM) recorded significantly higher EC (0.15 dS m⁻¹) followed by treatment T₁₀ (0 % P + PSB + RD NK + FYM) EC (0.14 dS m⁻¹). Lower EC was recorded in treatment T₅ (RD NPK + FYM + VAM @ 5 kg ha⁻¹), followed by treatments T₆ (RD NPK + FYM + PSB + VAM), T₇ (50 % P + RD NK + FYM) and T₈ (0 % P + RD NK + FYM) (0.05, 0.05, 0.05 and 0.05 dS m⁻¹). Inoculation of soil with PSB and AM fungi enhances the EC of soil by releasing some ions to the soil solution which are responsible for higher EC of soil. Giri *et al.* (2003) reported that the inoculation treatments with PSB + VAM significantly enhanced soluble salts content in soil.

Available nitrogen content of soil has increased compared to the initial status in all the treatments (Table 5) except in treatment T₂ (FYM @ 10 t ha⁻¹) (168.24 kg ha⁻¹), T₁₄ (173.12 kg ha⁻¹), T₈ (0 % P + RD NK + FYM) (176.52 kg ha⁻¹) and T₁₁ (50 % P + VAM + RD NK + FYM) (176.90 kg ha⁻¹) respectively. Available nitrogen status among the treatments differed significantly during tasseling stage of maize, and treatment T₂ (FYM @ 10 t ha⁻¹) (168.24 kg ha⁻¹) recorded lower available nitrogen. Treatment T₆ (RD NPK + FYM + PSB + VAM) and T₁₃ (50 % P + PSB + VAM + RD NK + FYM) recorded significantly higher available N (198.45 and 193.91 kg ha⁻¹) followed by treatment T₃ (RD NPK + FYM) (192.02 kg ha⁻¹), T₁₀ (0 % P + PSB + RD NK + FYM) (185.22 kg ha⁻¹) and RD NPK + FYM + PSB @ 4 kg ha⁻¹ (T₄) (184.46 kg ha⁻¹). However, after harvest of maize the available nitrogen declined compared to the initial. Application of RD NPK + FYM + PSB + VAM (T₆) and T₁₃ (50 % P + PSB + VAM + RD NK + FYM) recorded significantly higher available nitrogen content of 167.66 and 163.62 kg ha⁻¹ followed by treatment T₁₄ (0 % P + PSB + VAM + RD NK + FYM), T₁₀ (0 % P + PSB + RD NK + FYM) and T₇ (50 % P + RD NK + FYM) 156.55, 151.50 and 151.50 kg ha⁻¹ respectively and the lower available nitrogen (131.50 kg ha⁻¹) was noticed in treatment T₂ (FYM @ 10 t ha⁻¹) (Table 5). The low available nitrogen content may be due to the higher uptake by maize from soil. After harvest of maize and soybean crops there was significant reduction in the soil available N, P₂O₅, and K₂O levels in soil over initial status, mainly due to greater utilization of these nutrients (Suri *et al.*, 2013).

Available phosphorus content of soil varied significantly at tasseling stage and at harvest of maize. Available P has increased compared to initial value. The maximum available phosphorus was recorded at tasseling and at harvest 97.74 and 90.46 kg ha⁻¹ respectively in treatment T₁₃ (50 % P + PSB + VAM + RD NK + FYM), T₆ (RD NPK + FYM + PSB + VAM) recorded 94.62 and 93.29 kg ha⁻¹ and T₄ (RD NPK + FYM + PSB @ 4 kg ha⁻¹) 92.49 and 85.71 kg ha⁻¹ which were closely followed by treatment T₅ (RD NPK + FYM + VAM @ 5 kg ha⁻¹) (87.24 and 84.22 kg ha⁻¹) and T₉; 50 % P + PSB + RD NK + FYM (82.49 and 81.24 kg ha⁻¹). Lower P content was recorded on application of FYM @ 10 t ha⁻¹ (T₂) 69.62 and 63.82 kg ha⁻¹ (Table 5). The treatments with a combination of recommended fertilizer and microbial culture were on par with respect to P which is indicative of solubilisation of native phosphorus by micro-organisms (Suri *et al.*, 2011). Soluble P is released from insoluble phosphates by a variety of solubilization reactions involving rhizosphere microorganisms. Mycorrhizal plants can take up more P



Plate 3. Dr. V.R. Ramakrishna Parama major advisor and Dr. Veeranagappa during the field visit



Plate 4. Maize crop at tasseling stage

Table 5: Influence of P, PSB and VAM application on soil pH, EC and nutrient status of soil at tasseling stage and at harvest of maize in soil with high available phosphorus

Treatments	pH		EC (dSm ⁻¹)		Available N		Available P ₂ O ₅		Available K ₂ O		Available S (mg kg ⁻¹)	
					kg ha ⁻¹							
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	6.62	6.32	0.08	0.06	184.46	141.40	73.63	66.73	310.72	262.40	8.84	8.06
T ₂	6.37	6.25	0.09	0.06	168.24	131.50	69.62	63.82	302.26	248.58	7.78	7.32
T ₃	5.56	5.44	0.10	0.07	192.02	141.40	80.86	78.12	340.13	262.16	11.67	10.26
T ₄	5.86	5.59	0.10	0.08	184.46	139.38	92.49	85.71	298.32	253.23	9.96	7.33
T ₅	6.12	6.58	0.08	0.05	178.03	138.37	87.24	84.22	351.20	296.57	12.70	10.99
T ₆	6.01	6.47	0.09	0.05	198.45	167.66	94.62	93.29	382.54	319.43	13.19	11.20
T ₇	5.95	6.39	0.08	0.05	180.30	151.50	82.66	76.77	336.74	310.29	13.21	11.29
T ₈	6.10	6.20	0.07	0.05	176.52	133.32	76.07	68.20	304.76	285.88	13.07	11.20
T ₉	5.99	5.90	0.10	0.15	181.43	143.42	82.49	81.24	295.80	257.02	11.72	7.44
T ₁₀	5.55	5.55	0.12	0.14	185.22	151.50	80.03	76.77	283.40	242.48	12.88	10.26
T ₁₁	5.78	5.66	0.10	0.11	176.90	141.40	70.35	68.75	305.41	275.28	11.46	10.00
T ₁₂	6.06	6.10	0.12	0.13	184.08	143.42	67.40	64.26	348.94	298.22	12.59	10.34
T ₁₃	5.66	5.97	0.17	0.12	193.91	163.62	97.74	90.46	373.52	319.44	10.19	9.61
T ₁₄	5.87	6.00	0.13	0.13	173.12	156.55	82.81	73.20	366.18	311.43	10.79	9.60
Initial	6.02		0.10		178.22		63.94		364.48		16.10	
SEm±	0.15	0.15	0.006	0.01	5.21	4.56	3.51	2.90	13.74	5.61	1.12	0.91
CD (P = 0.05)	0.44	0.45	NS	0.02	15.15	12.41	10.22	8.64	40.74	16.39	3.26	2.68

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

than non-mycorrhizal plants, mainly from the same soluble P pool (Barea, 1991). Inoculation with phosphate-solubilizing bacteria (PSB) may help to solubilize the native soil P as well as P from rockphosphates for plant uptake. Solubilization of phosphorus by these phosphate solubilizing micro organisms is attributed to the excretion of organic acids like glutamic, succinic, lactic, oxalic, glyoxalic, maleic, fumaric, tartaric, alpha – ketobutyric, propionic and formic acid. Some of these acids (hydroxy acids) may form chelation with cations such as Ca^{2+} and Fe^{2+} , which result in effective solubilization of phosphates (Subbarao, 1986).

Available K content was decreased compared to initial value in all the treatments except in T_6 involving inoculation of soil with PSB and VAM (RD NPK + FYM + PSB + VAM), T_{13} (50 % P + PSB + VAM + RD NK + FYM) and T_{14} (0 % P + PSB + VAM + RD NK + FYM) at tasseling stage. The higher available potassium in soil at tasseling stage and at harvest of maize was recorded in (T_6) RD NPK + FYM + PSB + VAM (382.54, 319.43 kg ha⁻¹) followed by T_{13} (50 % P + PSB + VAM + RD NK + FYM) 373.52, 319.44 kg ha⁻¹ and 0 % P + PSB + VAM + RD NK + FYM (T_{14}) 366.18, 311.43 kg ha⁻¹, respectively. Treatment T_2 (FYM @ 10 t ha⁻¹) recorded significantly lower available K 302.26 and 248.58 kg ha⁻¹ at tasseling and at harvest as compared to other treatments (Table 5). Reduction in K content was mainly due to greater utilization of K₂O by the crop (Suri *et al.*, 2013).

4.1.1.2 Secondary nutrients status during tasseling and harvest of maize

Data pertaining to the status of available S, exchangeable Ca and Mg at tasseling stage and at harvest of maize are presented in Table 5, 6.

Among the treatments biofertilizers, dual inoculation of PSB+VAM with 50 % and without P fertilizers, FYM and NPK alone recorded significantly lower available sulphur content compared to uninoculated treatments. Treatment T_7 (50 % P + RD NK + FYM) 13.21, 11.29 mg kg⁻¹, T_6 (RD NPK + FYM + PSB + VAM) 13.19, 11.20 mg kg⁻¹ and (T_8) 0 % P + RD NK + FYM 13.07, 11.20 mg kg⁻¹ showed higher content of sulphur in soil at tasseling stage and at harvest of maize which were significantly superior over all other treatments. Lower sulphur content was observed in T_2 at tasseling stage and at harvest (7.78 and 7.32 mg kg⁻¹). Available sulphur content of soil has declined compared to initial at tasseling stage and at harvest of maize crop.

Exchangeable Ca and Mg status has decreased over the initial status in treatments which were inoculated with PSB and VAM and 50 % P or without P. Significantly higher exchangeable Ca content of 3.61 and 3.28 m.eq 100 g soil⁻¹ and Mg 3.35 and 2.32 m.eq 100 g soil⁻¹ at tasseling stage and at harvest were noticed in T_6 (RD NPK + FYM + PSB + VAM) which was on par with treatment T_8 (0 % P + RD NK + FYM) Ca 3.60 and 3.25 m.eq 100 g soil⁻¹ and Mg 3.00 and 2.28 m.eq 100 g soil⁻¹. Lower exchangeable Ca 3.00 and 2.70 m.eq 100 g soil⁻¹ and Mg 2.01 and 1.74 m.eq 100 g soil⁻¹ at tasseling and at harvest of maize were observed in T_{14} (0 % P + PSB + VAM + RD NK + FYM) this was on par with T_{11} (50 % P + VAM + RD NK + FYM); Ca 3.03 and 2.71 m.eq 100 g soil⁻¹ and Mg 2.02 and 1.65 m.eq 100 g soil⁻¹ (Table 6).

4.1.1.3 DTPA extractable micronutrients content of soil during tasseling and harvest stage of maize

The data on DTPA extractable micronutrients content of soil at tasseling stage and at harvest of maize are furnished in Table 6.

DTPA extractable micronutrients showed significant difference at tasseling stage and at harvest of maize crop. DTPA extractable micronutrient was decreased in soil compared to initial status in all the treatments.

A significant difference was observed in the status of iron in soil among different treatments. T₆ (RD NPK + FYM + PSB + VAM) showed significantly higher iron content 39.39 and 27.65 mg kg⁻¹ at tasseling and harvest of maize followed by T₃ (RD NPK + FYM) 35.35 and 27.84 mg kg⁻¹, lower iron content was observed in T₈ (0 % P + RD NK + FYM) 23.23 and 18.66 mg kg⁻¹ and T₇ (50 % P + RD NK + FYM) 25.25 and 19.72 mg kg⁻¹. Application of 50 % or without P application with inoculation of PSB and VAM resulted in decrease in iron content compared to application of full dose of P with single inoculation and combined inoculation.

Manganese content of soil ranged from 16.97 mg kg⁻¹ in T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) at harvest to 27.53 mg kg⁻¹ in T₃ (RD NPK + FYM) at tasseling of maize. Significantly higher manganese content was recorded in T₃ (RD NPK + FYM) 27.53 and 24.51 mg kg⁻¹ which was on par with T₇ (50 % P + RD NK + FYM) 27.23 and 23.82 mg kg⁻¹ at tasseling and at harvest of maize and the lower amount of Mn was observed in T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) 22.94 and 16.97 mg kg⁻¹. Inoculation of soil with P solublizers lowered the Mn content compared to uninoculated treatments except T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) and T₂ (FYM @ 10 t ha⁻¹).

Similarly, the DTPA extractable zinc content of soil was significantly higher in T₃ (RD NPK + FYM) at tasseling stage and at harvest of maize (2.67 and 2.83 mg kg⁻¹) and was closely followed by T₆ (RD NPK + FYM + PSB + VAM) 2.66 and 2.39 mg kg⁻¹ compared to other treatments and lower zinc was recorded in T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) 1.38 and 1.13 mg kg⁻¹. The zinc content of soil decreased compared to initial (2.59 mg kg⁻¹) in all treatments except T₃ (RD NPK + FYM) and T₆ (RD NPK + FYM + PSB + VAM).

Available copper content (Table 6) of soil was significantly higher in (T₆) RD NPK + FYM + PSB + VAM (1.61 and 1.46 mg kg⁻¹) and T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 1.60 and 1.31 mg kg⁻¹ followed by T₁₄ (0 % P + PSB + VAM + RD NK + FYM) 1.49 and 1.31 mg kg⁻¹ over rest of the treatments and lower copper content (1.16 and 0.76 mg kg⁻¹) was recorded in T₂ (RD NPK @ 150: 75: 40 kg ha⁻¹).

Decline in micronutrients content of soil may be ascribed to the positive interaction among the bio-fertilizers and soil micronutrients and decrease at the later period may be explained by the dilution effect due to higher biomass production (Hussain *et al.*, 2013).

Table 6: Influence of P, PSB and VAM application on soil Ca, Mg and micronutrients status at tasseling stage and at harvest of maize in soil with high available phosphorus

Treatments	Exch. Ca		Exch. Mg		DTPA micronutrients (mg kg ⁻¹)							
	m.eq (100 g soil) ⁻¹				Fe		Mn		Zn		Cu	
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	3.07	2.96	3.11	2.03	30.20	24.06	22.94	16.97	1.38	1.13	1.46	1.31
T ₂	3.08	3.02	2.21	2.10	33.32	25.38	23.18	21.82	1.98	2.53	1.16	0.76
T ₃	3.15	2.84	3.00	2.18	35.35	27.84	27.53	24.51	2.67	2.83	1.46	1.21
T ₄	3.33	2.92	2.48	2.17	29.25	20.58	25.26	24.24	2.42	2.13	1.20	1.02
T ₅	3.54	3.26	2.61	2.24	34.34	24.63	22.18	18.97	2.54	2.26	1.25	0.97
T ₆	3.61	3.28	3.35	2.32	39.39	27.65	26.78	24.04	2.66	2.39	1.61	1.46
T ₇	3.27	2.73	2.77	2.17	25.25	19.72	27.23	23.82	2.24	1.99	1.34	1.00
T ₈	3.60	3.25	3.00	2.28	23.23	18.66	24.83	20.09	2.48	2.13	1.23	0.92
T ₉	3.16	3.02	2.98	2.24	33.33	25.56	22.28	20.24	2.46	2.04	1.38	0.82
T ₁₀	3.14	3.04	2.52	2.20	27.27	20.60	22.89	16.97	1.60	1.70	1.40	1.13
T ₁₁	3.03	2.71	2.02	1.65	35.35	22.15	25.61	23.66	1.44	1.70	1.43	1.11
T ₁₂	3.19	3.11	2.60	2.23	33.36	23.86	22.26	24.09	2.54	2.04	1.43	1.16
T ₁₃	3.05	2.85	2.94	2.30	30.38	24.71	24.02	22.24	2.38	2.00	1.60	1.31
T ₁₄	3.00	2.70	2.01	1.74	30.36	22.10	22.96	20.36	1.56	1.79	1.49	1.31
Initial	3.35		2.50		40.21		30.83		2.59		1.97	
SEm±	0.12	0.09	0.15	0.08	1.03	1.56	1.64	0.46	0.09	0.08	0.05	0.05
CD at (P = 0.05)	0.36	0.25	0.44	0.24	3.13	4.66	4.90	1.38	0.28	0.23	0.15	0.15

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

4.1.1.4 Nutrient ratios and phosphatase enzyme activity in high available P soil

Data pertaining to the changes in soil nutrients ratios and phosphatase activity at tasseling stage and harvest of maize grown on high available P soil applied with PSB, VAM and graded levels of phosphorus is given in Table 7. Significant differences were recorded among treatments.

The ratio of N:P in soil after harvest has decreased significantly in all the treatments compared to initial. The highest ratio of N:P in soil at tasseling stage and at harvest (6.21 and 5.07) was recorded in T₁₂ (0 % P + VAM + RD NK + FYM). The lower N:P ratio was recorded in T₄ (RD NPK + FYM + PSB @ 4 kg ha⁻¹) 4.50 and 3.70.

The ratio of P:K in soil after maize harvest has increased in all the treatments over initial. Higher ratio of P:K in soil at tasseling and at harvest of maize were recorded in T₄ (RD NPK + FYM + PSB @ 4 kg ha⁻¹) (0.16 and 0.18), T₉ (50 % P + PSB + RD NK + FYM) (0.15 and 0.17) and T₁₀ (0 % P + PSB + RD NK + FYM) (0.15 and 0.17). The lowest ratio of P:K (0.10 and 0.11) was recorded in T₁₂ (0 % P + PSB + VAM + RD NK + FYM).

The P:S ratio in soil was increased in all the treatments compared to initial (0.78). Higher P:S ratio at harvest (2.14) was recorded in T₉ and lower P:S ratio (1.20) was recorded in T₁₂. There was no significant difference in P:Ca ratio among the treatments.

Large difference and increase in P:Zn ratio was observed compared to initial status. There were significant differences at tasseling stage and at harvest of maize. The values ranged from 10.48 in T₁ at tasseling stage to 4.95 in T₂ at harvest of maize. Treatment T₁ and T₁₄ recorded higher P:Zn ratio (10.48 and 10.43) at tasseling stage of maize and lower ratio was recorded in T₁₂ (5.21). After harvest the P:Zn ratio was significantly higher in T₁₁ (11.95) and lower P:Zn ratio was recorded in T₂ (4.95).

The acid phosphatase activity was higher in T₆ and T₁₃ at tasseling stage (65.85 and 64.73 µg of PNP g⁻¹ soil hr⁻¹) and lower activity was recorded in T₁ (27.30 µg of PNP g⁻¹ soil hr⁻¹). Higher acid phosphatase activity was observed in all the treatments compared to initial (20.15 µg PNP g⁻¹ soil hr⁻¹) acid phosphatase activity. Treatments with inoculation of PSB and VAM showed higher acid phosphatase activity compared to inoculation with either PSB or VAM and uninoculated treatments.

At harvest of maize, higher acid phosphatase activity was recorded in T₆ (60.21 µg of PNP g⁻¹ soil hr⁻¹) followed by T₁₃ (55.23 µg of p-nitrophenol g⁻¹ soil hr⁻¹) and lower activity was recorded in T₁ (22.75 µg of p-nitrophenol g⁻¹ soil hr⁻¹). All the treatments showed higher acid phosphatase activity at tasseling stages compared at harvest of maize (Table 7). The activities of acid and alkaline phosphatase were increased in treatments which received organic manures and biofertilizers. This may be because of application of FYM alone or in combination with inorganic fertilizers which created an ideal condition in the soil for the microorganisms to be active (Halstead and Sowden, 1986). It was also observed by Singaram and Kamalakumari (1995) that the activity of soil enzymes was

Table 7: Influence of P, PSB and VAM application on soil nutrient ratios and phosphatase activity at tasseling stage and at harvest of maize in soil with high available phosphorus

Treatments	N:P		P:K		P:S		P:Ca		P:Zn		Acid phosphatase (μg of PNP released g^{-1} soil h^{-1})	
	Nutrient ratios											
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	5.69	4.82	0.13	0.13	1.64	1.63	0.02	0.02	10.48	7.71	27.30	22.75
T ₂	5.49	4.68	0.12	0.14	1.76	1.71	0.02	0.02	6.91	4.95	54.09	45.08
T ₃	5.40	4.11	0.13	0.16	1.36	1.50	0.03	0.03	5.95	5.42	45.30	37.75
T ₄	4.50	3.70	0.16	0.18	1.82	2.30	0.03	0.03	7.51	7.90	38.40	32.00
T ₅	4.64	3.73	0.13	0.15	1.35	1.51	0.02	0.03	6.75	7.32	56.28	53.94
T ₆	4.77	4.08	0.13	0.15	1.41	1.64	0.03	0.03	6.99	7.67	65.85	60.21
T ₇	4.96	4.49	0.13	0.13	1.23	1.34	0.02	0.03	7.25	7.58	45.47	37.89
T ₈	5.27	4.44	0.13	0.13	1.14	1.20	0.02	0.02	6.03	6.29	55.79	43.99
T ₉	5.00	4.01	0.15	0.17	1.38	2.14	0.03	0.03	6.59	7.82	45.43	35.52
T ₁₀	5.26	4.49	0.15	0.17	1.22	1.47	0.03	0.02	9.83	8.87	47.34	36.95
T ₁₁	5.71	4.67	0.12	0.13	1.21	1.35	0.02	0.02	9.60	11.95	46.90	39.08
T ₁₂	6.21	5.07	0.10	0.11	1.05	1.20	0.02	0.02	5.21	6.19	40.96	36.13
T ₁₃	4.51	4.11	0.14	0.15	1.88	1.85	0.03	0.03	8.07	8.88	64.73	55.23
T ₁₄	4.75	4.86	0.12	0.12	1.51	1.50	0.03	0.03	10.43	8.03	55.85	35.87
Initial	6.33		0.09		0.78		0.02		4.85		25.15	
SEm±	0.21	0.13	0.01	0.01	0.11	0.08	0.02	0.01	0.70	0.83	1.5	1.1
CD at (P = 0.05 %)	0.62	0.39	0.03	0.04	0.33	0.24	NS	NS	2.10	2.51	4.5	3.2

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

higher and their effect was pronounced when FYM was applied in combination with chemical fertilizers. Similarly Piotrowska and Wilczewski (2012) reported that addition of FYM and biofertilizers increased the acid phosphatase activity compared to NPK alone.

4.1.1.5 Different P fractions and P adsorption in high available P soil

The results pertaining to the different fractions P in soil are presented in Table 8.

Sal-P as influenced by different treatments was lower after harvest of maize as compared to initial (19.86 mg kg^{-1}), low Sal-P was recorded in T_2 (8.10 mg kg^{-1}) and a higher content was recorded in T_{13} (19.34 mg kg^{-1}) which was on par with treatments which received 50 % or without P application with dual and single inoculation of PSB and VAM compared to uninoculated treatment.

At harvest of maize lower Al-P content of soil $301.25 \text{ mg kg}^{-1}$ was recorded in T_{14} (0 % P + PSB + VAM + RD NK + FYM) and a higher value ($360.15 \text{ mg kg}^{-1}$) was recorded in T_3 . The Al-P content in all the treatments has increased over its initial value. The Al-P content of soil as influenced by different treatments increased at harvest of maize, especially in those treatments which received P fertilizers and FYM alone. In the treatments which received organic manure and bio-inoculants, the Al-P showed a decreasing trend.

Significant difference in Fe-P content of soil was observed due to treatments at harvest of maize. The maximum value of Fe-P was recorded in T_3 ($225.30 \text{ mg kg}^{-1}$) followed by which received T_4 ($220.25 \text{ mg kg}^{-1}$). However, the minimum value was recorded in T_{14} ($174.36 \text{ mg kg}^{-1}$). Compared to initial value, there was decline in Fe-P in all those treatments where P solublizers 50 % or 0 % P applied. Al and Fe-P were the major fractions in soil which could be attributed to low pH and increased solubilization of Fe and Al under acidic conditions (Doddamani and Seshagiri Rao, 1988). Higher content of RS-P may be attributed to higher sesquioxides content. Bapat *et al.* (1965) and Kothandaraman and Krishnamurthy (1979) reported that laterite soil contained higher amount of Reductant-soluble P.

The results pertaining to reductant soluble P indicated that there were significant differences among the treatments after harvest of maize. The fraction ranged from $120.35 \text{ mg kg}^{-1}$ in T_{14} to $168.25 \text{ mg kg}^{-1}$ in T_3 at harvest of maize in high P soil (Table 8). The reductant soluble P was found to increase with increase in time in all the treatments. However, in all the treatments the RS-P values increased over the initial content.

After harvest of maize, Occl-P fractions varied from 26.30 mg kg^{-1} in T_2 to 66.40 mg kg^{-1} in T_3 (Table 8). Treatment T_3 and T_6 recorded significantly higher Occ-P (66.40 mg kg^{-1} and 64.25 mg kg^{-1}) over other treatments. Among the treatment inoculated treatments with PSB and application of AM fungi together with 50 % P or without P fertilizer recorded lower Occl-P compared to application of full dose P without P solublizers.

Table 8: Influence of phosphorus, PSB and VAM application on different fractions of phosphorus (mg kg⁻¹) in soil at harvest of maize in soil high in available P

Treatments	Different fractions of P (mg kg ⁻¹) in soil							
	Sal-P	Al-P	Fe -P	RS -P	Occl- P	Ca – P	Organic- P	Total-P
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	13.61	352.71	207.81	156.65	58.86	20.56	125.43	935.63
T ₂ -FYM (10 t ha ⁻¹)	8.10	321.21	185.21	132.14	26.30	18.30	132.99	824.25
T ₃ -RD NPK + FYM	15.6	360.15	225.30	168.25	66.40	23.10	155.78	1014.58
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	15.22	310.20	220.25	140.56	59.30	25.30	142.51	913.34
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	15.25	330.20	216.20	139.23	57.36	24.60	146.32	929.16
T ₆ -RD NPK + FYM + PSB + VAM	19.25	355.25	220.21	165.25	64.25	28.30	147.99	1000.5
T ₇ -50 % P + RD NK + FYM	15.36	365.55	199.81	168.23	55.36	19.25	149.75	973.31
T ₈ -0 % P + RD NK + FYM	14.55	329.57	211.82	130.22	55.94	18.63	143.91	904.64
T ₉ -50 % P + PSB + RD NK + FYM	17.67	321.25	182.20	135.36	45.36	27.10	136.83	865.77
T ₁₀ -0 % P + PSB + RD NK + FYM	17.23	304.25	180.20	132.25	36.25	28.30	132.28	830.76
T ₁₁ -50 % P + VAM + RD NK + FYM	16.12	329.00	186.57	133.25	41.25	26.10	139.22	871.51
T ₁₂ -0 % P + VAM + RD NK + FYM	15.35	315.25	179.28	130.50	38.25	29.10	134.53	842.26
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	19.34	322.01	182.36	145.25	36.25	27.20	138.25	870.66
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	17.44	301.25	174.36	120.35	33.14	29.40	131.15	807.09
Initial	19.86	261.85	206.78	109.58	36.14	31.12	143.98	819.78
SEm±	0.75	7.33	3.31	2.62	1.66	1.27	2.15	17.97
CD at (P = 0.05 %)	2.23	22.01	9.30	7.20	5.20	3.95	6.35	52.91

Results pertaining to the content of Ca-P in the soil after harvest of maize P are presented in Table 8. The Ca-P content has decreased in all the treatments compared to initial value (31.12 mg kg⁻¹). Higher Ca-P was recorded in T₁₃, T₁₂, T₁₀ and T₆ (29.40, 29.10 and 28.30 mg kg⁻¹, respectively) after harvest of maize. Lower Ca-P was recorded in T₂ treatment (18.30 mg kg⁻¹).

Organic-P content of soil has declined due to inoculation of PSB and VAM with addition of 50 % or without P fertilizer compared to initial status. The maximum decrease was recorded in T₁ (125.43 mg kg⁻¹) the maximum increase was recorded in T₃ (155.78 mg kg⁻¹). In T₂, T₉, T₁₀, T₁₁, T₁₂, T₁₃ and T₁₄ the decrease in organic-P contents were observed respectively. Microorganism plays a major role in organic P solubility, microbial production of organic acids and acid phosphatase activity play an important role in mineralizing organic P present in soil (Hussain *et al.*, 2013).

From the data it is clear that total P content of soil has increased except in T₁₄ in all treatments (807.09 mg kg⁻¹). The extent of decrease was drastic in T₁₄, *i.e.*, T₁₄ (0 % P + PSB + VAM + RD NK + FYM) (807.09 mg kg⁻¹). There was significant difference between T₁₄ and T₁₃ in total P content and T₃ (1014.58 mg kg⁻¹) was found to be superior among the treatments. In general, the total P content was decreased drastically with no P fertilizer application + NK fertilizer + organic matter + biofertilizer compared to treatments 50 % or full dose of P fertilizer + NK + organic matter + biofertilizers. High total P content of the soils may be attributed to higher oxides of iron and aluminium, addition of water soluble inorganic P fertilizers and low pH. Under high P condition the activity of P solubilizer decreased which led to low solubilization of total phosphorus to the soil solution for plant uptake.

P-solubilizing microorganisms are responsible mainly for organic acid production in soil which leads to release of phosphorus from different pools either by: (i) lowering the pH, or (ii) by enhancing chelation of the cations bound to P (iii) by competing with P for adsorption sites on the soil (iv) by forming soluble complexes with metal ions associated with insoluble P (Ca, Al, Fe) and thus P is released. The lowering in pH of the soil suggested the release of organic acids by the P-solubilizing microorganisms (Whitelaw 2000; Maliha *et al.*, 2004) via direct oxidation pathway that occurs on the outer face of the cytoplasmic membrane (Zaidi *et al.*, 2009).

Al and Fe-P were the major fractions and it was attributed to low pH and increased solubilization of Fe and Al under acid conditions (Doddamani and Seshagiri Rao, 1988). Higher content of RS-P may be attributed to higher sesquioxides content. Bapat *et al.*, (1965) and Kothandaraman and Krishnamurthy (1979) reported that laterite soil contained higher amount of reductant-soluble P.

The higher contribution of Al-P to the total P compared to saloid P might be ascribed to higher total aluminium content of soil (Vishwanath and Doddamani 1991). Higher Al-P compared to Ca-P can be attributed to the chemical indices of sesquioxides and advanced stage of weathering. This finding corroborates with the reports of Balasubramanian and Raj (1969).

Saloid P is the most soluble form of P in soil. Lower content of Saloid - P of the soil was due to low pH, high content of sesquioxides, high P fixing capacity of acid soils and low content of easily soluble Ca-P (Paramasivam and Udayasooryan, 1991).

Higher level of RS-P in soil was ascribed to the transformation of other forms of P to RS-P with lapse of time. Mongia and Bandyopadhyay (1996) also observed RS-P > Fe-P > Al-P was the dominant inorganic fraction in Alfisols owing to higher amount of amorphous Al and Fe, which favoured the formation of Al-P and Fe-P.

4.1.2 Effect of PSB, VAM and different level of phosphorus on growth of maize in high available P soil

4.1.2.1 Plant height, No. of leaves, leaf area, leaf area index and fresh weight of maize at different stages of crop growth

The data on plant height of maize at tasseling stage and at harvest is given in Table 9.

At tasseling stage and at harvest application of T₆ (RD NPK + FYM + PSB + VAM) 211.33 and 236.42 cm followed by T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 210.67 and 236.42 cm (T₆) recorded significantly higher plant height compared to no biofertilizers addition treatment T₂ (FYM @ 10 t ha⁻¹) 164.53 and 199.40 cm, respectively. Inoculation with PSB and VAM with FYM and NPK enhanced the plant height even with 50 per cent P. This may be due to the high utilization of P by plant. Yousefi *et al.*, (2011) reported significantly higher shoot height with combined application of PSB and AMF. Combined inoculation of seed with Rhizobium and phosphorus solubilizing bacteria resulted in higher plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net returns followed by rhizobium (Mehta *et al.*, 2012).

The number of leaves per plant was found to increase with application of biofertilizers along with decrease in the P fertilizers dosage. Higher number of leaves at tasseling and at harvest (14.70 and 16.73) and (14.40 and 16.40) was recorded in T₁₃ and T₁₄ followed by T₆ (14.10 and 15.80) respectively. Significantly lower value at tasseling and at harvest was observed in T₂ (11.20 and 11.87). Other treatments were on par except those uninoculated treatments. Higher number of leaves due to combined inoculation may be due to the high nutrient use efficiency provided by microorganisms to the plant. Application of TSP and biofertilizers plus 50 per cent P inoculated with *Acidithiobacillus* increased the number of leaves when biofertilizers was used as P source (Stamford *et al.*, 2007).

Higher leaf area was recorded at tasseling and at harvest of maize in T₆ (4503.27 and 5085.33 cm²) and T₁₃ (4421.80 and 4792.78 cm²), lower value was observed in T₂ at tasseling and at harvest of maize (3008.53 and 3286.33 cm²). Treatments with full dose of P with single and dual inoculation showed on par value to each other compare to the uninoculated treatments. Higher leaf area may be due to the high activity of PSB which is

Table 9: Influence of phosphorus, PSB and VAM application on growth parameters of maize at tasseling (60 DAS) and at harvest in high available phosphorus soil

Treatments	Plant height (cm)		No of leaves plant ⁻¹		Leaf area (cm ² plant ⁻¹)		Leaf area index	
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	175.53	200.10	11.40	13.60	3162.07	3598.67	1.26	2.00
T₂ -FYM (10 t ha ⁻¹)	164.53	199.40	11.20	11.87	3008.53	3286.33	1.14	1.71
T₃ -RD NPK + FYM	174.60	231.30	12.70	13.13	4111.07	4705.56	2.28	2.61
T₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	197.87	227.81	12.70	14.47	3913.20	4738.44	2.17	2.71
T₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	166.07	216.30	12.50	13.27	3467.67	4747.67	1.37	2.64
T₆ -RD NPK + FYM + PSB + VAM	211.33	236.42	14.10	15.80	4503.27	5085.33	2.50	2.83
T₇ -50 % P + RD NK + FYM	190.47	217.20	11.70	13.40	3911.40	4513.00	2.17	2.51
T₈ -0 % P + RD NK + FYM	178.53	209.81	11.50	13.00	3295.73	3943.44	1.83	2.19
T₉ -50 % P + PSB + RD NK + FYM	191.53	231.70	13.30	14.33	4067.87	4871.11	2.32	2.71
T₁₀ -0 % P + PSB + RD NK + FYM	182.20	230.01	13.00	13.73	3543.40	4477.33	1.97	2.49
T₁₁ -50 % P + VAM + RD NK + FYM	196.53	231.70	12.90	13.87	4043.93	4381.33	2.46	2.43
T₁₂ -0 % P + VAM + RD NK + FYM	185.93	225.91	12.90	14.47	3498.53	4038.00	1.39	2.24
T₁₃ -50 % P + PSB + VAM + RD NK + FYM	210.67	236.42	14.70	16.73	4421.80	4792.78	2.25	2.66
T₁₄ -0 % P + PSB + VAM + RD NK + FYM	195.33	227.50	14.40	16.40	4013.87	4688.22	2.23	2.60
SEm±	2.30	5.06	0.40	0.22	99.74	105.53	0.093	0.14
CD (P = 0.05 %)	6.95	14.70	1.30	0.65	289.93	382.36	0.287	0.41

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure and DAS: days after sowing

not only responsible for the solubility of phosphorus it also produced some plant growth promoting substances which helped in better crop growth. Mahala *et al.*, (2006) indicated that the 50 % phosphorus application through single superphosphate (SSP) with PSB recorded the higher leaf area of plant.

There was significant difference in leaf area index among the treatments. Higher leaf area index was recorded at tasseling and harvest of maize in T₆ (2.50 and 2.83) and T₁₃ (2.25 and 2.66) followed by T₁₄ (2.23 and 2.60) and a lower leaf area index was recorded in T₂ at tasseling stage and at harvest (1.14 and 1.17) (Table 9). Higher leaf area index is related to higher leaf biomass of plant through the application of biofertilizers and fertilizers.

4.1.2.2 Fresh weight and dry weight of maize as influenced by P sources and levels

At tasseling stage, the fresh weight of leaves, stover and roots weight of maize were significantly higher in T₆ (209.53, 414.47 and 151.53 g plant⁻¹, respectively) and T₁₃ (203.47, 410.67 and 149.40 g plant⁻¹, respectively) and significantly lower fresh weight of leaves, stover and roots of maize were recorded in T₂ (136.93, 282.53 and 71.73 g plant⁻¹, respectively). Significantly high biomass was recorded in T₆ and T₁₃ which was closely followed by T₁₄, higher biomass was recorded in T₆ and T₁₃ this may be due to the higher utilization of nutrients due to biofertilizers treatment compared to uninoculated treatments. Similar results were obtained by Pereira and Castro (2014) in which they explained that PSB had great potential to be used as biofertilizers in P-deficient soils, especially strains of *Pseudomonas sp.* EAV and *A. nicotinovorans* EAPAA since these strains promoted maize growth, constituting an attractive alternative to the phosphatic fertilizers amendments (Table 10).

Significantly higher dry weight of maize leaf at tasseling and at harvest was recorded in T₆ (58.20 and 59.02 g plant⁻¹, respectively) and T₁₃ (56.07 and 59.00 g plant⁻¹, respectively) followed by T₁₀ (54.40 and 56.24 g plant⁻¹, respectively) a lower leaf weight at tasseling and at harvest was recorded in T₂ (31.27 and 34.40 g plant⁻¹, respectively) (Table 10).

Similarly maximum stover weight at tasseling and at harvest was recorded in T₆ (79.53 and 129.24 g plant⁻¹) and was on par with all inoculated treatments. Low stover weight was recorded in T₂ at tasseling stage and at harvest (55.47 and 75.07 g plant⁻¹, respectively) followed by T₁ (64.67 and 95.22 g plant⁻¹, respectively). This may be due to low availability of nutrients for plant growth. The higher shoot weight may be due to the higher availability by the action of microorganisms.

During tasseling stage and at harvest, the T₁₃ treatment which received 50 % P + PSB + VAM + RD NK + FYM (32.33 and 45.87 g plant⁻¹, respectively) and T₁₄ (0 % P + PSB + VAM + RD NK + FYM) (32.33 and 45.77 g plant⁻¹, respectively) recorded significantly higher root weight and was on par with T₆ (RD NPK + FYM + PSB + VAM) (29.67 and 45.73 g plant⁻¹ respectively). This is due to application of high amount of nutrients to soil. Greater efficiency of P solubilizing bacteria through

Table 10: Influence of phosphorus, PSB and VAM application on fresh and dry biomass of maize at tasseling and at harvest in high available phosphorus soil

Treatments	Fresh weight (g plant ⁻¹) 60 DAS				Dry weight (g plant ⁻¹)							
					leaf		Stover		Root		Total	
	Leaf	stover	Root	Total	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T₁	138.40	294.93	99.13	532.46	33.47	48.24	64.67	95.22	24.67	32.13	122.81	175.59
T₂	136.93	282.53	71.73	491.19	31.27	34.40	55.47	75.07	23.67	27.47	110.41	136.94
T₃	172.87	368.67	112.00	653.54	46.67	52.44	75.20	106.09	26.33	32.80	148.20	191.33
T₄	175.60	403.80	144.80	724.20	48.20	53.29	79.13	124.11	26.00	43.73	153.33	221.13
T₅	151.20	357.93	118.20	627.33	45.53	51.64	68.27	126.27	29.33	40.53	143.13	218.44
T₆	209.53	414.47	151.53	775.53	58.20	59.02	79.53	129.24	29.67	45.73	167.40	233.99
T₇	158.33	360.00	109.13	627.46	42.13	50.07	66.27	108.87	24.67	32.67	133.07	192.61
T₈	144.00	298.00	82.33	524.33	33.40	51.07	64.13	106.22	22.67	28.33	120.20	185.62
T₉	178.73	388.47	144.07	711.27	53.33	55.38	77.07	119.20	25.33	39.73	155.73	214.31
T₁₀	155.80	357.93	112.53	626.26	54.40	56.24	69.27	116.29	23.33	36.13	147.00	208.66
T₁₁	183.67	407.47	135.87	727.01	50.00	56.13	74.93	119.98	26.33	36.60	151.26	212.71
T₁₂	169.40	393.33	114.33	677.06	39.07	58.22	72.73	116.18	29.00	39.73	140.80	214.13
T₁₃	203.47	410.67	149.40	753.54	56.07	59.00	73.80	126.14	32.33	45.87	162.20	231.01
T₁₄	178.00	399.27	144.80	722.07	51.13	51.29	74.47	117.40	32.33	45.77	157.93	214.46
SEm±	3.95	11.61	3.80	25.10	2.08	2.64	2.03	3.37	1.35	0.87	5.06	6.20
CD (P = 0.05 %)	11.47	33.92	11.05	75.25	6.06	7.66	5.90	10.22	3.92	2.53	15.18	18.6

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

co-inoculation with other beneficial bacteria and mycorrhiza increase the root growth (Khan *et al.*, 2009). Lower root weight at tasseling and at harvest were recorded in treatment T₂ (23.67 and 27.47 g plant⁻¹, respectively) which received FYM @ 10 t ha⁻¹.

The results pertaining to the effect of PSB, VAM and level of P fertilizer with FYM on total dry matter of maize at tasseling and at harvest are presented in Table 10. Significant increase in the total dry matter of maize 167.40 and 233.99 g per plant were recorded which received RD NPK + FYM + PSB + VAM. Significantly lower dry matter was recorded at tasseling and at harvest of maize was (110.41 and 136.94, respectively) in T₂ treatment received FYM @ 10 t ha⁻¹. The inoculated treatment providing the nutrients through solubilization and the inoculants were responsible for release of plant growth promoting substances like indol acetic acid etc. Similar results have been reported by Kaleeswari *et al.* (2007) who reported that the dissolution of P was significantly higher with P fertilizer + FYM + Phosphate solubilizing microorganisms irrespective of the P sources. Higher phosphatase activity was observed in FYM treated plots. Therefore, *Bacillus* spp. has the potential to be applied as booster inoculant to increase the efficacy of plant growth promotion (Kloepper *et al.*, 2004).

4.1.2.3 Yield attributes of maize under high available phosphorus soil

4.1.2.3.1 Number of cobs plant⁻¹

Among the treatments there were no significant differences observed with respect to number of cobs per plant between inoculated treatment and uninoculated treatment (Table 11).

4.1.2.3.2 No. of rows per cob

The treatments T₁₄ (0 % P + PSB + VAM + RD NK + FYM), T₁₃ (50 % P + PSB + VAM + RD NK + FYM) and T₆ (RD NPK + FYM + PSB + VAM) recorded higher number of rows per cob⁻¹ (17.20, 16.73 and 16.87 of rows cob⁻¹, respectively) and all inoculated treatments with PSB and VAM alone or in combination resulted in higher number of rows per cob than uninoculated treatment. Lower number of rows per cob were recorded in T₂ i.e. FYM @ 10 t ha⁻¹ (12.67 cob⁻¹) Table 11.

4.1.2.3.3 Number of seeds cob⁻¹

Among the treatments significantly higher number of seeds cob⁻¹ was recorded in T₁₄ (0 % P + PSB + VAM + RD NK + FYM) (36.20) and it was on par with rest of the dual and single inoculated treatments with P or without P fertilizer. Significantly lower number of seeds cob⁻¹ (19.27) was recorded by T₂ (FYM @ 10 t ha⁻¹). The higher number of seeds per cob due to dual inoculation of VAM fungus and PSB than with PSB alone can be attributed to the activity of the VAM fungus in transporting extra phosphorus solubilized by PSB from and beyond the root zone into the plant roots which in the absence of VAM hyphae gets refixed by soil constituents during the course of slower diffusion towards plant roots. These results are in accordance with the findings of Pereira

and Castro (2014) who reported that the higher seed yield and promoted maize growth, due to inoculation of PSB and VAM alone and combined inoculation.

4.1.2.3.3 Test weight (g)

The data on test weight of maize in high P soil are presented in Table 11. Test weight of the cob varied significantly with treatments. Higher test weight (33.40 g) was recorded in treatment T₁₃ (50 % P + PSB + VAM + RD NK + FYM) and 33.10 g in treatment T₁₄ (0 % P + PSB + VAM + RD NK + FYM) and was on par with T₆ (32.80g). While the test weight was lower in T₁ which received RD NPK @ 150: 75: 40 kg ha⁻¹ (23.00 g). As compared to uninoculated treatments the inoculated treatments showed significantly higher test weight.

4.1.2.3.4 Cob weight (g plant⁻¹)

The data on cob weight of maize in field experiment are presented in Table 11. The cob weight differed significantly among inoculated and uninoculated treatments. Higher cob weight was recorded in T₁₀ (0 % P + PSB + RD NK + FYM) (190.00 g) and was on par with other inoculated treatments including T₆ (189.87 g), T₁₂ (186.07 g) and T₁₃ (185.53 g) respectively. The weight of the cob was significantly lower in FYM @ 10 t ha⁻¹ (T₂) 117.40 g. Among uninoculated treatment the treatment which received RD NPK + FYM (T₃) showed higher cob weight (183.53 g).

4.1.2.3.5 Seeds weight (g per cob)

In inoculated and uninoculated treatments seed weight g per cob was higher in treatment T₆ (RD NPK + FYM + PSB + VAM) 174.00 g and was on par with other single inoculated and combined inoculated with full dose or 50 % or even without P fertilizer treatments like T₁₃ (170.60 g) and T₁₄ (168.13 g). The seed weight per cob was lower in T₂ (87.80 g) and T₁ (99.47 g) (Table 11).

4.1.2.3.6 Grain yield (q ha⁻¹)

Field experiments with high available soil P indicated positive impact of PSB and VAM on maize yield which was significantly higher (85.01 q ha⁻¹) on application of RD NPK + PSB + VAM + FYM (T₆) and it was on par with T₁₃, T₄ and T₅ (84.62, 82.35 and 82.12 q ha⁻¹, respectively) (Table 11 and Fig. 2) and it was followed by other inoculated treatments of recommended PSB, VAM, to which NK and FYM was applied without phosphorus. PSB and VAM together were capable of mobilizing soil P (Gryndler *et al.*, 1990) (Table 11). However, lower yield (50.85 q ha⁻¹ of maize grain) was recorded in T₂ (FYM alone) (Table 11). This indicates that with dual inoculation of efficient VAM strain and PSB along with 50 % P₂O₅ dose would result in saving 50 % P fertilizer impairing the yield of maize in an acidic Alfisol (Suri *et al.*, 2011). Similar results were reported by Mehta *et al.* (2012) who reported that the combined inoculation of seed with rhizobium and phosphorus solubilizing bacteria resulted in higher plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net return. Combined inoculation of AMF and PSM with decreasing the P level enhanced the growth of crop (Meena *et al.*, 2002).

Table 11: Influence of phosphorus, PSB and VAM application on growth and yield parameters of maize at harvest in high available phosphorus soil

Treatments	No. of cobs plant ⁻¹	No. of rows per cob	No. of seeds per row	100 seeds weight (g)	Weight of cob (g plant ⁻¹)	Seeds weight (g per cob)	Grain yield (q ha ⁻¹)	Stover yield (q ha ⁻¹)
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.0	13.07	21.93	23.0	126.93	99.47	66.01	75.89
T ₂ -FYM (10 t ha ⁻¹)	1.1	12.67	19.27	23.3	117.40	87.80	50.85	58.47
T ₃ -RD NPK + FYM	1.0	13.47	34.87	29.4	183.07	156.40	76.31	87.64
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	1.1	15.93	34.67	32.1	180.27	158.53	82.35	94.61
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	1.1	16.13	34.47	28.1	180.53	159.67	82.12	94.29
T ₆ -RD NPK + FYM + PSB + VAM	1.1	16.87	33.93	32.8	189.87	174.00	85.01	97.70
T ₇ -50 % P + RD NK + FYM	1.0	13.27	31.00	26.3	161.53	143.80	75.42	86.80
T ₈ -0 % P + RD NK + FYM	1.1	13.53	31.13	23.9	157.67	134.27	72.72	83.73
T ₉ -50 % P + PSB + RD NK + FYM	1.1	16.53	34.67	31.8	179.67	166.33	80.07	91.94
T ₁₀ -0 % P + PSB + RD NK + FYM	1.1	16.13	33.87	30.9	190.00	169.27	79.87	91.82
T ₁₁ -50 % P + VAM + RD NK + FYM	1.1	14.93	33.87	30.6	169.67	155.20	80.47	92.37
T ₁₂ -0 % P + VAM + RD NK + FYM	1.1	16.20	34.47	31.1	186.07	165.40	79.91	91.79
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	1.2	16.73	35.80	33.4	185.53	170.60	84.62	97.22
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	1.2	17.20	36.20	33.1	182.73	168.13	78.53	90.27
SEm±	0.06	0.66	1.63	1.48	8.67	5.91	1.50	1.62
CD (P = 0.05 %)	NS	1.90	4.73	4.30	25.20	17.17	4.35	4.71

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

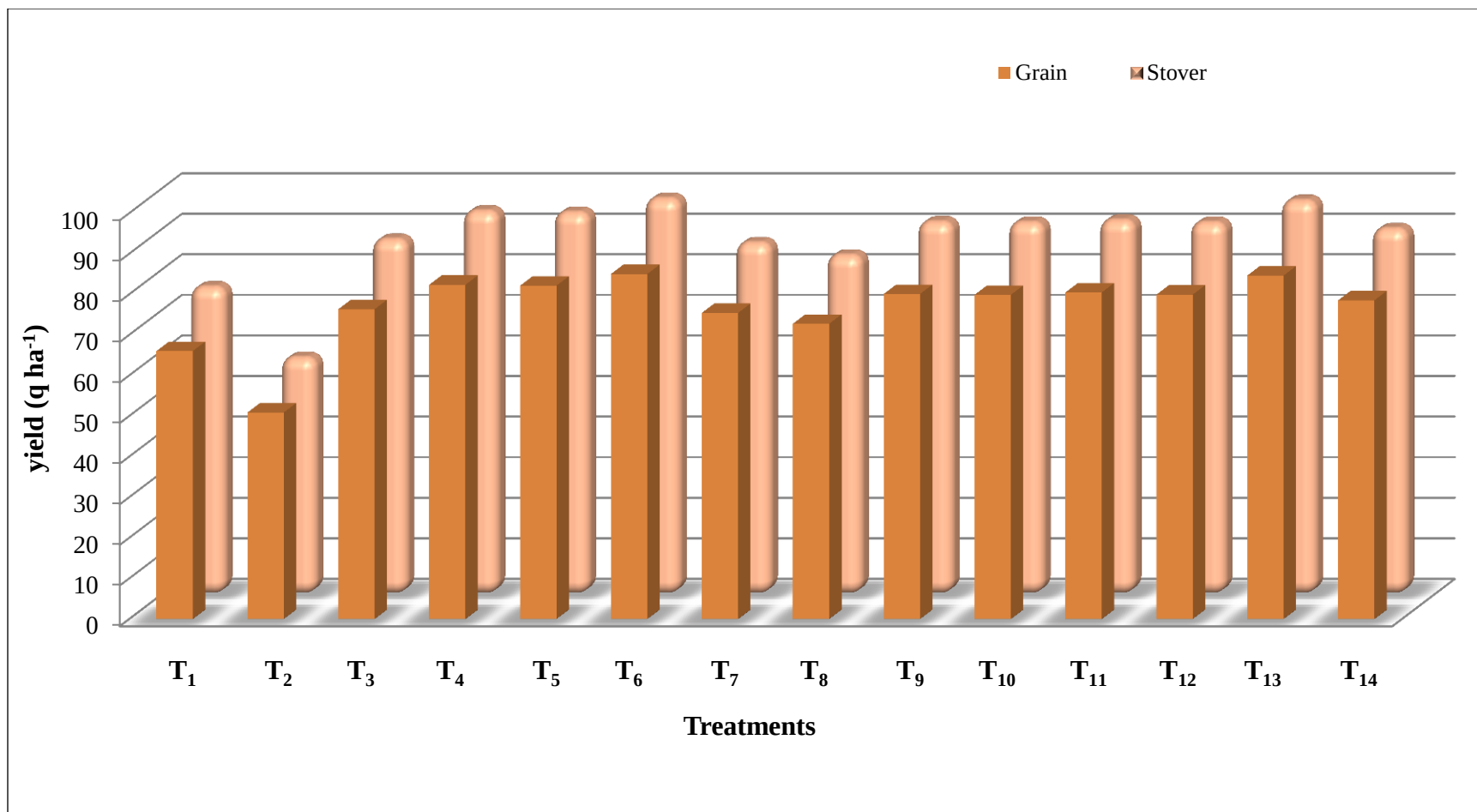


Fig. 2. Influence of P, PSB and VAM application on yield of maize (q ha⁻¹) in soil high in available phosphorus

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50% P + RD NK & FYM, T₈-0% P + RD NK & FYM, T₉-50% P + PSB + RD NK & FYM, T₁₀-0% P + PSB + RD NK & FYM, T₁₁-50% P + Mycorrhiza + RD NK & FYM, T₁₂-0% P + Mycorrhiza + RD NK & FYM, T₁₃-50% P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0% P + PSB + Mycorrhiza + RD NK & FYM.

4.1.2.3.6 Stover yield (q ha^{-1})

The stover yield was significantly higher (97.70 q ha^{-1}) with application of RD NPK + PSB + VAM + FYM (T_6) and was on par with T_{13} (97.22 q ha^{-1}) to which recommended PSB, VAM, NK, FYM and 50 % phosphorus was applied. PSB and VAM together were capable of enhancing the P use efficiency of soil for better plant growth (Gryndler *et al.*, 1990) (Table 11). Treatments T_4 (RD NPK+FYM+PSB) and T_5 (RD NPK+FYM+VAM) recorded on par (94.61 and 94.29 q ha^{-1}) maize stover yield (Table 11 and Fig. 2). However, lower yield of maize stover (58.47 q ha^{-1}) was recorded in T_2 (FYM alone). This indicates that with dual inoculation of efficient VAM strain and PSB along with 50 % P_2O_5 dose, 50 % of P fertilizer can be saved without impairing the yield of maize in an acidic Alfisol (Suri *et al.*, 2011).

4.1.3 Effect of PSB, VAM and different level of phosphorus on nutrient content of maize at tasseling stage in soil of high available P

4.1.3.1 Major nutrients content of different parts of maize at tasseling stage

The nitrogen content of maize crop at tasseling stage grown in high P soil varied significantly among treatments (Table 12). The nitrogen content of maize increased in treatment T_{14} receiving 0 % P + PSB + VAM + RD NK + FYM (1.30 % and it was on par with a treatment received RD NPK + FYM + PSB + VAM (T_6) 1.72, 1.07 and 1.20 % and T_{13} (50 % P + PSB + VAM + RD NK + FYM) 1.52, 1.01 and 1.41 % respectively. The lower nitrogen in maize leaves, stover and root was recorded in treatment which received T_2 FYM @ 10 t ha^{-1} (0.77 %). Inoculation with PSB + VAM registered high N uptake compared to uninoculated treatment. Higher nitrogen content of maize could be attributed to increased nitrogen availability in the soil. Among different parts of plant, the leaf under uninoculated condition showed high nitrogen content compared to stover and root but under dual inoculated situation without P fertilizer the nitrogen content was high in root compared to leaves and stover which may be due to the high transformation of nitrogen from organic and inorganic source.

The P content of maize crop at tasseling stage differed significantly among treatments (Table 12). The P content of maize at tasseling stage increased with application of full dose or 50 % P or without P and RD NK + FYM + PSB + VAM. The high P content in leaves, stover and root were observed in treatment T_{13} (50 % P + PSB + VAM + RD NK + FYM) 0.31, 0.29 and 0.15 % was on par with other treatments inoculated with microorganism i.e. T_6 (0.31, 0.29 and 0.09 %) and T_{14} (0.21 %) respectively. Lower P content (0.14 %) in maize crop was recorded in T_2 treatment (FYM @ 10 t ha^{-1}) 0.22, 0.18 and 0.04 % respectively. Among different parts of maize (leaf, stover and root) the content of P was higher in leaf except T_{13} .

Higher K content in leaves, stover and roots were recorded in treatment T_6 (2.82, 2.49 and 1.70 %) respectively and was on par with dual inoculation of PSB, AMF and 100 % P or without P application. Lower K content was observed in treatment T_2 (2.10, 2.00 and 1.12 %) (Table 12).

Table 12: Influence of phosphorus, PSB and VAM application on major nutrients content (%) of maize at tasseling stage in high available phosphorus soil

Treatments	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	leaves	stover	roots	leaves	stover	roots	leaves	stover	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.01	0.84	0.62	0.22	0.19	0.06	2.56	2.00	1.13
T ₂ -FYM (10 t ha ⁻¹)	1.00	0.65	0.66	0.22	0.18	0.04	2.46	1.77	1.08
T ₃ -RD NPK + FYM	1.65	0.91	0.84	0.31	0.19	0.05	2.71	2.39	1.25
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	1.96	0.83	0.84	0.28	0.22	0.04	2.42	2.53	1.05
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	1.61	0.79	0.67	0.27	0.21	0.06	2.45	2.13	1.12
T ₆ -RD NPK + FYM + PSB + VAM	1.72	1.07	1.20	0.32	0.29	0.09	2.82	2.49	1.70
T ₇ -50 % P + RD NK + FYM	1.16	0.89	1.15	0.23	0.28	0.06	2.41	2.27	1.45
T ₈ -0 % P + RD NK + FYM	0.91	0.81	1.02	0.19	0.18	0.05	2.11	2.02	0.88
T ₉ -50 % P + PSB + RD NK + FYM	1.10	1.07	0.91	0.29	0.14	0.12	2.30	2.54	0.99
T ₁₀ -0 % P + PSB + RD NK + FYM	1.17	1.42	0.85	0.31	0.19	0.07	2.64	2.27	1.07
T ₁₁ -50 % P + VAM + RD NK + FYM	1.05	1.02	0.73	0.29	0.26	0.10	2.28	1.92	1.01
T ₁₂ -0 % P + VAM + RD NK + FYM	1.02	0.96	0.67	0.25	0.25	0.08	2.54	1.79	1.10
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	1.52	1.01	1.41	0.31	0.29	0.15	2.83	2.57	1.34
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	1.73	1.08	1.21	0.28	0.28	0.09	2.70	2.45	1.27
SEm±	0.10	0.06	0.07	0.014	0.02	0.01	0.15	0.14	0.05
CD (P = 0.05 %)	0.29	0.17	0.21	0.04	0.05	0.03	0.42	0.40	0.14

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant N, P and K content. Similar results were reported by Wu *et al.* (2005). Higher N, P and K concentration in plants observed in dual inoculation with rhizobacteria and *G. intraradices*. The lowest N, P and K content was observed in plants grown in uninoculated and unfertilized pots. Either single treatment of chemical or organic fertilization resulted decrease in N, P and K concentration. The maximum P and K assimilation were obtained with the dual inoculation of *G. mosseae* and rhizobacteria. Fertilizer applications with compost showed high nutrient content compared to NPK or FYM alone. This supports the findings of Adediran *et al.* (2004) who observed increased plant nutrients concentration amended with inorganic fertilizer and compost.

4.1.3.2 Secondary nutrients content of different parts of maize at tasseling

At tasseling, combined inoculation of PSB+VAM recorded significantly higher sulphur content in different parts of maize (leaves, stover and root) (Table 13). T₆ (RD NPK + FYM + PSB + VAM) showed higher S content in maize (0.41, 0.28 and 0.26 %) and it was on par with other inoculated like 50 % P + PSB + VAM + RD NK + FYM (T₁₃) 0.41, 0.26 and 0.19 % and T₁₄ (0 % P + PSB + VAM + RD NK + FYM) 0.36, 0.22 and 0.25 % and T₄ (0.35, 0.17 and 0.27 %). FYM @ 10 t ha⁻¹ without inoculation (T₂) recorded significantly lower S content of 0.25, 0.11 and 0.19 % respectively.

Among the treatments, T₆ (RD NPK + FYM + PSB + VAM) recorded significantly higher content of Ca in leaves (0.79 %) and T₁₁ (50 % P + VAM + RD NK + FYM) 0.86 % compared to control (T₂) (FYM @ 10 t ha⁻¹) (0.73 %). However, stover and root Ca at tasseling recorded was higher in T₁₃ (50 % P + PSB + VAM + RD NK + FYM) (0.78 and 0.41 %, respectively) and on par with T₆ (RD NPK + FYM + PSB + VAM) 0.76 and 0.64 %. T₂ (FYM @ 10 t ha⁻¹) showed significantly lower Ca in stover and root (0.42 and 0.27 %) (Table 13).

Similar trend of calcium was followed with respect to magnesium content by maize leaves, stover and root. With respect to leaves, stover and roots the magnesium content was found to be higher in treatments T₆ (0.90, 0.44 and 0.69 %) followed by T₃ (0.86, 0.26 and 0.66 %) which was on par with T₁₃ (0.70, 0.41 and 0.66 %), and T₄ (0.67, 0.38 and 0.71 %) compared to T₂ (0.37, 0.17 and 0.26 %) (Table 13).

Combined inoculation with FYM and half dose of P fertilizer enhanced the plant to absorb more micronutrient compared to uninoculated treatment. This may be due to high solubility of micronutrients which easily can be taken up by maize crop. Nyoki and Ndakidemi (2014) found significant improvement in the uptake of secondary nutrient in the *B. japonicum* inoculated treatments over the control. Seed inoculation of chickpea with Rhizobium and PSB (phosphate solubilizing bacteria) increased total S, Ca and Mg content by the cropping system over no inoculation and inoculation with Rhizobium alone (Jat and Ahlawat, 2006).

Table 13: Influence of phosphorus, PSB and VAM application on secondary nutrients content (%) of maize at tasseling stage in high available phosphorus soil

Treatments	Sulphur (%)			Calcium (%)			Magnesium (%)		
	leaves	stover	roots	leaves	stover	roots	leaves	stover	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	0.31	0.12	0.21	0.73	0.73	0.45	0.47	0.31	0.45
T ₂ -FYM (10 t ha ⁻¹)	0.25	0.11	0.19	0.67	0.42	0.27	0.33	0.17	0.26
T ₃ -RD NPK + FYM	0.30	0.21	0.19	0.78	0.67	0.56	0.86	0.29	0.66
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	0.35	0.17	0.27	0.86	0.45	0.38	0.67	0.38	0.71
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	0.27	0.16	0.16	0.75	0.50	0.41	0.46	0.28	0.40
T ₆ -RD NPK + FYM + PSB + VAM	0.41	0.28	0.26	0.79	0.76	0.64	0.90	0.44	0.69
T ₇ -50 % P + RD NK + FYM	0.29	0.21	0.14	0.72	0.61	0.50	0.41	0.55	0.48
T ₈ -0 % P + RD NK + FYM	0.39	0.17	0.18	0.84	0.52	0.38	0.40	0.24	0.37
T ₉ -50 % P + PSB + RD NK + FYM	0.25	0.15	0.19	0.70	0.61	0.58	0.95	0.34	0.24
T ₁₀ -0 % P + PSB + RD NK + FYM	0.31	0.14	0.13	0.70	0.67	0.54	0.33	0.76	0.28
T ₁₁ -50 % P + VAM + RD NK + FYM	0.34	0.17	0.16	0.86	0.59	0.57	0.80	0.28	0.58
T ₁₂ -0 % P + VAM + RD NK + FYM	0.26	0.15	0.15	0.73	0.43	0.58	0.46	0.41	0.32
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	0.41	0.26	0.19	0.73	0.78	0.65	0.70	0.41	0.66
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	0.36	0.23	0.25	0.65	0.45	0.57	0.46	0.27	0.54
SEm±	0.02	0.01	0.017	0.03	0.05	0.05	0.05	0.04	0.04
CD (P = 0.05 %)	0.06	0.04	0.049	0.10	0.13	0.14	0.16	0.10	0.10

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.1.3.3 Micronutrients content of different parts of maize at tasseling

The data on concentration of micronutrients in maize leaves, stover and roots at tasseling stage are presented in Table 14.

Iron content of maize leaves, stover and roots at tasseling stage was significantly higher in T₆ (RD NPK + FYM + PSB + VAM) (73.36, 62.96 and 48.19 mg kg⁻¹) which were on par with T₁₁ received 50 % P + VAM + RD NK + FYM (71.26, 50.46 and 48.53 mg kg⁻¹), T₁₃ (74.13, 49.21 and 46.63 mg kg⁻¹) and T₉ (70.40, 48.57 and 49.55 mg kg⁻¹). Lower iron content of leaves, stover and roots was recorded in T₂ (FYM @ 10 t ha⁻¹) (47.56, 35.57 and 40.66 mg kg⁻¹).

The content of manganese at tasseling stage of maize leaves increased significantly in all treatments compared to T₁ which received RD NPK @ 150: 75: 40 kg ha⁻¹ (33.16 mg kg⁻¹) which recorded the lowest and T₆ received RD NPK + FYM + PSB + VAM recorded the higher leaf (37.25 mg kg⁻¹) manganese content. Combined and single inoculation recorded higher Mn content compared to uninoculated treatments.

Copper content of maize leaves, stover and roots at tasseling stage decreased (5.92, 2.18 and 4.08 mg kg⁻¹) significantly in the T₂ (FYM @ 10 t ha⁻¹) and significantly higher copper content was recorded in T₆ (7.93, 4.37 and 7.16 mg kg⁻¹) and T₁₃ (7.91, 4.16 and 7.13 mg kg⁻¹) at tasseling stage. Similar trend was observed in case of maize whole plant also.

Combined inoculation or single inoculation with PSB or AMF with FYM and fertilizer application showed significant differences with respect to zinc content at tasseling stage of maize leaves, stover and roots. The zinc content in maize leaves, stover and roots increased significantly in T₆ treatment which received RD NPK + FYM + PSB + VAM (27.92, 16.47 and 30.84 mg kg⁻¹), T₁₃ (25.86, 15.86 and 29.72 mg kg⁻¹) and T₁₄ (25.67, 15.81 and 29.05 mg kg⁻¹) respectively compared to the T₂ (FYM @ 10 t ha⁻¹). Significantly lower zinc content was recorded in T₂ (FYM @ 10 t ha⁻¹) (17.26, 8.40 and 20.17 mg kg⁻¹) respectively.

Higher concentration of micronutrients in combined inoculated or single inoculated treatment might be due to higher available micronutrients in soil which leads to higher uptake of micronutrients by plant. Lower content of micronutrient in FYM alone may be due to low mineralization rate. Nyoki and Ndakidemi (2014) reported the similar result in a significant content of micronutrients in the *B. japonicum* inoculated treatments over the control. Phosphorus supplementation (40 kg P ha⁻¹) also showed a significant increase in the content of some micronutrients while decrease in the uptake of Zn in some plant organs. There was also a significant interaction between *B. japonicum* inoculation and phosphorus in the root uptake of Zn for the field experiment. The same result found by Adediran *et al.* (2004) showed high content of micronutrients in mineral fertilizer compared to organic manure alone. Application of fertilizer nitrogen increased the yield, percent nitrogen content and the uptake of other nutrients. Nutrient accumulation in the maize leaves was greater than that in the other components of the plant (Hussaini *et al.*, 2008).

Table 14: Influence of phosphorus, PSB and VAM application on micronutrient content (mg kg⁻¹) of maize at tasseling stage in high available phosphorus soil

Treatments	Fe (mg kg ⁻¹)			Mn (mg kg ⁻¹)			Cu (mg kg ⁻¹)			Zn (mg kg ⁻¹)		
	leaves	stover	roots	leaves	stover	roots	leaves	stover	roots	leaves	stover	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	51.51	25.84	50.63	33.16	32.69	62.05	6.51	2.44	6.29	21.03	12.35	17.37
T ₂ -FYM (10 t ha ⁻¹)	47.56	35.57	40.66	36.63	48.12	44.69	5.92	2.18	4.08	17.26	8.40	20.17
T ₃ -RD NPK + FYM	63.92	42.26	50.41	37.61	57.43	49.97	6.18	3.96	4.42	22.53	14.10	25.55
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	60.39	48.40	49.10	51.97	83.07	49.61	7.91	4.32	5.00	25.34	15.05	25.17
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	57.40	54.62	46.31	29.40	67.21	52.44	5.47	2.60	2.99	23.29	12.86	25.47
T ₆ -RD NPK + FYM + PSB + VAM	73.36	62.96	48.19	37.25	82.27	80.37	7.93	4.37	7.16	27.92	16.47	30.84
T ₇ -50 % P + RD NK + FYM	70.12	42.31	38.81	30.34	69.53	37.98	5.77	1.97	4.99	20.78	13.93	26.73
T ₈ -0 % P + RD NK + FYM	52.78	44.53	45.83	22.25	75.90	43.49	6.30	2.47	5.94	15.72	12.15	24.01
T ₉ -50 % P + PSB + RD NK + FYM	70.40	48.57	49.55	37.21	91.17	58.54	5.01	2.38	6.05	24.91	14.02	27.64
T ₁₀ -0 % P + PSB + RD NK + FYM	61.61	33.21	36.67	68.33	66.98	45.07	4.95	4.63	3.54	21.53	12.31	19.73
T ₁₁ -50 % P + VAM + RD NK + FYM	71.26	50.46	48.53	27.38	83.73	60.09	5.51	2.27	3.84	23.48	13.15	18.92
T ₁₂ -0 % P + VAM + RD NK + FYM	46.68	41.09	40.63	37.49	66.78	51.34	5.08	3.45	6.07	20.79	10.06	24.41
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	74.13	49.21	46.63	29.70	82.79	70.82	7.91	4.16	7.13	25.86	15.86	29.72
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	58.43	44.13	44.61	48.12	81.50	40.1	6.93	3.88	4.10	25.67	15.81	29.05
SEm±	3.08	1.79	1.80	3.55	3.43	3.39	0.46	0.34	0.28	1.53	0.74	1.18
CD (P = 0.05 %)	8.97	5.24	5.25	10.32	9.98	9.86	1.35	0.98	0.81	4.60	2.16	4.78

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.1.4 Effect of PSB, VAM and different levels of phosphorus on nutrient uptake by maize at harvest in soil of high available P

4.1.4.1 Major nutrients uptake by different parts of maize at harvest

The data pertaining to nitrogen, phosphorus and potassium uptake by different parts of maize crop differed significantly due to PSB, AMF, FYM and chemical fertilizers application to the soil under high phosphorus status (Table 15).

The nitrogen uptake by different parts like leaves, stover, grain and roots of maize crop at harvest was significantly higher in T₆ (29.29, 41.61, 89.96 and 13.90 kg ha⁻¹, respectively) which received RD NPK + FYM + PSB + VAM and it was on par with T₁₃ (24.22, 39.08, 85.82 and 12.77 kg ha⁻¹, respectively). However, lower nitrogen uptake by leaves, stover, grain and roots was recorded in the T₂ received FYM @ 10 t ha⁻¹ (15.85, 14.41, 60.77 and 5.54 kg ha⁻¹, respectively). Combined inoculation and single inoculation has recorded higher nitrogen uptake compared to uninoculated treatment (Table 15). Among different parts of maize, grain showed higher nitrogen uptake compared to leaves, stover and root. Root showed lower nitrogen uptake.

Uptake of phosphorus by leaves, stover, grain, root and whole maize crop differed significantly among the treatments. Higher uptake of phosphorus by leaves, stover, grain and root of maize crop at harvest was recorded in treatment T₁₃ receiving 50 % P + PSB + VAM + RD NK + FYM (5.96, 6.38, 45.74 and 2.25 kg ha⁻¹, respectively) and T₆ which received RD NPK + FYM + PSB + VAM (5.51, 5.71, 41.85 and 2.19 kg ha⁻¹, respectively). However, lower uptake of phosphorus by leaves, stover, grain and roots (1.71, 2.99, 17.62 and 1.14 kg ha⁻¹, respectively) was recorded in the T₂ (FYM @ 10 t ha⁻¹). Combined inoculation showed higher phosphorus uptake compared to uninoculated treatments.

The total K uptake by maize leaves, stover, grain and roots varied significantly with the different inoculated and uninoculated treatments is presented in Table 15. Higher K uptake by leaves, stover, grain and roots was recorded in T₆ received RD NPK + FYM + PSB + VAM (39.72, 51.25, 63.13 and 26.83 kg ha⁻¹, respectively) and was on par with T₁₃ received 50 % P + PSB + VAM + RD NK + FYM (36.94, 50.53, 58.02 and 25.38 kg ha⁻¹, respectively). Lower plant K uptake by leaves, stover, grain and roots was recorded in T₂ (22.96, 21.09, 31.96 and 16.38 kg ha⁻¹, respectively) where only FYM @ 10 t ha⁻¹ was applied.

The use of biofertilizers (*G. mosseae* and VAM) resulted in the highest nitrogen, phosphorus and potassium uptake. This field experiment study also indicated that half dose of phosphorus application with combined microbial inoculation had similar effects when compared with full dose of phosphorus fertilizer with dual inoculation. Higher nutrient uptake in dual inoculated treatment could be attributed to increased nutrient availability in the soil. Higher uptake of major nutrients in above said treatment was due to higher growth attributing parameters and total dry matter production. This further influenced the manifestation of yield attributing characters and subsequently the yield of maize crop. Gupta *et al.* (2006) noticed that the effect of bio-fertilizer inoculation and phosphorus fertilization on N and P uptake. The practice of seed inoculation with

Table 15: Influence of phosphorus, PSB and VAM application on major nutrients uptake by maize crop (kg ha⁻¹) at harvest in high available phosphorus soil

Treatments	Nitrogen (kg ha ⁻¹)				Phosphorus (kg ha ⁻¹)				Potassium (kg ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	16.99	22.24	65.88	8.36	1.89	3.16	22.30	1.28	27.88	31.66	43.06	17.61
T ₂ -FYM (10 t ha ⁻¹)	15.85	14.41	60.77	5.54	1.71	2.99	17.62	1.14	22.96	21.09	31.96	16.38
T ₃ -RD NPK + FYM	18.53	28.40	81.93	11.30	3.13	4.03	28.69	1.50	28.94	38.42	48.94	17.35
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	22.15	30.23	83.33	12.05	3.40	4.56	36.90	2.02	33.19	39.53	54.63	22.69
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	17.07	29.80	74.67	9.19	2.83	4.11	33.67	1.93	29.08	38.07	44.88	20.41
T ₆ -RD NPK + FYM + PSB + VAM	29.29	41.61	89.96	13.90	5.51	5.71	41.85	2.19	39.72	51.25	63.13	26.83
T ₇ -50 % P + RD NK + FYM	17.97	23.82	76.75	7.85	1.91	3.17	29.18	0.91	29.63	35.13	46.49	17.45
T ₈ -0 % P + RD NK + FYM	16.28	18.30	80.61	8.77	1.85	2.35	33.24	0.96	28.87	32.42	45.96	13.89
T ₉ -50 % P + PSB + RD NK + FYM	19.56	24.65	79.49	5.58	3.18	3.02	38.88	1.54	29.13	46.21	57.90	15.29
T ₁₀ -0 % P + PSB + RD NK + FYM	21.14	21.77	75.07	7.50	3.81	4.83	38.99	2.04	30.90	40.15	56.93	15.37
T ₁₁ -50 % P + VAM + RD NK + FYM	15.69	29.29	78.56	11.05	1.84	4.57	37.13	0.93	33.02	41.50	55.39	22.33
T ₁₂ -0 % P + VAM + RD NK + FYM	13.44	20.10	74.98	10.90	1.89	4.47	28.39	0.78	23.11	43.99	53.41	15.91
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	24.22	39.08	85.82	12.77	5.96	6.38	45.74	2.25	36.94	50.53	58.02	25.38
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	22.19	27.98	80.61	10.55	3.97	5.56	40.54	2.07	35.85	41.23	57.48	23.08
SEm±	1.12	2.18	2.62	0.66	0.28	0.48	3.10	0.18	2.03	4.02	4.67	1.48
CD (P = 0.05 %)	3.26	6.34	7.85	1.91	0.82	1.41	9.09	0.53	5.89	11.68	13.59	4.33

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

phosphorus solubilizing bacteria showed a significant increase in N and P uptake over uninoculated treatment. Phosphorus application also resulted in significant increase in N and P uptake in seed and straw. NPK alone showed higher nutrient uptake compare to FYM alone which may be due to the high availability of these nutrients from NPK fertilizer. Total P uptake by maize was increased with increasing level of inorganic P in soils compared to organic manure (Garg and Bahl, 2008). Phosphorus and biofertilizers application significantly influenced the P uptake of crop. Seed inoculation with Rhizobium and phosphobacteria was significantly superior over no inoculation or phosphobacteria inoculation alone. Combined application of P at 26.2 kg ha⁻¹ and biofertilizers (Rhizobium and phosphobacteria) enhanced significant P uptake compared to other levels of P with biofertilizer (Dutta and Bandyopadhyay, 2009).

4.1.4.2 Secondary nutrients uptake by different parts of maize at harvest

The data on secondary nutrients uptake by leaves, stover, grains and roots of maize are represented in Table 16. Treatments differed significantly due to application of phosphorus and its microbial inoculants.

Higher uptake of sulphur by leaves, stover, grain and roots of maize plant was recorded in treatment T₆ (RD NPK + FYM + PSB + VAM) 6.84, 6.53, 7.65 and 4.59 kg ha⁻¹ respectively this was followed by treatment T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 5.69, 6.44, 7.50 and 3.88 kg ha⁻¹, respectively. However, lower uptake of sulphur (3.98, 3.39, 3.79 and 1.47 kg ha⁻¹, respectively) was recorded in T₂.

Calcium uptake by different parts of maize (leaves, stover, grain and roots) at harvest differed significantly in all the treatments compared to T₂ (FYM @ 10 t ha⁻¹). Ca uptake was significantly higher in treatment T₆ (19.70, 29.23, 30.02 and 8.56 kg ha⁻¹ in leaves, stover, grain and root, respectively) and was on par with T₁₃ (19.70, 29.12, 28.97 and 8.48 kg ha⁻¹, respectively). Lower Ca uptake was recorded in T₂ (14.18, 16.18, 15.05 and 5.07 kg ha⁻¹, respectively).

The same trend was observed for Mg uptake by maize crop. Within the treatments T₁₃ (50 % P+ RD NK + FYM + PSB + VAM) resulted in significantly higher uptake of Mg by leaves, stover, grain and roots (13.65, 30.32, 24.67 and 6.65 kg ha⁻¹, respectively). Lower Mg uptake was recorded in T₂ (FYM @ 10 t ha⁻¹) (4.17, 9.85, 9.34 and 2.59 kg ha⁻¹, respectively). However, higher total Mg uptake was recorded in T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 24.09 kg ha⁻¹ and was found on par with T₆ (RD NPK + FYM + PSB + VAM) 22.02 kg ha⁻¹. Lower Mg uptake by whole plant was recorded in T₂ (8.41 kg ha⁻¹, respectively). Microbial inoculated treatment showed higher Mg uptake compared to uninoculated treatments except in T₇ (50 % P + RD NK and FYM).

Secondary nutrients uptake was significantly higher in case of combined inoculation compared to uninoculated treatment which may be due to high acquisition of Ca, Mg and S by microorganisms. Combined inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant nutrient uptake (Wu *et al.*, 2005).

Table 16: Influence of phosphorus, PSB and VAM application on secondary nutrients uptake by maize crop (kg ha⁻¹) at harvest in high available phosphorus soil

Treatments	S (kg ha ⁻¹)				Ca (kg ha ⁻¹)				Mg (kg ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	4.29	3.83	4.74	1.84	14.96	18.37	16.17	5.82	6.01	11.42	13.10	3.63
T ₂ -FYM (10 t ha ⁻¹)	3.98	3.39	3.79	1.47	14.53	16.18	15.05	5.07	4.17	9.85	9.34	2.59
T ₃ -RD NPK + FYM	5.63	4.94	6.21	2.29	15.68	26.53	16.28	6.89	9.05	15.53	10.94	5.90
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	5.58	5.36	6.45	2.35	15.92	26.16	19.62	7.25	6.94	12.08	23.94	6.14
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	4.10	5.10	5.39	3.04	17.99	28.01	18.63	7.17	7.38	11.41	19.90	4.86
T ₆ -RD NPK + FYM + PSB + VAM	6.84	6.53	7.65	4.59	19.70	29.23	30.02	8.56	10.15	28.28	24.54	4.96
T ₇ -50 % P + RD NK + FYM	4.34	5.13	3.53	1.04	18.76	16.15	18.52	6.92	7.15	11.88	15.45	3.35
T ₈ -0 % P + RD NK + FYM	4.51	4.19	3.84	2.07	16.58	16.93	16.11	5.40	8.00	9.32	9.19	3.72
T ₉ -50 % P + PSB + RD NK + FYM	4.55	5.18	4.47	2.71	18.00	29.15	20.00	6.00	9.53	25.13	20.29	3.86
T ₁₀ -0 % P + PSB + RD NK + FYM	5.71	4.69	3.99	2.10	17.88	23.88	22.10	5.15	8.74	12.77	15.80	3.11
T ₁₁ -50 % P + VAM + RD NK + FYM	4.04	5.74	4.44	1.86	17.11	19.81	23.85	6.49	5.84	14.31	14.36	3.60
T ₁₂ -0 % P + VAM + RD NK + FYM	4.77	3.42	4.93	3.30	15.84	23.18	22.06	6.29	8.73	14.95	11.39	3.72
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	5.69	6.44	7.50	3.88	19.70	29.12	28.97	8.48	13.65	30.32	24.67	6.65
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	4.32	6.01	7.37	2.80	18.18	23.88	26.58	7.06	10.36	19.99	22.98	6.04
SEm±	0.39	0.56	0.41	0.19	1.00	1.66	1.00	0.51	0.87	1.01	1.56	0.30
CD (P = 0.05 %)	1.14	1.61	1.20	0.56	2.90	4.84	2.98	1.52	2.53	2.95	4.54	0.91

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.1.4.3 Micronutrients uptake by different parts of maize

The data pertaining to micronutrients uptake by different parts of maize crop due to PSB, AMF, FYM and chemical fertilizers application to the soil under high phosphorus condition is given in Table 17 and Table 18. Significant differences were observed among the treatments.

Among different parts higher Fe uptake was recorded by shoots and grains compared to roots and leaves. Iron uptake by leaves, stover, grain and roots of maize was higher in T₆ (806.00, 1040.90, 815.20 and 323.40 g ha⁻¹ respectively) which were on par with T₁₃ (797.70, 779.70, 671.00 and 601.60 g ha⁻¹) and lower was recorded in T₂ (301.40, 307.30, 336.10 and 246.10 g ha⁻¹).

Application of PSB, AMF and FYM, 50 % P or full dose P and NK fertilizers showed significant differences with respect to Mn uptake. Significantly higher Mn uptake by leaves, stover, grain and roots of maize 374.20, 808.10, 321.50 and 174.80 g ha⁻¹ respectively was recorded in T₆ treatment which was found superior compared to other treatments. Lower Mn uptake was recorded in T₁ (61.30, 340.80, 120.10 and 63.10 g ha⁻¹ respectively). Among different parts of maize stover showed high uptake of Mn compared to leaves, grain and root.

Uptake of zinc by maize leaves, stover, grain and root was significantly higher in most of the treatments with combined inoculation compared to single and uninoculated treatment. In T₆ (RD NPK + FYM + PSB + VAM) higher uptake of zinc by stover and grain was recorded (274.68 and 317.91 g ha⁻¹, respectively). Significantly lower uptake of zinc by leaves, stover, grain and root was recorded in T₂ (FYM @ 10 t ha⁻¹) 24.26, 99.41, 165.59 and 19.55 g ha⁻¹, respectively.

The uptake of Cu by different parts of maize plant differed significantly in all the treatments compared to T₁ (NPK alone) and T₂ (FYM @ 10 t ha⁻¹). Total Cu uptake by leaves, stover, grain and roots of maize was significantly higher in T₁₃ (41.53, 52.46, 197.57 and 32.37 g ha⁻¹) and was on par with T₆ (26.29, 58.47, 199.60 and 34.53 g ha⁻¹). Lower Cu uptake by plant was noticed in T₁ (19.29, 21.99, 74.95 and 14.06 g ha⁻¹). Among the various parts maximum Cu uptake was recorded by grains.

The micronutrients uptake was higher in case of combined inoculated treatments compared to single inoculated treatment; this may be due to the high solubility of micronutrient in soil through acid production which leads to higher uptake of these nutrients by plant. Gupta *et al.* (2006) observed the beneficial effect of bio-fertilizer inoculation and phosphorus fertilization on micronutrient uptake. The practice of seed inoculation with phosphorus solubilising bacteria showed a significant increase in Fe, Cu, Mn and Zn uptake over uninoculated treatments. Phosphorus application also resulted in significant increase in N and P uptake by seed and straw. These findings are in accordance with those of Das *et al.* (2007) who reported that the PSB and VAM with NK and FYM increased the micronutrient uptake by the crop.

Table 17: Influence of phosphorus, PSB and VAM application on Fe and Mn uptake (g ha⁻¹) by maize crop at harvest in high available phosphorus soil

Treatments	Fe (g ha ⁻¹)				Mn (g ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	309.00	305.60	238.60	270.70	61.30	340.80	120.10	63.10
T ₂ -FYM (10 t ha ⁻¹)	301.40	307.30	336.10	246.30	67.40	523.30	224.20	54.80
T ₃ -RD NPK + FYM	495.40	760.30	470.80	310.70	88.60	548.40	208.10	69.20
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	542.90	1015.90	730.00	294.70	222.50	486.30	174.20	177.90
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	641.00	959.40	668.10	396.50	318.30	518.80	176.50	249.10
T ₆ -RD NPK + FYM + PSB + VAM	806.00	1040.90	815.20	323.40	374.20	808.10	321.50	174.80
T ₇ -50 % P + RD NK + FYM	549.40	594.40	510.50	360.60	127.40	518.00	168.60	157.90
T ₈ -0 % P + RD NK + FYM	433.80	345.30	433.70	274.30	249.40	306.10	150.60	139.90
T ₉ -50 % P + PSB + RD NK + FYM	712.90	879.30	593.30	465.90	206.60	770.20	245.80	247.60
T ₁₀ -0 % P + PSB + RD NK + FYM	560.80	619.10	563.00	358.20	245.00	671.30	258.10	254.30
T ₁₁ -50 % P + VAM + RD NK + FYM	385.20	569.00	464.90	316.30	220.90	676.80	231.20	253.10
T ₁₂ -0 % P + VAM + RD NK + FYM	748.90	626.40	542.70	614.00	289.70	667.70	174.90	252.60
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	797.70	779.70	671.00	601.60	220.80	874.00	270.00	191.00
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	697.10	869.10	774.00	479.10	330.40	587.40	209.80	293.00
SEm±	36.10	53.50	16.10	34.90	15.20	64.10	19.50	15.90
CD (P = 0.05 %)	104.90	155.60	46.70	101.40	44.30	186.20	57.60	46.20

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Table 18: Influence of phosphorus, PSB and VAM application on uptake of Zn and Cu (g ha⁻¹) by maize crop at harvest in high available phosphorus soil

Treatments	Zn (g ha ⁻¹)				Cu (g ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	30.54	111.83	173.77	23.09	19.29	21.99	74.95	14.06
T ₂ -FYM (10 t ha ⁻¹)	24.26	99.41	165.59	19.55	17.40	22.12	86.33	13.41
T ₃ -RD NPK + FYM	27.86	173.96	319.94	26.68	24.33	33.79	161.08	26.16
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	30.15	192.93	309.87	20.99	18.84	37.14	165.53	20.08
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	27.73	177.89	237.47	19.69	18.51	42.50	108.76	15.43
T ₆ -RD NPK + FYM + PSB + VAM	35.12	274.68	317.91	31.26	26.29	58.47	199.60	34.53
T ₇ -50 % P + RD NK + FYM	30.67	196.85	252.05	21.45	21.32	36.03	123.54	18.77
T ₈ -0 % P + RD NK + FYM	27.08	109.87	276.38	16.94	19.62	23.47	90.45	15.24
T ₉ -50 % P + PSB + RD NK + FYM	26.29	131.45	252.51	17.79	26.42	49.86	154.54	19.88
T ₁₀ -0 % P + PSB + RD NK + FYM	24.46	244.60	274.88	15.50	29.95	42.24	135.18	12.56
T ₁₁ -50 % P + VAM + RD NK + FYM	22.89	137.99	262.45	17.07	19.49	36.74	128.25	18.84
T ₁₂ -0 % P + VAM + RD NK + FYM	31.59	199.47	213.92	28.51	25.18	40.84	135.57	20.67
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	38.13	266.83	311.50	30.15	41.53	52.46	197.57	32.31
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	34.07	246.56	273.90	26.49	36.69	52.06	127.66	14.91
SEm±	1.64	18.51	13.28	2.09	2.42	5.36	9.55	1.50
CD (P = 0.05 %)	4.84	53.82	39.89	6.02	7.13	15.57	27.73	4.32

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.1.4.4 Correlation between available P, nitrogen, potassium, fractions of soil P with maize yield

The correlation coefficient of available P with soil pH, nitrogen, potassium and fractions of P with yield of maize are presented in Table 19. The data showed that yield of maize was positively and significantly correlated with available P (0.673**), saloid- P (0.908**), Ca-P (0.732**) and available nitrogen (0.569*). The available nitrogen positively and significantly correlated with available P (0.627*), saloid P (0.780**) and Ca-P (0.590*).

Available P was positively and significantly correlated with saloid P (0.679**) and the relationship was positive with Org-P (0.475), Ca-P (0.401) and reductant P (0.397). Saloid P was significantly and positively correlated with Ca-P (0.731**). Al-P was significantly and positively correlated with reductant-P, Fe-P, occluded-P and organic P (0.906**, 0.697**, 0.610* and 0.565**, respectively).

Relationship of Fe-P was positive and significant with occluded P, organic P and reductant P (0.922**, 0.668** and 0.631*). The reductant P was positively and significantly correlated with occluded and organic P (0.713** and 0.585**). Occluded P was significantly and positively correlated with organic P (0.651**). There was a negative correlation between Ca-P and organic P.

The significant positive correlation between yield, available N, P, saloid P and Ca-P may be due to the synergistic effect among them but pH negatively correlated with Ca-P and organic P of soil. Similar results were obtained by Rossella *et al.* (2007) who indicated on the basis of a correlation analysis of soil properties that soil nitrate content and pH were inversely correlated. N was positively correlated with all forms of soil P, as well as with $\text{NH}_4\text{-N}$ and soil water content. Total P was correlated with available and organic P, as well as with $\text{NH}_4\text{-N}$. Phosphorus fixation was positively correlated with different pools of iron and aluminum compounds (Chatterjee *et al.*, 2014).

4.2 Field experiment: Studies on the residual effect of different levels of phosphorus, phosphorus solublizers and FYM in soil high available and total phosphorus soils on performance of cowpea under maize - cowpea cropping system

4.2.1 Changes in chemical properties of soil at 60 days after sowing and at harvest of cowpea

4.2.1.1 Soil pH, EC and NPK

The data on soil pH, EC, major nutrients and sulphur status of soil at 60 DAS and at harvest (plate 5 and 6) of cowpea is given in Table 20.

Table 19: Correlation of available P, nitrogen, potassium, fractions of soil P with maize yield in high available phosphorus soil

	yield q ha ⁻¹	pH	Avail. - N	Avail. - P	Avail. - K	Saloid - P	Al - P	Fe - P	Reductant - P	Occluded - P	Ca - P	Organic -P
Yield q ha⁻¹	1											
pH	-0.217	1										
Avail. - N	0.569*	0.081	1									
Avail. -P	0.673**	0.005	0.627*	1								
Avail. - K	0.443	0.531	0.640*	0.345	1							
Saloid - P	0.908**	-0.187	0.780**	0.679**	0.496	1						
Al - P	-0.103	0.342	0.083	0.123	0.218	-0.036	1					
Fe - P	0.087	0.139	-0.171	0.356	-0.024	-0.056	0.610*	1				
Reductant - P	0.073	0.159	0.294	0.397	0.178	0.137	0.906**	0.631*	1			
Occluded - P	0.281	0.128	-0.022	0.389	0.075	0.184	0.697**	0.922**	0.713**	1		
Ca - P	0.732**	-0.313	0.590*	0.401	0.248	0.731**	-0.491	-0.372	-0.288	-0.237	1	
Organic - P	0.341	-0.016	0.058	0.474	0.263	0.201	0.565*	0.668**	0.585*	0.651*	-0.169	1

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

Table 20: Residual effect of P, PSB and VAM on soil pH, EC, nutrient status after 60 days of sowing and at harvest of cowpea in soil with high available phosphorus

Treatments	pH		EC dSm ⁻¹		Available N		Available P ₂ O ₅		Available K ₂ O		Available S (mg kg ⁻¹)	
					kg ha ⁻¹							
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	5.66	5.47	0.58	0.26	128.45	100.86	44.77	40.06	235.17	210.13	9.63	6.36
T ₂	5.87	5.27	0.51	0.25	133.47	106.49	56.00	48.28	207.63	181.31	8.37	7.56
T ₃	6.10	6.25	0.40	0.23	166.25	121.75	73.28	66.80	285.12	240.23	13.53	9.82
T ₄	5.81	5.22	0.69	0.34	131.80	99.85	71.08	64.20	247.36	225.10	8.36	6.42
T ₅	5.29	6.16	0.54	0.26	131.80	98.85	68.39	57.56	235.12	210.36	7.95	6.60
T ₆	5.22	5.65	0.48	0.29	113.73	103.45	68.46	56.89	291.23	275.32	7.88	6.29
T ₇	5.58	6.14	0.39	0.22	147.52	143.84	66.05	66.46	281.36	269.32	10.04	7.51
T ₈	5.80	5.47	0.25	0.25	129.79	98.44	51.37	47.59	273.08	249.12	11.72	9.29
T ₉	5.81	5.43	0.30	0.32	145.84	104.50	60.03	52.40	239.21	190.23	10.14	6.90
T ₁₀	5.52	5.39	0.28	0.30	133.13	120.82	57.34	53.58	226.12	209.32	9.63	8.10
T ₁₁	5.01	5.10	0.32	0.32	130.79	101.20	52.27	48.69	255.32	239.12	10.47	7.56
T ₁₂	5.83	5.64	0.30	0.32	150.53	138.80	55.18	53.31	271.21	261.23	8.09	6.77
T ₁₃	5.23	5.52	0.67	0.32	109.05	100.49	56.89	42.64	260.12	241.32	8.83	7.50
T ₁₄	5.05	5.38	0.69	0.32	123.43	100.22	55.78	40.06	269.32	241.03	7.77	6.82
Initial	6.02		0.10		178.22		63.94		364.48		16.10	
SEm±	0.10	0.07	0.025	0.01	2.091	4.71	2.30	4.29	8.37	6.58	0.932	0.43
CD (P = 0.05 %)	0.28	0.22	0.073	0.03	6.097	13.68	6.89	12.47	24.34	19.12	2.708	1.23

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P + RD NK & FYM, T₈-0 % P + RD NK & FYM, T₉-50 % P + PSB + RD NK & FYM, T₁₀-0 % P + PSB + RD NK & FYM, T₁₁-50 % P + Mycorrhiza + RD NK & FYM, T₁₂-0 % P + Mycorrhiza + RD NK & FYM, T₁₃-50 % P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P + PSB + Mycorrhiza + RD NK & FYM.



Plate 7. Dr. V. R. Ramakrishna, Major advisor, Dr. A. Manjunath and I. S. Aftab Hussain, Advisory members during selection of low available P soil for pot culture experiment



Plate 8. Pot culture experiment on maize at tasseling stage

At 60 DAS and at harvest, application of RD NPK + FYM (T_3) recorded significantly higher pH (6.10 and 6.25) compared to all other treatments except T_7 at harvest which was on par pH 6.14. Lower pH of 5.01 and pH 5.10 was recorded in T_{11} ; RD FYM (10 tonnes). Soil pH decreased due to residual effect of dual inoculation which may be due to the higher production of organic acids. These results are in accordance with the findings of Mahanta and Rai, (2008) who reported that the acids produced by microorganism have the effect of decreasing the pH of the medium. Hence, the treatments consisting of inoculation with PSB lowered pH, closer to the optimum P availability. As the levels of P (without PSB) decreased for soybean crop, the soil pH also decreased and the lowest value was recorded under control plots (7.23). Under P deficiency, legumes including soybean is known to extrude large quantities of organic acids, especially citric, malonic, malic etc.. Adediran *et al.* (2004) reported that at postharvest period, soil pH decreased by 0.1 and 0.5 units at Ilora and between 0.1 and 0.3 units at Ibadan. There was a slight increase in soil pH on the plot that received organic fertilizer compared with control and MFert at Ilora. This was not so at Ibadan.

EC was significantly higher (0.69 and 0.34 dS m^{-1}) in T_4 (RD NPK + FYM + PSB (PSB @ 4 kg ha^{-1}) at 60 DAS and at harvest which was on par with T_{14} and T_{13} (0.69 and 0.67 dS m^{-1}) and it was significantly lower at 60 DAS and at harvest stage in T_7 (50 % P + RD NK + FYM) 0.39 and 0.22 dS m^{-1} compared to other treatments.

Significantly lower available N at 60 DAS and at harvest of cowpea was recorded in T_{14} treatment (0 P% + RD NK + FYM + PSB + VAM) 123.43 and 100.22 kg ha^{-1} , T_6 (113.73 and 103.45 kg ha^{-1}) and T_{13} (109.05 and 100.22 kg ha^{-1}) compared to single inoculated and uninoculated other treatments and it was higher available N (147.52 and 143.84 kg ha^{-1}) was recorded in T_7 (50 % P + RD NK + FYM) compared to all other treatments at both the stages this may be due to lower uptake of nitrogen and build up nitrogen by the legume plant. Similar observations were reported by Hemalatha *et al.* (2013) who inferred that inclusion of legumes in a cropping system helped to improve soil fertility resulting in higher yield of the succeeding crop (s) compared to preceding exhaustive cereal or other non-legume crops. There was build-up of N and P_2O_5 with the inclusion of legumes in cropping system. The superiority in building up of soil available nitrogen and phosphorus was in the order of cropping patterns having all legumes > legumes+cereals > all cereals. Residual effect of higher P levels up to 80 kg P_2O_5 ha^{-1} significantly increased the seed and straw yields after mustard harvest. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop as well as on the available N and P in soil (Mahala *et al.*, 2006).

Treatment T_3 which received RD NPK + FYM recorded significantly higher available phosphorus at 60 DAS and at harvest (73.28 and 66.80 kg ha^{-1}) compared to other treatments. Lower available P was observed in T_1 [RD NPK @ (150: 75: 40 kg ha^{-1})] at both the stages. Dual and single inoculation with 50 % or without P fertilizers showed lower available P compared to single inoculated with full dose of P and uninoculated treatments except T_1 . Results indicated that the depletion of available P take place by plant through the residual effect of microorganism. Similar results were reported

by Kaleeswari *et al.* (2007). Dissolution of P was significantly higher with P fertilizer + FYM + Phosphate solubilizing microorganisms irrespective of the P sources. Higher phosphatase activity was observed in FYM treated plots. Mahanta and Rai (2008) reported the similar findings on available P status of the soil which was improved by the addition of bio-fertilizers. Rock phosphate performed very poorly, but when inoculated with both bio-fertilizers, it was comparable to super phosphate.

Available K decreased compared to initial ($364.91 \text{ kg ha}^{-1}$) in all treatments and was higher in treatment T₆ (RD NPK + FYM + PSB + VAM) 291.23 and $275.32 \text{ kg ha}^{-1}$. Lower available potassium in soil 50 DAS and at harvest of cowpea was recorded in T₂ (FYM @ 10 t ha^{-1}) 207.63 and $181.31 \text{ kg ha}^{-1}$ as compared to other treatments (Table 20). The available K at harvest of cowpea decreased in all treatments compared to 60 DAS. Suri *et al.* (2013) reported that after harvest of maize and soybean crops there was a significant reduction in the soil available K₂O level in soil under pot experiments over initial status which was mainly due to greater utilization of K₂O by the crops.

4.2.1.2 Secondary nutrients status under high available P soils as influenced by P fertilizers and inoculants

Data pertaining to the status of available S, exchangeable Ca and Mg at 60 DAS and after harvest of cowpea as residual crop is presented in Table 20 and 21.

Inoculation of soil with PSB+VAM and 50 % P or without P fertilizers + FYM + NK recorded significantly lower sulphur status compared to single inoculated and uninoculated treatments (Table 20). Application of RD NPK + FYM (T₃) and T₈ (0 % P + RD NK + FYM) showed significantly higher content of sulphur at 60 DAS and at harvest (13.53 and 9.82 mg kg^{-1} and 11.72 and 9.29 mg kg^{-1} , respectively). The lower sulphur content was observed in T₁₄ (7.77 mg kg^{-1}) at 60 DAS whereas at harvest T₁ recorded lower sulphur status (6.82 mg kg^{-1}). Available sulphur declined compared to initial at 60 DAS and at harvest of cowpea.

Exchangeable Ca and Mg content of soil were decreased compared to the initial 3.35 and $2.50 \text{ m.eq (100 g soil)}^{-1}$ in all treatments at both the stages. Significantly higher exchangeable Ca (2.44 and $2.23 \text{ m.eq (100 g soil)}^{-1}$) and Mg (2.11 and $1.11 \text{ m.eq 100 g soil}^{-1}$) at 60 DAS and at harvest was recorded in T₃ (RD NPK + FYM) at 60 DAS which was on par with the application of 50 % P + RD NK + FYM (T₇) (Ca: 2.33 and $2.14 \text{ m.eq 100 g soil}^{-1}$) and (Mg: 1.51 and $1.06 \text{ m.eq 100 g soil}^{-1}$), at 60 DAS and at harvest of cowpea as a residual crop. The lower exchangeable Ca (2.03 and $1.83 \text{ m.eq 100 g soil}^{-1}$) and Mg (0.88 and $0.75 \text{ m.eq 100 g soil}^{-1}$) was recorded in T₁₄ at 60 DAS and at harvest respectively (Table 21).

Residual effect of FYM after first crop was higher than the chemical or mineral fertilizers. The secondary nutrients status was high in case of treatment where FYM was applied which may be due to the mineralization of organic matter by microorganism. Results showed that application of organic manure gave higher residual effect on the nutrient status of soil than inorganic fertilizer. This supported the findings of Adediran *et al.*, (2004) who observed increased secondary nutrient status in soils amended with

Table 21: Residual effect of P, PSB and VAM on soil Ca, Mg and micronutrients status after 60 days of sowing and at harvest of cowpea in soil with high available phosphorus

Treatments	Exchangeable Ca		Exchangeable Mg		Fe		Mn		Zn		Cu	
	m.eq (100 g soil) ⁻¹				DTPA micronutrients (mg kg ⁻¹)							
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	2.22	1.87	1.35	0.81	23.41	12.86	14.03	5.26	1.54	1.09	1.17	0.81
T ₂	2.27	2.14	1.70	1.09	32.74	18.51	16.42	6.60	2.10	1.14	1.49	0.90
T ₃	2.44	2.23	2.11	1.11	31.58	19.26	18.59	6.23	2.35	1.94	1.51	0.95
T ₄	2.19	2.02	1.50	1.01	21.73	18.06	18.57	5.59	1.55	1.92	0.84	0.76
T ₅	2.26	2.03	1.46	1.09	32.13	18.48	14.82	5.53	1.69	1.21	0.89	0.78
T ₆	2.15	2.00	1.36	0.98	33.78	23.87	18.81	7.02	2.20	1.91	1.05	0.80
T ₇	2.33	2.14	1.51	1.06	31.97	16.90	17.00	8.32	1.85	1.59	1.12	0.69
T ₈	2.25	2.10	1.33	1.00	32.34	17.75	14.97	5.71	1.22	0.65	1.03	0.82
T ₉	2.17	1.87	1.02	0.88	28.16	18.10	17.16	6.24	1.56	1.42	1.07	0.72
T ₁₀	2.13	2.05	1.22	1.05	25.15	22.16	20.58	9.81	1.23	1.03	1.04	0.89
T ₁₁	2.03	2.02	1.64	0.77	30.05	20.83	19.38	6.23	1.56	0.99	1.16	0.73
T ₁₂	2.28	2.12	1.11	0.75	33.89	23.94	20.48	8.87	1.90	1.48	1.27	0.85
T ₁₃	2.14	1.95	0.96	0.78	34.74	29.29	21.83	9.68	1.81	1.55	1.20	0.76
T ₁₄	2.03	1.83	0.88	0.73	24.96	26.21	21.92	9.88	1.53	1.70	0.80	0.71
Initial	3.35		2.50		49.21		30.83		2.59		1.97	
SEm±	0.10	0.06	0.06	0.05	1.03	0.83	0.95	0.27	0.104	0.08	0.05	0.03
CD at (P = 0.05 %)	0.30	0.16	0.17	0.16	2.99	2.42	2.76	0.80	0.302	0.22	0.14	0.09

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P + RD NK & FYM, T₈-0 % P + RD NK & FYM, T₉-50 % P + PSB + RD NK & FYM, T₁₀-0 % P + PSB + RD NK & FYM, T₁₁-50 % P + Mycorrhiza + RD NK & FYM, T₁₂-0 % P + Mycorrhiza + RD NK & FYM, T₁₃-50 % P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P + PSB + Mycorrhiza + RD NK & FYM.

organic materials. There was improvement in soil nutrient status on the organically fertilized plots. The Ca increased by 26–96 %, Mg by 6–19 %.

4.2.1.3 DTPA extractable micronutrients content in high available P soil

The data on DTPA extractable micronutrients content of soil at 60 DAS and at harvest of cowpea crop is presented in Table 21. DTPA extractable micronutrients showed significant difference at 60 DAS and after harvest of cowpea crop. Micronutrient status of soil has decreased in all treatments compared to initial (49.21, 30.83, 2.59 and 1.97 mg kg⁻¹).

The DTPA iron content of soil at 60 DAS and at harvest of cowpea was significantly higher in the treatment T₁₃ which received 50 per cent P + PSB + VAM + RD NK + FYM (34.74 and 29.29 mg kg⁻¹) and was on par with T₁₂ which received 0 per cent P + VAM + RD NK + FYM (33.89 mg kg⁻¹) and T₆ which received RD NPK + FYM + PSB + VAM (33.78 mg kg⁻¹) at 60 DAS respectively. Lower iron content at 60 DAS and at harvest was recorded in T₁ (23.41 and 12.86 mg kg⁻¹).

With respect to DTPA extractable manganese status of soil at 60 DAS and after the harvest of cowpea in different treatments, a significant difference was observed. The manganese content of soil at 60 DAS and at harvest of cowpea was significantly higher in T₁₄ (21.92 and 9.88 mg kg⁻¹), followed by T₁₃ which received 50 % P + RD NK + FYM + PSB + VAM (21.83 and 9.68 mg kg⁻¹) respectively. DTPA Mn status at 60 DAS and at harvest of cowpea was lower in T₁ which received only NPK (14.03 and 5.26 mg kg⁻¹).

DTPA-zinc content of soil at 60 DAS and at harvest of cowpea was significantly higher in the treatment T₃ which received RD NPK + FYM (2.35 and 1.94 mg kg⁻¹) followed by T₆ which received RD NPK + FYM + PSB + VAM (2.20 and 1.91 mg kg⁻¹) and lower zinc content was recorded on application of T₈ (0 % P + RD NK + FYM) 1.22 and 0.65 mg kg⁻¹.

Among different levels of P fertilizer with microbial inoculation or without microbial inoculation (PSB and VAM) significant differences in DTPA copper status of soil at 60 DAS and at harvest of cowpea was observed. The copper content of soil was significantly higher in treatment T₃ received NPK alone (1.51 and 0.95 mg kg⁻¹) followed by T₂ (FYM alone) (1.49 and 0.90 mg kg⁻¹) and lower copper content at 60 DAS and at harvest of cowpea was observed in T₁₄ (0.80 and 0.71 mg kg⁻¹).

Application of organic manures showed significant residual effect on micronutrient status compared to inorganic fertilizer. Similar results have been obtained by Adediran *et al.* (2004) in which they explained that application of organic manures gave higher residual effect on the nutrient status of soil than inorganic fertilizer.

4.2.1.4 Nutrient ratios and phosphatase enzyme activity in high available P soil

Data pertaining to the changes in soil nutrients ratios and phosphatase activity at 60 days after of sowing and after harvest of cowpea as a residual crop grown on soil of high available P with adding PSB, VAM and fertilizers is given in Tables 22. Significant differences were observed among treatments with respect to the nutrient ratios compared to initial increased in all the parameters except N:P and P:Ca .

The ratio of N:P in soil decreased significantly in all the treatments compared to initial. The higher ratio of N:P in soil at 60 DAS and at harvest (6.52 and 5.92) was recorded in T₁ (RD NPK alone) and on par with T₁₂ (50 % P + VAM + RD NK + FYM) 6.20 3.78 and 3.53.

Significantly higher P:K ratio in soil at 60 DAS (0.15) and at harvest (0.15) was recorded in T₄ (PSB + RD NPK + FYM) and T₅ (VAM + RD NPK + FYM). The lower ratio of P:K was recorded in T₈ 0.10 and 0.09.

The ratio of P:S at both the stages of crop was found to increase over the initial value. The highest P:S ratio in soil at 60 DAS and at harvest were recorded in T₆ (RD NPK + FYM + PSB + VAM), 1.71 and 1.96 respectively and T₄ RD NPK + FYM + PSB (1.67 and 1.78) respectively whereas lower P:S ratio was recorded in T₈ (RD NK + FYM) 0.86 and 1.01. There was no significant difference in P:Ca ratio at 60 DAS and at harvest in all the treatments.

Large difference and increase in P:Zn was observed compared to initial. The values ranged from 14.38 in T₈ (0 % P + RD NK + FYM) at harvest to 5.24 in T₂ at 60 DAS of cowpea. Treatment T₁₀ and T₄ (RD NPK + FYM + PSB) recorded highest P:Zn ratio (9.16 and 9.01) at 60 DAS of cowpea soil and lower ratio was recorded in T₂ (5.24). After harvest the P:Zn ratio was significantly higher in T₈ (14.38) and lower in T₁₄ (0 % P + RD NK + FYM + PSB + VAM) (4.63).

The acid phosphatase activity at 60 DAS and at harvest of cowpea was significantly higher in T₁₄ (0 % P + RD NK + FYM + PSB + VAM) 39.43 and 27.14 $\mu\text{g of PNP g}^{-1} \text{ soil hr}^{-1}$) respectively and T₁₂ at (37.34 and 26.26 $\mu\text{g of PNP g}^{-1} \text{ soil hr}^{-1}$) and lower activity was recorded in T₁ (18.30 and 14.06 $\mu\text{g of PNP g}^{-1} \text{ soil hr}^{-1}$). All the treatments recorded higher activity of phosphatase compared to initial (25.15 $\mu\text{g PNP g}^{-1} \text{ soil hr}^{-1}$) activity. Treatments with dual inoculation showed higher acid phosphatase activity compared to single inoculated and uninoculated treatments Table 22.

The change in phosphatase activity may be because of application of FYM alone or in combination with inorganic fertilizers which create an ideal condition in the soil for the microorganisms to be active (Halstead and Sowden, 1986). It was also observed by Singaram and Kamalakumari (1995) that the activity of soil enzymes was found to be higher and their effect was pronounced when FYM was applied in combination with chemical fertilizers. Similarly Piotrowska and Wilczewski (2012) reported that addition of FYM and biofertilizers increased the acid phosphatase activity compared to NPK

Table 22: Residual effect of P, PSB and VAM on nutrient ratios in soil and phosphatase activity after 60 days of sowing and at harvest of cowpea in soil with high available phosphorus

Treatments	N:P		P:K		P:S		P:Ca		P:Zn		Acid phosphatase (μg of PNP released g ⁻¹ soil h ⁻¹)	
	Nutrient ratios										60 DAS	At harvest
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest		
T ₁	6.52	5.92	0.10	0.10	0.91	1.24	0.02	0.02	5.71	7.26	18.30	14.06
T ₂	5.42	5.01	0.14	0.13	1.31	1.25	0.02	0.02	5.24	8.32	30.35	21.66
T ₃	5.16	4.14	0.14	0.15	1.06	1.34	0.03	0.03	6.13	6.83	20.89	14.91
T ₄	3.78	3.53	0.15	0.15	1.67	1.78	0.03	0.03	9.01	6.50	20.34	14.52
T ₅	4.38	3.90	0.15	0.15	1.69	1.71	0.03	0.03	7.95	9.34	19.39	15.84
T ₆	4.21	4.13	0.12	0.11	1.71	1.96	0.03	0.03	6.11	5.85	22.06	17.74
T ₇	5.08	4.92	0.12	0.13	1.29	1.74	0.03	0.03	7.01	8.21	23.46	16.74
T ₈	5.74	4.70	0.10	0.09	0.86	1.01	0.02	0.02	8.27	14.38	31.46	24.45
T ₉	5.52	4.53	0.13	0.15	1.16	1.49	0.03	0.03	7.56	7.25	24.89	17.76
T ₁₀	5.28	5.12	0.13	0.14	1.17	1.30	0.03	0.03	9.16	10.22	34.89	25.90
T ₁₁	5.69	4.72	0.11	0.11	0.98	1.27	0.03	0.02	6.58	9.66	31.76	22.67
T ₁₂	6.20	5.69	0.11	0.11	1.34	1.55	0.02	0.02	5.70	7.08	37.34	26.65
T ₁₃	4.36	5.34	0.12	0.10	1.27	1.12	0.03	0.02	6.17	5.40	29.40	23.98
T ₁₄	5.03	5.70	0.11	0.09	1.41	1.15	0.03	0.02	7.16	4.63	39.43	27.14
Initial	6.33		0.09		0.78		0.02		4.85		25.15	
SEm±	0.41	0.36	0.009	0.010	0.13	0.15	0.10	0.03	0.51	0.70	1.7	1.21
CD at (P = 0.05 %)	1.23	1.15	0.027	0.030	0.40	0.45	NS	NS	1.52	2.10	5.2	3.71

T₁-RD NPK (150: 75: 40 kg ha^{-1}), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha^{-1}), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha^{-1}), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

alone. The increased activities of acid phosphatase secreted was under P-deficient conditions when compared with those under P-sufficient (inorganic P) conditions which ranged from 2.7 times (glycerophosphate) to 5 times (negligible P, phytin) higher. Legumes secreted the maximum amount of acid phosphatase within 2 weeks after germination, and then the activity decreased gradually (Yadav and Tarafdar 2001).

4.2.1.5 Different P fractions

Results pertaining to the contents of different fractions of P in the soil after harvest of cowpea as a residual crop in high available P soil treated with different level of P with or without inoculation of phosphorus solublizers are presented in Table 23.

The Sal-P fraction in soil has decreased after harvest of cowpea in high P soil as compared to initial (19.86 mg kg^{-1}), a lower Sal-P was recorded in T_2 (4.50 mg kg^{-1}) and a higher content was recorded in T_{13} (10.74 mg kg^{-1}) which is on par with T_6 (10.69 mg kg^{-1}). The results are in accordance with the study by Shi *et al.*, (2015) who demonstrated that P in cultivated soils changed during winter as a result of changes in labile P fractions possibly due to the solubilization of residual fertilizer P combined with environmental factors.

At harvest of cowpea lower soil Al-P was recorded in T_{14} ($265.57 \text{ mg kg}^{-1}$) and a higher value was recorded in T_7 ($322.26 \text{ mg kg}^{-1}$) which was on par with T_3 , T_6 and T_1 (317.50 , 313.18 and $310.95 \text{ mg kg}^{-1}$). The Al-P content in treatments increased over the initial value ($261.85 \text{ mg kg}^{-1}$). The Al-P content of soils as influenced by different treatments was found to decrease at harvest of cowpea, especially in those treatments which received 50 % P fertilizers or without P fertilizer along with biofertilizers. In the treatments which received organic manure and bio-inoculants, Al-P showed an increasing trend.

The maximum increment in Fe-P from $206.78 \text{ mg kg}^{-1}$ (initial) was recorded in T_6 ($241.47 \text{ mg kg}^{-1}$) which is on par with T_3 ($236.32 \text{ mg kg}^{-1}$). The minimum Fe-P was recorded in T_{14} ($182.89 \text{ mg kg}^{-1}$). Compared to initial there was a decline in Fe-P in the treatments where dual inoculation was made compared to single and uninoculated treatments Al and Fe-P were the major fractions and this was attributed to low soil pH and increased solubilization of Fe and Al under acidic conditions (Doddamani and Sheshagiri Rao, 1988). The production of organic acids during the decomposition of compost may cause solubilization of the native phosphorus and the transformation of inorganically bound Fe-P and Ca-P into available form (Jat and Ahlawat 2006). Application of vermicompost increased the bacterial population in the rhizosphere. It might be due to the fact that vermicompost besides providing optimum environment for microorganisms growth also provides essential nutrients for feeding them and favorable C:N and C:P ratio for their multiplication.

The results pertaining to reductant soluble P indicated that there were significant differences among the treatments after harvest of cowpea. The reductant P ranged from $144.22 \text{ mg kg}^{-1}$ in T_{14} to $201.60 \text{ mg kg}^{-1}$ in T_3 at harvest in high P soil (Table 23).

Table 23: Residual effect of phosphorus, PSB and VAM on different fractions of phosphorus (mg kg⁻¹) in cowpea at harvest in high available phosphorus soil

Treatments	Different fractions of P (mg kg ⁻¹) in soil							
	Sal – P	Al –P	Fe –P	Red –P	Occl-P	Ca –P	Organic P	Total P
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	7.56	310.95	217.98	187.72	50.32	15.37	100.57	890.47
T ₂ -FYM (10 t ha ⁻¹)	4.50	283.17	194.27	158.35	22.49	13.68	107.54	767.12
T ₃ -RD NPK + FYM	8.67	317.50	236.32	201.62	56.77	17.27	125.34	942.74
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	8.46	273.47	231.02	168.44	50.70	18.91	114.44	846.79
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	8.47	291.10	226.77	166.85	49.04	18.39	117.52	859.22
T ₆ -RD NPK + FYM + PSB + VAM	10.69	313.18	241.47	198.02	54.93	21.16	126.47	945.12
T ₇ -50 % P + RD NK + FYM	8.53	322.26	209.59	201.60	47.33	14.39	120.46	904.25
T ₈ -0 % P + RD NK + FYM	8.08	290.55	222.18	156.05	47.83	15.42	115.86	837.53
T ₉ -50 % P + PSB + RD NK + FYM	9.82	283.21	191.11	162.21	38.78	20.26	109.07	796.91
T ₁₀ -0 % P + PSB + RD NK + FYM	9.57	268.22	189.02	158.48	30.99	21.16	105.33	765.90
T ₁₁ -50 % P + VAM + RD NK + FYM	8.96	290.04	195.70	159.68	35.27	19.51	111.27	802.75
T ₁₂ -0 % P + VAM + RD NK + FYM	8.53	277.92	188.05	156.38	32.70	21.75	107.27	775.53
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	10.74	283.88	191.28	174.06	30.99	22.58	109.84	805.63
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	9.69	265.57	182.89	144.22	28.33	24.22	104.06	742.63
Initial	19.86	261.85	206.78	109.58	36.14	31.12	143.98	819.78
SEm±	0.42	6.26	3.47	3.14	1.42	0.95	2.39	17.66
CD (P = 0.05 %)	1.24	18.80	9.75	8.63	4.45	2.95	7.04	51.72

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Treatment T₃ varied significantly compared to the rest of the treatments. The lower reductant soluble P was recorded in T₁₄ (144.22 mg kg⁻¹) higher reductant P recorded in T₃ (201.62 mg kg⁻¹) and on par with T₇ (201.60 mg kg⁻¹) and T₆ (198.02 mg kg⁻¹) and it was increased with increase in time in all the treatments. However, in all the treatments the RS-P values increased than initial.

After harvest of cowpea the soil Occl-P fraction varied from 22.49 mg kg⁻¹ in T₂ to 56.77 mg kg⁻¹ in T₃. Significantly higher value was recorded in T₃ which is on far with T₆ (54.93 mg kg⁻¹). The lower values of Occl-P was recorded in T₂. Among the treatment single and dual inoculated treatment with PSB and AM with half or without P fertilizer recorded lower Occl-P compared to the treatment without P solublizers except in T₂.

Results pertaining to the contents of Ca-P in the soil after harvest of residual cowpea under low P soil is presented in Table 25. The Ca-P content decreased in all the treatment compared to initial (31.12 mg kg⁻¹). Higher Ca-P was recorded in T₁₄ (24.22) which was on par with T₁₃ (22.58), T₁₂ and (21.75). Lower value of Ca-P was recorded in T₂ (13.68 mg kg⁻¹).

The difference in Organic-P content of same treatment combinations varied widely among dual and single inoculation with 50 % or without P fertilizer but it was comparatively declined in all treatments from initial status. The maximum decrement was noticed in T₁ (100.57 mg kg⁻¹) the maximum increment was recorded in T₆ (126.47 mg kg⁻¹). Microorganism plays a major role in organic P solubility. Microbial production of organic acids and acid phosphatase has important role in mineralization of organic P present in soil (Hussain *et al.*, 2013).

From the data it was clear that total P content increased in all treatments over initial 819.78 mg kg⁻¹ to 942.74 mg kg⁻¹ in T₃ and it ranged from 742.63 mg kg⁻¹ in T₁₄ to 942.74 mg kg⁻¹ in T₃ and was found to be superior among the treatments. In general the total P content has decreased drastically in treatments with 50 % P or without P fertilizer + NK fertilizer + organic matter + biofertilizer treatments compared to treatments containing full dose of P fertilizer +NK+ organic matter + biofertilizers. The high total P content of the soils may be attributed to higher oxides of iron and aluminium, continuous addition of water soluble inorganic P fertilizers and low pH and under high P condition the activity of PS decreased which led to lower solubilization of total phosphorus to the soil solution for plant growth.

P-solubilizing microorganisms are responsible mainly for organic acid production in soil which led to release of phosphorus from different pools either by: (i) lowering the pH, or (ii) by enhancing chelation of the cations bound to P (iii) by competing with P for adsorption sites on the soil (iv) by forming soluble complexes with metal ions associated with insoluble P (Ca, Al, Fe) and thus P gets released. The lowering in pH of the soil suggested the release of organic acids by the P-solubilizing microorganisms (Whitelaw 2000; Maliha *et al.*, 2004) via the direct oxidation pathway that occurs on the outer face of the cytoplasmic membrane (Zaidi *et al.*, 2009). Al and Fe-P were the major fractions and it was attributed to low pH and increased solubilization of Fe and Al under acid

conditions (Doddamani and Sheshagiri Rao, 1988). Higher content of RS-P may be attributed to higher sesquioxides content. Bapat *et al* (1965) and Kothandaraman and Krishnamurthy (1979) reported that laterite soil contained higher amount of Reductant-soluble P. The higher contribution of Al-P to the total P compared to saloid P might be ascribed to higher total aluminium content of soil (Vishwanath and Doddamani, 1991). Higher Al-P compared to Ca-P can be attributed to the chemical indices of sesquioxides and advanced stage of weathering. This finding corroborates with Balasubramanian and Raj (1969). Saloid P is the most soluble form of P in soil. Lower content of Saloid - P of the soil was due to low pH, high content of sesquioxides, high P fixing capacity of acid soils and low content of easily soluble Ca-P (Paramasivam and Udayasuryan, 1991). Higher level of RS-P in soil is ascribed to the transformation of other forms of P to RS-P with lapse of time. Mongia and Bandyopadhyay (1996) also observed there were the dominant inorganic fraction in Alfisols (RS-P > Fe-P > Al-P) owing to higher amount of amorphous Al and Fe, which favoured the formation of Al-P and Fe-P.

4.2.2 Residual effect of PSB, VAM and different level of phosphorus on growth of cowpea under high available P soil

4.2.2.1 Plant height, No. of leaves, leaf area, leaf area index and fresh weight of different parts of cowpea at different stages of crop growth

The data on growth attributes of cowpea at 60 DAS and at harvest of crop is presented in Table 24.

The plant height ranged from 71.00 cm at 60 DAS in T₆ to 24.03 cm at harvest in T₁. At 60 DAS and at harvest application of RD NPK + FYM + PSB + VAM (T₆) 34.13 and 71.00 cm and T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 34.07 and 67.93 cm recorded significantly higher plant height respectively. Inoculated treatments showed higher plant height compared to uninoculated treatments. Dual inoculation with FYM and NPK enhanced the plant height even with 50 per cent P also that may be due to the high utilization of P by plant. Yousefi *et al.* (2011) reported that the higher shoot height with combined application of PSB and AMF. Combined inoculation of seed with Rhizobium and phosphorus solubilizing bacteria resulted in higher plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net return followed by rhizobium (Metha *et al.*, 2012).

It was observed that at 60 DAS and at harvest RD NPK + FYM + PSB + Mycorrhiza recorded significantly higher number of branches plant⁻¹ (2.33 and 4.67 plant⁻¹ respectively) it was on par with T₁₃ (2.22 and 4.53 plant⁻¹ respectively) and T₁₄ (2.53 and 4.53 plant⁻¹). Lower number of branch was observed in treatment T₁ (1.20 and 3.13 plant⁻¹ respectively). Combination of PSB with VAM and organic fertilizer and FYM showed more number of branches compared to uninoculated treatments.

In general, the number of leaves per plant of cowpea was found to be increased due to residual effect of biofertilizers with full dose of P or 50 per cent P fertilizers doses. The maximum number of leaves at 60 DAS and at harvest (32.20 and 72.80) were

Table 24: Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea after 60 days after sowing (60 DAS) and at harvest in high available phosphorus soil

Treatments	Plant height (cm)		No. of branch plant ⁻¹		No of leaves plant ⁻¹		Leaf area (cm ² plant ⁻¹)		Leaf area index	
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	24.13	44.93	1.20	3.13	15.93	55.53	158.28	438.08	0.28	0.73
T ₂ -FYM (10 t ha ⁻¹)	27.03	48.53	1.40	3.60	18.13	58.53	194.02	449.23	0.32	0.75
T ₃ -RD NPK + FYM	32.13	64.73	2.00	4.33	25.73	65.93	213.93	574.66	0.36	0.96
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	30.93	64.80	2.00	4.40	30.73	72.47	223.45	568.01	0.37	0.95
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	29.93	62.00	2.00	4.33	22.13	63.87	191.98	488.99	0.32	0.81
T ₆ -RD NPK + FYM + PSB + VAM	34.93	71.00	2.33	4.67	32.20	72.80	263.35	611.05	0.44	1.02
T ₇ -50 % P + RD NK + FYM	27.47	44.93	1.73	3.13	22.67	59.93	193.89	509.42	0.32	0.85
T ₈ -0 % P + RD NK + FYM	31.89	49.00	2.00	3.27	18.67	49.67	174.32	459.77	0.29	0.77
T ₉ -50 % P + PSB + RD NK + FYM	34.13	65.33	2.00	3.87	27.53	65.67	203.71	532.93	0.34	0.89
T ₁₀ -0 % P + PSB + RD NK + FYM	28.27	60.07	2.00	3.80	26.67	59.07	184.57	462.82	0.31	0.77
T ₁₁ -50 % P + VAM + RD NK + FYM	31.67	64.53	2.00	4.33	25.27	61.00	232.26	588.46	0.39	0.98
T ₁₂ -0 % P + VAM + RD NK + FYM	27.00	59.13	2.13	4.00	19.20	68.00	167.86	454.27	0.26	0.76
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	34.07	67.93	2.20	4.53	30.27	67.20	234.89	604.46	0.39	1.01
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	31.93	62.87	2.20	4.53	29.00	65.73	224.97	566.94	0.37	0.94
SEm±	1.12	3.01	0.09	0.24	0.84	1.85	8.28	15.60	0.01	0.03
CD (P = 0.05 %)	3.27	8.82	0.26	0.73	2.43	5.61	24.07	45.34	0.04	0.08

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure and DAS: days after sowing

recorded in T₆ followed by T₄ (30.73 and 72.47) and T₁₃ (30.27 and 67.20) respectively. Minimum number of leaves at 60 DAS and at harvest were observed in T₁ (15.93 and 58.53). Higher number of leaves in dual or combine inoculation may be due to the high nutrient use efficiency provided by microorganisms to the plant. Similar findings were reported by Stamford *et al.* (2007) who reported that the TSP and biofertilizers plus 50 per cent P inoculated with *Acidithiobacillus* increased leaves number. They also concluded that biofertilizers might be used as P source.

Higher value of leaf area (cm²) was recorded at 60 DAS and at harvest of cowpea in T₆ (263.35 and 611.05 cm²) on par with T₁₃ (234.89 and 604.46 cm²) and T₁₁ (232.26 and 588.46 cm²) lower value was observed in T₁ at 60 DAS and at harvest of cowpea (158.28 and 438.08 cm²). Residual effect of full dose P with single and dual inoculation showed higher value compared to uninoculated treatments. High leaf area may be due to the high activity of PSB which was not only responsible for the solubility of phosphorus but also producing some plant growth promoting substances which helped in better crop growth. Mahala *et al.* (2006) indicated that the 50 % phosphorus application through single superphosphate (SSP) with PSB recorded the highest leaf area of plant.

There was a significant difference in leaf area index among the treatments. Higher leaf area index was recorded at 60 DAS and at harvest of cowpea in T₆ (0.44 and 1.02) followed by T₁₃ (0.39 and 1.01) T₁₁ (0.39 and 0.98) and a lower leaf area index was recorded in T₁ at 60 DAS and at harvest (0.28 and 0.73) (Table 25). Higher leaf area index is related with higher leaf biomass by plant through the residual effect of biofertilizers.

At 60 DAS the fresh weight of leaf, haulm and root of cowpea (Table 26) were significantly higher in T₆ (12.80, 14.33 and 6.57 g plant⁻¹) followed by T₁₃ (12.53, 13.83 and 5.96 g plant⁻¹). Significantly lower fresh weight of leaf, haulm and root of cowpea were recorded in T₁ (4.87, 5.83 and 3.93 g plant⁻¹). Similarly higher fresh biomass was recorded in T₆ (33.70 g plant⁻¹) and T₁₃ followed by T₁₄. Lower biomass was recorded in T₁ (14.71 g plant⁻¹). The higher fresh biomass may be due to the higher utilization of nutrient by PSB and VAM inoculation compared to uninoculated treatments. Similar results were obtained by Pereira and Castro (2014) in which they explained that the PSB have great potential to be used as biofertilizers in P-deficient soils, especially strains of *Pseudomonas sp.* EAV and *A. nicotinovorans* EAPAA since both promoted maize growth, constituting an attractive alternative to the phosphatic fertilizers amendments. Single superphosphate was the preferred P source, both bioinoculants improved plant growth, and up to 25 % farmyard manure did not reduce maize yields. P source had no residual effect on *V. unguiculata*, but bioinoculants, farmyard manure and N and P all increased yields (Surendra and Sharanappa 2000). Similar result was reported by Mahala *et al.* (2006). Mahanta *et al.* (2014) also opined that the root cation exchange capacity (CEC) of soybean and wheat treated with 0.5 P + PSB + VAM same treatment produced 2.3 and 2.6 % higher root length density (RLD) in soybean and wheat, respectively in comparison to 1.0 P. The P inflow rate under 0.5 P + PSB + VAM was 9.2 and 4.6 % higher than 1.0 P in soybean and wheat, respectively indicating higher acquisition of P through VAM, although higher rhizospheric P availability was recorded in 1.0 P. The

root RLD and P inflow rate were closely related to P concentration and content in root, shoot and nodule, specific root length, root diameter and internal P requirement. The better root property observed in 0.5 P + PSB + VAM which also enhanced yield of soybean and wheat, respectively as compared to 1.0 P. Inoculation of PSB and VAM could substitute 50 % P of soybean–wheat cropping system with better root property and higher grain and haulm yield in semi-arid sub tropics of the Indo-Gangetic plains. Gupta *et al.* (2006) also reported that haulm yield was influenced significantly during the growth of urdbean by the inoculation treatment. The enhanced straw yield on seed inoculation with PSB was mainly owing to increased yield attributes.

4.2.2.2 Dry weight of different parts of cowpea

Significantly higher dry weight of cowpea leaf at 60 DAS and at harvest was recorded in T₆ (4.13 and 8.43 g plant⁻¹) and T₁₃ (4.13 and 8.05 g plant⁻¹) which were followed by T₉ (3.87 and 7.92 g plant⁻¹) a lower leaf weight at 60 DAS and at harvest of cowpea was recorded in T₁ (2.07 and 5.87 g plant⁻¹) (Table 25).

Similarly maximum haulm weight at 60 DAS and at harvest of cowpea was recorded in T₆ (5.25 and 17.27 g plant⁻¹) all dual inoculated treatments were on par to each other. Lower weight of haulm was recorded in T₈ at 60 DAS and at harvest (1.87 and 9.27 g plant⁻¹) this may be due to low availability of nutrients for plant growth. The higher haulm yield may be attributed to the high availability of nutrients through releasing nutrients to the soil solution by microorganisms.

At both the crop stages T₆ (RD NPK + FYM + PSB + VAM) (2.16 & 4.01 g plant⁻¹) and T₁₃ (0 % P + PSB + VAM + RD NK + FYM) (2.07 & 3.69 g plant⁻¹) recorded significantly higher root weight. This is may be due to high amount of nutrients to plants through dissolution by microorganism. Greater efficiency of P solubilizing bacteria through co-inoculation with other beneficial bacteria and mycorrhiza increased the growth of roots of crop (Khan *et al.* 2009). While significantly lower weight of root at 60 DAS and at harvesting was recorded in T₁ (1.32 & 2.55 g plant⁻¹, respectively).

The results pertaining to the effect of PSB, VAM and level of P fertilizer with FYM on the total dry weight of cowpea at 60 DAS and at harvest is presented in Table 29. Total dry matter of cowpea was highest on application of RD NPK + FYM + PSB + VAM (T₆) 11.54 and 29.71 g per plant, followed by 50 % P + PSB + VAM + RD NK + FYM application (T₁₃) 10.94 and 26.87 g per plant at 60 DAS and at harvest respectively. Significantly lower dry matter was recorded at 60 DAS and at harvest of cowpea in T₁; RD NPK @ 150: 75: 40 kg ha⁻¹ (5.54 and 19.16 g plant⁻¹ respectively). The inoculated treatment provided the nutrients through solubilization to plant and they were responsible for plant growth promoting substances like indol acetic acid etc. Similar results have been reported by Kaleeswari *et al.* (2007). Dissolution of P was significantly higher with P fertilizer + FYM + phosphate solubilizing microorganisms irrespective of the P sources. Higher phosphatase activity was observed

Table 25: Residual effect of phosphorus, PSB and VAM on fresh and dry biomass of cowpea after 60 days after sowing (60 DAS) and at harvest in high available phosphorus soil

Treatments	Fresh weight (g plant ⁻¹) 60 DAS				Dry weight (g plant ⁻¹)							
					leaf		Haulm		Root		Total	
	Leaf	Haulm	Root	Total	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T₁	4.87	5.83	3.93	14.70	2.07	5.87	2.10	9.83	1.32	2.55	5.54	19.16
T₂	5.20	6.26	5.03	16.49	2.27	7.27	2.23	10.80	1.50	3.13	6.00	21.20
T₃	9.67	8.52	5.36	23.55	3.20	7.81	2.97	16.27	1.75	3.62	7.92	27.70
T₄	12.00	13.65	5.51	31.05	3.80	7.56	4.63	16.47	1.72	3.46	10.15	27.49
T₅	6.47	10.70	5.41	22.58	3.33	7.66	3.83	16.13	1.79	3.41	8.95	27.20
T₆	12.80	14.33	6.57	33.70	4.13	8.43	5.25	17.27	2.16	4.01	11.54	29.71
T₇	7.40	6.77	4.00	18.10	2.60	6.78	2.59	12.00	1.37	2.56	6.51	21.34
T₈	5.93	5.35	4.49	15.77	2.47	6.72	1.87	9.27	1.45	2.61	5.79	17.69
T₉	11.80	9.29	5.48	26.57	3.87	7.92	3.23	15.60	1.73	3.21	9.09	26.50
T₁₀	10.13	8.71	5.27	24.11	2.80	6.83	3.57	15.13	1.67	3.30	8.04	25.26
T₁₁	9.53	11.29	4.62	25.44	3.07	7.69	3.99	16.07	1.45	2.79	8.51	27.18
T₁₂	8.20	8.71	3.62	20.53	2.80	7.76	3.23	13.53	1.19	2.92	7.22	24.21
T₁₃	12.53	13.83	5.96	31.87	4.13	8.05	5.00	16.47	2.07	3.69	10.94	27.81
T₁₄	11.93	13.16	5.49	31.14	3.80	7.66	4.69	15.73	1.77	3.48	10.26	26.87
SEm±	0.48	0.38	0.26	1.51	0.16	0.26	0.21	0.66	0.09	0.14	0.50	1.10
CD (P = 0.05 %)	1.39	1.12	0.75	4.50	0.45	0.77	0.61	2.01	0.27	0.43	1.52	3.28

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P + RD NK & FYM, T₈-0 % P + RD NK & FYM, T₉-50 % P + PSB + RD NK & FYM, T₁₀-0 % P + PSB + RD NK & FYM, T₁₁-50 % P + Mycorrhiza + RD NK & FYM, T₁₂-0 % P + Mycorrhiza + RD NK & FYM, T₁₃-50 % P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P + PSB + Mycorrhiza + RD NK & FYM.

in FYM treated plots. Therefore, *Bacillus* spp. had the potential to be applied as booster inoculants to increase the efficacy of plant growth promotion and elicitation of systemic disease protection in the field (Kloepper *et al.*, 2004). The interaction effects between vermicompost, biofertilizer and vermicompost phosphorus on grain yield of chickpea revealed that biofertilizer inoculation with and without vermicompost increased the grain yield but the magnitude of increase was relatively greater with no vermicompost. It indicated the synergy between both the factors, i.e., vermicompost and biofertilizer in enhancing the productivity of the crop (Jat and Ahlawat, 2006).

4.2.2.3 Yield attributes of cowpea under high available phosphorus soil

The data pertaining to the residual effect of phosphorus levels, biofertilizers and organic manure on yield and yield component of cowpea are presented in Table 26.

Among the treatments residual effect of T₆ (RD NPK + FYM + PSB + Mycorrhiza) resulted in higher number of pods plant⁻¹ (9.78 pods plant⁻¹) which was on par with (T₁₃) inoculation of PSB + Mycorrhiza + 50 % P₂O₅ + RD NK & FYM (9.67) and T₄ (9.56). Residual effect of inoculated treatment was higher compared to uninoculated treatments like T₁ [RD NPK 150: 75: 40 kg ha⁻¹] 5.22 pods plant⁻¹.

Treatment which received T₆ (RD NPK + FYM + PSB + Mycorrhiza) resulted in higher number of seeds pod⁻¹ (13.33) and it was on par with 50 % P₂O₅ + PSB + Mycorrhiza + RD NK & FYM (T₁₃; 13.00) and T₁₄; 13.00 pod⁻¹. Lower number of seeds pod⁻¹ was recorded in uninoculated treatment T₁ [RD NPK 150: 75: 40 kg ha⁻¹] (9.67).

Application of 50 % P₂O₅ + PSB + RD NK & FYM (T₉) resulted in higher 1000 seeds weight (126.67 g) followed by 50 % P₂O₅ + PSB + Mycorrhiza + RD NK & FYM (T₁₃; 123.37 g). Lower 1000 seeds weight was recorded in T₁ (RD NPK 150: 75: 40 kg ha⁻¹; 117.73 g).

Among the treatments T₁₃ (50 % P + RD NK + FYM + PSB + Mycorrhiza) recorded significantly higher weight of pods (27.32) which was on par with T₆ (RD NPK + FYM + PSB + Mycorrhiza) 25.74 g plant⁻¹ and T₁₄ (0 % P + RD NK + FYM + PSB + Mycorrhiza) 25.74 g plant⁻¹. Significantly lower pods weight (12.87 g plant⁻¹) was recorded in (T₁) RD NPK (150: 75: 40 kg ha⁻¹).

Dual inoculation of T₁₃ (50 % P + PSB + Mycorrhiza + RD NK & FYM) recorded significantly higher seed weight (g per pod) of cowpea (8.43 g pod⁻¹) and was on par with T₆ (RD NPK + FYM + PSB + Mycorrhiza) 8.40 g pod⁻¹ and T₄ (RD NPK + FYM + PSB @ 4 kg ha⁻¹) 8.02 g pod⁻¹. T₁ recorded significantly lower seed weight (3.58 g plant⁻¹).

Significantly higher seed and haulm yield of 13.73 and 19.23 q ha⁻¹ was recorded in T₆ which received RD NPK + FYM + PSB + Mycorrhiza, followed by T₁₃ (50 % P + PSB + Mycorrhiza + RD NK & FYM) and T₉ (50 % P + PSB + RD NK & FYM) recording of 13.14 and 18.39 q ha⁻¹ and 12.83 and 17.97 q ha⁻¹ respectively. Significantly lower seed and haulm yield of 7.27 and 9.71 q ha⁻¹ was recorded in T₁

Table 26: Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea at harvest in high available phosphorus soil

Treatments	No. of pods plant ⁻¹	No. of seeds per pod	1000 seeds weight (g)	Weight of pods (g plant ⁻¹)	Seeds weight (g per pod)	Seed yield (q ha ⁻¹)	Haulm yield (q ha ⁻¹)
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	5.22	9.67	113.80	17.23	3.58	7.27	9.71
T ₂ -FYM (10 t ha ⁻¹)	5.36	10.33	116.13	12.87	4.40	8.87	12.41
T ₃ -RD NPK + FYM	6.44	11.67	117.73	21.38	5.13	10.57	14.79
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	9.56	12.00	120.67	19.60	8.02	12.50	17.50
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	7.44	11.00	121.67	23.17	6.27	11.83	16.57
T ₆ -RD NPK + FYM + PSB + VAM	9.78	13.33	122.67	25.74	8.40	13.73	19.23
T ₇ -50 % P + RD NK + FYM	6.00	10.67	104.67	18.22	5.01	8.63	10.17
T ₈ -0 % P + RD NK + FYM	5.44	10.33	104.00	16.04	4.62	6.93	12.09
T ₉ -50 % P + PSB + RD NK + FYM	8.67	11.00	126.67	24.35	7.66	12.83	17.97
T ₁₀ -0 % P + PSB + RD NK + FYM	8.44	11.00	118.83	21.78	7.36	9.97	13.95
T ₁₁ -50 % P + VAM + RD NK + FYM	7.89	11.33	111.53	21.38	6.89	10.73	15.03
T ₁₂ -0 % P + VAM + RD NK + FYM	7.11	11.00	113.97	18.81	5.87	9.73	13.63
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	9.67	13.00	123.37	27.32	8.43	13.14	18.39
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	8.56	13.00	122.17	25.74	7.24	9.50	13.30
SEm±	0.54	0.73	1.63	1.58	0.74	0.94	1.31
CD (P = 0.05 %)	1.59	2.11	4.73	4.55	2.20	2.72	3.81

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

[RD NPK (150: 75: 40 kg ha⁻¹)]. Among the treatment combined inoculated treatments recorded higher seed and haulm yield of cowpea compared to uninoculated treatment (Table 26 and Fig. 3). Mahanta and Rai (2008) have reported the similar findings where application of 50 % recommended dose of P as SP + PSB + VAM recorded the highest yield during the first year in soybean (2.0 t/ha) and during both the years in wheat (4.4 and 4.6 t/ha in the first and second years respectively), application of 50 % RD P as RP + PSB + VAM registered the highest seed yield (2.2 t/ha) during the second year in soybean. Dual inoculation enhanced seed yield by 28.3 and 28.0 % over no inoculation and by 8.9 and 6.9 % over single inoculation alone. Application of 26 kg P/ha increased the seed yield of chickpea by 38.0 and 40.8 % over no phosphorus and 9.8 and 6.9 % over 13 kgP/ha in 1999-2000 and 2000-01, respectively as reported by Jat and Ahlawat (2006). Mahala *et al.* (2004) reported that the residual effect of P sources was found equally effective in improving the yield of mustard. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the seed and straw yields of mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop. Typic Ustochrepts of the Indo-Gangetic plains. Mahanta *et al.* (2014) also opined that the better root property observed in 0.5 P + PSB + VAM enhanced 4.1 and 4.9% seed yield of soybean and wheat, respectively as compared to 1.0 P. Inoculation of PSB and VAM could substitute 50 % P of soybean–wheat cropping system with better root property and higher seed yield in semi-arid sub tropics of the Indo-Gangetic plains. Adediran *et al.* (2004) studied on residual effect of the applied fertilizers on cowpea showed greater advantage of organic fertilizer application over the MFert. The cowpea yield on plots fertilized with compost and OBF were higher than that from the MFert. At Ibadan, a much better effect was obtained from applying at the highest rate (10 t ha⁻¹). Phosphorus solubilizing bacteria (PSB) inoculation influenced 1,000 seed weight, and pods plant⁻¹ and seeds pod⁻¹ respectively (Gupta *et al.*, 2006).

4.2.3 Residual effect of PSB, VAM and different level of phosphorus on nutrient content of cowpea at 60 DAS in soil of high available P

4.2.3.1 Major nutrients content in different parts of cowpea

The data related to the residual effect of PSB, VAM, inorganic fertilizer and FYM on major nutrient content of cowpea leaves, haulm and roots are presented in Table 27.

The nitrogen content in different parts of cowpea grown in high P soil varied significantly among treatments. The total nitrogen content in leaves, haulm and roots of cowpea were higher in treatment T₆ (RD NPK + FYM + PSB + VAM) 2.61, 1.93 and 1.56 per cent respectively and it was on par with T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 2.55, 1.71 and 1.51 per cent respectively. The lower nitrogen content in cowpea was recorded in treatment which received T₁ (RD NPK) 1.22, 1.38 and 1.02 per cent respectively. Among leaves, haulm and roots the nitrogen content was higher in leaves followed by haulm and lower content was noticed in roots of cowpea. Combined inoculation of PSB+VAM registered high N content compared to uninoculated treatment. Higher nitrogen content could be attributed to increased nitrogen availability in the soil.

Table 27: Residual effect of phosphorus, PSB and VAM on major nutrients content (%) of cowpea at 60 DAS in high available phosphorus soil

Treatments	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	leaves	haulm	roots	Leaves	haulm	roots	leaves	haulm	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.22	1.38	1.02	0.30	0.16	0.18	0.78	0.95	0.57
T ₂ -FYM (10 t ha ⁻¹)	1.96	1.29	1.16	0.41	0.24	0.23	0.91	1.00	0.65
T ₃ -RD NPK + FYM	2.20	1.52	1.23	0.46	0.36	0.30	0.97	1.28	0.67
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	2.21	1.37	1.68	0.50	0.48	0.35	1.12	1.53	0.97
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	2.05	1.27	1.29	0.37	0.45	0.27	0.98	1.15	0.77
T ₆ -RD NPK + FYM + PSB + VAM	2.61	1.93	1.56	0.63	0.53	0.46	1.25	1.70	0.89
T ₇ -50 % P + RD NK + FYM	1.12	1.29	1.16	0.38	0.33	0.32	0.99	1.00	0.75
T ₈ -0 % P + RD NK + FYM	1.43	1.23	1.26	0.45	0.37	0.20	0.87	1.23	0.62
T ₉ -50 % P + PSB + RD NK + FYM	2.01	1.86	1.49	0.48	0.41	0.40	0.98	1.46	0.84
T ₁₀ -0 % P + PSB + RD NK + FYM	1.88	1.41	1.21	0.42	0.41	0.32	0.93	1.46	0.92
T ₁₁ -50 % P + VAM + RD NK + FYM	1.98	1.52	1.40	0.57	0.41	0.36	0.91	1.54	0.51
T ₁₂ -0 % P + VAM + RD NK + FYM	1.95	1.41	0.83	0.47	0.35	0.38	0.87	1.41	0.63
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	2.55	1.71	1.51	0.57	0.42	0.42	1.20	1.58	0.88
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	2.08	1.67	1.38	0.54	0.49	0.41	0.91	1.48	0.85
SEm±	0.07	0.04	0.07	0.02	0.02	0.02	0.06	0.08	0.03
CD (P = 0.05 %)	0.20	0.12	0.20	0.07	0.06	0.06	0.17	0.23	0.08

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure, DAS: days after sowing

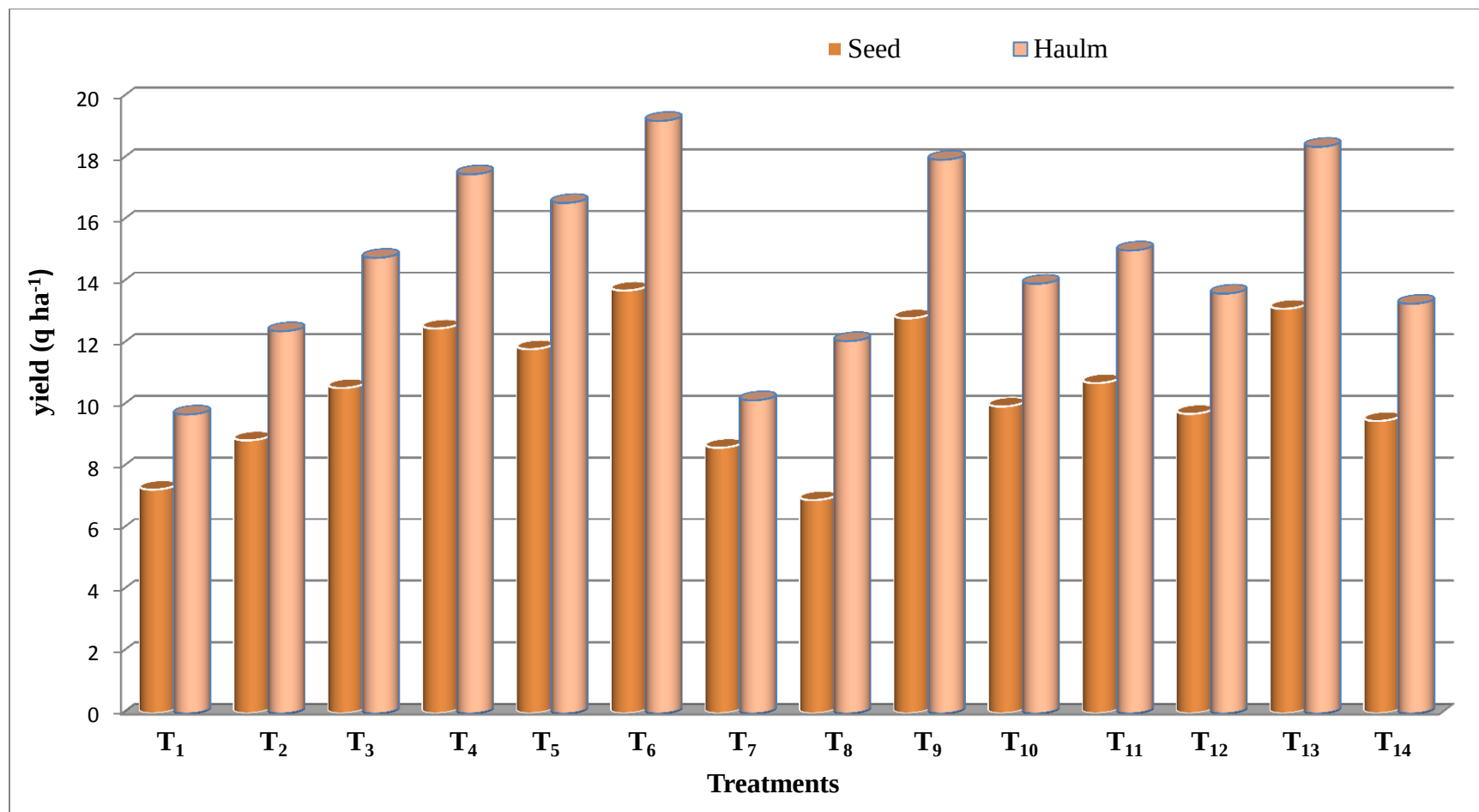


Fig. 3. Residual effect of phosphorus, PSB and VAM on yield of cowpea (kg ha⁻¹) in high available phosphorus soil

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50% P + RD NK & FYM, T₈-0% P + RD NK & FYM, T₉-50% P + PSB + RD NK & FYM, T₁₀-0% P + PSB + RD NK & FYM, T₁₁-50% P + Mycorrhiza + RD NK & FYM, T₁₂-0% P + Mycorrhiza + RD NK & FYM, T₁₃-50% P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0% P + PSB + Mycorrhiza + RD NK & FYM.

Among different part of plant the leaf under uninoculated condition showed high nitrogen content compared to haulm and root but under dual inoculated situation without P fertilizer the nitrogen content high in root compared to leaf and haulm may be due to the high transformation of nitrogen from organic and inorganic source.

The P content of cowpea crop differed significantly among the treatments (Table 27). The P content of cowpea at 60 DAS with residual effect on full dose or 50 % P or without P and RD NK + FYM + PSB + VAM recorded higher P. The higher P content in leaves, haulm and root were observed in treatment which received T₆ (RD NPK + PSB + VAM + + FYM) 0.63, 0.53 and 0.46 per cent respectively and was on par with other treatments inoculated with microorganism like T₁₄ (0.54, 0.49 and 0.44 % respectively) and T₁₃ (0.57, 0.50 and 0.42 % respectively). Lower P content in leaves, haulm and root of cowpea crop was recorded (T₁) 0.30, 0.16 and 0.18 per cent respectively. Among different parts of cowpea (leaf, haulm and root) the P content was higher in leaf. Mahanta and Rai (2008) have reported the similar finding to P uptake and utilization efficiencies by the crop which increased on application of both PSB and VAM under both the sources of P.

Higher K content in leaves, haulm and roots was recorded in T₆ (1.25, 1.70 and 0.89 % respectively) and was on par with dual inoculation of PSB, AMF with 50 % P T₁₃ (1.20, 1.58 and 0.88 % respectively). Lower K content was observed in T₁ (0.78, 0.95 and 0.57 %).

Dual inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant N, P and K content. The similar results were found by (Wu *et al.*, 2005). Higher N, P and K concentration in plants observed on combined inoculation with rhizobacteria and *G. intraradices*. The lower N, P and K uptake was detected in plants grown in uninoculated and unfertilized pots. Either single treatment of chemical or organic fertilization resulted decrease in N, P and K concentration. The maximum P and K assimilation were obtained with the dual inoculation of *G. mosseae* and rhizobacteria. Fertilizer applications with compost showed high nutrient content compared to NPK or FYM alone. This supports the findings of Adediran *et al.* (2004) who observed the increase in plant nutrients concentration amended with inorganic fertilizer and compost. Application of vermicompost improved the overall physico-chemical environment of the soil, which caused the improvement in growth and yield attributes, yield, N and P content of chickpea (Jat and Ahlawat, 2006). Mahala *et al.* (2006) reported that the residual effect of P sources was found equally effective in improving nutrient uptake of mustard. Residual effect of URP+PSB recorded the higher available P in the soil after mustard harvest. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the nutrient uptake of mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop.

4.2.3.2 Secondary nutrients content in different parts of cowpea at 60 DAS

Residual effect of combined inoculation of PSB+VAM recorded significantly higher content of secondary nutrient in different parts of cowpea (leaves, haulm and root)

Table 28: Residual effect of phosphorus, PSB and VAM on secondary nutrients content (%) of cowpea at 60 DAS in high available phosphorus soil

Treatments	Sulphur (%)			Calcium (%)			Magnesium (%)		
	leaves	haulm	roots	Leaves	haulm	roots	leaves	haulm	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	0.15	0.20	0.21	1.19	0.59	0.29	0.31	0.52	0.22
T ₂ -FYM (10 t ha ⁻¹)	0.30	0.21	0.22	1.35	0.78	0.36	0.39	0.55	0.25
T ₃ -RD NPK + FYM	0.35	0.44	0.47	1.47	0.82	0.40	0.60	0.88	0.27
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	0.26	0.30	0.31	1.22	0.86	0.28	0.23	0.82	0.43
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	0.22	0.23	0.37	1.41	0.74	0.32	0.59	0.97	0.36
T ₆ -RD NPK + FYM + PSB + VAM	0.46	0.45	0.57	1.69	0.87	0.46	0.72	0.45	0.44
T ₇ -50 % P + RD NK + FYM	0.20	0.31	0.23	1.48	0.71	0.27	0.35	0.76	0.29
T ₈ -0 % P + RD NK + FYM	0.28	0.23	0.21	1.13	0.69	0.26	0.46	0.57	0.28
T ₉ -50 % P + PSB + RD NK + FYM	0.21	0.26	0.36	1.45	0.76	0.30	0.46	0.85	0.34
T ₁₀ -0 % P + PSB + RD NK + FYM	0.17	0.37	0.27	1.33	0.83	0.29	0.44	0.55	0.33
T ₁₁ -50 % P + VAM + RD NK + FYM	0.23	0.32	0.28	1.50	0.78	0.31	0.48	0.82	0.37
T ₁₂ -0 % P + VAM + RD NK + FYM	0.21	0.25	0.27	1.25	0.67	0.24	0.35	0.72	0.23
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	0.45	0.44	0.48	1.63	0.86	0.44	0.70	0.51	0.44
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	0.26	0.34	0.31	1.61	0.77	0.29	0.68	0.69	0.35
SEm±	0.01	0.01	0.02	0.04	0.02	0.02	0.03	0.07	0.03
CD (P = 0.05 %)	0.04	0.03	0.06	0.11	0.06	0.05	0.08	0.20	0.08

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure, DAS: days after sowing

is presented in Table 28. T₆ (RD NPK + FYM + PSB + VAM) showed higher S content in leaves, haulm and roots (0.46, 0.45 and 0.57 per cent, respectively) and was on par with other inoculated like T₁₃ (50 per cent P + PSB + VAM + RD NK + FYM) 0.45, 0.44 and 0.51 % in leaves, stover and roots respectively. Uninoculated treatment T₁ recorded significantly lower S content in leaves, haulm and roots (0.15, 0.20 and 0.21 per cent, respectively).

Among the treatments T₆ (RD NPK + FYM + PSB + VAM) showed significantly higher Ca content in leaves, haulm and root (1.69, 0.87 and 0.46 per cent respectively) followed by T₁₃ (50 per cent P + PSB + VAM + RD NK + FYM) 1.63, 0.86 and 0.44 per cent at 60 DAS of cowpea compared to the T₂ (FYM @ 10 t ha⁻¹) (1.35, 0.78 and 0.76 % respectively). T₁ [RD NPK (150: 75: 40 kg ha⁻¹)] showed significantly lower Ca in leaves, haulm and root (1.19, 0.59 and 0.29 per cent) Table 28.

Similar trend of calcium was followed with respect to magnesium content by the residual crop in leaves, haulm and root. Magnesium content in leaves, haulm and root was found to be significantly higher in T₆ (0.72, 0.45 and 0.44 per cent respectively) followed by T₁₃ (0.70, 0.50 and 0.44 per cent respectively). Lower Mg content was recorded in T₁ (0.31, 0.52 and 0.22 per cent respectively) in leaves, haulm and root of cowpea.

Residual effect of P sources was found to be equally effective in improving the nutrient uptake of mustard. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the secondary nutrient uptake by mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop (Mahala *et al.* 2006).

4.2.3.3 Micronutrients content of different parts of cowpea at 60 DAS

The data on residual effect of PSB, VAM, chemical fertilizer and FYM on concentration of micronutrients in leaves, haulm and roots of cowpea at 60 DAS are presented in Table 29.

Iron content in different parts (leaves, haulm and roots) of cowpea at 60 DAS was significantly higher in T₆ (RD NPK + FYM + PSB + VAM) 94.11, 90.70 and 69.31 mg kg⁻¹ which were on par with T₁₃ (86.33, 82.21 and 71.26 mg kg⁻¹). The lower iron content of leaves, haulm and roots were recorded in T₁ which received RD NPK (150: 75: 40 kg ha⁻¹) (36.53, 37.81 and 41.72 mg kg⁻¹). Residual effects of uninoculated treatments were significantly lower than the residual effect of combined inoculated treatment with full dose of P or half dose of P.

The content of manganese at 60 DAS of cowpea in leaves, haulm and roots varied significantly in all the treatments except in T₈ which received 0 % P + RD NK & FYM 20.52, 20.94 and 19.06 mg kg⁻¹ which recorded the lower content and T₆ (RD NPK + FYM + PSB + VAM) recorded the higher leave, haulm and roots (50.17, 58.55 and 34.94 mg kg⁻¹). Similar trend was observed for total Mn content. PSB and VAM inoculation recorded higher content of Mn compared to uninoculated treatments.

Table 29: Residual effect of phosphorus, PSB and VAM on micronutrient content (mg kg⁻¹) of cowpea at 60 DAS in high available phosphorus soil

Treatments	Fe (mg kg ⁻¹)			Mn (mg kg ⁻¹)			Cu (mg kg ⁻¹)			Zn (mg kg ⁻¹)		
	leaves	Haulm	roots	leaves	Haulm	roots	Leaves	Haulm	roots	leaves	Haulm	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	36.53	37.81	41.72	27.32	27.72	20.96	13.60	4.74	3.54	6.89	13.24	6.04
T ₂ -FYM (10 t ha ⁻¹)	45.66	44.67	47.36	27.55	30.67	20.79	10.91	4.29	3.02	8.09	19.74	11.56
T ₃ -RD NPK + FYM	54.85	43.95	56.95	33.72	35.78	24.39	14.64	6.66	7.78	12.13	21.73	12.74
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	51.36	45.40	52.41	41.10	29.68	19.50	14.06	9.02	7.39	17.59	18.37	10.11
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	50.19	42.55	49.96	25.62	34.80	28.15	13.02	7.11	6.81	10.30	19.01	9.31
T ₆ -RD NPK + FYM + PSB + VAM	94.11	90.70	71.26	50.17	58.55	34.94	17.58	10.32	10.65	18.23	22.82	13.27
T ₇ -50 % P + RD NK + FYM	51.10	44.92	49.44	24.69	33.65	21.97	11.89	7.22	4.64	12.32	17.44	8.57
T ₈ -0 % P + RD NK + FYM	49.60	47.21	45.58	20.52	20.94	19.06	12.85	8.29	5.82	12.88	15.15	6.43
T ₉ -50 % P + PSB + RD NK + FYM	47.94	52.47	56.55	26.45	32.01	21.45	15.08	5.84	6.04	11.81	18.06	9.61
T ₁₀ -0 % P + PSB + RD NK + FYM	52.07	82.14	52.46	22.89	37.88	25.49	15.42	6.66	5.55	8.09	20.60	12.08
T ₁₁ -50 % P + VAM + RD NK + FYM	49.17	54.31	68.55	25.59	37.53	20.74	16.45	4.23	7.39	10.28	18.20	7.61
T ₁₂ -0 % P + VAM + RD NK + FYM	49.52	89.31	61.50	23.22	34.11	28.81	13.54	8.49	6.22	13.44	17.75	9.09
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	86.33	82.21	71.26	46.53	57.37	31.61	17.09	10.03	9.06	17.58	21.70	13.16
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	72.44	81.61	65.92	41.99	56.36	29.58	15.36	8.35	7.51	14.20	20.53	11.87
SEm±	3.12	3.57	2.30	1.73	2.57	1.73	0.53	0.34	0.45	0.87	0.97	0.52
CD (P = 0.05 %)	9.07	10.39	6.68	5.07	7.48	5.02	1.54	0.99	1.30	2.63	2.90	1.51

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure, DAS: days after sowing

Copper content of cowpea leaves, haulm and roots at 60 DAS recorded significantly lower values (10.91, 4.09 and 3.02 mg kg⁻¹ respectively) in the T₂ (FYM @ 10 t ha⁻¹) and significantly higher copper content was recorded in T₆ (17.58, 10.32 and 10.65 mg kg⁻¹ respectively) followed by T₁₃ (17.09, 10.03 and 9.06 mg kg⁻¹ respectively). Similar trend was observed in case of total Cu content.

Residual effect of combined inoculation or single inoculation or uninoculation with PSB or AMF with FYM and fertilizer application showed significant differences with respect to zinc content at 60 DAS of cowpea. The zinc content of cowpea leaves, haulm and roots was significantly higher in T₆ (RD NPK + FYM + PSB + VAM, 18.23, 22.82 and 13.27 mg kg⁻¹) and lower zinc content (6.89, 13.24 and 6.04 mg kg⁻¹ respectively) was observed in T₁ [RD NPK (150: 75: 40 kg ha⁻¹)]. Higher concentration of micronutrients in combined inoculated or single inoculated treatment might be due to higher available micronutrients in soil which led to higher uptake of micronutrients by plant. Lower content of micronutrient in FYM alone is due to low mineralization rate. Nyoki and Ndakidemi (2014) reported the similar result on significant content of micronutrients in the *B. japonicum* inoculated treatments over the control. Phosphorus supplementation (40 kg P ha⁻¹) also showed a significant increase in the content of some micronutrients while decreasing the uptake of Zn in some plant organs. There was also a significant interaction between *B. japonicum* inoculation and phosphorus in the root uptake of Zn for the field experiment. The same result was found by Adediran *et al.* (2004). Mineral fertilizer showed high content of micronutrients compared to organic manure alone. Application of fertilizer nitrogen, the yield, percent nitrogen content and the uptake of other nutrients were increased. Nutrient accumulation in the maize leaves was greater than that in the other components of the plant (Hussaini *et al.*, 2008).

4.2.4 Residual effect of PSB, VAM and different level of phosphorus on nutrient uptake by cowpea at harvest in soil of high available P

4.2.4.1 Major nutrients uptake by different parts of cowpea at harvest

The data pertaining to nitrogen, phosphorus and potassium uptake by different parts and whole plant of cowpea differed significantly due to residual effect PSB, AMF, FYM and chemical fertilizers in soil with high available and total P (Table 30).

Nitrogen uptake by leaves, haulm, seed and roots of cowpea crop at harvest was significantly higher in T₆ which received RD NPK + FYM + PSB + VAM (35.68, 37.44, 82.25 and 7.10 kg ha⁻¹, respectively). However, lower nitrogen uptake by leaves, haulm, seed and roots was recorded in T₂ (15.92, 25.54, 58.06 and 4.30 kg ha⁻¹, respectively). Residual effect of PSB and VAM inoculation and single inoculation with full dose of P fertilizer recorded higher nitrogen uptake compared to the residual effect of single inoculated with 50 per cent or without of P and uninoculated treatment. Among different parts of cowpea, seed showed higher nitrogen uptake compared to leaves, haulm and root. Root showed lower nitrogen uptake.

Uptake of phosphorus by leaves, haulm, seed and root significantly differed among the treatments. Higher uptake of phosphorus by leaves, haulm, seed and root

of cowpea crop was recorded in T₆ which received RD NPK + FYM + PSB + VAM (5.66, 6.36, 29.22 and 1.76 kg ha⁻¹) respectively. However, lower uptake of phosphorus by leaves, haulm, seed and roots (2.43, 1.10, 12.12 and 0.90 kg ha⁻¹, respectively) was recorded in T₂ (FYM @ 10 t ha⁻¹). Residual effect of combined inoculation and single inoculation with full dose of P showed higher phosphorus uptake compared to single inoculated treatment with 50 per cent of P or without P and uninoculated treatments.

The total uptake of K by cowpea leaves, haulm, seed and roots significantly varied with inoculated and uninoculated treatments and presented in Table 30. Higher K uptake in leaves, haulm, seed and roots were recorded in T₆ (8.85, 28.98, 25.63 and 6.80 kg ha⁻¹ respectively). Lower plant K uptake was recorded in T₁ which received RD NPK @ 150: 75: 40 kg ha⁻¹ (4.60, 12.89, 9.59 and 2.22 kg ha⁻¹ respectively) by leaves, haulm, seed and roots.

Results of enhanced uptake of nutrients due to use of biofertilizers (*G. mosseae* and VAM) resulted in the highest nitrogen, phosphorus and potassium uptake. This field experiment study also indicated that half dose of the recommended phosphorus application with combined inoculation had similar effects when compared with full dose of phosphorus fertilizer with dual inoculation. Higher nutrient uptake in dual inoculated treatment could be attributed to increased nutrient availability in the soil. Higher uptake of major nutrients in the above said treatment was due to higher growth attributing parameters and total dry matter production. This further influenced the manifestation of yield attributing characters and subsequent yield of maize crop. Mahala *et al.* (2006) reported that the residual effect of P sources was found equally effective in improving the yield and nutrient uptake of mustard. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the seed and straw yields, nutrient uptake and the available N and P status of soil after mustard harvest. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop as well as on the available N and P in soil. Gupta *et al.* (2006) noticed that the effect of bio-fertilizer inoculation and phosphorus fertilization on N and P uptake. The seed inoculation with phosphorus solubilizing bacteria showed a significant increase in N and P uptake over uninoculated treatment. Phosphorus application also resulted in significant increase of N and P uptake in seed and straw. NPK alone showed higher nutrient uptake compare to FYM alone may be due to the high availability of these nutrients from NPK fertilizer. Total P uptake by maize increased with increasing level of inorganic P in soils compared to organic manure (Garg and Bahl, 2008). Phosphorus and biofertilizers application significantly influenced the P uptake of crop. Seed inoculation with Rhizobium and phosphobacteria was significantly superior over no inoculation or phosphobacteria inoculation alone. Combined application of P at 26.2 kg ha⁻¹ and bio-fertilizers (Rhizobium and phosphobacteria) enhanced significantly higher P uptake compared to other levels of P with biofertilizers (Dutta and Bandyopadhyay, 2009). Application of vermicompost improved the overall physico-chemical environment of the soil, N and P uptake in dry matter and in the seeds of chickpea (Jat and Ahlawat, 2006). Phosphorus application also resulted in significant increase in N and P uptake in seed and straw.

Table 30: Residual effect of phosphorus, PSB and VAM on major nutrients uptake by cowpea (kg ha⁻¹) at harvest in high available phosphorus soil

Treatments	Nitrogen (kg ha ⁻¹)				Phosphorus (kg ha ⁻¹)				Potassium (kg ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	23.47	21.82	70.11	6.63	2.63	1.85	13.82	1.04	4.60	11.89	9.59	2.22
T ₂ -FYM (10 t ha ⁻¹)	22.92	18.54	58.06	4.30	2.43	1.10	12.12	0.90	5.36	15.09	10.30	2.27
T ₃ -RD NPK + FYM	17.40	32.65	67.37	6.08	4.13	4.60	18.86	0.84	7.25	20.34	14.38	2.95
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	24.12	35.12	80.57	5.75	3.21	5.37	27.48	0.84	5.66	24.02	24.36	2.54
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	27.32	30.52	78.41	5.29	3.30	6.35	23.89	1.29	6.49	31.95	18.38	2.84
T ₆ -RD NPK + FYM + PSB + VAM	35.68	37.44	82.25	7.10	5.66	6.36	29.22	1.76	8.85	28.98	25.63	6.80
T ₇ -50 % P + RD NK + FYM	33.41	13.58	75.12	4.90	3.49	4.96	16.32	0.94	6.55	14.33	15.19	2.27
T ₈ -0 % P + RD NK + FYM	26.95	21.21	67.42	4.39	2.81	2.08	16.48	0.57	6.26	14.30	15.30	2.30
T ₉ -50 % P + PSB + RD NK + FYM	25.69	28.37	77.44	6.23	4.18	4.75	22.14	0.77	5.12	16.24	21.50	2.39
T ₁₀ -0 % P + PSB + RD NK + FYM	28.85	30.14	67.49	6.77	2.82	4.17	22.39	0.69	6.78	21.08	16.63	2.92
T ₁₁ -50 % P + VAM + RD NK + FYM	31.91	29.82	64.81	5.04	5.18	2.98	17.19	0.87	8.71	14.52	19.50	2.25
T ₁₂ -0 % P + VAM + RD NK + FYM	24.88	35.00	68.28	4.79	3.33	2.55	20.27	0.51	7.09	15.34	18.88	2.53
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	32.24	29.35	81.45	5.83	3.61	5.13	26.48	0.80	7.35	23.45	22.06	3.21
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	29.79	24.05	76.53	6.66	3.60	4.31	25.20	1.06	5.00	13.08	24.70	3.12
SEm±	0.94	1.41	2.48	0.26	0.12	0.14	0.57	0.04	0.22	0.49	1.20	0.14
CD (P = 0.05 %)	2.73	4.11	7.20	0.76	0.36	0.39	1.65	0.13	0.64	1.42	3.56	0.39

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.2.4.2 Secondary nutrients uptake by different parts of cowpea at harvest

The data on the residual effect of P solubilizers, chemical fertilizer and FYM on the uptake of secondary nutrients by cowpea leaves, haulm, seed, root is presented in Table 31. Significant differences were observed with respect to secondary nutrients uptake among the treatments.

Higher uptake of sulphur by leaves, haulm, seed and root of cowpea plant was recorded in treatment T₆ receiving (RD NPK + FYM + PSB + VAM) 2.71, 7.76, 5.37 and 2.13 kg ha⁻¹ respectively. However, lower uptake of sulphur (1.06, 2.14, 1.53 and 0.54 kg ha⁻¹ respectively) was recorded in T₁ which received RD NPK @ 150: 75: 40 kg ha⁻¹.

The uptake of calcium by cowpea leaves, haulm, seed and roots at harvest differed significantly in all the treatments compared to T₁. Ca uptake by leaves, haulm, seed and root was significantly higher in treatment T₆ (32.47, 14.40, 29.08 and 2.84 kg ha⁻¹ respectively). Lower Ca uptake was recorded in T₂ (17.01, 3.27, 11.14 and 1.84 kg ha⁻¹ respectively).

The same trend was observed in case of Mg uptake by cowpea crop. Significantly higher uptake of Ca by leaves, haulm, seed and roots (13.96, 12.09, 24.68 and 2.43 kg ha⁻¹, respectively) were noticed in T₆. Lower Mg uptake was recorded in T₂ (FYM @ 10 t ha⁻¹) (2.28, 3.03, 11.14 and 1.23 kg ha⁻¹ respectively). Among the treatments, inoculated treatments showed higher Mg uptake compared to uninoculated treatments.

The secondary nutrient uptake was significantly high in case of combined inoculation compared to uninoculated treatment may be due to high acquisition of the nutrients by the microorganisms. Inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant nutrient uptake (Wu *et al.*, 2005).

4.2.4.3 Micronutrients uptake by cowpea at harvest

The data pertaining to micronutrients uptake by different parts of cowpea crop due to the residual effect of PSB, AMF, FYM and chemical fertilizers in soil with high available phosphorus are presented in Tables 32 and 33.

Iron uptake by cowpea leaves, haulm, kernel and root was significantly higher in T₆ (286.35, 297.00, 148.41 and 150.87 g ha⁻¹ respectively). Lower iron uptake was observed in T₂ (154.56, 113.83, 66.84 and 94.05 g ha⁻¹ respectively). Among the treatment the iron uptake was more in inoculated treatments compared to uninoculated treatments.

Residual effect of PSB, AMF, FYM, 50 % P or full dose P and NK fertilizer showed significant differences with respect to Mn uptake by cowpea crop. The Mn uptake in cowpea leaves, haulm, kernels and root increased significantly in the treatment T₁₃ (148.71, 96.06, 37.26, and 10.74 g ha⁻¹ respectively). Lower Mn uptake by leaves, haulm, seed and root was recorded in T₁ (50.07, 38.10, 14.13 and 5.70 g ha⁻¹

Table 31: Residual effect of phosphorus, PSB and VAM on secondary nutrients uptake by cowpea (kg ha⁻¹) at harvest in high available phosphorus soil

Treatments	S (kg ha ⁻¹)				Ca (kg ha ⁻¹)				Mg (kg ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.06	2.14	1.53	0.54	27.02	3.74	12.91	2.91	3.36	6.63	11.81	1.58
T₂ -FYM (10 t ha ⁻¹)	1.49	4.02	1.80	0.80	17.01	3.27	11.14	1.84	2.28	3.03	11.14	1.23
T₃ -RD NPK + FYM	1.11	3.45	4.63	1.14	27.04	4.31	21.32	1.95	9.72	5.28	18.69	1.70
T₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	2.31	4.77	3.40	0.79	29.40	8.17	24.34	2.21	10.11	9.68	19.43	1.66
T₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	1.90	5.97	3.11	0.99	29.17	7.16	22.41	2.48	8.39	10.61	17.92	1.69
T₆ -RD NPK + FYM + PSB + VAM	2.71	7.76	5.37	2.13	32.47	14.40	29.08	2.84	13.96	12.09	24.68	2.43
T₇ -50 % P + RD NK + FYM	1.51	3.76	2.12	0.59	23.69	5.21	22.85	1.72	8.70	6.26	17.18	1.34
T₈ -0 % P + RD NK + FYM	1.54	2.22	2.21	0.83	18.73	4.66	11.94	1.77	6.47	4.38	12.08	1.40
T₉ -50 % P + PSB + RD NK + FYM	1.90	3.45	2.64	0.62	27.92	5.92	25.51	2.44	7.91	8.64	19.18	1.78
T₁₀ -0 % P + PSB + RD NK + FYM	1.68	5.48	2.24	0.80	27.45	11.62	24.41	2.49	7.02	10.09	17.02	1.31
T₁₁ -50 % P + VAM + RD NK + FYM	1.68	4.25	1.92	0.70	30.69	10.42	22.32	1.88	11.53	10.42	19.92	1.52
T₁₂ -0 % P + VAM + RD NK + FYM	1.68	3.82	2.19	0.56	24.22	10.29	22.13	2.35	7.33	10.61	19.19	1.53
T₁₃ -50 % P + PSB + VAM + RD NK + FYM	2.46	6.35	4.49	1.39	31.81	11.68	28.44	2.69	11.57	11.25	21.05	2.41
T₁₄ -0 % P + PSB + VAM + RD NK + FYM	1.46	5.62	4.21	1.03	30.11	7.23	26.63	2.65	9.53	10.99	19.14	1.69
SEm±	0.06	0.20	0.08	0.05	2.68	0.25	0.63	0.10	0.36	0.28	0.49	0.08
CD (P = 0.05 %)	0.19	0.58	0.23	0.14	0.70	0.72	1.82	0.29	1.05	0.81	1.43	0.23

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Table 32: Residual effect of phosphorus, PSB and VAM on Fe and Mn uptake (g ha⁻¹) by cowpea at harvest in high available phosphorus soil

Treatments	Fe (g ha ⁻¹)				Mn (g ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	255.93	126.36	81.72	101.82	50.07	38.10	14.13	5.70
T ₂ -FYM (10 t ha ⁻¹)	154.56	113.85	66.84	94.05	56.67	52.35	15.81	6.42
T ₃ -RD NPK + FYM	217.98	173.34	112.44	113.04	105.66	59.79	31.71	6.99
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	275.79	148.02	123.12	113.94	131.55	76.23	31.02	7.74
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	268.32	201.15	118.62	126.69	92.58	94.83	22.59	7.68
T ₆ -RD NPK + FYM + PSB + VAM	286.35	297.00	148.41	150.87	139.47	66.00	35.04	7.92
T ₇ -50 % P + RD NK + FYM	186.72	147.96	89.52	84.12	79.29	38.19	16.41	5.85
T ₈ -0 % P + RD NK + FYM	171.96	119.04	93.84	91.77	114.87	52.68	17.22	8.40
T ₉ -50 % P + PSB + RD NK + FYM	207.48	259.62	124.14	116.97	107.07	80.73	26.43	8.01
T ₁₀ -0 % P + PSB + RD NK + FYM	206.28	239.07	131.58	128.37	74.31	99.93	45.81	9.21
T ₁₁ -50 % P + VAM + RD NK + FYM	264.33	179.70	134.88	118.89	115.53	62.67	32.25	6.84
T ₁₂ -0 % P + VAM + RD NK + FYM	241.05	197.40	125.88	109.11	98.10	71.25	42.90	9.93
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	280.47	294.45	144.45	150.54	148.71	96.06	37.26	10.74
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	191.55	261.48	133.02	144.42	85.32	82.86	50.61	9.69
SEm±	7.41	7.08	3.24	5.49	4.11	1.86	0.87	0.36
CD (P = 0.05 %)	23.49	20.55	9.42	16.02	12.00	5.61	2.52	1.08

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Table 33: Residual effect of phosphorus, PSB and VAM on Zn and Cu uptake (g ha⁻¹) by cowpea at harvest in high available phosphorus soil

Treatments	Zn (g ha ⁻¹)				Cu (g ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	4.62	14.22	17.67	1.50	7.56	9.75	7.62	2.64
T ₂ -FYM (10 t ha ⁻¹)	7.80	18.57	17.76	2.28	6.78	9.63	6.84	1.92
T ₃ -RD NPK + FYM	8.85	30.48	27.30	2.55	7.23	16.41	9.45	2.55
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	8.52	30.42	31.44	0.00	7.50	15.30	12.66	2.22
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	6.06	29.55	26.10	2.73	7.59	14.94	10.11	2.43
T ₆ -RD NPK + FYM + PSB + VAM	11.73	36.84	37.17	3.30	8.85	18.12	19.26	3.09
T ₇ -50 % P + RD NK + FYM	7.44	26.43	25.47	1.83	7.35	10.98	8.34	1.77
T ₈ -0 % P + RD NK + FYM	5.67	15.96	23.31	1.89	7.14	8.25	6.42	1.74
T ₉ -50 % P + PSB + RD NK + FYM	9.30	29.76	29.52	2.25	8.19	14.28	9.27	2.01
T ₁₀ -0 % P + PSB + RD NK + FYM	7.17	33.57	32.46	2.46	7.92	13.74	8.91	2.22
T ₁₁ -50 % P + VAM + RD NK + FYM	7.05	22.95	22.92	1.77	7.50	12.45	11.97	1.74
T ₁₂ -0 % P + VAM + RD NK + FYM	6.72	29.10	22.65	1.95	6.66	12.15	12.60	2.04
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	9.99	36.00	35.88	3.18	8.43	16.59	14.79	2.76
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	8.55	35.91	29.01	2.94	7.47	14.94	12.09	2.67
SEm±	0.27	0.81	0.75	0.12	2.40	0.36	0.33	0.09
CD (P = 0.05 %)	0.81	2.37	2.19	0.33	0.75	1.08	0.96	0.30

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

respectively). Among the different parts of cowpea roots showed low uptake of Mn compared to leaves, kernal and root.

Uptake of zinc by cowpea leaves, haulm, seed and roots were significantly higher in most of the treatments with dual inoculation compared to single and uninoculated treatment. In T₆ (RD NPK + FYM + PSB + VAM) uptake of zinc by leaves, haulm, seed and root was maximum (11.73, 36.84, 37.17 and 3.30 g ha⁻¹, respectively). Significantly lower uptake of zinc by leaves, haulm, seed and root was recorded in T₁ (4.62, 14.22, 17.67 and 1.50 g ha⁻¹, respectively).

The uptake of Cu by cowpea leaves, haulm, kernal and roots at harvest significantly differed in all the treatments. Cu uptake was significantly higher in treatments T₆ (8.85, 18.12, 19.26 and 3.09 g ha⁻¹ respectively) by leaves, haulm, seed and root, respectively. Lower Cu uptake was recorded in T₂ (6.78, 9.63, 6.84 and 1.92 g ha⁻¹ respectively).

The micronutrients uptake was higher in case of dual inoculated treatments compared to single inoculated treatment, single inoculated treatments showed higher nutrient uptake compare to uninoculated treatments this may be due to higher solubility of micronutrients in soil through acid production which led to higher uptake of these nutrients by plant. Gupta *et al.* (2006) observed that the beneficial effect of bio-fertilizer inoculation and phosphorus fertilization on micronutrients uptake. The practice of seed inoculation with phosphorus solubilizing bacteria showed a significant increase in Fe, Cu, Mn and Zn uptake over uninoculated treatment. These findings are in accordance with those of Das *et al.* (2007) who had reported that the PSB and VAM with NK and FYM increased the micronutrient uptake by the crop.

4.2.5 Correlation of available NPK, soil pH, different fractions of phosphorus with cowpea yield

The correlation coefficients between yield, available P, available nitrogen, available K, and different fractions of phosphorus are given in Table 34. There was a significant and positive correlation observed between yield of cowpea and saloid P, Ca- P and others positively correlated, Yield was significantly correlated with saloid P ($r^2 = 0.564^*$), Ca- P ($r^2 = 0.583^*$) and positive correlation was found with available P ($r^2 = 0.127$).

Soil pH was significantly correlated with available P ($r^2 = 0.582^*$), Al-P ($r^2 = 0.629^*$), occluded P ($r^2 = 0.538^*$) and organic P ($r^2 = 0.618^*$). Available nitrogen was positively correlated with Al-P ($r^2 = 0.272^*$), reductant P ($r^2 = 0.314^*$) and organic P ($r^2 = 0.160^*$) however the relationship was not significant. Available P was significantly and positively correlated with organic P ($r^2 = 0.744^*$). The available K was positively correlated with other parameter.

Saloid P was significantly correlated with Ca-P ($r^2 = 0.762$). The Al-P was significantly correlated with Fe-P, Reductant – P, occluded – P and organic-P ($r^2 = 0.624^*$, 0.906^* , 0.697^* and 0.618^* respectively). Fe- P was significantly correlated with

Table 34: Correlation between soil phosphorus, nitrogen, potassium, different fractions of phosphorus and yield of cowpea as a residual crop in high available phosphorus soil

	yield q ha ⁻¹	pH	Avail. - N	Avail. - P	Avail. - K	Saloid - P	Al - P	Fe - P	Reductant - P	Occluded - P	Ca - P	Organic -P
Yield q ha⁻¹	1											
pH	0.074	1										
Avail. - N	0.376	0.477	1									
Avail. -P	0.127	0.582*	0.510	1								
Avail. - K	0.109	0.305	0.385	0.233	1							
Saloid - P	0.564*	0.095	-0.050	0.021	0.395	1						
Al - P	-0.147	0.629*	0.272	0.401	0.379	-0.037	1					
Fe - P	0.165	0.453	-0.163	0.546*	0.267	-0.003	0.624*	1				
Reductant - P	0.100	0.627*	0.314	0.539*	0.372	0.136	0.906**	0.653*	1			
Occluded - P	0.116	0.538*	-0.021	0.561*	0.310	0.184	0.697**	0.919**	0.713**	1		
Ca - P	0.583*	-0.224	-0.129	-0.256	0.177	0.762**	-0.546*	-0.377	-0.360	-0.308	1	
Organic - P	0.230	0.618*	0.160	0.744**	0.512	0.214	0.618*	0.745**	0.641*	0.687**	-0.189	1

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

reductant P, occluded – P and organic P ($r^2=0.653^*$, 0.919^* and 0.745^*). Reductant P was significantly and positively correlated occluded P and organic P ($r^2= 0.713^*$ and 0.641^*). Occluded P was significantly and positively correlated with organic P ($r^2= 0.687^*$).

There was a significant and positive correlation between different fractions of phosphorus. Shi *et al.* (2015) reported similar results on P fractions which were significantly correlated with other soil chemical properties and environmental conditions ($P = 0.005$). Changes in resin-P, NaOH-Po, and HCl-P were positively correlated with CaM_3 and MgM_3 , but negatively correlated with cumulative snowpack. Changes in $\text{NaHCO}_3\text{-Pi}$ and NaOH-Pi fractions were positively correlated with the changes in TC and TN but negatively correlated with that in pH. Changes of $\text{NaHCO}_3\text{-Po}$ and residual P were positively correlated with cumulative snowpack and the changes in AlM_3 , FeM_3 , and KM_3 . Root rhizosphere pH and root dry matter were found to be two of the most important parameters influencing other root properties and grain yield. Near perfect linear relationship of P inflow rate and grain yield with root rhizosphere pH and RLD showed that differences in these parameters were associated with differences in root CEC and RLD (Mahanta *et al.*, 2014).

4.3 Pot experiment: Studies on the effect of application of different levels of phosphorus, phosphorus solubilizers and FYM to soil low available and high total phosphorus on performance of maize in maize - cowpea cropping system under green house conditions

4.3.1 Effect of PSB, VAM, FYM and chemical fertilizers on soil chemical properties at tasseling and at harvest of maize

4.3.1.1 Soil pH, EC and NPK in low available P

Data on the effect of PSB, VAM, FYM and levels of single super phosphate on soil pH, EC, major nutrients content in soil at tasseling and at harvest (plate 7 and 8) of maize are presented in Table 35.

There were no significant differences in soil pH at tasseling but after harvest of maize it was significantly differed. Compared to initial pH, was slightly increased in all treatments. Among the treatments at tasseling stage the pH was declined in T_{13} (50 % P + PSB + VAM + RD NK + FYM) (6.10). Higher pH recorded in T_7 (6.62) followed by all the treatments, except PSB with VAM inoculation.

The pH was slightly higher at tasseling stage compared to harvest of maize in treatment with single inoculation and full dose of P. Among the treatments pH decreased in those treatments which inoculated with PSB and VAM. Decrease in pH may be due to the production of organic acids by phosphorus solubilizer into the rhizosphere. Organic acids were released by PSB with an associated fall in pH, and as a consequence of these events the P concentration in broth culture increased (Sperber, 1957). Hussain *et al.* (2013) reported a decrease in soil pH by phosphate solubilizing bacteria through production of organic acids.



Plate 5. Cowpea at maturity stage



Plate 6. Tagging five plants in each plots of cowpea

There was significant difference in EC of soil among the treatments at tasseling and after harvest of maize (Table 35). Treatment T₄ recorded significantly higher EC (0.48 dS m⁻¹) at tasseling stage it was on par with all treatment except T₁, T₂, T₉ and T₁₃. Lower EC was recorded in T₁ (0.27 dS m⁻¹). Inoculation of soil with PSB and AM enhanced the EC of soil by releasing some ions to the soil solution which are responsible for salinity of soil. Giri *et al.* (2003) reported that the inoculation significantly enhanced soil EC. At harvest of maize the EC was significantly higher in T₁₁ (0.45 dS m⁻¹) which was on par with T₁₀, T₁₂, T₉ and T₄ (0.42, 0.39, 0.38 and 0.36 dS m⁻¹ respectively) and lower EC was recorded in T₂ (0.28 dS m⁻¹). The EC after harvest of maize was slightly decreased compared to tasseling stage (60 DAS).

Available nitrogen content of soil has declined compared to initial (201.32 kg ha⁻¹) in all treatments except in T₆, T₄ and T₇ which were slightly increased. At tasseling stage T₆ (RD NPK + FYM + PSB + VAM) and T₄ (0 % P + RD NK + FYM) recorded significantly higher available N (208.23 and 204.64 kg ha⁻¹ respectively) and was on par with all treatment except T₁₄, T₅, T₂ and T₁. Available nitrogen status among the treatments was significantly differed during tasseling stage of maize wherein T₂ (FYM @ 10 t ha⁻¹) (158.34 kg ha⁻¹) indicated lower available nitrogen. At harvest of maize, T₃ recorded significantly higher available N (191.89 kg ha⁻¹) and was on par with T₄, T₆, T₇, T₉, T₁₃ and T₁₁ (190.89, 186.85, 184.88, 182.81, 182.00 and 181.90 kg ha⁻¹, respectively). However, after harvest of maize the available nitrogen has declined compared to initial and tasseling stage. Lower available nitrogen after harvest of maize (136.85 kg ha⁻¹) was recorded in T₂ (FYM @ 10 t ha⁻¹). Low available nitrogen in soil may be due to the higher uptake by maize from soil. After harvest of maize and soybean crops revealed that there was a significant reduction in the soil available N, P₂O₅, and K₂O levels in soil compared to initial status, mainly due to greater utilization of these nutrients (Suri *et al.*, 2013).

Available phosphorus content of soil varied significantly at tasseling stage and at harvest of maize. Available P content was increased compared to the initial (20.81 kg ha⁻¹) status. The maximum available phosphorus content was recorded at tasseling in PSB + VAM + RD NPK + FYM (T₆; 42.76 kg ha⁻¹) and was on par with T₄, T₅, and T₃ (41.38, 39.12 and 36.29 kg ha⁻¹, respectively) lower P status was recorded in FYM @ 10 t ha⁻¹ (T₂; 25.57 kg ha⁻¹). Similar trend was observed at harvest of maize significantly higher available phosphorus was recorded in T₆ (36.70 kg ha⁻¹) followed by T₄, T₅ and T₃ (34.10, 33.10 and 32.26 kg ha⁻¹ respectively) Lower available P recorded in T₂ (22.50 kg ha⁻¹) (Table 37). The treatments with a combination of recommended fertilizer and microbial culture were on par with respect to P which is indicative of solubilization of native phosphorus by micro-organisms (Suri *et al.*, 2011). Inoculation with phosphate-solubilizing bacteria (PSB) may help to solubilize native soil P as well as P from

Table 35: Influence of P, PSB and VAM application on soil pH, EC and nutrient status of soil at tasseling stage and at harvest of maize in soil with low available phosphorus

Treatments	pH		EC (dSm ⁻¹)		Available N		Available P ₂ O ₅		Available K ₂ O		Available S (mg kg ⁻¹)	
							kg ha ⁻¹					
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T₁	6.17	6.37	0.27	0.31	160.06	141.40	33.20	27.59	276.14	255.34	18.43	16.76
T₂	6.53	6.50	0.28	0.28	158.34	136.85	25.57	22.50	262.89	243.57	17.21	15.56
T₃	6.41	6.37	0.38	0.34	198.66	191.90	36.29	32.26	287.53	259.56	21.97	18.66
T₄	6.39	6.54	0.48	0.36	204.46	190.89	41.38	34.10	277.34	258.23	20.92	17.56
T₅	6.34	6.45	0.35	0.32	172.60	169.88	39.12	33.10	280.25	255.34	19.84	16.85
T₆	6.06	6.25	0.40	0.34	208.23	186.85	42.76	36.70	305.00	270.99	19.98	16.49
T₇	6.38	6.62	0.38	0.29	204.00	184.88	25.33	22.72	270.06	257.54	22.58	20.07
T₈	6.38	6.27	0.45	0.24	182.64	161.60	23.74	22.92	291.17	261.77	20.58	18.26
T₉	6.46	6.11	0.33	0.38	190.67	182.81	32.13	23.17	280.44	286.50	20.45	19.76
T₁₀	6.34	6.19	0.40	0.42	178.12	167.25	25.96	23.47	298.45	286.57	20.89	16.36
T₁₁	6.38	6.37	0.40	0.45	198.19	181.90	31.28	26.73	298.45	273.68	18.72	16.85
T₁₂	6.37	6.45	0.40	0.39	186.65	173.92	30.76	28.27	294.81	279.40	19.73	18.26
T₁₃	6.24	6.10	0.30	29.00	181.38	182.00	34.29	30.11	316.65	279.96	17.90	16.96
T₁₄	6.25	6.19	0.45	0.40	160.81	151.50	29.13	24.76	290.44	262.63	17.19	15.36
Initial	5.80		0.29		201.32		20.81		308.33		21.45	
SEm±	0.08	0.08	0.03	0.03	8.99	3.13	1.51	2.00	8.19	10.13	0.72	0.81
CD (P = 0.05 %)	NS	0.25	0.12	0.10	34.31	9.39	5.78	6.00	26.25	30.40	2.12	2.34

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

rock phosphates for plant uptake. Solubilization of phosphorus by these phosphate solubilizing micro organisms is attributed to the excretion of organic acids like glutamic, succinic, lactic, oxalic, glyoxalic, maleic, fumaric, tartaric, alpha – ketobutyric, propionic and formic acid. Some of these acids (hydroxy acids) may form chelation with cations such as Ca^{2+} and Fe^{2+} , which result in effective solubilization of phosphates (Subbarao, 1986).

Available K content of soil was decreased compared to initial in all the treatments except on dual inoculation of soil with PSB and VAM i.e. T_{13} (50 % P + PSB + VAM + RD NK + FYM) at tasseling stage. The higher available potassium in soil at tasseling stage of maize was recorded in T_{13} (50 % P + PSB + VAM + RD NK + FYM) 316.65 kg ha^{-1} and was on par with T_6 , T_{10} , T_{11} , T_{12} and T_8 (305.00, 298.45, 298.45, 294.81 and 291.17 kg ha^{-1} , respectively). T_2 (FYM @ 10 t ha^{-1}) recorded significantly lower available K (262.89 kg ha^{-1}). Significantly higher available K at harvest of maize was recorded in T_{13} (279.96 kg ha^{-1}) and was on par with all treatments except T_1 and T_2 and T_5 . Lower available K was recorded in T_2 (243.57 kg ha^{-1}). The available K at harvest of maize was decreased in all treatments compared at tasseling stage of maize. Suri *et al.* (2013) reported after harvest of maize and soybean crops that there was a significant reduction in the soil available K_2O level in soil after crop harvest in pot experiments over initial status, mainly due to greater utilization of K_2O by the crops.

Similar results have been obtained by Suri *et al.* (2011) in which they explained facts suggesting that PSB inoculation was useful in replenishing the available P status of soil, co-inoculation of PSB with either VAM (*Glomus intraradices*) or VAM (*Glomus mosseae*) coupled with 75 % recommended P_2O_5 dose remained statistically at par with the 100 % P_2O_5 dose with respect to soil fertility status. Thus, this study indicated that dual inoculation of PSB and VAM coupled with 75 % of the recommended P_2O_5 dose can bring an economy of about 25 % of applied P in maize in a P-deficient acidic Alfisol (Suri *et al.*, 2006).

4.3.1.2 Secondary nutrients status during tasseling and harvest of maize

Data pertaining to the status of available S and exchangeable Ca and Mg at tasseling stage and at harvest of maize are presented in Tables 35 and 36.

Among the biofertilizer treatment dual inoculation of PSB+VAM with 50 % and without P fertilizers, FYM and NPK alone recorded significantly lower sulphur compared to uninoculated treatments (Table 37). Treatment T_7 (50 % P + RD NK + FYM) showed the significant higher content of sulphur in soil at tasseling stage (22.58 mg kg^{-1}) and was on par with T_3 , T_4 , T_{10} and T_8 (21.97, 20.92, 20.89 and 20.58 mg kg^{-1} respectively). Lower sulphur value was recorded in T_{14} (17.19 mg kg^{-1}) and the similar trend was recorded at harvest of maize wherein T_7 was significantly higher (20.07 mg kg^{-1}) on par with T_9 , T_{12} and T_3 (19.76, 18.26 and 18.66 mg kg^{-1} , respectively). The lower sulphur content was observed in T_{14} at harvest (15.36 mg kg^{-1}). Available sulphur declined compared to initial at tasseling and at harvest of maize.

Exchangeable Ca content of soil has increased compared to initial value (3.81 m.eq (100 g soil⁻¹) but after harvest of maize it declined in T₁₄, T₁₀ and T₂. Exchangeable Mg decreased compared to initial level (2.70 m.eq 100 g soil⁻¹) in all treatments even after harvest of maize also in all the treatments. Significantly higher exchangeable Ca (5.50 and 4.61 m.eq 100 g soil⁻¹) and Mg (2.89 and 2.55 m.eq 100 g soil⁻¹) at tasseling and at harvest were recorded in T₆ (RD NPK + FYM + PSB + VAM). The lower exchangeable Ca (3.71 and 3.40 m.eq 100 g soil⁻¹) in T₂ and lower Mg (1.32 and 1.86 m.eq 100 g soil⁻¹) in T₁ at tasseling and at harvest of maize were observed (Table 36).

4.3.1.3 DTPA extractable micronutrients content of low available P soil

The data on DTPA extractable micronutrients content of soil at tasseling stage and at harvest of maize crop are furnished in Table 36.

DTPA extractable micronutrients showed significant difference at tasseling stage and at harvest of maize crop. DTPA extractable micronutrients content of soil has decreased compared to initial status in all treatments except zinc content of soil.

A significant difference was observed in iron status among different treatments. Iron status ranged from 14 mg kg⁻¹ in T₁ (RD NPK) at harvest to 32.94 mg kg⁻¹ in T₆ (RD NPK + FYM + PSB + VAM) at tasseling stage. Among the treatments application of RD NPK + FYM + PSB + VAM (T₆) showed significantly higher iron content 32.94 mg kg⁻¹ at tasseling stage and was on par with T₁₃, T₉ and T₄ (29.79, 28.93 and 28.89 mg kg⁻¹ respectively) and lower iron content was recorded in T₁ (21.80 mg kg⁻¹). Similar trend was observed at harvest of maize where significantly higher iron recorded in T₁₃ (25.06 mg kg⁻¹) followed by T₆, T₅ and T₁₁ (25.00, 22.73 and 21.79 mg kg⁻¹ respectively). Lower iron at harvest was observed in T₁ (14.14 mg kg⁻¹). Iron content was decreased at harvest compared to tasseling in all treatments.

Manganese content of soil ranged from 8.09 mg kg⁻¹ in T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) at harvest of maize to 19.37 mg kg⁻¹ in T₁₀ (RD NPK +PSB+VAM+ FYM). Significantly higher manganese content in T₆ (19.37 mg kg⁻¹) was recorded which was on par with T₁₀ (18.65 and 14.15 mg kg⁻¹) at tasseling and at harvest of maize the significantly higher Mn content was recorded in T₆ (14.15 mg kg⁻¹) followed by T₁₃, T₁₄, T₅ and T₄ (14.15, 13.14, 13.14 and 13.14 mg kg⁻¹, respectively). Lower amount of Mn at tasseling stage and at harvest was observed in RD NPK @ 150: 75: 40 kg ha⁻¹ (T₁; 14.21 and 8.09 mg kg⁻¹). Inoculation of soil with P solublizers showed higher Mn content compare to uninoculated treatments.

Available copper content (Table 36) of soil was significantly higher in T₆ (RD NPK + FYM + PSB + VAM) (1.16 and 0.84 mg kg⁻¹) followed by other treatments. Lower copper content (0.91 mg kg⁻¹) at tasseling stage of maize and lower copper was recorded in T₁₁ (0.67 mg kg⁻¹) at harvest of maize in pot experiment. However available copper content when compare to initial (1.20 mg kg⁻¹) found to decrease in all the treatments.

Table 36: Influence of P, PSB and VAM application on soil Ca, Mg and micronutrients status at tasseling stage and at harvest of maize in soil with low available phosphorus

Treatments	Exch. Ca		Exch. Mg		DTPA micronutrients (mg kg ⁻¹)							
	m.eq (100 g soil) ⁻¹				Fe		Mn		Zn		Cu	
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	4.65	4.12	1.32	1.86	21.80	14.14	14.21	8.09	1.93	1.81	0.91	0.70
T ₂	3.71	3.65	1.57	2.01	24.96	20.20	15.92	10.11	2.01	2.13	0.98	0.77
T ₃	4.92	3.90	1.99	2.27	27.00	18.94	15.00	13.14	2.50	1.96	1.14	0.82
T ₄	5.04	3.87	2.52	2.39	28.89	21.97	16.08	12.13	2.78	1.92	1.10	0.79
T ₅	4.85	4.30	2.33	2.21	25.00	22.73	16.15	13.14	2.62	2.11	1.06	0.79
T ₆	5.50	4.61	2.89	2.55	32.94	25.00	19.37	14.15	2.85	2.36	1.16	0.84
T ₇	4.46	4.13	2.09	1.86	26.10	19.70	13.52	10.07	2.28	1.95	1.01	0.77
T ₈	4.20	3.81	2.00	2.38	25.04	21.21	15.45	9.10	2.21	2.24	1.01	0.73
T ₉	5.04	4.04	1.69	1.89	28.93	24.76	14.31	13.14	2.85	1.66	1.14	0.77
T ₁₀	5.95	3.47	1.97	2.00	22.28	20.51	18.65	13.17	2.50	1.73	1.07	0.73
T ₁₁	5.30	4.16	2.06	2.12	23.20	21.79	14.63	12.15	2.37	1.90	1.05	0.67
T ₁₂	4.46	4.12	1.66	2.28	20.70	20.54	15.39	12.13	2.46	1.69	1.01	0.73
T ₁₃	5.04	4.23	2.63	2.44	29.79	25.06	17.51	14.15	2.21	2.16	1.10	0.81
T ₁₄	4.01	3.69	1.86	2.33	22.54	20.85	13.69	13.14	2.39	1.92	1.05	0.71
Initial	3.81		2.70		38.31		20.46		1.93		1.20	
SEm±	0.14	0.29	0.22	0.14	1.12	1.10	0.49	0.66	0.15	0.23	0.07	0.03
CD at (P = 0.05 %)	0.53	0.87	0.85	0.42	4.23	3.34	1.85	1.97	0.45	0.70	0.21	0.11

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P + RD NK & FYM, T₈-0 % P + RD NK & FYM, T₉-50 % P + PSB + RD NK & FYM, T₁₀-0 % P + PSB + RD NK & FYM, T₁₁-50 % P + Mycorrhiza + RD NK & FYM, T₁₂-0 % P + Mycorrhiza + RD NK & FYM, T₁₃-50 % P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P + PSB + Mycorrhiza + RD NK & FYM.

Similarly, the DTPA extractable zinc content of soil was significantly higher in T₆ (RD NPK + FYM + PSB + VAM) at tasseling stage (2.85 mg kg⁻¹) followed by T₉, T₄, T₅, T₁₀ and T₃ (2.85, 2.78, 2.62, 2.50 and 2.50 mg kg⁻¹ respectively) and at harvest of maize significantly higher zinc content was recorded in T₆ (2.36 mg kg⁻¹) followed by others treatments and lower zinc value at tasseling and at harvest was recorded in T₁ (RD NPK @ 150: 75: 40 kg ha⁻¹) 1.93 and 1.81 mg kg⁻¹ respectively. The content of zinc was increased when compared to initial (2.59 mg kg⁻¹) in all the treatments.

Decline in micronutrients content of soil may be due to positive interaction among the bio-fertilizers and soil micronutrients and decrease at the later period may be explained by the dilution effect due to higher biomass production (Hussain *et al.*, 2013). Increase in zinc content may be due to the low uptake by plant. This result is in line with Nyoki and Ndakidemi (2014) who reported a significant improvement in the uptake of micronutrients in the *B. japonicum* inoculated treatments over the control. Phosphorus supplementation (40 kg P ha⁻¹) also showed a significant increase in the uptake of some micronutrients while decreasing the uptake of Zn in some plant organs. There was also a significant interaction between *B. japonicum* inoculation and phosphorus in the root uptake of Zn under field experiment.

4.3.1.4 Nutrient ratios and phosphatase enzyme activity in low available P soil

Data pertaining to the changes in soil nutrients ratios and phosphatase activity at tasseling and at harvest of maize grown on soil low in available P applied with PSB, VAM and with graded levels of phosphorus showed that there was significant difference among treatment. The nutrient ratios compared to initial decreased in all treatments (Tables 37).

The ratio of N:P in soil has decreased significantly in all the treatments compared to initial. The higher ratio of N:P in soil at tasseling and at harvest (14.07 and 13.82) was recorded in T₂ [RD FYM (10 tonne)] and on par with T₃ (RD NPK + FYM) 12.44 and 13.52. The lower N:P ratio were recorded in T₉ (50 % P + PSB + RD NK & FYM) 8.87 at tasseling stage and at harvest lower was recorded in T₁₃ (9.07). Among the treatment combined PSB with VAM inoculated treatment with full dose of P or 50 per cent showed higher N:P ratio.

The ratio of P:K in soil has increased in all the treatments compared to initial (0.02). The lower ratio of P: K in soil at tasseling and harvest observed in T₂ (0.05 and 0.05). Higher P: K ratio was recorded in T₄ (RD NPK + FYM + PSB @ 4 kg ha⁻¹) (0.10 and 0.09) all others treatment recorded on par.

Similarly the P: S ratio in soil has increased in all the treatments compared to initial (0.11). Significantly higher P:S ratio was recorded in maize soil at tasseling and at harvest (0.57 and 0.54) and (0.52 and 0.52) in T₁₃ (50 % P + PSB + VAM + RD NK + FYM) and T₆. Significantly lower P:S ratio was recorded in T₂ at tasseling and at harvest of maize (0.29 and 0.28).

Table 37: Influence of P, PSB and VAM application on soil on soil nutrient ratios and phosphatase activity at tasseling stage and at harvest of maize in soil with low available phosphorus

Treatments	N:P		P:K		P:S		P:Ca		P:Zn		Acid phosphatase (μg of PNP released g ⁻¹ soil h ⁻¹)	
	Nutrient ratios										60 DAS	At harvest
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest		
T ₁	10.96	11.65	0.06	0.06	0.35	0.32	0.01	0.007	2.48	2.38	33.04	16.26
T ₂	14.07	13.82	0.05	0.05	0.29	0.28	0.01	0.005	1.77	1.65	55.46	22.22
T ₃	12.44	13.52	0.07	0.07	0.34	0.34	0.01	0.008	2.27	2.58	44.82	20.98
T ₄	9.04	11.10	0.10	0.09	0.46	0.44	0.01	0.010	2.89	3.19	46.47	22.87
T ₅	10.03	9.87	0.07	0.08	0.39	0.46	0.01	0.009	2.34	2.90	50.22	29.47
T ₆	8.97	9.72	0.09	0.09	0.52	0.52	0.01	0.009	2.89	2.89	68.41	45.18
T ₇	9.38	9.85	0.08	0.07	0.34	0.34	0.01	0.008	2.67	2.80	55.03	27.08
T ₈	11.37	10.42	0.07	0.07	0.35	0.38	0.01	0.009	2.58	2.46	61.80	38.59
T ₉	8.77	11.65	0.09	0.07	0.47	0.35	0.01	0.009	2.70	3.35	52.88	28.10
T ₁₀	10.14	10.53	0.07	0.07	0.38	0.43	0.01	0.010	2.50	3.25	67.29	29.41
T ₁₁	9.36	10.05	0.09	0.08	0.51	0.48	0.01	0.010	3.17	3.38	56.76	37.93
T ₁₂	8.96	9.09	0.09	0.08	0.47	0.47	0.01	0.010	3.01	4.03	68.34	35.55
T ₁₃	8.87	9.07	0.09	0.09	0.57	0.54	0.01	0.011	3.70	3.36	59.57	39.39
T ₁₄	9.20	10.86	0.08	0.08	0.51	0.49	0.01	0.009	2.92	3.09	65.49	37.92
Initial	38.74		0.02		0.11		0.003		1.20		22.19	
SEm±	0.85	0.71	0.01	0.01	0.07	0.06	0.01	0.001	0.34	0.51	1.82	2.10
CD at (P = 0.05 %)	2.55	2.13	0.03	0.03	0.21	0.18	NS	0.003	1.01	1.51	5.45	6.29

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹, T₅-RD NPK + FYM + Mycorrhiza (VAM@ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P₂O₅ + RD NK & FYM, T₈-0 % P₂O₅ + RD NK & FYM, T₉-50 % P₂O₅ + PSB + RD NK & FYM, T₁₀-0 % P₂O₅ + PSB + RD NK & FYM, T₁₁-50 % P₂O₅ + Mycorrhiza + RD NK & FYM, T₁₂-0 % P₂O₅ + Mycorrhiza + RD NK & FYM, T₁₃-50 % P₂O₅ + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P₂O₅ + PSB + Mycorrhiza + RD NK & FYM

There was no significant difference in P:Ca ratio at tasseling stage but after harvest it differed significantly. Higher P:Ca ratio of soil was recorded in T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 0.011 at harvest of maize and lower was recorded in T₂ (0.005).

Large difference and increase in P:Zn ratio was observed compared to initial (1.20). There were significant differences at tasseling and at harvest of maize. The ratio ranged from 4.03 in T₁₂ to 1.65 in T₂ at harvest of maize soil. Treatment T₁₃ recorded highest P:Zn ratio (3.70) at tasseling stage of maize soil and lower was recorded in T₂ (1.77). After harvest the P:Zn ratio was significantly higher in T₁₂ (4.03) and lower P:Zn ratio was recorded in T₂ (1.65). The P:Zn ratio increased in all treatments at harvest compared to tasseling stage of maize except T₁₃, T₈, T₂ and T₁.

Significantly higher acid phosphatase activity was recorded at tasseling stages in T₆, T₁₂ and T₁₀ (68.41, 68.34 and 67.29 μg of PNP g^{-1} soil hr^{-1}) and significantly lower activity was recorded in T₁ (33.04 μg of PNP g^{-1} soil hr^{-1}). All treatments showed increase in acid phosphatase activity compared to Initial 22.19 μg PNP g^{-1} soil hr^{-1} acid phosphatase activity. At harvest of maize, higher acid phosphatase activity was recorded in T₆ (45.18 μg of PNP g^{-1} soil hr^{-1}) respectively closely followed by T₁₃ (39.39 μg of p-nitrophenol g^{-1} soil hr^{-1}) and lower was recorded in T₁ (16.26 μg of p-nitrophenol g^{-1} soil hr^{-1}). All treatments showed higher acid phosphatase activity at tasseling stage compared to harvest stage (Table 37). Compared to NPK alone the activities of acid and alkaline phosphatase have increased in treatments which received organic manures and biofertilizers (Table 37). This may be because of application of FYM alone or in combination with inorganic fertilizers which create an ideal condition in the soil for the microorganisms to be active (Halstead and Sowden, 1986). It was also observed by Singaram and Kamalakumari (1995) that the activity of soil enzymes was found to be higher and their effect was pronounced when FYM was applied in combination with chemical fertilizers. Similarly Piotrowska and Wilczewski (2012) reported addition of FYM and biofertilizers increased the acid phosphatase activity compared to NPK alone.

4.3.1.5 Different P fractions in soil of low available P

Results pertaining to the contents of different fractions of P in the soil are presented in the Table 38.

The Sal-P as influenced by different treatments was lower after harvest of maize compared to initial (19.80 mg kg^{-1}), a low sal-P was recorded in T₂ (7.06 mg kg^{-1}) and a higher content was recorded in T₆ (12.37 mg kg^{-1}) which is on par with treatment T₄ (11.13 mg kg^{-1}) which received RD NPK +FYM +PSB 4 kg ha^{-1} . Saloid P was significantly higher in dual inoculation with RD NPK and FYM may due to solubilization of other fraction.

At harvest of maize, low Al-P content was recorded in T₁₄ (288.30 mg kg^{-1}) and a higher value was recorded in T₃ (387.50 mg kg^{-1}) followed by T₄ (372.99 mg kg^{-1}). The Al-P content in treatments has decreased than initial value (443.77 mg kg^{-1}). The Al-P content of soils as influenced by different treatments decreased at harvest of maize,

especially in those treatments which received 50 % P fertilizers or without P fertilizer along with biofertilizers. In the treatments which received organic manure and bio-inoculants, Al-P showed a decreasing trend.

The significant difference in Fe-P content of soil was found at harvest of maize crop. The Fe-P content of soil was decreased slightly compared to initial value (331.24 mg kg⁻¹). Significantly higher Fe-P was recorded in T₃ (318.50 mg kg⁻¹). However the minimum was recorded in T₁₄ (225.60 mg kg⁻¹). Compared to initial there was decline in Fe-P in all the treatments. Al-P and Fe-P were the major fractions and it was attributed to low pH and increased solubilization of Fe and Al under acid conditions (Doddamani and Seshagiri Rao, 1988). Higher content of RS-P may be attributed to higher sesquioxides content. Bapat *et al* (1965) and Kothandaraman and Krishnamurthy (1979) reported that laterite soil contained higher amount of Reductant-soluble P.

The results pertaining to reductant soluble P indicated that there were significant differences among the treatments after harvest of maize crop. The reductant P ranged from 187.91 mg kg⁻¹ in T₁₄ to 287.66 mg kg⁻¹ in T₃ at harvest of maize crop in low P soil (Table 38). Treatment T₃ varied significantly superior compared to the rest of the treatments. The lower reductant soluble P was recorded in T₁₄ (187.90 mg kg⁻¹). However, in all the treatments the RS-P values increased than initial (240.01 mg kg⁻¹).

After harvest of maize the Occl-P fractions varied from 111.28 mg kg⁻¹ in T₁₄ to 192.60 mg kg⁻¹ in T₃ (Table 40). Significantly higher value was recorded in T₃ which was on par with T₁ (176.34 mg kg⁻¹). The lower values of Occl-P was recorded in T₁₄. Among the treatments single and combined inoculated treatments with PSB and AM with half or without P fertilizer recorded lower Occl-P compared to the treatment and without P solublizers.

Results pertaining to the contents of Ca-P in the soil after harvest of maize crop of low P soil are presented in the Table 40. The Ca-P content has decreased in all the treatment compared to initial (38.70 mg kg⁻¹). Higher Ca-P was recorded in T₆ (7.58) which was on par with T₃ (7.36), T₁₄ (7.28) and T₁₃ (7.19). Lower value of Ca-P was recorded in T₂ (5.56 mg kg⁻¹). All treatments showed lower Ca-P over initial (38.70 mg kg⁻¹).

The difference in organic-P content of same treatment combinations varied widely and were higher from dual and single inoculation with 50 % or without P fertilizer but it was comparatively lower in dual and single inoculation with 50 % or without P fertilizer from initial. The maximum decrease in organic-P was recorded in T₁₄ (53.24 mg kg⁻¹) and the significant increase was recorded in T₃ (82.39 mg kg⁻¹) followed by T₄ (74.67 mg kg⁻¹). Microorganism play a major role in organic P solubility. Microbial production of organic acids and acid phosphatase has important role in mineralizing organic P present in soil (Hussain *et al.* 2013).

Table 38: Influence of phosphorus, PSB and VAM application on different fractions of phosphorus (mg kg⁻¹) in maize at harvest in low available phosphorus soil

Treatments	Different fractions of P (mg kg ⁻¹) in soil							
	Sal – P	Al –P	Fe –P	Red –P	Occl-P	Ca –P	Organic- P	Total P
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	9.20	332.48	266.87	234.31	176.34	6.29	54.75	1106.90
T ₂ -FYM (10 t ha ⁻¹)	7.06	294.50	233.56	211.11	124.12	5.56	61.56	960.61
T ₃ -RD NPK + FYM	10.31	387.50	318.50	287.66	192.60	7.36	82.39	1318.06
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	11.13	372.99	265.41	218.07	154.08	6.38	74.67	1129.94
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	10.87	367.78	257.45	215.75	145.52	6.42	73.15	1103.52
T ₆ -RD NPK + FYM + PSB + VAM	12.37	353.40	246.84	211.11	141.24	7.58	70.61	1068.89
T ₇ -50 % P + RD NK + FYM	7.92	337.90	249.49	255.19	171.20	6.63	68.53	1123.93
T ₈ -0 % P + RD NK + FYM	7.06	297.60	238.87	220.39	154.08	5.69	62.53	1010.56
T ₉ -50 % P + PSB + RD NK + FYM	9.54	356.50	260.11	208.79	141.24	6.81	64.81	1073.66
T ₁₀ -0 % P + PSB + RD NK + FYM	8.35	325.50	244.18	199.51	124.12	6.25	59.26	991.04
T ₁₁ -50 % P + VAM + RD NK + FYM	9.89	334.80	265.41	215.75	145.52	6.63	62.96	1066.65
T ₁₂ -0 % P + VAM + RD NK + FYM	9.07	313.10	241.53	197.19	115.56	6.12	57.61	963.38
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	10.49	294.50	238.87	204.15	136.96	7.19	55.48	971.03
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	10.23	288.30	225.60	187.91	111.28	7.28	53.24	905.65
Initial	19.80	443.77	331.24	240.01	181.52	38.70	114.87	1185.03
SEm±	0.43	8.40	8.23	3.48	5.14	0.16	1.55	28.07
CD (P = 0.05 %)	1.28	24.49	23.62	10.44	14.98	0.57	4.97	82.33

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

From the data it is clear that total P content of soil was increased in all treatments compared to initial (846.0 mg kg⁻¹). T₁₄ showed significantly lower total P 905.65 mg kg⁻¹. T₃ (1318.06 mg kg⁻¹) was found to be significantly superior among the treatments followed by T₉ (1073.66 mg kg⁻¹). In general the total P content has decreased drastically in treatments without P fertilizer + NK fertilizer + organic matter + biofertilizer treatments compared to treatments containing 50 % or full dose of P fertilizer +NK+ organic matter + biofertilizers (Table 38). The high total P content of the soils may be attributed to higher oxides of iron and aluminum, continuous addition of water soluble inorganic P fertilizers and low pH and under high P condition the activity of PS decreased which led to low solubilization of total phosphorus to the soil solution for plant growth.

P-solubilizing microorganisms are responsible mainly for organic acid production in soil which leads to release of phosphorus from different pools either by: (i) lowering the pH, or (ii) by enhancing chelation of the cations bound to P (iii) by competing with P for adsorption sites on the soil (iv) by forming soluble complexes with metal ions associated with insoluble P (Ca, Al, Fe) and thus P is released. The lowering in pH of the soil suggests the release of organic acids by the P-solubilizing microorganisms (Whitelaw 2000; Maliha *et al.* 2004) via the direct oxidation pathway that occurs on the outer face of the cytoplasmic membrane (Zaidi *et al.* 2009). Phosphate solubilizing organisms have been reported to solubilize inorganic fixed form of P by excreting organic acids that directly dissolves fixed phosphatic materials of soil (Bairva *et al.* 2012). Soloid P is the most soluble form of P in soil. Lower content of Soloid - P of the soil was due to low pH, high content of sesquioxides, high P fixing capacity of acid soils and low content of easily soluble Ca-P (Paramasivam and Udayasuryan, 1991). Higher level of RS-P in soil is ascribed to the transformation of other forms of P to RS-P with lapse of time. Mongia and Bandyopadhyay (1996) also observed the RS-P > Fe-P > Al-P were the dominant inorganic fraction in Alfisols owing to higher amount of amorphous Al and Fe, which favoured the formation of Al-P and Fe-P.

4.3.2 Effect of PSB, VAM and different level of phosphorus on growth of maize in of low available P soil

4.3.2.1 Plant height, No. of leaves, leaf area and leaf area index of maize recorded at different stages of crop growth

The data on plant height of maize at tasseling stage and at harvest are given in Table 39.

At tasseling and at harvest T₆ (RD NPK + FYM + PSB + VAM) showed significantly higher plant height (189.0 and 214.50 cm) and was on par with all other treatments except T₁ (145.3 and 177.8 cm) and T₂ [RD FYM (10 tonne)] (110.8 and 131.5 cm).

Table 39: Influence of phosphorus, PSB and VAM application on growth and yield parameters of maize at tasseling stage (60 DAS) and at harvest in low available phosphorus soil

Treatments	Plant height (cm)		No of leaves plant ⁻¹		Leaf area (cm ² plant ⁻¹)		Leaf area index	
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	145.3	177.8	7.3	10.75	1193.01	1704.3	1.33	0.95
T ₂ -FYM (10 t ha ⁻¹)	110.8	131.5	7.3	9.5	1053.15	1504.5	1.17	0.84
T ₃ -RD NPK + FYM	176.3	192.5	8.5	12.5	1500.8	2362.5	1.67	1.31
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	187.8	213.8	10.5	13.75	2105.25	2807.5	2.34	1.67
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	185.3	208.3	8.5	13.25	1664.6	2378.0	1.85	1.32
T ₆ -RD NPK + FYM + PSB + VAM	189.0	214.5	9.0	13.75	2238.11	3197.3	2.49	1.78
T ₇ -50 % P + RD NK + FYM	171.3	212.5	9.3	12.5	1755.21	2455.5	1.94	1.36
T ₈ -0 % P + RD NK + FYM	166.3	203.0	8.3	10.75	1330.21	1934.0	1.48	1.07
T ₉ -50 % P + PSB + RD NK + FYM	181.5	199.8	8.8	13.25	1653.75	2500.3	1.84	1.39
T ₁₀ -0 % P + PSB + RD NK + FYM	162.5	208.8	7.6	12.75	1353.8	2499.8	1.50	1.39
T ₁₁ -50 % P + VAM + RD NK + FYM	177.3	194.8	9.5	11.75	1830.5	2615.0	2.03	1.45
T ₁₂ -0 % P + VAM + RD NK + FYM	152.0	178.8	8.5	11.5	1647.8	2354.0	1.83	1.31
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	178.5	208.8	10.3	13.75	2108.96	3012.8	2.34	1.56
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	170.3	201.8	8.8	12	1718.85	2144.0	1.91	1.19
SEm±	9.79	10.7	0.60	0.889	63.651	90.93	0.07	0.06
CD (P = 0.05 %)	27.36	30.5	2.29	2.546	242.865	346.95	0.27	0.19

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure and DAS: days after sowing

The number of leaves was significantly higher (10.5 and 13.75) in T₄ (RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹) but it was significantly lower in T₂ (RD FYM (10 tonne) at tasseling stage and at harvest stage (7.3 and 9.5).

Significantly higher leaf area (2238.11 and 3197.3 cm² respectively) was recorded in treatment T₆ receiving RD NPK + FYM + PSB + VAM compared to other treatments and it was on par with T₁₃ (50 % P₂O₅ + PSB + Mycorrhiza + RD NK & FYM) at both the stages, but lower leaf area (1053.15 and 1504.5 cm²) was recorded in T₂ [RD FYM (10 tonne)] compared to all other treatments at both the stages.

Significantly lower leaf area index (1.17 and 0.84) was observed in T₂ [RD FYM (10 tonne)] at both the stages. The higher significant leaf area index (2.49 and 1.78) observed in T₆ (RD NPK + FYM + PSB + VAM) at both the stages and was on par with T₄ (2.34 and 1.67) compared to all other treatments.

4.3.2.2 Fresh weight and dry weight of maize as influenced by P sources and levels

The data on weight parameters of maize at tasseling and at harvest are presented in Table 40.

In maize, significantly higher fresh weight [leaves (89.52 g plant⁻¹), stover (188.94 g plant⁻¹) and roots (59.10 g plant⁻¹)] was recorded in T₆ (RD NPK + FYM + PSB + VAM). The lower weight of leaves (53.98 g plant⁻¹), stover (115.02 g plant⁻¹) and roots (38.66 g plant⁻¹) was recorded in T₂ [RD FYM (10 tonne)] treatments. The significant and higher total fresh weight (337.56 g plant⁻¹) of maize plant was recorded in T₆ (RD NPK + FYM + PSB + VAM), but lower (207.66 g plant⁻¹) was in T₂ [RD FYM (10 tonne)].

Among the treatments, T₆ (RD NPK + FYM + PSB + VAM) recorded significantly higher total dry weight (76.90 g plant⁻¹) at tasseling stage and after harvest in T₄ (138.62 g plant⁻¹) compared to all other treatments, but lower total dry weight (43.24 g plant⁻¹ and 101.47 g plant⁻¹) was recorded in T₂ [RD FYM (10 tonne)] treatments at both the stages of the crop.

Co-inoculation of VAM + PSB with FYM increased fresh and dry matter of maize compared to other treatments respectively. Mahanta and Rai (2008) have reported similar finding to them this application of 50 % recommended dose of P as SP + PSB + VAM recorded the highest yield during the first year in soybean (2.0 t/ha) and during both the years in wheat (4.4 and 4.6 t/ha in the first and second years respectively), but that of 50 % RD of P as a RP + PSB + VAM registered the highest grain yield (2.2 t/ha) during the second year in soybean. The individual application of PSB or VAM with FYM also increased fresh and dry weight of stover significantly compared to the FYM and NPK alone. similar trend had been obtained by Suri *et al.* (2013) in which they explained the beneficial effect of VAM inoculation on maize yield was attributed to greater exploration of soil volume by its hyphal network, leading to greater overall nutrient- and water-use efficiencies.

Table 40: Influence of phosphorus, PSB and VAM application on fresh and dry biomass of maize at tasseling stage and at harvest in low available phosphorus soil

Treatments	Fresh weight (g plant ⁻¹) 60 DAS				Dry weight (g plant ⁻¹)							
	Leaf	Stover	Root	Total	leaf		Stover		Root		Total	
					60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T₁	59.18	116.19	39.97	215.34	13.80	37.73	26.66	55.03	8.74	20.99	49.20	113.75
T₂	53.98	115.02	38.66	207.66	12.89	34.24	22.87	47.10	7.48	20.13	43.24	101.47
T₃	61.75	140.40	42.56	244.71	17.37	31.64	28.97	70.05	8.89	24.95	55.23	126.64
T₄	79.35	179.12	56.47	314.94	27.24	38.00	35.26	74.12	11.12	26.50	73.62	138.62
T₅	68.48	165.28	56.47	290.23	24.74	36.02	35.02	68.15	11.90	25.23	71.66	129.40
T₆	89.52	188.94	59.10	337.56	27.71	37.62	36.75	72.29	12.44	25.50	76.90	135.41
T₇	69.70	151.50	56.19	277.39	21.99	35.04	31.78	68.60	10.81	21.54	64.58	125.18
T₈	66.07	153.40	44.59	264.06	23.37	29.73	29.99	59.08	10.81	19.28	64.17	108.09
T₉	58.97	139.59	46.10	244.66	23.25	31.11	28.15	69.18	11.03	22.40	62.43	122.69
T₁₀	56.16	116.22	32.11	204.49	13.77	36.02	28.09	70.17	7.71	24.66	49.57	130.85
T₁₁	71.63	162.81	52.99	287.43	16.11	34.10	30.43	72.23	9.96	22.40	56.50	128.73
T₁₂	60.76	139.59	43.89	244.24	19.87	39.24	28.56	68.48	9.83	19.85	58.26	127.57
T₁₃	69.42	160.16	50.47	280.05	21.08	33.62	30.70	72.27	11.61	22.11	63.39	128.00
T₁₄	67.42	143.78	43.68	254.88	18.77	33.07	31.00	69.35	8.93	20.99	58.70	123.41
SEm±	1.54	4.53	1.48	8.12	0.86	1.56	0.84	1.73	0.24	2.03	1.87	2.02
CD (P = 0.05 %)	4.47	13.23	4.31	24.01	2.50	4.88	2.43	5.04	0.69	3.33	5.62	6.05

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

4.3.2.3 Yield attributes of maize under low available phosphorus soil

4.3.2.3.1 Number of cobs plant⁻¹

Among the treatments no significant differences observed with respect to number of cobs per plant. Even between inoculated and uninoculated treatment also no significant difference was observed (Table 41).

4.3.2.3.2 No. of rows per cob

Among the treatments application of PSB + VAM + RD N P K + FYM (T₆) recorded significantly higher number of rows 13.75 per cob followed by T₅, T₃, T₁₀, T₁₁, T₁₂ and T₁₃ (13.50, 13.50, 12.50, 12.25, 12.00 and 12.00 rows cob⁻¹, respectively). Lower numbers of rows were recorded in T₂ (FYM @ 10 t ha⁻¹) 8.75 cob⁻¹.

4.3.2.3.3 Number of seeds row⁻¹

Among the treatments significantly higher number of seeds row⁻¹ (21.25) was recorded with T₆ (PSB + VAM + RD NPK + FYM) and it was on par with rest of the single inoculated with P or without P fertilizer like T₉ and T₅ (19.00 and 17.25 seeds row⁻¹). Significantly lower seed row⁻¹ (9.50) was recorded by T₂ (FYM @ 10 t ha⁻¹). The higher number of seeds per row due to combined inoculation of VAM fungus and PSB than with PSB alone can be attributed to the activity of the VAM fungus in transporting extra phosphorus solubilized by PSB from and beyond the root zone into the plant roots which in the absence of VAM hyphae refixed by soil constituents during the course of slower diffusion towards plant roots. These results are in accordance with the findings of Pereira and Castro (2014) in maize. They reported the higher seed yield and promoted maize growth, due to inoculation of PSB and VAM alone and combined inoculation.

4.3.2.3.3 Test weight (g)

The data on test weight of maize in low P soil are presented in the Table 41. Test weight of the 100 seeds varied significantly with treatments. Higher test weight (17.79 g) was recorded with application PSB + VAM + RD N P K + FYM (T₆) and 17.62 g in treatment T₁₄ which received 0 % P + PSB + VAM + RD NK + FYM and was on par with T₁₃ treatment (16.51 g). While the test weight was lower in T₂ (12.89 g). As compared to uninoculated treatments the inoculated treatments showed higher test weight.

4.3.2.3.4 Cob weight (g plant⁻¹)

The data on cob weight of maize in pot experiment are presented in the Table 41. The cob weight differed significantly among inoculated and uninoculated treatments. Higher cob weight was recorded in T₆ (55.50 g) and was on par with treatment including T₄ (43.75 g), T₁₃ (43.13 g) and T₅ (42.00 g) respectively. The weight of the cob was significantly lower in T₁ (20.10 g).

Table 41: Influence of phosphorus, PSB and VAM application on growth and yield parameters of maize at harvest in low available phosphorus soil

Treatments	No. of cobs plant ⁻¹	No. of rows per cob	No. of seeds per row	100 seeds weight (g)	Weight of cob (g plant ⁻¹)	Seeds weight (g per cob)	Grain yield (g pot ⁻¹)	Stover yield (g pot ⁻¹)
T₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1	9.25	10.75	14.19	20.10	20.25	20.25	27.40
T₂ -FYM (10 t ha ⁻¹)	1	8.75	9.50	12.89	27.78	18.60	18.60	25.17
T₃ -RD NPK + FYM	1	13.50	15.25	13.69	41.00	26.50	26.50	35.86
T₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	1	10.75	16.25	13.04	43.75	32.68	32.68	44.23
T₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	1	13.50	17.25	11.97	42.00	30.46	30.46	41.22
T₆ -RD NPK + FYM + PSB + VAM	1	13.75	21.25	17.79	55.50	36.45	36.45	49.33
T₇ -50 % P + RD NK + FYM	1	11.00	14.75	14.61	38.63	22.73	22.73	30.76
T₈ -0 % P + RD NK + FYM	1	10.00	11.25	14.50	36.75	23.90	23.90	32.34
T₉ -50 % P + PSB + RD NK + FYM	1	10.75	19.00	15.61	40.50	32.22	32.22	43.60
T₁₀ -0 % P + PSB + RD NK + FYM	1	12.50	14.25	12.20	28.50	24.57	24.57	33.25
T₁₁ -50 % P + VAM + RD NK + FYM	1	12.25	13.75	15.85	36.25	30.30	30.30	41.01
T₁₂ -0 % P + VAM + RD NK + FYM	1	12.00	15.75	15.07	36.00	25.96	25.96	35.13
T₁₃ -50 % P + PSB + VAM + RD NK + FYM	1	12.00	13.75	16.51	43.13	33.35	33.35	45.13
T₁₄ -0 % P + PSB + VAM + RD NK + FYM	1	10.75	13.50	17.62	37.00	29.42	29.42	39.82
SEm±	0.116	0.92	1.726	1.03	5.03	2.55	2.55	3.45
CD (P = 0.05 %)	N/A	2.635	4.942	3.11	14.41	7.31	7.31	9.89

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.3.2.3.5 Seeds weight (g per cob)

In inoculated and uninoculated treatments seed weight (g per cob) was higher at T₆ (RD NPK + FYM + PSB + VAM) 36.45 g and was on par with other single inoculated and combine inoculated with full dose or 50 % or even without P fertilizer treatments like T₁₃, T₄, T₉, T₅, T₁₁ and T₁₄ (33.35, 32.68, 32.22, 30.46, 30.30 and 29.42 g). The seed weight g per cob was lower in T₁ (20.25 g) as represented in Table 41.

4.3.2.3.6 Grain yield (g pot⁻¹)

Pot experiments with low available and high total P indicated positive impact of PSB and VAM on maize yield which was significantly higher (36.45 g pot⁻¹) on application of T₆ (RD NPK + PSB + VAM + FYM) and was on par with other single inoculated and combine inoculated with full dose or 50 % or even without P fertilizer treatments like T₁₃, T₄, T₉, T₅, T₁₁ and T₁₄ (33.35, 32.68, 32.22, 30.46, 30.30 and 29.42 g pot⁻¹). Lower grain yield was recorded in T₂ (18.60 g pot⁻¹) as represented in Table 41 and Fig. 4. This indicates that with dual inoculation of efficient VAM strain and PSB along with 50 % P dose, 50 % of fertilizer P can be saved without impairing the yield of maize in an acidic Alfisol (Suri *et al.*, 2011). The similar results were reported by Mehta *et al.* (2012) who reported that the combined inoculation of seed with rhizobium and phosphorus solubilizing bacteria resulted in higher plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net return. Combined inoculation of AMF and PSM with decreasing the P level enhanced the growth of crop (Meena *et al.*, 2002).

4.3.2.3.7 Stover yield (q ha⁻¹)

The stover yield was significantly higher (49.33 g pot⁻¹) with application of RD NPK + PSB + VAM + FYM (T₆) followed by T₁₃, T₄, T₅, T₁₁ and T₁₄ (45.13, 44.23, 41.22, 41.01 and 39.82 g pot⁻¹). However, lower yield of maize stover (25.17 g pot⁻¹) was recorded in T₂ (FYM alone) (Table 41 and Fig. 4). This indicates that with combined inoculation of efficient VAM strain and PSB along with 50 % P dose, 50 % of P fertilizer can be saved without impairing the yield of maize in an acidic Alfisol (Suri *et al.*, 2011).

4.3.3 Effect of PSB, VAM and different level of phosphorus on nutrient content of maize at tasseling stage in soil of low available P

4.3.3.1 Major nutrients content of different parts of maize at tasseling

The nitrogen content of maize at tasseling grown in low P soil varied significantly among treatments shown in Table 42. The nitrogen content of maize leaves, stover and root increased with application of RD NPK + FYM + PSB + VAM (T₆) 2.64, 2.59 and 0.63 per cent respectively which was on par with treatments receiving T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 2.63, 2.57 and 0.63 per cent respectively the lower nitrogen in maize leaves, stover and roots were recorded in T₂ which received FYM @ 10 t ha⁻¹ (0.75, 0.63 and 0.46 %). Combined inoculation of PSB+VAM registered high N uptake by all plant parts compared to uninoculated treatment. Higher nitrogen content could be attributed to increased nitrogen availability in the soil. Among different parts of plant, leaf showed high nitrogen content compared to stover and root for all the treatments.

Table 42: Influence of phosphorus, PSB and VAM application on major nutrients content (%) of maize at tasseling stage in low available phosphorus soil

Treatments	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	Leaves	Stover	Roots	Leaves	Stover	Roots	Leaves	Stover	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.26	0.71	0.50	0.17	0.18	0.08	2.18	1.57	0.96
T ₂ -FYM (10 t ha ⁻¹)	0.75	0.63	0.46	0.16	0.12	0.05	1.87	1.49	0.78
T ₃ -RD NPK + FYM	1.22	1.02	0.62	0.22	0.24	0.10	2.58	2.30	1.11
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	0.99	0.91	0.54	0.22	0.20	0.13	2.15	2.42	0.93
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	1.50	0.90	0.56	0.23	0.19	0.14	2.18	1.89	1.00
T ₆ -RD NPK + FYM + PSB + VAM	2.64	2.59	0.63	0.27	0.29	0.16	2.98	2.47	1.51
T ₇ -50 % P + RD NK + FYM	2.20	1.10	0.49	0.19	0.19	0.10	2.40	1.91	1.04
T ₈ -0 % P + RD NK + FYM	1.76	0.94	0.54	0.15	0.16	0.09	2.45	2.03	1.30
T ₉ -50 % P + PSB + RD NK + FYM	2.57	1.27	0.47	0.20	0.18	0.12	2.04	2.26	0.88
T ₁₀ -0 % P + PSB + RD NK + FYM	1.46	1.71	0.51	0.21	0.17	0.11	2.34	2.02	0.96
T ₁₁ -50 % P + VAM + RD NK + FYM	2.31	1.63	0.59	0.22	0.23	0.10	2.02	1.70	0.90
T ₁₂ -0 % P + VAM + RD NK + FYM	2.06	1.56	0.55	0.21	0.28	0.10	2.26	1.59	0.98
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	2.63	2.57	0.63	0.25	0.28	0.15	2.59	2.31	1.29
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	2.22	1.32	0.60	0.22	0.19	0.14	2.51	2.28	1.19
SEm±	0.20	0.10	0.05	0.02	0.015	0.01	0.13	0.10	0.05
CD (P = 0.05 %)	0.61	0.29	0.16	0.06	0.045	0.03	0.37	0.30	0.15

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

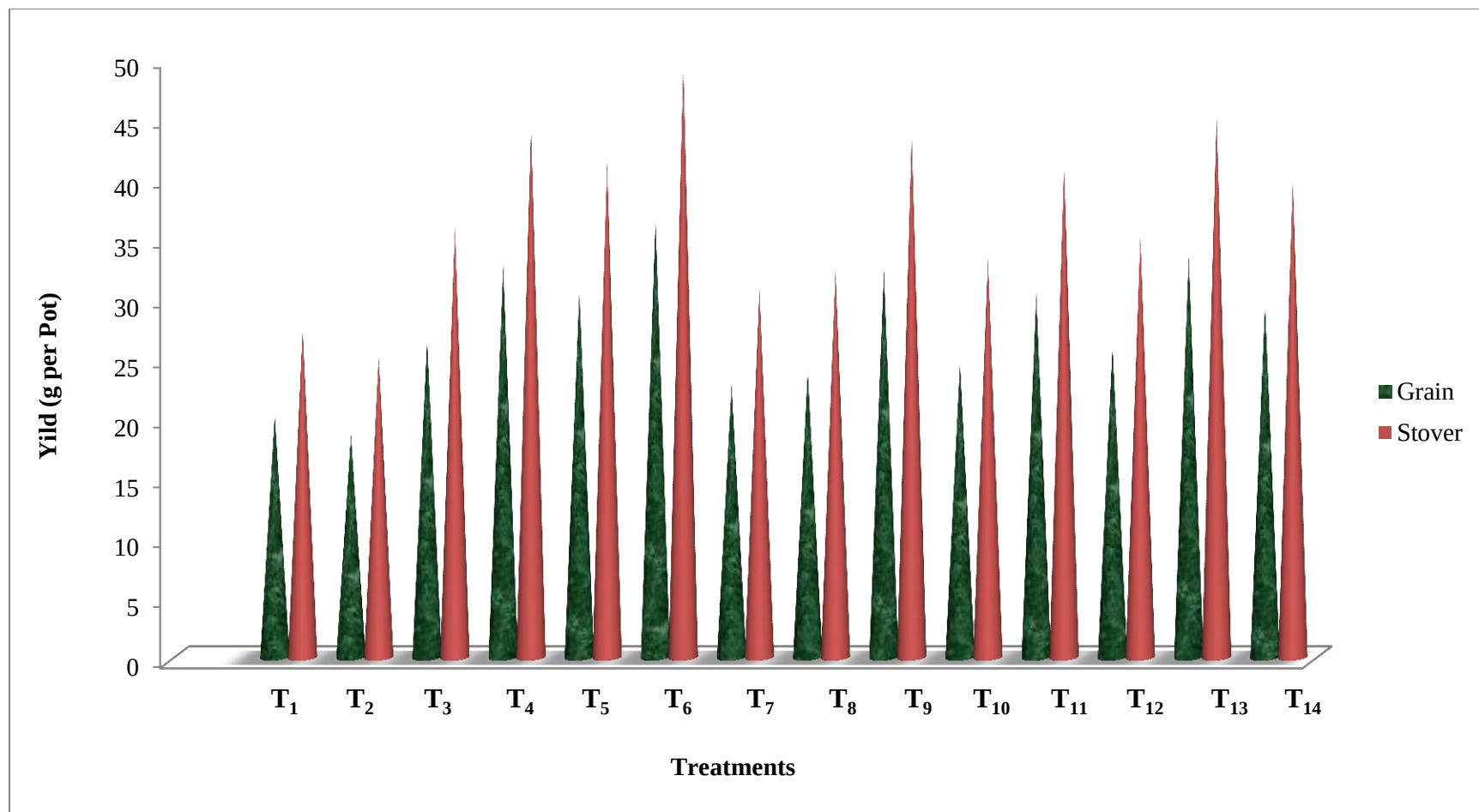


Fig. 4. Influence of phosphorus, PSB and VAM application on yield of maize (g pot⁻¹) in low available phosphorus soil

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50% P + RD NK & FYM, T₈-0% P + RD NK & FYM, T₉-50% P + PSB + RD NK & FYM, T₁₀-0% P + PSB + RD NK & FYM, T₁₁-50% P + Mycorrhiza + RD NK & FYM, T₁₂-0% P + Mycorrhiza + RD NK & FYM, T₁₃-50% P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0% P + PSB + Mycorrhiza + RD NK & FYM.

The P content in maize leaves, stover and root differed significantly among treatments shown in Table 42. The P content of maize leaves, stover and root at tasseling stage increased with application of full dose or 50 % P or without P and RD NPK + FYM + PSB + VAM. The high P content observed in treatment receiving T₆ (RD NPK + FYM + PSB + VAM) 0.27, 0.29 and 0.16 per cent respectively which were on par with other treatments inoculated with microorganism like T₁₃, T₁₂, , T₃, T₅, T₁₁, , T₄ and T₁₄ respectively. Lower P content in maize leaves, stover and roots crop were recorded in T₂ (FYM @ 10 t ha⁻¹) 0.16, 0.12 and 0.05 % respectively. Among different parts of maize (leaf, stover and root) the content of P was lower in root.

Higher K content in leaves, stover and roots were recorded in RD NPK + FYM + PSB + VAM (T₆: 2.98, 2.47 and 1.51 % respectively) and were on par with T₁₃ (50 % P + PSB + VAM + RD NPK + FYM) 2.59, 2.31 and 1.29 % respectively. Lower K content was observed in T₂ (1.87, 1.49 and 0.78 %) (Table 42).

4.3.3.2 Secondary nutrients content (%) of different parts of maize at tasseling stage in low available phosphorus soil

At tasseling stage combined inoculation of PSB+VAM recorded significantly higher sulphur content in different parts of maize (leaves, stover and root) (Table 43). Similarly S content in whole plant was high in dual inoculated treatment. T₆ (RD NPK + FYM + PSB + VAM) showed higher S content in leaves, stover and roots (0.33, 0.22 and 0.20 respectively), on par with other inoculated treatments like T₁₃ (50 % P + PSB + VAM + RD NPK + FYM) (0.32, 0.19 and 0.17 per cent respectively). Significantly lower S content was recorded in (T₂) 0.18, 0.09 and 0.10 per cent respectively leaves stover and roots of maize plant. Irrespective of the treatments, higher sulphur content was recorded in leaves as compared to other plant parts.

Within the treatments T₆ (RD NPK + FYM + PSB + VAM) resulted significantly higher Ca content in maize leaves, stover and roots (1.30, 1.24 and 1.10 % respectively) (Table 43) which was closely followed by other microorganisms inoculated treatments T₁₃ (50 % P + PSB + VAM + RD NPK + FYM) (1.27, 1.22 and 1.07 per cent respectively), T₁₄ (1.25, 1.17 and 1.00 per cent respectively). Lower Ca content in maize leaves, stover and root were recorded in uninoculated treatments like T₂ (FYM @ 10 t ha⁻¹) (1.22, 1.02 and 0.65 % respectively). Higher Ca content was recorded in the leaves and stover as compared to the root for all the treatments.

Similar trend of calcium was followed with respect to magnesium content by maize leaves, stover and root. Among different parts of maize plant, leaves and stover recorded higher values as compared to root. With respect to plant (leaves, stover and roots) the magnesium content was found to be significantly higher in treatment T₆ (0.92, 0.41 and 0.33 per cent respectively) which is on par with T₁₃ and T₄ (Table 43). Lower Mg content was recorded in treatments T₂ (0.45, 0.32 and 0.21 % respectively).

Table 43: Influence of phosphorus, PSB and VAM application on secondary nutrients content (%) of maize at tasseling stage in low available phosphorus soil

Treatments	Sulphur (%)			Calcium (%)			Magnesium (%)		
	leaves	stover	roots	leaves	stover	roots	leaves	stover	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	0.20	0.13	0.12	1.25	1.16	0.75	0.45	0.32	0.21
T ₂ -FYM (10 t ha ⁻¹)	0.18	0.09	0.10	1.22	1.02	0.65	0.31	0.32	0.25
T ₃ -RD NPK + FYM	0.24	0.16	0.14	1.28	1.20	0.93	0.65	0.30	0.14
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	0.23	0.18	0.13	1.43	1.15	0.95	0.83	0.35	0.23
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	0.22	0.14	0.14	1.25	1.14	0.78	0.45	0.36	0.22
T ₆ -RD NPK + FYM + PSB + VAM	0.33	0.22	0.20	1.31	1.24	1.10	0.92	0.41	0.33
T ₇ -50 % P + RD NK + FYM	0.23	0.17	0.13	1.19	1.12	0.84	0.40	0.34	0.25
T ₈ -0 % P + RD NK + FYM	0.30	0.15	0.10	1.18	1.10	0.72	0.39	0.29	0.24
T ₉ -50 % P + PSB + RD NK + FYM	0.29	0.18	0.15	1.25	1.22	0.97	0.78	0.36	0.24
T ₁₀ -0 % P + PSB + RD NK + FYM	0.25	0.14	0.11	1.19	1.10	0.90	0.32	0.36	0.22
T ₁₁ -50 % P + VAM + RD NK + FYM	0.24	0.15	0.13	1.23	1.18	0.97	0.46	0.35	0.22
T ₁₂ -0 % P + VAM + RD NK + FYM	0.23	0.12	0.12	1.22	1.01	0.95	0.68	0.32	0.24
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	0.32	0.19	0.17	1.27	1.22	1.07	0.87	0.39	0.32
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	0.26	0.15	0.15	1.25	1.17	1.00	0.45	0.37	0.29
SEm±	0.02	0.01	0.01	0.06	0.08	0.08	0.05	0.03	0.02
CD (P = 0.05 %)	0.05	0.03	0.04	0.17	0.22	0.23	0.15	0.08	0.04

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.3.3.3 Micronutrients content of different parts of maize at tasseling stage

Results pertaining to the direct effect of microbial inoculants, FYM and chemical fertilizer on micronutrient contents (mg kg^{-1}) in maize at tasseling stage of pot experiment are presented in the Table 44.

Iron content of different parts of maize plant like leaves, stover and roots at tasseling stage was significantly higher in the T_{13} which received 50 % P + RD NPK + FYM + PSB + VAM (68.90, 45.73 and 40.11 mg kg^{-1} respectively) and was on par with T_6 received RD NPK + FYM + PSB + VAM (68.14, 45.16 and 39.29 mg kg^{-1} respectively). The lower iron content of leaves, stover and roots were recorded in T_1 received RD NPK @ 150: 75: 40 kg ha^{-1} (37.31, 18.72 and 22.67 mg kg^{-1} respectively).

The content of manganese at tasseling stage of maize leaves, stover and roots were increased significantly in all treatments except T_1 received RD NPK @ 150: 75: 40 kg ha^{-1} (23.58, 23.25 and 30.13 mg kg^{-1} respectively) which recorded the lowest and T_6 RD NPK + FYM + PSB + VAM recorded the highest leaves, stover and roots (38.59, 58.90 and 51.38 mg kg^{-1} respectively) manganese content. Combined and single inoculation recorded higher compared to uninoculated treatments.

Copper content of maize leaves, stover and roots at tasseling stage was (4.30, 2.74 and 3.05 mg kg^{-1} respectively) significantly lower in T_2 (FYM @ 10 t ha^{-1}) and significantly higher copper content was recorded in T_6 (8.47, 5.51 and 7.60 mg kg^{-1} respectively) which was on par with T_{13} (8.26, 4.55 and 7.20 mg kg^{-1} respectively) at tasseling stage in leaves, stover and roots.

Combined inoculation or single inoculation with PSB or AMF with FYM and fertilizer application showed significant differences with respect to zinc content at tasseling stage of maize leaves, stover and roots showed significantly higher in T_6 (21.75, 12.83 and 24.03 mg kg^{-1} respectively) and T_{13} (20.15, 12.36 and 23.16 mg kg^{-1} respectively). The lower zinc content in leave, stover and root was recorded in T_2 (13.45, 6.54 and 15.71 mg kg^{-1} respectively).

Table 44: Influence of phosphorus, PSB and VAM application on micronutrient content (mg kg⁻¹) of maize at tasseling stage in low available phosphorus soil

Treatments	Fe (mg kg ⁻¹)			Mn (mg kg ⁻¹)			Cu (mg kg ⁻¹)			Zn (mg kg ⁻¹)		
	Leaves	Stover	Roots	Leaves	Stover	Roots	Leaves	Stover	Roots	Leaves	Stover	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	37.31	18.72	22.67	23.58	23.25	36.13	6.86	4.20	4.36	16.20	7.84	19.02
T ₂ -FYM (10 t ha ⁻¹)	38.45	25.77	34.97	23.92	30.58	31.00	4.30	2.74	3.05	13.45	6.54	15.71
T ₃ -RD NPK + FYM	46.30	30.61	36.52	26.75	40.84	39.76	7.93	4.44	4.96	20.78	10.76	21.08
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	43.74	35.06	35.57	36.96	59.07	36.06	6.64	3.57	3.45	19.74	11.73	19.61
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	41.58	39.57	33.55	20.91	47.79	34.18	6.13	3.92	3.35	18.15	10.02	19.84
T ₆ -RD NPK + FYM + PSB + VAM	68.14	45.61	39.29	38.59	58.90	51.38	8.47	5.51	7.60	21.75	12.83	24.03
T ₇ -50 % P + RD NK + FYM	55.87	35.65	33.78	26.49	47.63	32.05	8.08	4.27	6.96	16.19	10.85	20.83
T ₈ -0 % P + RD NK + FYM	38.23	30.26	33.20	15.82	53.97	30.93	7.77	4.35	6.99	14.25	9.47	18.71
T ₉ -50 % P + PSB + RD NK + FYM	64.03	29.39	35.89	26.46	64.83	41.63	5.62	2.67	6.78	19.41	10.92	21.54
T ₁₀ -0 % P + PSB + RD NK + FYM	44.63	24.06	26.56	21.58	49.44	39.90	6.55	4.19	3.97	16.77	9.59	15.37
T ₁₁ -50 % P + VAM + RD NK + FYM	33.81	30.76	29.43	19.47	59.54	31.29	6.18	2.55	4.31	18.29	10.25	16.74
T ₁₂ -0 % P + VAM + RD NK + FYM	42.32	24.87	35.15	26.66	47.49	29.92	5.70	3.87	6.81	16.38	9.62	13.53
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	68.90	42.73	40.11	21.12	58.87	42.73	8.26	4.55	7.20	20.15	12.36	23.16
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	64.56	31.97	32.31	34.22	57.96	36.52	7.06	3.77	6.66	17.55	10.99	19.91
SEm±	2.23	1.34	1.20	2.12	2.44	2.22	0.52	0.38	0.31	1.19	0.58	0.92
CD (P = 0.05 %)	6.50	4.00	3.60	6.34	7.10	6.66	1.51	1.10	0.91	3.58	1.68	3.72

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.3.4 Effect of PSB, VAM and different level of phosphorus on nutrient uptake by maize at harvest in soil of low available P

4.3.4.1 Major nutrients uptake by different parts of maize at harvest

The data pertaining to nitrogen, phosphorus and potassium uptake (kg ha^{-1}) at harvest by different parts of maize differed significantly due to PSB, AMF, FYM and chemical fertilizers application to the soil under phosphorus deficient condition (Table 45).

The nitrogen uptake by different parts like leaves, stover, grain and roots of maize crop at harvest was significantly higher in T_6 (54.30, 40.35, 106.08 and 25.17 kg ha^{-1} , respectively) which received RD NPK + FYM + PSB + VAM was on par with T_{13} (55.20, 36.60, 101.97 and 23.55 kg ha^{-1} respectively). However, lower nitrogen uptake by leaves, stover, grain and roots was recorded in the T_2 received FYM @ 10 t ha^{-1} (9.27, 11.49, 35.28 and 6.90 kg ha^{-1} , respectively). Combined inoculation and single inoculation were recorded higher nitrogen uptake compared to uninoculated treatment (Table 45). Among different parts of maize, grain showed higher nitrogen uptake compared to leaves, stover and root. Root showed lower nitrogen uptake.

Uptake of phosphorus by leaves, stover, grain, root and total by maize crop significantly differed among the treatments. Higher uptake of phosphorus by leaves, stover, grain and root of maize crop at harvest was recorded in T_6 receiving RD NPK + FYM + PSB + VAM ($11.16, 15.20, 31.84$ and 6.72 kg ha^{-1} respectively) followed by T_{13} - 50 % P + PSB + VAM + RD NK + FYM ($11.04, 14.84, 24.40$ and 5.92 kg ha^{-1} respectively). However, lower uptake of phosphorus in leaves, stover, grain and roots ($3.84, 2.92, 9.48$ and 2.36 kg ha^{-1} , respectively) was recorded in the T_2 (FYM @ 10 t ha^{-1}). Combined inoculation showed higher phosphorus uptake compared to uninoculated treatments.

The K uptake by maize leaves, stover, grain and roots significantly varied with the different inoculated and uninoculated treatments is presented in Table 45. Higher leaves, stover, grain and roots K uptake was recorded in T_6 received RD NPK + FYM + PSB + VAM ($39.62, 98.34, 92.06$ and 21.06 kg ha^{-1} respectively) and was on par with T_{13} received 50 % P + PSB + VAM + RD NK + FYM ($36.16, 87.30, 85.26$ and 20.46 kg ha^{-1} respectively). Lower plant K uptake by leaves, stover, grain and roots was recorded in T_2 ($16.08, 31.60, 35.32$ and 4.34 kg ha^{-1} respectively) where RD NPK (150: 75: 40 kg ha^{-1}) was applied.

Results of enhanced uptake of nutrients by use of biofertilizers (*G. mosseae* and VAM) resulted in the highest nitrogen, phosphorus and potassium uptake. This field experiment study also indicated that half phosphorus application with combined inoculation had similar effects when compared with full dose of phosphorus fertilizer with dual inoculation. Higher nutrient uptake in dual inoculated treatment could be attributed to increased nutrient availability in the soil. Higher uptake of major nutrients in above said treatment was due to higher growth attributing parameters and total dry matter production. This further influenced the manifestation of yield attributing characters and subsequent by yield of maize crop. Gupta *et al.* (2006) noticed that the effect of bio-

Table 45: Influence of phosphorus, PSB and VAM application on major nutrients uptake by maize (kg ha⁻¹) at harvest in low available phosphorus soil

Treatments	Nitrogen (kg ha ⁻¹)				Phosphorus (kg ha ⁻¹)				Potassium (kg ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	12.03	15.78	60.93	6.90	6.88	6.52	11.16	2.72	12.96	13.40	26.42	4.56
T ₂ -FYM (10 t ha ⁻¹)	9.27	11.49	35.28	6.90	3.84	2.92	9.48	2.36	16.08	31.60	35.32	4.34
T ₃ -RD NPK + FYM	23.64	24.81	90.18	11.79	8.16	8.96	22.84	3.64	30.12	54.76	84.64	8.24
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	14.91	27.21	85.29	19.02	7.92	10.44	18.56	3.84	29.76	69.84	72.64	9.64
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	22.83	27.09	75.00	15.81	6.08	11.00	17.00	4.32	25.98	74.88	79.86	9.70
T ₆ -RD NPK + FYM + PSB + VAM	54.30	40.35	106.08	25.17	11.16	15.20	31.84	6.72	39.62	98.34	92.06	21.06
T ₇ -50 % P + RD NK + FYM	33.75	21.51	80.40	15.36	7.24	8.12	14.32	3.40	25.38	48.54	60.36	6.72
T ₈ -0 % P + RD NK + FYM	25.89	28.83	41.52	11.67	6.16	9.68	12.28	2.84	18.52	54.52	46.46	5.12
T ₉ -50 % P + PSB + RD NK + FYM	38.34	27.90	83.19	18.00	8.48	11.52	18.36	3.52	27.96	76.88	79.18	8.78
T ₁₀ -0 % P + PSB + RD NK + FYM	48.99	28.17	67.20	15.60	7.40	14.56	12.12	3.52	25.34	66.76	49.72	7.84
T ₁₁ -50 % P + VAM + RD NK + FYM	35.70	28.98	87.21	14.22	7.76	10.40	12.60	5.44	30.38	70.42	56.38	11.84
T ₁₂ -0 % P + VAM + RD NK + FYM	33.81	28.77	81.75	11.61	7.28	10.16	21.56	4.08	29.66	69.58	82.68	10.08
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	55.20	36.60	101.97	23.55	11.04	14.84	24.40	5.92	36.16	87.30	85.26	20.46
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	36.45	29.49	93.39	21.00	9.12	10.40	17.96	3.64	33.20	83.10	59.50	15.44
SEm±	2.10	1.29	6.90	1.05	0.52	0.64	1.96	0.28	1.70	3.00	5.14	0.92
CD (P = 0.05 %)	8.04	4.89	20.52	4.05	2.00	2.48	6.64	1.12	6.50	11.48	19.60	3.54

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

fertilizer inoculation and phosphorus fertilization on N and P uptake. The practice of seed inoculation with phosphorus solubilizing bacteria showed a significant increase in N and P uptake over uninoculated treatment. Phosphorus application also resulted in significant increase of N and P uptake in seed and straw. NPK alone showed higher nutrient uptake compare to FYM alone may due to the high availability of these nutrients from NPK fertilizer. Total P uptake by maize increased with increasing level of inorganic P in soils compared to organic manure (Garg and Bahl, 2008). Phosphorus and biofertilizers application significantly influenced the P uptake of crop. Seed inoculation with Rhizobium and phosphobacteria was significantly superior over no inoculation or phosphobacteria inoculation alone. Combined application of P at 26.2 kg ha⁻¹ and bio-fertilizers (Rhizobium and phosphobacteria) enhanced significantly P uptake compared to other levels of P with biofertilizer (Dutta and Bandyopadhyay, 2009).

4.3.4.2 Secondary nutrients uptake by different parts of maize at harvest

The data on secondary nutrients uptake by leaves, stover, grains and roots in maize soil significantly differed among treatments as represented in (Table 46).

Higher uptake of sulphur by leaves, stover, grain and root of maize plant were recorded in treatment T₆ receiving RD NPK + FYM + PSB + VAM (13.85, 15.57, 37.50 and 11.78 kg ha⁻¹ respectively). However, lower uptake of sulphur (6.71, 2.75, 6.97 and 2.84 kg ha⁻¹, respectively) was recorded in T₂ (FYM @ 10 t ha⁻¹).

The uptake of calcium by maize leaves, stover, grain and roots at harvest significantly differed in all the treatments compared to T₂ received FYM @ 10 t ha⁻¹ Table 46. Significantly higher Ca uptake was recorded in treatments T₆ (38.58, 31.59, 20.04 and 11.58 kg ha⁻¹ respectively) followed by T₁₃ (28.02, 32.61, 19.62 and 8.43 kg ha⁻¹ respectively). Significantly lower (11.76, 8.58, 9.27 and 2.43 kg ha⁻¹) calcium uptake was recorded in the treatments T₁ respectively.

Magnesium uptake by leaves, stover, grain and root also varied significantly among the treatments. Significantly higher values for Mg uptake was found in treatment T₆ (RD NPK + FYM + PSB + VAM) by leaves, stover, grain and root (20.40, 28.83, 12.10 and 33.03 kg ha⁻¹ respectively) which is on par with T₁₃ - 50 % P + PSB + VAM + RD NK + FYM (20.15, 27.75, 11.90 and 28.05 kg ha⁻¹ respectively). Lower values for Mg uptake were recorded in treatment T₁ -RD NPK @ 150: 75: 40 kg ha⁻¹ (11.70, 11.68, 3.88 and 7.98 kg ha⁻¹ respectively) (Table 46).

Table 46: Influence of phosphorus, PSB and VAM application on secondary nutrients uptake by maize crop (kg ha⁻¹) at harvest in low available phosphorus soil

Treatments	S (kg ha ⁻¹)				Ca (kg ha ⁻¹)				Mg (kg ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	7.31	6.54	13.24	4.47	11.76	8.58	9.27	2.43	11.70	11.68	3.88	7.98
T ₂ -FYM (10 t ha ⁻¹)	6.71	2.75	6.97	2.84	15.75	17.85	9.36	2.67	15.45	17.08	3.95	8.18
T ₃ -RD NPK + FYM	13.16	13.07	25.46	9.63	22.83	21.03	18.54	5.43	12.85	17.65	7.28	17.43
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	11.18	9.72	14.02	10.23	20.46	18.03	12.21	6.42	17.33	23.90	9.55	18.73
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	8.60	7.57	18.58	7.22	20.16	19.62	10.95	5.79	18.63	27.13	5.53	17.45
T ₆ -RD NPK + FYM + PSB + VAM	13.85	15.57	37.50	11.78	38.58	31.59	20.04	11.58	20.40	28.83	12.10	33.03
T ₇ -50 % P + RD NK + FYM	12.73	11.52	20.21	6.36	23.58	17.94	10.74	4.35	17.65	19.93	5.15	12.58
T ₈ -0 % P + RD NK + FYM	10.41	9.63	19.01	4.82	20.34	28.92	11.04	4.17	15.25	16.98	7.43	11.83
T ₉ -50 % P + PSB + RD NK + FYM	10.49	11.01	21.24	6.88	25.26	25.44	14.70	5.43	19.48	22.95	4.95	16.33
T ₁₀ -0 % P + PSB + RD NK + FYM	12.38	11.27	12.99	5.68	22.59	24.69	11.34	6.27	19.63	24.85	5.55	16.88
T ₁₁ -50 % P + VAM + RD NK + FYM	13.42	13.85	28.55	8.43	23.67	19.05	16.14	9.45	16.63	18.78	5.80	20.18
T ₁₂ -0 % P + VAM + RD NK + FYM	13.33	11.61	16.94	6.88	25.74	21.30	18.48	6.57	14.33	14.20	3.80	19.95
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	12.38	15.82	32.42	11.44	28.02	32.61	19.62	8.43	20.15	27.75	11.90	31.95
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	12.90	12.13	18.75	10.92	25.23	22.56	15.63	8.01	17.00	24.85	11.90	28.05
SEm±	0.77	0.77	1.12	0.69	1.11	1.02	0.90	0.42	1.05	1.20	0.43	1.68
CD (P = 0.05 %)	2.92	2.84	4.39	2.49	4.29	3.87	3.45	1.65	4.03	4.58	1.63	6.35

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.3.4.3 Micronutrients uptake by different parts by maize at harvest

Results pertaining to the micronutrients uptake (mg kg^{-1}) by maize at tasseling stage in pot culture experiment with phosphorus deficient soil are presented in Tables 47 and 48.

Iron uptake of cowpea leaves, stover, grain and root was significantly higher in treatment T_6 (657.72, 617.76, 667.56 and 475.32 g ha^{-1} respectively). Lower iron uptake was observed in T_1 (277.08, 78.84, 231.24 and 123.84 g ha^{-1}). Among the treatment the iron uptake was more in inoculated treatment compared to uninoculated treatments.

PSB, AMF, FYM, 50 % P or full dose P and NK fertilizer showed significant differences with respect to Mn uptake of maize crop. The Mn uptake in maize leaves, stover, grain and root increased significantly in the treatments T_6 (304.29, 112.98, 141.54, and 209.16 g ha^{-1} respectively). Lower Mn uptake by leaves, haulm, grain and root were recorded in T_1 (115.92, 37.38, 46.83 and 22.68 g ha^{-1} respectively). Among the different parts of cowpea roots showed lower uptake of Mn compared to leaves, grain and stover.

Uptake of zinc by maize leaves, stover, grain and root was significantly higher in most of the treatments with combined inoculation compared to single and uninoculated treatment. T_{13} (50 per cent P + RD NK + FYM + PSB + VAM) showed significantly higher uptake of zinc by leaves, stover, grain and root (110.50, 193.00, 232.50 and 107.00 g ha^{-1} respectively). Significantly lower uptake of zinc by leaves, haulm, grain and root was recorded in T_1 (53.00, 47.50, 75.00 and 15.50 g ha^{-1} respectively).

The uptake of Cu by maize leaves, stover, grain and roots at harvest differed significantly in all the treatments compared to T_1 received NPK alone. The leaves, haulm, grain and root Cu uptake was significantly higher in treatments T_{13} (32.50, 23.50, 34.00 and 45.00 g ha^{-1} respectively) lower Cu uptake was recorded in T_1 (11.00, 10.00, 25.50 and 13.00 g ha^{-1} respectively).

The micronutrients uptake was higher in case of dual inoculated treatments compared to single inoculated treatment, single inoculated treatments showed higher nutrient uptake compare to uninoculated treatments this may be due to the high solubility of micronutrient in soil through acid production which leads to higher uptake of these nutrients by plant. Gupta *et al.* (2006) noticed that the effect of bio-fertilizer inoculation and phosphorus fertilization on micronutrient uptake. The practice of seed inoculation with phosphorus solubilising bacteria showed a significant increase in Fe, Cu, Mn and Zn uptake over uninoculated treatment. Phosphorus application also resulted in significant increase of N and P uptake in seed and straw. These findings are in accordance with those of Das *et al.* (2007) who reported that the PSB and VAM with NK and FYM increased the micronutrient uptake by crop.

Table 47: Influence of phosphorus, PSB and VAM application on Fe and Mn uptake (g ha⁻¹) by maize crop at harvest in low available phosphorus soil

Treatments	Fe (g ha ⁻¹)				Mn (g ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	277.08	78.84	231.24	123.84	115.92	37.38	46.83	22.68
T ₂ -FYM (10 t ha ⁻¹)	396.12	170.04	267.24	130.80	156.87	50.40	53.97	32.34
T ₃ -RD NPK + FYM	531.00	275.88	546.00	267.72	233.94	58.80	119.49	110.25
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	380.76	345.84	448.08	318.84	187.53	74.55	107.52	156.66
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	454.08	577.56	430.80	236.16	175.56	81.69	101.85	123.90
T ₆ -RD NPK + FYM + PSB + VAM	657.72	617.76	667.56	475.32	304.29	112.98	141.54	209.16
T ₇ -50 % P + RD NK + FYM	442.08	295.32	426.60	202.44	254.52	61.53	70.77	107.94
T ₈ -0 % P + RD NK + FYM	409.20	279.84	382.44	191.64	202.44	58.38	72.24	86.31
T ₉ -50 % P + PSB + RD NK + FYM	590.28	420.24	527.16	250.80	224.07	77.49	91.77	104.58
T ₁₀ -0 % P + PSB + RD NK + FYM	527.16	261.24	390.24	203.04	216.93	47.67	66.15	95.76
T ₁₁ -50 % P + VAM + RD NK + FYM	502.68	250.80	486.48	328.92	223.44	45.15	91.98	154.77
T ₁₂ -0 % P + VAM + RD NK + FYM	502.20	436.44	435.48	257.28	201.18	71.19	88.62	116.13
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	651.48	601.68	664.80	450.12	270.27	90.51	129.99	162.12
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	451.92	355.56	490.32	276.60	230.37	75.18	128.94	189.84
SEm±	29.88	22.08	28.32	18.24	12.18	4.83	5.25	8.61
CD (P = 0.05 %)	114.12	84.36	107.88	69.48	46.20	18.27	19.74	32.55

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Table 48: Influence of phosphorus, PSB and VAM application on Zn and Cu uptake (g ha⁻¹) by maize crop at harvest in low available phosphorus soil

Treatments	Zn (g ha ⁻¹)				Cu (g ha ⁻¹)			
	Leaves	Stover	Grain	Roots	Leaves	Stover	Grain	Roots
T₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	53.00	47.50	75.00	15.50	11.00	10.00	25.50	13.00
T₂ -FYM (10 t ha ⁻¹)	70.50	84.00	112.00	18.50	24.50	19.50	22.00	14.00
T₃ -RD NPK + FYM	102.00	118.50	187.00	54.00	19.50	22.50	23.00	29.50
T₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	88.50	129.50	178.50	103.00	22.00	20.50	36.00	44.50
T₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	84.00	141.00	195.50	64.00	28.00	23.50	26.50	29.50
T₆ -RD NPK + FYM + PSB + VAM	104.00	142.50	207.50	105.00	29.00	18.00	43.50	43.00
T₇ -50 % P + RD NK + FYM	104.00	115.50	181.50	49.00	14.50	16.00	20.50	26.00
T₈ -0 % P + RD NK + FYM	80.50	113.00	195.00	37.50	13.50	14.50	20.00	22.00
T₉ -50 % P + PSB + RD NK + FYM	109.50	143.00	194.50	41.50	19.50	22.00	29.50	37.50
T₁₀ -0 % P + PSB + RD NK + FYM	99.00	120.00	123.00	41.00	21.50	19.50	25.50	26.00
T₁₁ -50 % P + VAM + RD NK + FYM	86.00	113.00	144.50	65.00	18.00	16.00	24.50	29.50
T₁₂ -0 % P + VAM + RD NK + FYM	100.00	94.00	208.50	53.00	15.00	15.50	35.00	37.50
T₁₃ -50 % P + PSB + VAM + RD NK + FYM	110.50	193.00	232.50	107.00	32.50	23.50	34.00	45.00
T₁₄ -0 % P + PSB + VAM + RD NK + FYM	76.00	190.50	231.50	79.00	24.00	22.00	30.50	36.00
SEm±	5.00	7.50	10.00	4.50	2.00	2.00	3.00	2.50
CD (P = 0.05 %)	19.00	29.00	38.00	16.50	8.50	7.00	11.00	10.50

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

4.3.5 Correlation coefficient between available P, nitrogen, potassium, fractions of soil P with yield of maize grain

The correlation coefficient of available P with pH, nitrogen, potassium, fractions of P with yield of maize grain in pot culture soil are presented in Table 49. The data showed that the yield of maize positively and significantly correlated with available PNK (0.891**, 0.741**, 0.555**), saloid- P (0.802**) and Ca-P (0.589*). The available nitrogen has positively and significantly correlated with available P (0.718*), saloid P (0.745**) and Ca-P (0.692*).

Available P was positively and significantly correlated with available K (0.621*) saloid P (0.601*) and organic P (0.475). Saloid P was significantly positively correlated with Ca-P (0.763**). Al-P was significantly and positively correlated with organic, Fe, occluded and Reductant P (0.855**, 0.802**, 0.612* and 0.574* respectively).

Fe-P was positively and significantly correlated with reductant, occluded and organic P (0.811**, 0.790** and 0.711**). The reductant P positively significantly correlated with occluded and organic P (0.713** and 0.585**). Occluded P was significantly positively correlated with organic P (0.919** and 0.668**). Occluded P was significantly positively correlated with organic P (0.593*). There was positive correlation between Ca-P and organic P.

4.4 Pot experiment: Studies on the residual effect of different levels of phosphorus, phosphorus solubilizers with FYM to soil low in available P and high total phosphorus on performance of residual cowpea in maize - cowpea cropping system

4.4.1 Residual effect of PSB, VAM, FYM and chemical fertilizers on soil properties during cowpea growth in low available P with low total P soil

4.4.1.1 Soil pH, EC, NPK and S in low available P

Effect of phosphorus application, PSB and VAM inoculation on soil properties (pH, EC, available NPK and S) at different stages of cowpea grown as a residual crop (plate 9 and 10) under low available P soil is presented in Table 50. At 60 days there was no significant difference observed among the treatments however higher pH was noticed in T₄ (6.47) and lower pH was observed in T₁₃ (6.30). After the harvest significantly higher soil pH was noticed in T₁₄ followed by T₂, T₁₂, T₅ and T₆ (6.60, 6.59, 6.58 and 6.51 respectively). However, lower soil pH observed in T₁₁ (5.89). There was a slight increase in soil pH after the crop harvest, compared to the initial status.

Electrical conductivity exhibited non significant result at 60 DAS. However after the harvest there was a significant difference observed among the treatments, higher EC was recorded in T₉ treatment (0.349 ds m⁻¹) followed by T₁₁ and T₁₂ (0.326 and 0.325 respectively) whereas treatment T₇ recorded lower soluble salts content (0.160 ds m⁻¹).

Table 49: Correlation between soil phosphorus, nitrogen, potassium, different fractions of phosphorus and yield of maize crop in low available and high total phosphorus soil

	yield q ha ⁻¹	pH	Avail. - N	Avail. - P	Avail. - K	Saloid – P	Al - P	Fe - P	Reductant - P	Occluded - P	Ca - P	Organic -P
Yield q ha⁻¹	1											
pH	-0.214	1										
Avail. - N	0.741**	-0.387	1									
Avail. -P	0.891**	-0.318	0.718**	1								
Avail. - K	0.555*	-0.665**	0.500	0.621*	1							
Saloid - P	0.802**	-0.200	0.745**	0.601*	0.186	1						
Al - P	0.347	0.279	0.404	0.035	-0.048	0.521	1					
Fe - P	.037	0.191	0.319	-0.169	-0.110	0.288	0.802**	1				
Reductant - P	-0.279	0.417	-0.051	-0.370	-0.405	-0.051	0.574*	0.811**	1			
Occluded - P	-0.178	0.320	-0.042	-0.293	-0.359	0.054	0.612*	0.790**	0.919**	1		
Ca - P	0.589*	-0.409	0.692**	0.491	0.297	0.763**	0.325	0.293	0.166	0.151	1	
Organic - P	0.140	0.404	0.367	-0.026	-0.279	0.352	0.855**	0.711**	0.668**	0.593*	0.236	1

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

Table 50: Residual effect of P, PSB and VAM on soil pH, EC, nutrient status after 60 days of sowing and at harvest of cowpea in soil with low available phosphorus

Treatments	pH		EC dSm ⁻¹		Available N		Available P ₂ O ₅		Available K ₂ O		Available S (mg kg ⁻¹)	
					kg ha ⁻¹							
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	6.34	6.03	0.30	0.185	132.21	130.34	23.10	14.38	221.05	205.75	13.64	10.75
T ₂	6.46	6.59	0.33	0.170	164.58	143.51	23.93	22.92	225.35	194.25	15.02	13.75
T ₃	6.44	6.05	0.35	0.165	169.85	145.52	32.25	25.49	249.56	237.25	15.21	13.89
T ₄	6.47	5.94	0.31	0.143	163.57	160.18	29.45	26.41	258.23	238.07	14.50	14.30
T ₅	6.36	6.54	0.33	0.162	170.85	155.43	31.45	24.52	255.34	241.61	14.44	14.21
T ₆	6.37	6.51	0.30	0.220	159.81	149.91	33.04	29.64	273.68	245.89	15.14	14.74
T ₇	6.44	6.47	0.32	0.160	171.85	127.61	19.15	18.06	257.54	228.12	20.61	16.67
T ₈	6.44	6.05	0.32	0.205	160.56	154.91	17.85	14.74	281.77	244.85	15.96	14.65
T ₉	6.39	5.99	0.30	0.349	163.57	151.66	17.80	14.46	246.50	229.28	17.90	14.34
T ₁₀	6.41	6.10	0.30	0.312	160.31	166.93	24.64	15.45	256.57	220.46	15.00	11.11
T ₁₁	6.38	5.89	0.31	0.326	172.35	148.77	25.40	15.09	228.99	215.50	17.60	13.00
T ₁₂	6.42	6.58	0.31	0.325	152.28	161.42	22.25	15.76	269.40	239.96	16.70	12.34
T ₁₃	6.30	6.54	0.31	0.265	166.84	156.29	21.75	19.54	260.96	251.17	15.31	13.79
T ₁₄	6.35	6.60	0.31	0.298	163.82	143.76	22.41	18.61	252.63	240.57	16.83	11.62
Initial	5.80		0.09		201.32		20.81		308.33		21.45	
SEm±	0.10	0.12	0.01	0.01	2.66	4.98	0.51	1.15	2.99	4.86	0.92	1.08
CD (P = 0.05 %)	NS	0.44	NS	0.03	10.15	19.02	1.96	4.38	9.05	15.02	2.76	4.13

T₁-RD NPK (150: 75: 40 kg ha⁻¹), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.



Plate 9. Cowpea in pot experiment at 20 days after sowing



Plate 10. Cowpea in pot culture experiment at maturity stage

Available nitrogen content of soil at 60 DAS was significantly higher in 50 per cent P + Mycorrhiza + RD NK & FYM (T_{11} : 172.35 kg ha⁻¹) followed by T_7 (50 % P₂O₅ + RD NK & FYM) (171.85 and 170.85 kg ha⁻¹ respectively) and were superior over rest of the treatments. Lower available N was observed in T_1 : 132.21 kg ha⁻¹. At harvest of cowpea significantly higher available N was recorded in T_{10} (166.93 kg ha⁻¹) which was on par with T_{12} , T_4 , T_5 , T_{13} , T_8 , T_9 and T_6 (161.42, 160.18, 156.29, 155.43, 154.91, 151.66 and 149.91 kg ha⁻¹ respectively) whereas T_7 (127.61 kg ha⁻¹) recorded lower available N content.

Application of T_6 (RD NPK+FYM+PSB+Mycorrhiza) recorded significantly higher available P₂O₅ (36.04 kg ha⁻¹) followed by T_3 and T_5 (32.25 and 31.45 kg ha⁻¹) at 60 DAS and it was superior over rest of the treatments however, lower P status was observed in RD NPK (T_1 : 23.10 kg ha⁻¹). At harvest treatment T_6 (29.64 kg ha⁻¹) recorded significantly higher available P status compared to all other treatments, whereas T_1 recorded lower P status (14.38 kg ha⁻¹). When compared to initial value the P status of soil was increased in all the treatments.

Significantly higher available K at 60 DAS was recorded in (T_8) 0 % P + Rec NK & FYM (281.77 kg ha⁻¹) followed by T_6 (273.68 kg ha⁻¹) and the lower available K was recorded in T_1 (221.05 kg ha⁻¹). At harvest higher available K was noticed in T_{13} (50 % P+PSB+Mycorrhiza+Rec NK&FYM) 251.17 kg ha⁻¹ followed by T_6 , T_8 , T_5 , T_{14} and T_{12} (245.89, 244.85, 241.61, 240.57 and 239.96 kg ha⁻¹ respectively). Treatment T_2 (FYM alone) recorded lower K status (194.25 kg ha⁻¹). Potassium content decreased in all the treatments compared to initial (308.33 kg ha⁻¹).

Significantly lower available S at 60 DAS and at harvest was recorded in T_1 (13.64 and 10.75 mg kg⁻¹ respectively). At 60 DAS higher available S was observed in T_7 (20.61 mg kg⁻¹) followed by T_9 (17.90 mg kg⁻¹). Whereas at harvest T_7 recorded significantly higher available sulphur (16.67 mg kg⁻¹). Lower was recorded in T_1 (10.75 mg kg⁻¹).

Inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant N, P and K content. The similar results were obtained by Wu *et al.* 2005 who reported that higher N, P and K concentration in plants on combined inoculation with rhizobacteria and *G. intraradices*. The lower N, P and K uptake was detected in plants grown in uninoculated and unfertilized pots. Either single treatment of chemical or organic fertilization resulted decreased N, P and K concentration. The maximum P and K assimilation were obtained with the dual inoculation of *G. mosseae* and rhizobacteria. Fertilizer applications with compost showed high nutrient content compared to NPK or FYM alone. This supports the findings of Adediran *et al.* (2004) who observed the increase in plant nutrients concentration amended with inorganic fertilizer and compost. Application of vermicompost improved the overall physico-chemical environment of the soil, which caused the improvement in growth and yield attributes, yield, N and P content of chickpea (Jat and Ahlawat, 2006). Mahala *et al.* (2004) reported that the residual effect of P sources was found equally effective in improving nutrient uptake of mustard. Residual effect of URP+PSB recorded

the higher available P in the soil after mustard harvest. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the nutrient uptake of mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop.

4.4.1.2 Ca, Mg and DTPA extractable micronutrients content of low available P soil

Effect of phosphorus and phosphorus inoculants application on soil Ca, Mg and micronutrients content at 60 DAS and at harvest of cowpea is given in Table 51. At 60 DAS T₅ (RD NPK+FYM+Mycorrhiza) recorded significantly higher exchangeable Ca content (3.54 m eq /100 g soil) followed by T₁₀ (0 % P+PSB+RD NK & FYM), T₁ (RD NPK) and T₄ (RD NPK+FYM+PSB@4 kg/ha) and T₁₃ (50 % P + PSB + VAM + RD NK + FYM) (3.52, 3.52, 3.47 and 3.47 m eq/100 soil). Lower Ca content was recorded in T₁₂ (0 % P+Mycorrhiza+RD NK& FYM). Similar trend of result was observed at harvest of the crop.

Exchangeable Mg content of soil differed significantly at both the crop stages, significant higher Mg content was recorded in T₁₄ (2.68 m eq/100g soil) at 60 DAS which was superior over all the other treatments and lower Mg of 1.19 meq/100 g soil was observed in T₁. At harvest T₅ (50 % P+RD NK&FYM) recorded significantly higher Mg content (2.02 meq/100g soil) over all other treatments and T₁ recorded the lower Mg value (1.05 meq/100 g soil).

Significant difference was noticed among the treatments with respect to micronutrients content in soil due to application of FYM, nutrients and microbial inoculants of phosphorus. At 60 DAS T₄ recorded significantly higher Fe content (19.80 mg kg⁻¹) followed by T₇ (20.92 mg kg⁻¹) and were superior over rest of the treatments. Lower Fe content of 11.60 and 9.90 mg/kg were recorded in T₁ (Redc. NPK) at 60 days after sowing and at harvest respectively. At harvest treatment T₄ was on par with T₇ and T₁₁ (19.80, 18.81 and 18.81 mg kg⁻¹ respectively).

Higher Mn content (8.42 mg kg⁻¹) of soil at 60 DAS was recorded in T₃ followed by T₂ and T₄ (8.42, 8.39 and 8.27 mg kg⁻¹ respectively) which were significantly superior to all other treatments, whereas lower Mn content was noticed in T₁₀ (5.98 mg kg⁻¹). At harvest of cowpea T₆ (RD NPK+FYM+PSB+Mycorrhiza) 9.24 mg kg⁻¹ recorded significantly higher manganese content and was on par with T₄ and T₁₁ (9.00 and 8.23 mg kg⁻¹). Treatment which received T₈ (0 % P + RD NK & FYM) recorded lower Mn content (4.88 mg kg⁻¹).

DTPA Zn content of soil differed significantly due to treatments. However higher Zn content of 4.15 mg kg⁻¹ in soil was recorded on application of 50 % P +PSB + Mycorrhiza +RD NK & FYM (T₉) and was found superior compared to rest of the treatments. At harvest treatment which received T₆ (RD NPK+FYM+PSB+Mycorrhiza) 2.95 mg kg⁻¹ recorded significantly higher Zn content which was on par with T₁₁ (50 % P+Mycorrhiza+Rec NK & FYM, 2.87 mg kg⁻¹) and superior over all other treatments. Lower Zn content of 1.81 and 0.99 mg kg⁻¹ was recorded in T₁ at 60 DAS and at harvest respectively.

Table 51: Residual effect of P, PSB and VAM on soil Ca, Mg and micronutrients status after 60 days of sowing and at harvest of cowpea in soil with low available phosphorus

Treatments	Exchangeable Ca		Exchangeable Mg		Fe		Mn		Zn		Cu	
	m.eq (100 g soil) ⁻¹				DTPA micronutrients (mg kg ⁻¹)							
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁	3.52	2.50	1.19	1.05	11.60	9.90	6.90	5.73	1.81	0.99	0.59	0.73
T ₂	3.35	2.38	1.77	1.69	19.51	16.83	8.39	6.22	2.65	1.07	0.62	0.54
T ₃	2.60	1.85	1.96	1.20	19.69	14.85	8.42	7.94	2.91	0.94	0.79	0.87
T ₄	3.47	2.47	2.24	1.45	21.14	19.80	8.27	9.00	3.69	2.37	0.67	0.74
T ₅	3.54	2.51	2.09	2.02	19.11	16.83	6.81	7.44	3.14	1.21	0.73	0.83
T ₆	2.78	1.97	2.05	1.32	20.10	15.84	6.81	9.24	2.94	2.95	0.67	0.77
T ₇	3.42	2.43	1.75	1.46	20.24	18.81	7.22	5.14	3.62	2.25	0.95	0.80
T ₈	3.26	2.31	2.24	1.47	18.23	15.84	7.44	4.88	3.66	2.54	0.92	0.80
T ₉	3.45	2.45	2.21	1.38	20.92	14.85	7.42	7.10	4.15	2.01	0.78	0.82
T ₁₀	3.52	2.50	1.80	1.39	17.76	15.84	5.98	7.73	2.91	1.65	0.63	0.74
T ₁₁	3.35	2.38	2.30	1.14	20.14	18.81	7.07	8.23	3.11	2.87	0.73	0.66
T ₁₂	2.60	1.85	2.30	1.29	19.65	15.84	6.50	6.48	2.90	2.35	0.73	0.66
T ₁₃	3.47	2.47	2.06	1.75	19.97	14.85	6.61	7.73	2.76	2.03	0.67	0.61
T ₁₄	3.54	2.51	2.68	1.93	18.85	15.84	7.18	6.73	2.43	2.24	0.62	0.56
Initial	3.81		2.70		38.31		25.46		1.93		1.20	
SEm±	0.07	0.32	0.05	0.23	0.31	1.46	0.23	2.40	0.10	0.17	0.04	0.04
CD at (P = 0.05 %)	0.27	1.22	0.18	0.06	1.17	5.58	0.87	0.78	0.38	0.66	0.14	0.15

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P + RD NK & FYM, T₈-0 % P + RD NK & FYM, T₉-50 % P + PSB + RD NK & FYM, T₁₀-0 % P + PSB + RD NK & FYM, T₁₁-50 % P + Mycorrhiza + RD NK & FYM, T₁₂-0 % P + Mycorrhiza + RD NK & FYM, T₁₃-50 % P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P + PSB + Mycorrhiza + RD NK & FYM.

Significantly higher Cu content of 0.95 mg/kg was noticed on application of 50 % P +RD NK & FYM (T₇) followed by T₈ (0 % P +RD NK & FYM) 0.92 mg kg⁻¹ and were superior compared to all other treatments. At 60 DAS T₁ recorded lower Cu content (0.59 mg kg⁻¹) whereas at harvest T₂ recorded lower value (0.54 mg kg⁻¹). All treatments did not differ significantly at harvest of cowpea except T₃ (0.87 mg kg⁻¹) which was superior compared to all the treatments.

Residual effect of P sources was found equally effective in improving the nutrient uptake by mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop (Mahala *et al.* 2004).

4.4.1.3 Nutrient ratios and phosphatase enzyme activity in soil of low available P

Data pertaining to the changes in soil nutrients ratios and phosphatase activity at tasseling stages and after the harvest of cowpea grown as a residual crop on soil with low available P applied PSB, VAM and with graded levels of phosphorus is provided in Table 52. There was significant difference among treatment. The nutrient ratios compared to initial value was decreased in all the treatments.

The ratio of N:P in soil decreased significantly in all the treatments compared to initial (38.74). The highest ratio of N:P in soil at 60 DAS of cowpea (12.45) was recorded in T₁₂ (0 % P + VAM + RD NK + FYM) but at harvest it was higher (13.06) in T₁₀. The lower N:P ratio at 60 DAS was recorded in T₄ (7.23) but after harvest of cowpea the N:P ratio (7.23) was lower in T₃ compared to other treatment.

The ratio of P:K in soil where was cowpea grown, increased in all the treatments compared initial (0.02). The highest ratio of P:K in soil of cowpea at 60 DAS was in T₆ (0.10) and T₁₀ (0.10) but in case of harvest T₃ (0.10) showed higher P:K ratio. The lowest ratio of P:K at 60 DAS was recorded in (T₈): 0.06 but after harvest of cowpea the P:K was significantly lower in T₁: 0.05 (Table 52).

P:S ratio in soil after harvest of cowpea had increased in all the treatments compared to initial value (0.11). The highest P:S ratio in cowpea soil at 60 DAS and at harvest (0.65 and 0.52) and (0.57 and 0.51) were recorded in T₆ (RD N P K + PSB + VAM + FYM) and T₁₀ (0 % P + PSB + RD NK + FYM). Lowest P:S ratio was recorded in T₉ at 60 DAS and at harvest of cowpea in low P soil (0.35 and 0.22).

There was significant differences in P:Ca ratio among the treatments. T₆ (RD NPK + FYM + PSB + Mycorrhiza) increased P:Ca significantly at 60 DAS of cowpea (0.018) on par with 0 % P + Mycorrhiza + RD NK & FYM (T₁₂) 0.015. Lower P:Ca ratio 0.008 recorded in T₁ received RD NPK (150: 75: 40 kg ha⁻¹). Among the treatment significantly higher P:Ca at harvest of cowpea was noticed in T₄ (RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹) 0.019 on par with T₃ (0.018), T₇ (0.017) and it was superior over rest of the treatment and T₁ (0.005) (Table 52).

Table 52: Residual effect of P, PSB and VAM on soil nutrient ratios and phosphatase activity after 60 days of sowing and at harvest of cowpea in soil with low available phosphorus

Treatments	N:P		P:K		P:S		P:Ca		P:Zn		Acid phosphatase (μg of PNP released g ⁻¹ soil h ⁻¹)	
	Nutrient ratios										60 DAS	At harvest
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest		
T ₁	10.36	15.53	0.07	0.05	0.39	0.35	0.008	0.005	3.15	3.79	15.15	12.14
T ₂	12.45	10.72	0.07	0.08	0.39	0.43	0.009	0.012	2.23	5.58	36.88	29.55
T ₃	12.06	7.73	0.07	0.10	0.41	0.47	0.012	0.018	2.16	8.94	17.37	13.92
T ₄	10.05	10.39	0.08	0.08	0.53	0.48	0.010	0.019	1.97	2.90	17.74	14.21
T ₅	9.83	10.86	0.08	0.07	0.54	0.45	0.011	0.013	2.47	5.28	16.41	13.15
T ₆	7.23	8.66	0.10	0.08	0.65	0.52	0.018	0.015	3.36	2.62	22.16	17.76
T ₇	11.46	8.54	0.07	0.08	0.32	0.40	0.010	0.017	1.85	2.96	24.24	19.42
T ₈	11.49	12.71	0.06	0.06	0.39	0.37	0.010	0.011	1.70	2.14	39.63	31.75
T ₉	11.73	12.68	0.07	0.06	0.35	0.22	0.009	0.012	1.50	2.66	31.02	24.85
T ₁₀	8.31	13.06	0.09	0.07	0.57	0.51	0.012	0.012	2.96	3.46	49.37	39.56
T ₁₁	8.67	11.92	0.10	0.07	0.50	0.43	0.013	0.011	2.85	1.94	31.61	25.33
T ₁₂	8.74	12.38	0.08	0.07	0.47	0.47	0.015	0.012	2.68	2.48	41.48	33.24
T ₁₃	9.80	9.67	0.08	0.08	0.50	0.52	0.011	0.020	2.75	3.56	33.72	27.02
T ₁₄	9.34	9.34	0.08	0.08	0.47	0.50	0.011	0.014	3.22	3.07	44.98	36.04
Initial	38.74		0.02		0.11		0.003		1.20		22.19	
SEm±	0.91	1.03	0.008	0.001	0.04	0.12	0.006	0.009	0.93	1.53	6.11	4.90
CD at (P = 0.05 %)	2.71	3.10	0.024	0.003	0.12	0.04	0.002	0.003	0.31	0.51	2.03	1.63

T₁-RD NPK (150: 75: 40 kg ha^{-1}), **T₂**-RD FYM (10 tonne), **T₃**-RD NPK + FYM, **T₄**-RD NPK + FYM + PSB (PSB @ 4 kg ha^{-1}), **T₅**-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha^{-1}), **T₆**-RD NPK + FYM + PSB + Mycorrhiza, **T₇**-50 % P + RD NK & FYM, **T₈**-0 % P + RD NK & FYM, **T₉**-50 % P + PSB + RD NK & FYM, **T₁₀**-0 % P + PSB + RD NK & FYM, **T₁₁**-50 % P + Mycorrhiza + RD NK & FYM, **T₁₂**-0 % P + Mycorrhiza + RD NK & FYM, **T₁₃**-50 % P + PSB + Mycorrhiza + RD NK & FYM, **T₁₄**-0 % P + PSB + Mycorrhiza + RD NK & FYM.

Large difference and increase in P:Zn was observed compared to initial (1.20). There were significant differences 60 DAS and at harvest in cowpea. The values ranged from 8.94 in T₃ at harvest to 1.50 in T₉ at 60 DAS of cowpea. The T₆, T₁₄ and T₁ recorded highest P:Zn ratio (3.35, 3.22 and 3.15) at 60 DAS of cowpea and lowest was recorded in T₉ (1.50). After harvest the P:Zn ratio was significantly higher in T₃, T₂ and T₅ (8.94, 5.58 and 5.28) and lower P:Zn ratio was recorded in T₁₁ (1.94).

At 60 DAS and at harvest of cowpea, higher acid phosphatase activity was recorded in T₁₀ (49.37 and 39.56 μg of PNP g^{-1} soil hr^{-1} respectively) on par with T₁₄ (44.98 and 36.04 μg of p-nitrophenol g^{-1} soil hr^{-1} respectively) and lower was recorded in T₁ (15.15 and 12.14 μg of p-nitrophenol g^{-1} soil hr^{-1} respectively). All the treatments showed higher acid phosphatase activity at 60 DAS of cowpea compared to harvest of cowpea soil (Table 52). Compared to the residual effect of NPK alone the activities of acid phosphatase have increased in treatments which received organic manures and biofertilizers (Table 52). This may be because of application of FYM alone or in combination with inorganic fertilizers which create an ideal condition in the soil for the microorganisms to be active (Halstead and Sowden, 1986). It was also observed by Singaram and Kamalakumari (1995) that the activity of soil enzymes was found to be higher and their effect was pronounced when FYM was applied in combination with chemical fertilizers. Similarly Piotrowska and Wilczewski (2012) reported addition of FYM and biofertilizers increased the acid phosphatase activity compared to NPK alone. Experiments of Yadav and Tarafdar (2001) showed that an organic P concentration of 250 mg L^{-1} and above, and an inorganic P concentration $<50 \text{ mg L}^{-1}$ provided the most suitable conditions for plants to secrete a maximum amount of acid phosphatase.

4.4.1.5 Different P fractions in soil of low available P

Residual effect of application of P combined with its inoculants on various phosphorus fractions after maize – cowpea cropping sequence in low available P soil is given in Table 53.

Among the different fractions of phosphorus saloid – P was significantly high in T₆ (RD NPK + FYM + PSB + VAM) 5.71 mg kg^{-1} followed by T₄ (RD NPK + FYM + PSB) (5.13 mg kg^{-1}) which were superior over all other treatments. However lower saloid-P was noticed in T₂ (FYM alone) (3.26 mg kg^{-1}) and T₈ (0 % P + RD NK + FYM) (3.26 mg kg^{-1}). Data on Al-P reveals that application of T₃ (RD NPK + FYM) 357.05 mg kg^{-1} recorded significantly higher Al-P followed by T₄ (RD NPK + FYM + PSB) and T₅ (RD NPK + FYM + VAM) (343.68 and 338.89 mg kg^{-1} respectively) which were superior over all other treatments with lower Al-P content in T₁₄ (0 % P + PSB + VAM + RD NK + FYM: 265.65 mg kg^{-1}).

The significant difference in Fe-P content of soil was found at harvest of cowpea crop. The maximum increment in Fe-P from 240.01 mg kg^{-1} (initial) was recorded in T₃ (RD NPK + FYM) (298.78 mg kg^{-1}). The minimum was recorded in T₁₄ (0 % P + PSB + VAM + RD NK + FYM) 211.63 mg kg^{-1} .

The results pertaining to reductant soluble P indicated that there were significant differences among the treatments after harvest of cowpea crop. The reductant P ranged from 267.67 mg kg⁻¹ in T₄ to 174.85 mg kg⁻¹ in T₁₄ at harvest of cowpea crop in low P soil (Table 53). Treatment T₄ varied significantly compared to the rest of the treatments. The lower reductant soluble P was recorded in T₁₄ (174.85 mg kg⁻¹) higher reductant P in T₄ (267.67 mg kg⁻¹). However, in all the treatments the RS-P values increased than initial.

After harvest of cowpea, the Occl-P fractions of soil varied from 147.20 mg kg⁻¹ in T₃ to 85.05 mg kg⁻¹ in T₁₄ (Table 53). Significantly higher value was recorded in T₃ which was followed by T₁ (134.77 mg kg⁻¹). The lower values of Occl-P was recorded in T₁₄. Among the treatment single and dual inoculated treatment with PSB and VAM with half or without P fertilizer recorded lower Occl-P compared to other treatment without P solublizers except T₂.

Results pertaining to the contents of Ca-P in the soil after harvest of maize crop low in P are presented in the Table 53. The Ca-P content decreased in all the treatment compared to initial (38.70 mg kg⁻¹). Higher Ca-P was recorded in T₆ (5.77) which is on par with T₃, T₁₄, T₁₃ and T₉ (5.61, 5.54, 5.48 and 5.18 mg kg⁻¹). Lower value of Ca-P was recorded in T₂ and the value was 4.24 mg kg⁻¹.

The difference in Organic-P content of same treatments combinations varied widely higher from dual and single inoculation with 50 % or without P fertilizer but it was comparatively decline in all treatments from initial (114.87 mg kg⁻¹). The maximum decrease in organic-P was recorded in T₁ (43.48 mg kg⁻¹) the maximum increase was recorded in T₃ (66.59 mg kg⁻¹). Microorganism plays a major role in organic P solubility. Microbial production of organic acids and acid phosphatase has important role in mineralizing organic P present in soil (Hussain *et al.* 2013).

From the data it was clear that total P content of soil has decreased in all the treatments except T₃ RD NPK + FYM compared to initial (1185.05 mg kg⁻¹). Among the treatment T₃ (1175.66 mg kg⁻¹) was found to be superior to other treatments. In general the total P content has decreased drastically in treatments without P fertilizer + NK fertilizer + organic matter + biofertilizer treatments compared to treatments containing full dose of P fertilizer +NK+ organic matter + biofertilizers (Table 53). The high total P content of the soils may be attributed to higher oxides of iron and aluminium, continuous addition of water soluble inorganic P fertilizers and low pH and under high P condition the activity of PS decreased which lead to low solubilization of total phosphorus to the soil solution for plant growth.

Shi *et al.* (2015) demonstrated that P in cultivated soils changed during winter as a result of changes in labile P fractions possibly due to the solubilization of residual fertilizer P combined with environmental factors.

Table 53: Residual effect of phosphorus, PSB and VAM on different fractions of phosphorus (mg kg⁻¹) in cowpea at harvest low available phosphorus soil

Treatments	Different fractions of P (mg kg ⁻¹) in soil							
	Sal – P	Al –P	Fe –P	Red –P	Occl-P	Ca –P	Organic P	Total P
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	4.24	306.35	250.36	218.02	134.77	4.79	43.48	962.01
T ₂ -FYM (10 t ha ⁻¹)	3.26	271.36	219.11	196.43	94.86	4.24	49.78	839.04
T ₃ -RD NPK + FYM	4.76	357.05	298.78	267.67	147.20	5.61	66.59	1147.66
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	5.13	343.68	248.98	202.91	117.76	4.86	60.23	983.55
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	5.01	338.89	241.51	200.75	111.22	4.89	58.99	961.26
T ₆ -RD NPK + FYM + PSB + VAM	5.71	325.63	231.55	196.43	107.95	5.77	56.79	929.83
T ₇ -50 % P + RD NK + FYM	3.65	311.35	234.05	237.45	130.85	5.05	55.38	977.78
T ₈ -0 % P + RD NK + FYM	3.26	274.22	224.09	205.07	117.76	4.33	50.58	879.31
T ₉ -50 % P + PSB + RD NK + FYM	4.40	328.49	244.00	194.27	107.95	5.18	58.17	942.46
T ₁₀ -0 % P + PSB + RD NK + FYM	3.85	299.92	229.07	185.64	94.86	4.76	53.74	871.84
T ₁₁ -50 % P + VAM + RD NK + FYM	4.56	308.49	248.98	200.75	111.22	5.05	56.67	935.72
T ₁₂ -0 % P + VAM + RD NK + FYM	4.19	288.50	226.57	183.48	88.32	4.66	52.36	848.08
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	4.84	271.36	224.09	189.96	104.68	5.48	50.51	850.92
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	4.72	265.65	211.63	174.85	85.05	5.54	48.68	796.12
Initial	19.80	443.77	331.24	240.01	181.52	38.70	114.87	1185.03
SEm±	0.20	7.74	7.72	3.24	3.93	0.20	1.58	27.35
CD (P = 0.05 %)	0.59	22.57	22.16	9.72	11.45	0.59	4.58	79.64

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

A linear relationship between acid phosphatase activity and release of inorganic P from different organic P compounds has been observed, but the conditions under which the maximum secretion of acid phosphatase takes place, to most efficiently exploit the organic P compounds present in the soil, are unknown Yadav and Taradfdar (2001). The relatively low Ca-P content in the acid soils as compared to other fractions is evidently due to the unstable nature of Ca-P in these soils and conversion of Ca-P into insoluble Al-P and Fe-P. Similar were the observations of Doddamani and Sheshagiri Rao (1988).

4.4.2 Residual effect of PSB, VAM and different level of phosphorus on growth parameters of cowpea in soil of low available P

4.4.2.1 Plant height, No. of leaves, leaf area and leaf area index of cowpea recorded at different stages of growth

The data pertaining to the residual effect of biofertilizers, chemical fertilizer and organic manure on growth and yield parameters of cowpea are presented in Table 54.

The data on cowpea plant height at 60 DAS and at harvest are presented in Table 54. The plant height ranged from 74.08 cm at harvest in T₆ to 21.50 cm at 60 DAS in T₁. 60 DAS and at harvest residual effect of RD NPK + FYM + PSB + VAM (T₆) 34.00 and 74.42 cm and T₄ (PSB + RD NPK + FYM) 33.03 and 74.04 cm recorded significantly higher plant height respectively on par with all inoculated treatment including T₃. Inoculated treatments showed increase in height compared to uninoculated. RD NPK (150: 75: 40 kg ha⁻¹) (T₁) showed 21.50 and 40.58 cm, respectively at 60 DAS and at harvest. Inoculation with FYM and NPK enhance the crop height even with 50 per cent P also that may be due to the high utilization of P by plant. Yousefi *et al.* (2011) reported that the highest shoot height with combined application of PSB and AMF. Combined inoculation of seed with Rhizobium and phosphorus solubilizing bacteria resulted in higher plant height, dry matter accumulation, yield attributes, seed yield, straw yield and net return followed by Rhizobium (Mehta *et al.* 2012). Number of branches plant⁻¹ (Table 54) at 60 DAS was non significant but at harvest RD NPK + FYM + PSB + Mycorrhiza (T₆) recorded significantly higher number of branches plant⁻¹ (3.42 plant⁻¹ respectively) it was on par with T₄ (3.25 plant⁻¹) and T₅ (3.08 plant⁻¹). Least number of branches was noticed in treatment T₁ (1.17 plant⁻¹). Combination of PSB with VAM and organic fertilizer and FYM showed more number of branches compared to uninoculated treatments.

In general, the number of leaves per cowpea plant was found to increase due to residual effect of biofertilizers with full dose of P. The highest number of leaves at 60 DAS and at harvest (11.25 and 61.75) were recorded in T₄ on par with T₆ (11.00 and 60.67) respectively. Significantly lower numbers of leaves at 60 DAS and at harvest were observed in T₁ (5.75 and 11.25). High number of leaves in dual or combined inoculation may be due to the high nutrient use efficiency provided by microorganisms to the plant (Table 54). The similar finding by Stamtford *et al.* (2007) was reported that the TSP and biofertilizers plus 50 per cent P inoculated with *Acidithiobacillus* increased leaves number. They concluded that biofertilizers may be used as P source.

Higher value of leaf area cm^2 was recorded at 60 DAS and at harvest of cowpea in T_6 (154.84 and 591.50 cm^2) on par with T_4 (154.79 and 559.50 cm^2) and lower value was observed in T_1 at 60 DAS and at harvest of cowpea (99.73 and 198.35 cm^2). Residual effect of full dose P with single and dual inoculation showed higher value compared to uninoculated treatments. Higher leaf area may be due to the high activity of PSB which is not only responsible for the solubility of phosphorus it is producing some plant growth promoting substances also which is helping in growth of plant. Mahala *et al.* (2006) indicated that the 50 % phosphorus application through single superphosphate (SSP) with PSB recorded the highest leaf area of plant. There was significant difference in plant leaf area index among the treatments. Higher leaf area index was recorded at 60 DAS and harvest of cowpea in T_6 (0.26 and 0.49 respectively) on par with T_4 (0.26 and 0.47 respectively) and a lower leaf area index was recorded in T_1 at 60 DAS and at harvest (0.17 and 0.17) (Table 54). Higher leaf area index is related with higher leaf biomass by plant through the residual effect of biofertilizers.

Bairva *et al.* (2012) indicated that superiority of dual inoculation of seed with Rhizobium+PSB recorded significantly higher plant height, no of branches plant^{-1} and dry weight of nodules per plant at 45 DAS and harvest stage over rest of the treatment. Dual inoculation of seed with Rhizobium+PSB also recorded significantly higher yield components (*viz.*), number of pods/plant, pod length, pod weight, number of seeds/pod and shelling percentage and consequently increased seed and biological yield (*i.e.*, 18.02 and 63.96 q ha^{-1}) over control (15.62 and 57.55 q ha^{-1}), respectively. The growth parameters, yield components and seed yield showed positive response to foliar application of plant growth regulators. This could be attributed to increased availability of P with each successive level and its positive effect on growth attributes and subsequently on yield components (Jat and Ahlawat 2004). P rate of 39.3 kg/ha produced 48 % more pods/plant, 9 % more seeds/pod and 3 % higher test weight than control.

The seed inoculation with dual bio-fertilizers (rhizobium and phosphobacterin) enhanced significantly plant height (45.9 cm), number of branches (4.9/plant) and dry matter accumulation (11.7 g/plant), followed by inoculation with phosphobacterin alone. This treatment increased 12 and 14 %, respectively, in primary branches and dry matter over control (no seed inoculation) and also that of 5 and 6 %, respectively, over phosphobacterin inoculation. This indicated that rhizobia bacterial strain might act synergistically with phosphate-solubilizing bacterial strain in promoting chickpea growth. The co-inoculation of Rhizobium and phosphobacterin also brought conspicuous development in nodulation and increased significantly nodule number, nodule weight, leghaemoglobin content and nitrogenase activity over indigenous strains already present in the soil. (Dutta and Bandyopadhyay, 2008).

Table 54: Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea 60 days after sowing (60 DAS) and at harvest in low available phosphorus soil

Treatments	Plant height (cm)		No. of branches plant ⁻¹		No of leaves plant ⁻¹		Leaf area (cm ² plant ⁻¹)		Leaf area index	
	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	21.50	40.58	1.00	1.17	5.75	11.25	99.73	198.00	0.17	0.17
T ₂ -FYM (10 t ha ⁻¹)	27.00	58.08	1.00	1.58	6.50	13.42	103.76	215.17	0.18	0.18
T ₃ -RD NPK + FYM	32.25	63.83	1.00	2.50	9.50	29.50	135.28	409.33	0.23	0.34
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	33.03	74.08	1.25	3.25	11.25	61.75	154.79	559.50	0.26	0.47
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	32.75	71.58	1.25	3.08	10.75	53.83	128.33	453.17	0.21	0.38
T ₆ -RD NPK + FYM + PSB + VAM	34.00	74.42	1.50	3.42	11.00	60.67	154.84	591.50	0.26	0.49
T ₇ -50 % P + RD NK + FYM	28.00	63.50	1.00	2.42	9.25	36.25	126.38	437.83	0.21	0.36
T ₈ -0 % P + RD NK + FYM	27.85	46.25	1.00	1.75	5.75	28.25	109.35	306.67	0.17	0.26
T ₉ -50 % P + PSB + RD NK + FYM	32.50	66.17	1.00	2.92	6.50	41.83	136.56	359.25	0.23	0.30
T ₁₀ -0 % P + PSB + RD NK + FYM	29.50	62.67	1.00	2.42	9.75	45.92	138.44	494.67	0.23	0.41
T ₁₁ -50 % P + VAM + RD NK + FYM	31.75	62.67	1.00	2.17	7.75	46.58	147.60	462.42	0.25	0.39
T ₁₂ -0 % P + VAM + RD NK + FYM	32.25	64.42	1.00	2.33	8.00	34.33	140.77	460.33	0.23	0.38
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	32.75	66.50	1.00	2.67	8.50	35.17	152.20	397.25	0.25	0.33
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	30.25	58.08	1.00	2.00	6.25	33.50	121.71	327.83	0.20	0.27
SEm±	1.80	2.14	0.12	0.17	0.78	1.29	8.68	9.33	0.02	0.01
CD (P = 0.05 %)	5.40	8.18	NS	0.66	2.97	4.91	33.12	35.62	0.06	0.03

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure and DAS: days after sowing

4.4.2.2 Fresh biomass and dry weight of different parts of cowpea as a residual crop recorded at 60 DAS and harvest

The data pertaining to the fresh biomass at 60 DAS and dry matter of leaves, haulm, root and whole cowpea plant at 60 DAS and at harvest as a residual crop in a P deficient soil are furnished in (Table 55).

At 60 DAS the fresh weight of leaf, haulm and root of cowpea grown as a residual crop were significantly higher in T₆ (5.50, 4.48 and 2.58 g plant⁻¹ respectively) closely followed T₄ (5.50, 4.45 and 2.25 g plant⁻¹ respectively) and T₅ (5.50, 3.63 and 2.08 g plant⁻¹ respectively). Significantly lower fresh weight of leaves, haulm and root of cowpea were recorded in T₁ (2.50, 2.43 and 1.30 g plant⁻¹ respectively). Similarly the significantly higher fresh biomass of whole plant was recorded in T₆ (12.56 g plant⁻¹) on par with T₄, T₅ and T₁₁ (12.20, 11.21 and 11.06 g plant⁻¹ respectively). Lower biomass was recorded in T₁ (6.71 g plant⁻¹). The higher fresh biomass may be due to the high utilization of nutrient by PSB and VAM inoculated treatment compared to uninoculated treatments. Similar results were obtained by Pereira and Castro (2014) and they explained that the PSB has great potential to be used as biofertilizers in P-deficient soils, especially strains of *Pseudomonas* sp. EAV and *A. nicotinovorans* EAPAA since both promoted maize growth, constituting an attractive alternative to the phosphatic fertilizers amendments. Single superphosphate was the preferred P source, both bioinoculants improved plant growth, and up to 25 % farmyard manure did not reduce maize yields. P source had no residual effect on *V. unguiculata*, but bioinoculants, farmyard manure and N and P all increased yields (Surendra and Sharanappa, 2000). Similar results were reported by Mahala *et al.* (2006) who got significant response of mustard crop to residual phosphorus. The residual effect of increase in P level from 40 to 80 kg P₂O₅ ha⁻¹ significantly increased the accumulation of N and P by mustard. Mahanta *et al.* (2014) also opined that the root cation exchange capacity (CEC) of soybean and wheat treated with 0.5 P + PSB + VAM produced 2.3 and 2.6 % higher root length density (RLD) in soybean and wheat, respectively in comparison to 1.0 P. The P inflow rate under 0.5 P + PSB + VAM was 9.2 and 4.6 % higher than 1.0 P in soybean and wheat, respectively indicating higher acquisition of P through VAM, although higher rhizospheric P availability was recorded in 1.0 P. The root RLD and P inflow rate were closely related to P concentration and content in root, shoot and nodule, specific root length, root diameter and internal P requirement. The better root property observed in 0.5 P + PSB + VAM enhanced yield of soybean and wheat, respectively as compared to 1.0 P. Inoculation of PSB and VAM could substitute 50 % P of soybean-wheat cropping system with better root property and higher grain and haulm yield in semi-arid sub tropics of the Indo-Gangetic plains. Gupta *et al.* (2006) also reported haulm yield was influenced significantly during the growth of urdbean by the inoculation treatment. The enhanced straw yields on seed inoculation with PSB was mainly owing to increased yield attributes.

Significantly higher dry weight of cowpea leaf at 60 DAS and at harvest was recorded in T₆ (1.92 and 9.05 g plant⁻¹ respectively) and on par with T₄ (1.91 and 8.80 g plant⁻¹ respectively) which closely followed by T₅ (1.86 and 8.19 g plant⁻¹ respectively) a

lower leaf weight at 60 DAS and at harvest of cowpea was recorded in T₁ (0.65 and 2.50 g plant⁻¹ respectively) (Table 55).

Similarly maximum haulm weight at 60 DAS and at harvest of cowpea with P deficient soil was recorded in T₆ (1.53 and 12.14 g plant⁻¹ respectively) on par with T₄ (1.53 and 11.27 g plant⁻¹ respectively) and T₅ (1.45 and 10.84 g plant⁻¹ respectively). Lower weight of haulm was recorded in T₁ at 60 DAS and harvest (0.88 and 4.78 g plant⁻¹ respectively) this may be due to low availability of nutrients for plant growth. The higher haulm yield may be due to the high availability of nutrients through releasing nutrients to the soil solution by microorganisms.

At 60 DAS of cowpea and at harvest the root weight in T₆ received RD NPK + FYM + PSB + VAM was recorded significantly higher (0.79 & 3.54 g plant⁻¹ respectively) and on par with T₄ received PSB + VAM + RD N P K + FYM (0.73 & 3.50 g plant⁻¹ respectively) which closely followed by T₅ (0.69 and 3.34 g plant⁻¹ respectively). This is may be due to high amount of nutrients to plants through dissolution by microorganism. Greater efficiency of P solubilizing bacteria through co-inoculation with other beneficial bacteria and mycorrhiza increased the growth of roots of crop (Khan *et al.* 2009). While significantly lower yield of roots weight at 60 DAS and harvest were recorded in treatment T₁ (0.46 & 1.59 g plant⁻¹) respectively (Table 55).

The results pertaining to the effect of PSB, VAM and level of P fertilizer with FYM on the total dry matter of cowpea at 60 DAS and at harvest are presented in Table 55. Significant increase in the Total dry matter of cowpea (g per plant) were recorded with the residual effect of RD NPK + FYM + PSB + VAM (T₆) 4.24 and 24.73 g per plant respectively, T₄ received PSB + VAM + RD NPK + FYM (4.17 and 23.57 g per plant respectively) and T₅ (4.04 and 22.37 g per plant respectively) at 60 DAS and at harvest. The significantly lower dry matter was recorded at 60 DAS and at harvest of cowpea (2.09 and 8.77 g per plant respectively) in T₁ residual effect of (RD NPK @ 150: 75: 40 kg ha⁻¹). The inoculated treatment providing the nutrients through solubilization to plant and also they are responsible for plant growth promoting substances like indol acetic acid etc. Similar results have been reported by Kaleeswari *et al.* (2007), that the dissolution of P was significantly higher with P fertilizer + FYM + phosphate solubilizing microorganisms irrespective of the P sources. Higher phosphatase activity was observed in FYM treated plots. Therefore, *Bacillus* spp. has the potential to be applied as booster inoculants to increase the efficacy of plant growth promotion and elicitation of systemic disease protection in the field (Kloepper *et al.*, 2004). The interaction effects between vermicompost, biofertilizer and vermicompost phosphorus on grain yield of chickpea revealed that biofertilizer inoculation with and without vermicompost increased the grain yield but the magnitude of increase was relatively greater with no vermicompost. It indicated the synergy between both the factors, i.e., vermicompost and biofertilizer in enhancing the productivity of the crop (Jat and Ahlawat, 2006).

Table 55: Residual effect of phosphorus, PSB and VAM on fresh and dry biomass of cowpea 60 days after sowing (60 DAS) and at harvest in low available phosphorus soil

Treatments	Fresh weight (g plant ⁻¹) 60 DAS				Dry weight (g plant ⁻¹)							
	Leaf	Haulm	Root	Total	leaf		Haulm		Root		Total	
					60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T₁	2.98	2.43	1.30	6.71	0.65	2.50	0.88	4.78	0.46	1.59	1.99	8.87
T₂	3.00	3.23	1.60	7.83	0.76	2.91	1.33	4.95	0.39	1.54	2.48	9.40
T₃	4.00	4.45	2.48	10.93	1.42	7.63	1.43	8.57	0.65	2.70	3.50	18.90
T₄	5.50	4.45	2.25	12.20	1.91	8.80	1.53	11.27	0.73	3.50	4.17	23.57
T₅	5.50	3.63	2.08	11.21	1.89	8.19	1.45	10.84	0.69	3.34	4.03	22.37
T₆	5.50	4.48	2.58	12.56	1.92	9.05	1.53	12.14	0.79	3.54	4.24	24.73
T₇	4.00	3.53	1.88	9.41	1.53	7.67	1.30	9.34	0.55	2.47	3.38	19.48
T₈	3.50	2.53	1.35	7.38	1.34	5.04	0.88	5.86	0.37	1.83	2.59	12.73
T₉	3.75	3.65	2.03	9.43	1.42	7.93	1.32	7.89	0.68	2.67	3.42	18.49
T₁₀	3.50	3.23	1.98	8.71	1.25	7.85	1.18	9.44	0.67	3.05	3.10	20.34
T₁₁	4.00	3.08	1.80	8.88	1.37	8.44	1.18	9.00	0.63	2.83	3.18	20.27
T₁₂	3.75	3.45	1.80	9.00	1.27	7.42	1.35	9.22	0.58	2.71	3.20	19.35
T₁₃	5.25	3.73	2.08	11.06	1.87	7.27	1.40	9.34	0.68	2.63	3.95	19.24
T₁₄	3.00	2.88	1.48	7.36	1.24	5.53	1.00	6.50	0.56	2.09	2.80	14.12
SEm±	0.51	0.21	0.11	0.91	0.19	0.38	0.08	0.40	0.04	0.14	0.30	0.61
CD (P = 0.05 %)	1.94	0.79	0.41	2.71	0.73	1.45	0.32	1.54	0.16	0.54	0.91	1.81

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50 % P + RD NK & FYM, T₈-0 % P + RD NK & FYM, T₉-50 % P + PSB + RD NK & FYM, T₁₀-0 % P + PSB + RD NK & FYM, T₁₁-50 % P + Mycorrhiza + RD NK & FYM, T₁₂-0 % P + Mycorrhiza + RD NK & FYM, T₁₃-50 % P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0 % P + PSB + Mycorrhiza + RD NK & FYM.

4.4.2.3 Yield and yield components of cowpea as a residual crop under P deficient soil (pot experiment)

The data pertaining to the residual effect of biofertilizers, chemical fertilizer and organic manure on yield and yield component of cowpea are presented in Table 56.

Among the treatments T_6 (RD NPK + FYM + PSB + Mycorrhiza) resulted in higher number of pods plant⁻¹ (7.1 pods plant⁻¹) on par with (T_4) residual effect of PSB + RD NPK & FYM (7.1 pods plant⁻¹) and T_5 (VAM + RD NPK & FYM) 6.5 pods plant⁻¹. Lower number of pods per plant recorded in uninoculated treatment T_1 [RD NPK (150: 75: 40 kg ha⁻¹)] 3.9 pods plant⁻¹.

Among the Treatments T_6 (RD NPK + FYM + PSB + Mycorrhiza) resulted in higher number of seeds pod⁻¹ (14.00 seeds pod⁻¹) and it was on par with T_4 (PSB + RD NPK & FYM) 13.75 seeds pod⁻¹ and T_5 (13.50 pod⁻¹) lower seeds pod⁻¹ was recorded in treatment uninoculated like T_1 [RD NPK (150: 75: 40 kg ha⁻¹)] (6.00 seeds pod⁻¹).

With regard to T_3 (RD NPK & FYM) higher 1000 seeds weight of 100.85 g was observed followed by T_5 (PSB + RD NPK & FYM) 100.65 g and T_6 (RD NPK + FYM + PSB + Mycorrhiza) 101.64 g and lower 1000 seeds weight was recorded in uninoculated T_1 [RD NPK (150: 75: 40 kg ha⁻¹)] 57.03 g.

Among treatments T_4 (RD NPK + FYM + PSB) recorded the higher weight of pods g plant⁻¹ 11.00 which was on par with T_6 (RD NPK + FYM + PSB + Mycorrhiza) 10.71 g plant⁻¹ and T_{14} (RD NPK + FYM + Mycorrhiza) 10.09 g plant⁻¹. Significantly lower pods weight (3.97 g plant⁻¹) was recorded in T_1 (RD NPK (150: 75: 40 kg ha⁻¹)).

Inoculation of PSB + Mycorrhiza + RD NPK & FYM (T_6) recorded significantly higher seed weight g per pod of cowpea (8.79 g pod⁻¹) on par with T_4 (RD NPK + FYM + PSB) 8.63 g pod⁻¹ and T_4 (RD NPK + FYM + VAM @ 5 kg ha⁻¹) 7.91 g pod⁻¹. Uninoculated treatment T_1 recorded significantly lower seed weight (2.70 g plant⁻¹).

Significantly higher seed and haulm yield of 21.60 and 29.73 g pot⁻¹ was recorded in T_6 which received RD NPK + FYM + PSB + Mycorrhiza, followed by T_4 (PSB + RD NPK & FYM) and T_5 (Mycorrhiza + RD NK & FYM) recording of 21.21 and 28.94 g pot⁻¹ and 19.44 and 27.27 g pot⁻¹ respectively. Significantly lower seed and haulm yield of 6.75 and 10.74 g pot⁻¹ was recorded in T_1 [RD NPK (150: 75: 40 kg ha⁻¹)]. Among the treatment dual inoculated treatments showed higher seed and haulm yield of cowpea compared to uninoculated treatment (Table 56 and Fig. 5). Mahanta and Rai (2008) have reported similar finding to application of 50 % recommended dose of P as SP + PSB + VAM recorded the highest yield during the first year in soybean (2.0 t/ha) and during both the years in wheat (4.4 and 4.6 t/ha in the first and second years respectively), but that of 50 % RD P as RP + PSB + VAM registered the highest seed yield (2.2 t/ha) during the second year in soybean. Dual inoculation enhanced seed yield by 28.3 and 28.0 % over no inoculation and by 8.9 and 6.9 % over single inoculation alone. Application of 26 kg P/ha increased the seed yield of chickpea by 38.0 and 40.8% over no phosphorus and 9.8 and 6.9 % over 13 kgP/ha in 1999-2000 and 2000-01, respectively

Table 56: Residual effect of phosphorus, PSB and VAM on growth and yield parameters of cowpea at harvest in low available phosphorus soil

Treatments	No. of pods plant ⁻¹	No. of seeds per pod	1000 seeds weight (g)	Weight of pods (g plant ⁻¹)	Seeds weight (g per pod)	Seed yield (g pot ⁻¹)	Haulm yield (g pot ⁻¹)
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	3.9	6.00	57.03	3.97	2.75	6.76	10.74
T ₂ -FYM (10 t ha ⁻¹)	4.2	6.50	81.11	4.43	3.29	8.09	11.96
T ₃ -RD NPK + FYM	5.4	12.25	100.85	7.14	5.44	13.37	19.29
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	7.1	13.75	100.65	11.00	8.63	21.21	28.94
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	6.5	13.50	98.87	10.09	7.91	19.44	27.27
T ₆ -RD NPK + FYM + PSB + VAM	7.1	14.00	101.64	10.71	8.79	21.60	29.73
T ₇ -50 % P + RD NK + FYM	5.7	12.25	92.83	7.42	5.46	13.40	20.05
T ₈ -0 % P + RD NK + FYM	4.0	10.25	100.45	5.09	3.84	9.43	13.76
T ₉ -50 % P + PSB + RD NK + FYM	5.6	11.00	96.11	6.84	5.04	12.39	18.50
T ₁₀ -0 % P + PSB + RD NK + FYM	5.7	12.25	95.02	7.78	5.40	13.26	21.02
T ₁₁ -50 % P + VAM + RD NK + FYM	5.3	11.75	89.20	8.24	6.10	14.99	22.25
T ₁₂ -0 % P + VAM + RD NK + FYM	5.2	13.00	99.27	6.50	4.99	12.25	17.56
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	5.4	12.25	103.02	7.46	5.40	13.26	20.16
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	5.0	11.25	98.08	6.05	4.68	11.49	16.35
SEm±	0.3	0.64	2.52	0.41	0.30	0.73	1.10
CD (P = 0.05 %)	1.3	2.43	9.62	1.55	1.13	2.78	4.20

*RD: recommended dose, PSB: Phosphorus Solubilizing Bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

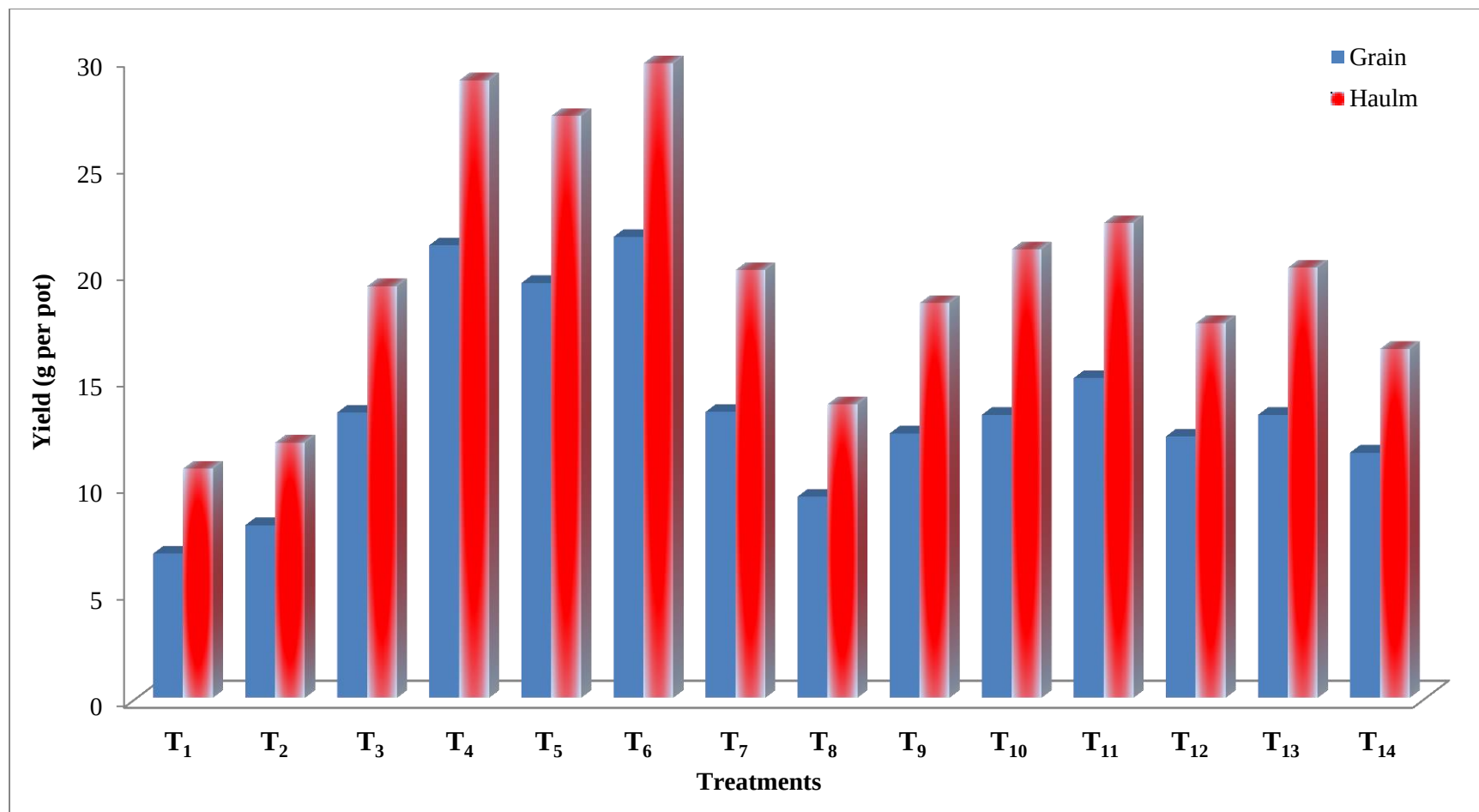


Fig. 5. Residual effect of phosphorus, PSB and VAM on yield of cowpea (g pot⁻¹) in low available phosphorus soil

T₁-RD NPK (150: 75: 40 kg ha⁻¹), T₂-RD FYM (10 tonne), T₃-RD NPK + FYM, T₄-RD NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-RD NPK + FYM + Mycorrhiza (VAM @ 5 kg ha⁻¹), T₆-RD NPK + FYM + PSB + Mycorrhiza, T₇-50% P + RD NK & FYM, T₈-0% P + RD NK & FYM, T₉-50% P + PSB + RD NK & FYM, T₁₀-0% P + PSB + RD NK & FYM, T₁₁-50% P + Mycorrhiza + RD NK & FYM, T₁₂-0% P + Mycorrhiza + RD NK & FYM, T₁₃-50% P + PSB + Mycorrhiza + RD NK & FYM, T₁₄-0% P + PSB + Mycorrhiza + RD NK & FYM.

as reported by Jat and Ahlawat (2006). Mahala *et al.* (2004) reported that the residual effect of P sources was found equally effective in improving the yield of mustard. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the seed and straw yields of mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop. Typic Ustochrepts of the Indo-Gangetic plains. Mahanta *et al.* (2014) also opined that the better root property observed in 0.5 P + PSB + VAM enhanced 4.1 and 4.9 % seed yield of soybean and wheat, respectively as compared to 1.0 P. Inoculation of PSB and VAM could substitute 50 % P of soybean–wheat cropping system with better root property and higher seed yield in semi-arid sub tropics of the Indo-Gangetic plains. Adediran *et al.* (2004) studied on residual effect of the applied fertilizers on cowpea showed greater advantage of organic fertilizer application over the MFert. The cowpea yield on plots fertilized with compost and OBF were higher than that from the MFert. At Ibadan, a much better effect was obtained from applying at the highest rate (10 t ha⁻¹). Phosphorus solubilizing bacteria (PSB) inoculation influenced 1,000-seed weight and pods plant⁻¹ and seeds pod⁻¹ respectively (Gupta *et al.*, 2006).

4.4.3 Residual effect of PSB, VAM and different level of phosphorus on nutrient content of cowpea at 60 DAS in soil of low available P

4.4.3.1 Major nutrients content in plant different parts at 60 DAS

The data related to the residual effect of PSB, VAM, inorganic fertilizer and FYM on major nutrient content of cowpea leaves, haulm and roots are presented in Table 57.

The nitrogen content of cowpea whole crop at 60 DAS in low P soil varied significantly among treatments (Table 57). The nitrogen content by leaves, haulm and roots of cowpea has increased with residual effect of T₆ (RD NPK + FYM + PSB + VAM) 2.33, 3.05 and 0.94 per cent respectively it was on par with T₁₃ (50 % P + PSB + VAM + RD NK + FYM) 2.19, 2.97 and 0.91 per cent and the lower nitrogen in leaves, haulm and roots of cowpea were recorded in treatment (T₁) RD NPK (150: 75: 40 kg ha⁻¹) 1.72, 2.34, 0.72 and 4.78 percent respectively. Among the leaves, haulm and roots the nitrogen content was higher in haulm followed by leaves and lower was in roots of cowpea. Residual effect of dual inoculation of PSB + VAM registered high N uptake compared to uninoculated treatment. Higher nitrogen content could be attributed to increased nitrogen availability in the soil. Among different part of plant the haulm under inoculated or uninoculated condition showed high nitrogen content compare to leaves and root.

The P content of whole cowpea plant differed significantly among treatments shown in the Table 57. The P content of cowpea at 60 DAS increased with residual effect full dose or 50 % P or without P and RD NK + FYM + PSB + VAM. The high P content in leaves, haulm and root were observed in treatment received T₆ (RD NPK + PSB + VAM + FYM) 0.76, 0.52 and 0.32 per cent respectively was on par with other treatments inoculated with microorganism like T₁₃ (0.71, 0.50 and 0.31 % respectively) and others inoculated treatment respectively. Lower P content in leaves, haulm and root of cowpea crop was recorded at (T₁) RD NPK @ 150: 75: 40 kg ha⁻¹ 0.28, 0.38 and 0.08 per cent respectively. Among different parts of cowpea (leaf, haulm and root) the content of P was higher in leaves.

Table 57: Residual effect of phosphorus, PSB and VAM on major nutrients content (%) of cowpea at 60 DAS in low available phosphorus soil

Treatments	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	leaves	haulm	roots	Leaves	haulm	roots	leaves	haulm	roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.72	2.34	0.69	0.28	0.38	0.08	1.38	1.95	0.71
T ₂ -FYM (10 t ha ⁻¹)	1.89	2.61	0.72	0.44	0.45	0.15	1.38	1.98	0.88
T ₃ -RD NPK + FYM	2.15	2.77	0.79	0.68	0.47	0.27	1.60	1.98	1.08
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	1.92	2.71	0.82	0.68	0.43	0.31	1.52	2.26	1.05
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	1.88	2.14	0.86	0.65	0.35	0.25	1.43	2.23	1.08
T ₆ -RD NPK + FYM + PSB + VAM	2.33	3.05	0.94	0.76	0.52	0.32	1.70	2.53	1.22
T ₇ -50 % P + RD NK + FYM	1.98	2.64	0.78	0.57	0.36	0.14	1.57	2.24	0.94
T ₈ -0 % P + RD NK + FYM	1.97	2.47	0.76	0.55	0.39	0.10	1.36	2.17	0.67
T ₉ -50 % P + PSB + RD NK + FYM	2.10	2.77	0.80	0.63	0.39	0.29	1.62	2.07	0.95
T ₁₀ -0 % P + PSB + RD NK + FYM	2.04	2.72	0.85	0.67	0.49	0.23	1.64	2.17	1.05
T ₁₁ -50 % P + VAM + RD NK + FYM	2.17	2.84	0.90	0.60	0.46	0.24	1.42	2.22	1.00
T ₁₂ -0 % P + VAM + RD NK + FYM	1.86	2.74	0.90	0.67	0.48	0.25	1.53	2.37	0.86
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	2.19	2.97	0.91	0.71	0.50	0.31	1.78	2.52	1.18
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	2.13	2.75	0.92	0.65	0.47	0.25	1.62	2.17	0.99
SEm±	0.09	0.06	0.06	0.02	0.02	0.01	0.03	0.10	0.06
CD (P = 0.05 %)	0.27	0.23	0.17	0.08	0.06	0.04	0.12	0.37	0.19

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure, DAS: days after sowing

Higher K content in leaves, haulm and roots were recorded in T₁₃ (1.20, 1.58 and 0.88 per cent respectively) and was on par with dual inoculation of PSB, AMF with 100 percent P like T₆ (1.70, 2.53 and 1.22 per cent respectively). Lower K content was observed in T₁ (1.38, 1.95 and 0.71 per cent respectively).

Combined inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant N, P and K content. The same results found by (Wu *et al.* 2005) higher N, P and K concentration in plants observed in dual inoculation with rhizobacteria and *G. intraradices*. The lowest N, P and K uptake was detected in plants grown in uninoculated and unfertilized pots. Either single treatment of chemical or organic fertilization resulted decrease in N, P and K concentration. The maximum P and K assimilation were obtained with the dual inoculation of *G. mosseae* and rhizobacteria. Fertilizer applications with compost showed high nutrient content compared to NPK or FYM alone. This supports the findings of Adediran *et al.* (2004) who observed increased plant nutrients concentration amended with inorganic fertilizer and compost. Mahala *et al.* (2004) reported that the residual effect of P sources was found equally effective in improving nutrient uptake of mustard. Residual effect of increasing P levels up to 80 kg P₂O₅ ha⁻¹ significantly increased the nutrient uptake in mustard. Residual effect of FYM also had a significant positive impact on these aspects of mustard crop as well as on the available N and P in soil. Dutta and Bandyopadhyay (2009) revealed that the P and biofertilizers application significantly influenced the P uptake of chickpea. Seed inoculation with Rhizobium and phosphobacteria was significantly superior over no inoculation or phosphobacteria inoculation alone. Combined application of P at 26.2 kg ha⁻¹ and bio-fertilizers (Rhizobium and phosphobacteria) enhanced significantly P uptake compared to other levels of P with bio-fertilizer.

4.4.3.2 Secondary nutrients content (%) in different parts of cowpea at 60 DAS

Residual effect of combined inoculation of PSB+VAM recorded significantly higher secondary nutrient content in different parts of cowpea (leaves, haulm and root) (Table 58). T₆ (RD NPK + FYM + PSB + VAM) showed higher S content in leaves, haulm and roots (0.46, 0.62 and 0.36 per cent, respectively) on par with T₁₃ (50 per cent P + PSB + VAM + RD NK + FYM) 0.42, 0.54 and 0.34 per cent respectively in leaves, haulm and roots. Uninoculated T₁ recorded significantly lower S content in leaves, haulm and roots (0.18, 0.20 and 0.14 per cent) respectively. S content was more in haulm compared to leaves and root.

Among the treatments, T₆ (RD NPK + FYM + PSB + VAM) showed significantly higher residual effect on Ca content of leaves, haulm and root (1.20, 1.08 and 1.40 per cent respectively) and T₁₃ (50 per cent P + PSB + VAM + RD NK + FYM) 1.17, 0.75 and 1.40 per cent respectively at 60 DAS of cowpea compared to the T₂ (RD NPK (150: 75: 40 kg ha⁻¹) (0.72, 0.46 and 0.61 %, respectively) (Table 58).

Similar trend of calcium was followed with respect to magnesium content by cowpea residual crop leaves, haulm and root. With respect to whole plant (leaves, haulm and root) the magnesium content was found to be significantly higher in

Table 58: Residual effect of phosphorus, PSB and VAM on secondary nutrients content (%) of cowpea at 60 DAS in low available phosphorus soil

Treatments	Sulfur (%)			Calcium (%)			Magnesium (%)		
	Leaves	Haulm	Roots	Leaves	Haulm	Roots	Leaves	Haulm	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	0.18	0.20	0.14	0.72	0.46	0.62	0.38	0.44	0.23
T ₂ -FYM (10 t ha ⁻¹)	0.21	0.27	0.16	0.72	0.46	0.61	0.58	0.47	0.25
T ₃ -RD NPK + FYM	0.21	0.43	0.26	0.86	0.67	0.69	0.62	0.49	0.26
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	0.23	0.27	0.26	0.86	0.65	0.82	0.61	0.65	0.42
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	0.24	0.44	0.27	0.91	1.03	0.91	0.58	0.71	0.34
T ₆ -RD NPK + FYM + PSB + VAM	0.46	0.62	0.36	1.20	1.08	1.40	0.77	0.82	0.57
T ₇ -50 % P + RD NK + FYM	0.20	0.46	0.29	0.95	0.65	0.84	0.53	0.59	0.31
T ₈ -0 % P + RD NK + FYM	0.21	0.40	0.27	1.08	0.61	0.74	0.60	0.80	0.42
T ₉ -50 % P + PSB + RD NK + FYM	0.36	0.49	0.28	1.17	0.60	0.94	0.41	0.67	0.35
T ₁₀ -0 % P + PSB + RD NK + FYM	0.22	0.34	0.31	0.84	0.58	0.86	0.52	0.65	0.34
T ₁₁ -50 % P + VAM + RD NK + FYM	0.38	0.36	0.30	1.06	0.64	0.90	0.39	0.63	0.34
T ₁₂ -0 % P + VAM + RD NK + FYM	0.35	0.34	0.24	0.88	0.65	0.79	0.43	0.51	0.27
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	0.42	0.54	0.34	1.17	0.75	1.40	0.68	0.81	0.55
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	0.38	0.33	0.27	1.13	0.70	0.72	0.63	0.46	0.24
SEm±	0.02	0.03	0.01	0.06	0.03	0.06	0.03	0.04	0.06
CD (P = 0.05 %)	0.06	0.12	0.03	0.18	0.10	0.18	0.10	0.12	0.17

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure, DAS: days after sowing

treatments T₆ (0.77, 0.82 and 0.57 per cent respectively) closely followed by T₁₃ (0.68, 0.81 and 0.55 per cent respectively). Lower Mg content was recorded in T₁ (0.38, 0.44 and 0.23 per cent respectively) in leaves, haulm and root of cowpea as a residual crop (Table 58).

4.4.3.3 Micronutrients content of different parts of cowpea at 60 DAS

The data on residual effect of PSB, VAM, chemical fertilizer and FYM on concentration of micronutrients of cowpea leaves, haulm and roots at 60 DAS are presented in Table 59.

Iron content of different parts of cowpea like leaves, haulm and roots at 60 DAS was significantly higher in the T₆ (RD NPK + FYM + PSB + VAM) (111.63, 87.62 and 83.18 mg kg⁻¹ respectively) which were on par with T₁₃ (110, 78.91 and 83.77 mg kg⁻¹ respectively). The lower iron content of leaves, haulm and roots were recorded in T₁ which received RD NPK (150: 75: 40 kg ha⁻¹) (64.02, 58.88 and 49.96 mg kg⁻¹ respectively).

The manganese content of cowpea leaves, haulm and roots at 60 DAS were increased significantly in treatments T₁₃ received 50 % P + RD NK + FYM + PSB + VAM (39.65, 30.64 and 22.83 mg kg⁻¹ respectively) and lower content of Mn in T₁ (27.60, 18.86 and 9.91 per cent respectively). Combined inoculation recorded higher content of Mn compared to uninoculated treatments.

Copper content of cowpea leaves, haulm and roots at 60 DAS significantly decreased (6.51, 12.10 and 4.88 mg kg⁻¹ respectively) in the T₁ [RD NPK (150: 75: 40 kg ha⁻¹)] and significantly higher copper content was recorded in T₆ (9.28, 17.71 and 9.41 mg kg⁻¹ respectively) and T₁₃ (9.24, 17.64 and 9.09 mg kg⁻¹ respectively) at 60 DAS.

Residual effect of combined inoculation or single inoculation or uninoculation with PSB or AMF with FYM and fertilizer application showed significant differences with respect to zinc content at 60 DAS of cowpea leaves, haulm and roots. The zinc content of cowpea leaves, haulm and roots increased significantly in the T₆ received RD NPK + FYM + PSB + VAM (17.30, 19.76 and 23.13 mg kg⁻¹ respectively), T₁₃ (17.31, 19.76 and 23.09 mg kg⁻¹ respectively) and lower zinc content was noticed in T₂ (14.67, 16.93 and 11.89 mg kg⁻¹ respectively).

Higher concentration of micronutrients in combined inoculated or single inoculated treatment might be due to higher available micronutrients in soil which leads to higher uptake of micronutrients by plant. Lower content of micronutrient in FYM alone is due to low mineralization rate. Nyoki and Ndakidemi (2014) reported the similar result in a significant content of micronutrients in the *B. japonicum* inoculated treatments over the control. Phosphorus supplementation (40 kg P ha⁻¹) also showed a significant increase in the content of some micronutrients while decreasing the uptake of Zn in some plant organs. There was also a significant interaction between *B. japonicum* inoculation and phosphorus in the root uptake of Zn for the field experiment. Adediran *et al.* (2004) found that mineral fertilizer showed high content of micronutrients compared to organic

Table 59: Residual effect of phosphorus, PSB and VAM on micronutrient content (mg kg⁻¹) of cowpea at 60 DAS in low available phosphorus soil

Treatments	Fe (mg kg ⁻¹)			Mn (mg kg ⁻¹)			Cu (mg kg ⁻¹)			Zn (mg kg ⁻¹)		
	Leaves	Haulm	Roots	Leaves	Haulm	Roots	Leaves	Haulm	Roots	Leaves	Haulm	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	64.02	58.88	49.96	27.60	22.86	9.91	6.51	12.10	4.88	15.10	17.28	13.06
T ₂ -FYM (10 t ha ⁻¹)	76.45	64.76	57.06	32.42	23.87	11.04	7.25	13.26	8.44	14.67	16.93	11.89
T ₃ -RD NPK + FYM	79.17	67.09	68.60	34.15	23.73	12.33	9.23	13.57	9.33	14.83	16.95	16.57
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	64.07	84.22	63.24	31.97	23.13	10.01	7.09	11.56	7.50	15.41	18.23	18.60
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	75.29	70.87	60.10	32.42	19.16	14.71	7.42	6.77	6.68	13.43	18.83	22.53
T ₆ -RD NPK + FYM + PSB + VAM	111.63	87.62	83.18	35.02	28.58	18.05	9.28	17.71	9.91	17.41	19.76	23.09
T ₇ -50 % P + RD NK + FYM	92.56	59.38	58.45	39.39	22.22	10.84	5.69	10.45	6.25	14.83	16.50	15.49
T ₈ -0 % P + RD NK + FYM	69.15	60.48	54.88	35.02	21.68	12.24	6.26	7.35	4.80	16.07	13.28	20.93
T ₉ -50 % P + PSB + RD NK + FYM	84.54	63.19	63.36	35.35	19.02	14.07	7.91	10.24	7.16	16.15	16.19	17.76
T ₁₀ -0 % P + PSB + RD NK + FYM	79.16	78.38	82.32	35.72	22.61	14.22	10.34	10.26	8.85	17.14	17.82	21.94
T ₁₁ -50 % P + VAM + RD NK + FYM	108.21	80.84	80.82	33.33	20.34	20.88	8.73	6.88	5.55	12.85	18.38	13.75
T ₁₂ -0 % P + VAM + RD NK + FYM	87.37	95.30	67.06	38.07	23.17	18.14	8.24	7.66	6.69	14.34	16.91	16.58
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	110.03	78.91	83.77	39.65	30.64	22.83	9.24	17.64	9.09	17.30	18.83	23.13
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	92.05	73.30	79.40	38.98	20.73	22.39	8.73	10.18	8.67	14.83	15.45	21.50
SEm±	2.92	2.21	2.23	0.86	0.56	0.71	0.46	0.52	0.26	0.70	0.46	0.66
CD (P = 0.05 %)	8.74	8.45	8.50	2.56	2.14	2.72	1.28	1.98	1.01	2.11	1.77	2.51

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure, DAS: days after sowing

manure alone. Application of fertilizer nitrogen, the yield, percent nitrogen content and the uptake of other nutrients were increased. Nutrient accumulation in the maize leaves was greater than that in the other components of the plant (Hussaini *et al.* 2008). This was also reported by Kaleeswari *et al* (2007) who observed that the dissolution of P was significantly higher with P fertilizer + Phosphate solubilizing microorganisms irrespective of the P sources.

4.4.4 Residual effect of PSB, VAM and different level of phosphorus on nutrient uptake by cowpea at harvest in soil of low available P

4.4.4.1 Major nutrients uptake by different parts of cowpea at harvest

The data pertaining to nitrogen, phosphorus and potassium uptake by different parts and whole plant of cowpea differed significantly due to residual effect of PSB, AMF, FYM and chemical fertilizers in soil with low available and total P (Table 60).

Nitrogen uptake by leaves, haulm, seed and roots of cowpea crop at harvest was significantly higher in T₆ (63.65, 35.00, 52.47 and 8.60 kg ha⁻¹ respectively) which received RD NPK + FYM + PSB + VAM and was on par with T₁₃ (56.14, 31.37, 48.60 and 8.32 kg ha⁻¹ respectively). However, lower nitrogen uptake by leaves, haulm, seed and roots was recorded in the T₁ received RD NPK (150: 75: 40 kg ha⁻¹) (12.43, 4.95, 13.00 and 1.62 kg ha⁻¹, respectively). Residual effect of dual inoculation and single inoculation with full dose of P fertilizer recorded higher nitrogen uptake compared to the residual effect of single inoculated with 50 per cent or without of P and uninoculated treatment (Table 60). Among different parts of cowpea seed showed higher nitrogen uptake compared to leaves, haulm and root. Root showed lower nitrogen uptake.

Uptake of phosphorus by leaves, haulm, seed, root and whole cowpea crop significantly differed among the treatments (Table 60). Higher uptake of phosphorus by leaves, haulm, seed and root of cowpea crop at harvest was recorded in T₆ received RD NPK + FYM + PSB + VAM (9.82, 5.26, 66.01 and 1.19 kg ha⁻¹) respectively and on par with 50 % P + PSB + Mycorrhiza + RD NK & FYM (T₁₃) 8.12, 5.20, 61.13 and 1.19 kg ha⁻¹ respectively and T₁₄ receiving 0 % P + PSB + VAM + RD NK + FYM (6.76, 4.41, 54.32 and 1.10 kg ha⁻¹ respectively). However, lower uptake of phosphorus by leaves, haulm, seed and roots (1.07, 1.22, 22.03 and 0.21 kg ha⁻¹, respectively) was recorded in the T₁ RD NPK (150: 75: 40 kg ha⁻¹). Residual effect of combined inoculation and single inoculation with full dose of P showed higher phosphorus uptake compared to single inoculated treatment with 50 per cent of P or without P and uninoculated treatments.

The total uptake of K by cowpea leaves, haulm, seed and roots varied significantly with the different inoculated and uninoculated treatments is presented in the Table 60. Higher leaves, haulm, seed and roots K uptake were recorded in T₆ received RD NPK + FYM + PSB + VAM (22.20, 24.05, 56.58 and 6.23 kg ha⁻¹ respectively) and was on par with T₁₃ received 50 % P + PSB + Mycorrhiza + RD NK & FYM (18.23, 20.78, 54.60 and 5.43 kg ha⁻¹ respectively) and T₁₄ (16.88, 19.14, 52.42 and 5.36 kg ha⁻¹ respectively). Lower plant K uptake by leaves, haulm, seed and roots was recorded

Table 60: Residual effect of phosphorus, PSB and VAM on major nutrients uptake by cowpea (kg ha⁻¹) at harvest in low available phosphorus soil

Treatments	Nitrogen (kg ha ⁻¹)				Phosphorus (kg ha ⁻¹)				Potassium (kg ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	12.43	4.95	13.00	1.62	1.07	1.22	22.03	0.21	4.72	5.80	28.59	0.80
T ₂ -FYM (10 t ha ⁻¹)	12.57	6.55	21.25	3.21	1.73	1.29	28.80	0.26	4.81	8.37	29.56	1.80
T ₃ -RD NPK + FYM	41.64	15.71	26.89	4.97	5.34	1.77	24.36	0.68	13.51	12.33	26.65	3.64
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	41.05	30.43	36.50	4.69	4.43	3.66	45.21	0.74	13.41	16.79	43.14	4.11
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	52.67	27.08	32.98	5.74	5.81	3.97	44.45	1.10	14.90	12.63	40.17	3.90
T ₆ -RD NPK + FYM + PSB + VAM	63.65	35.00	52.47	8.60	9.82	5.26	66.01	1.19	22.20	24.05	56.58	6.23
T ₇ -50 % P + RD NK + FYM	31.59	19.97	28.05	5.10	4.05	2.31	36.58	0.74	12.44	13.11	33.47	3.29
T ₈ -0 % P + RD NK + FYM	30.98	16.71	22.75	3.78	3.47	1.82	28.52	0.44	9.97	10.52	24.99	3.14
T ₉ -50 % P + PSB + RD NK + FYM	48.01	25.57	30.16	4.65	5.34	3.52	48.29	0.63	14.15	18.91	49.86	3.28
T ₁₀ -0 % P + PSB + RD NK + FYM	40.02	24.30	29.51	4.81	5.05	0.80	39.35	0.67	14.42	5.68	37.10	3.73
T ₁₁ -50 % P + VAM + RD NK + FYM	42.53	27.51	34.31	6.20	6.42	3.91	45.99	1.02	17.54	18.53	42.40	3.94
T ₁₂ -0 % P + VAM + RD NK + FYM	42.82	25.01	34.32	7.62	4.95	2.39	48.99	0.97	15.33	18.02	41.53	4.71
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	56.14	31.37	48.60	8.32	8.12	5.20	61.13	1.19	18.23	20.78	54.60	5.43
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	55.34	27.41	46.61	6.44	6.76	4.41	54.62	0.80	16.88	19.14	52.42	5.36
SEm±	2.22	1.05	1.74	0.30	0.28	0.14	2.35	0.04	0.76	0.72	2.23	0.20
CD (P = 0.05 %)	8.46	4.02	6.64	1.13	1.09	0.53	8.98	0.17	2.90	2.74	8.52	0.78

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

in T₁ received RD NPK @ 150: 75: 40 kg ha⁻¹ (4.72, 5.80, 28.59 and 0.80 kg ha⁻¹ respectively).

Results of enhanced uptake of nutrients use of biofertilizers (*G. mosseae* and VAM) resulted in the higher nitrogen, phosphorus and potassium uptake. This field experiment study also indicated that half dose of the phosphorus application with combined inoculation had similar effects when compared with full dose of phosphorus fertilizer with dual inoculation. Higher nutrient uptake in dual inoculated treatment could be attributed to increased nutrient availability in the soil. Higher uptake of major nutrients in above said treatment was due to higher growth attributing parameters and total dry matter production. This further influenced the manifestation of yield attributing characters and subsequently by yield of maize crop. Gupta *et al.* (2006) noticed that the effect of bio-fertilizer inoculation and phosphorus fertilization on N and P uptake. The practice of seed inoculation with phosphorus solubilizing bacteria showed a significant increase in N and P uptake over uninoculated treatment. Phosphorus application also resulted in significant increase in N and P uptake in seed and straw. NPK alone showed higher nutrient uptake compare to FYM alone may due to the high availability of these nutrients from NPK fertilizer. Total P uptake by maize increased with increasing level of inorganic P in soils compared to organic manure (Garg and Bahl, 2008). Phosphorus and biofertilizers application significantly were influenced the P uptake of crop. Seed inoculation with Rhizobium and phosphobacteria was significantly superior over no inoculation or phosphobacteria inoculation alone. Combined application of P at 26.2 kg ha⁻¹ and bio-fertilizers (Rhizobium and phosphobacteria) enhanced significantly P uptake compared to other levels of P with biofertilizer (Dutta and Bandyopadhyay, 2009).

4.4.4.2 Uptake of secondary nutrients by cowpea at harvest

The data on the residual effect of P solubilizers, chemical fertilizer and FYM on the uptake of secondary nutrients by cowpea leaves, haulm, seeds, roots and whole plant significantly differed among treatments (Table 61). Significant differences were observed with respect to secondary nutrients uptake by cowpea.

Higher uptake of sulphur by leaves, haulm, seed and root of cowpea plant was recorded in treatment T₆ receiving RD NPK + FYM + PSB + VAM (8.96, 7.72, 32.68 and 3.28 kg ha⁻¹) respectively and on par with T₁₃ which received 50 % P + PSB + VAM + RD NK + FYM (6.00, 7.08, 29.80 and 2.44 kg ha⁻¹ respectively). However, lower uptake of sulphur (1.40, 3.22, 4.70 and 0.80 kg ha⁻¹, respectively) was recorded in T₁ received RD NPK @ 150: 75: 40 kg ha⁻¹.

The uptake of calcium by cowpea leaves, haulm, seed and roots at harvest differed significantly in all the treatments compared to T₁. The leaves, haulm, seed and root Ca uptake was significantly higher in treatments T₆ (32.56, 20.19, 4.52 and 4.44 kg ha⁻¹) and on par with T₁₃ (31.34, 16.80, 4.20 and 4.38 kg ha⁻¹) and others inoculated treatment with full dose of P or 50 per cent of P. Lower Ca uptake was recorded in T₁ (8.98, 6.27, 1.16 and 1.55 kg ha⁻¹ respectively).

Table 61: Residual effect of phosphorus, PSB and VAM on secondary nutrients uptake by cowpea (kg ha⁻¹) at harvest in low available phosphorus soil

Treatments	S (kg ha ⁻¹)				Ca (kg ha ⁻¹)				Mg (kg ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	1.40	3.22	4.70	0.80	8.98	6.27	1.16	1.55	4.19	4.70	1.13	1.64
T ₂ -FYM (10 t ha ⁻¹)	1.44	3.42	12.28	0.82	11.52	6.74	1.71	1.55	4.33	5.26	2.07	1.82
T ₃ -RD NPK + FYM	2.18	3.26	14.36	1.24	22.66	13.79	3.05	3.60	12.91	12.25	7.17	3.28
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	4.24	5.22	19.82	1.10	29.81	15.15	2.27	3.39	9.10	11.26	7.01	2.70
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	4.90	8.50	17.20	1.18	29.33	11.66	1.19	2.27	7.48	7.25	6.96	4.02
T ₆ -RD NPK + FYM + PSB + VAM	8.96	7.72	32.68	3.28	32.56	20.19	4.52	4.44	19.50	16.45	9.97	6.31
T ₇ -50 % P + RD NK + FYM	2.70	2.42	9.18	1.30	19.53	0.23	1.19	2.39	11.20	8.16	3.78	2.20
T ₈ -0 % P + RD NK + FYM	6.08	4.02	7.46	1.58	16.43	7.97	1.35	1.97	9.58	6.72	3.36	1.95
T ₉ -50 % P + PSB + RD NK + FYM	2.72	5.54	27.76	1.60	22.43	13.50	2.39	1.50	12.42	8.61	6.26	3.72
T ₁₀ -0 % P + PSB + RD NK + FYM	2.50	4.72	26.54	1.56	23.43	6.98	2.10	2.73	11.24	5.04	3.29	3.65
T ₁₁ -50 % P + VAM + RD NK + FYM	4.84	3.22	22.12	2.12	24.28	9.83	3.29	2.81	10.63	13.45	4.42	3.28
T ₁₂ -0 % P + VAM + RD NK + FYM	4.10	4.92	15.78	1.84	20.65	11.73	3.27	1.89	10.84	12.17	3.25	2.32
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	6.00	7.08	29.80	2.44	31.34	16.80	4.20	4.38	15.47	13.38	7.63	4.49
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	4.82	6.26	18.62	1.72	15.81	14.01	3.41	2.76	14.25	12.84	5.04	3.53
SEm±	0.24	0.28	1.00	0.10	1.28	0.60	0.14	0.14	0.62	0.52	0.32	0.18
CD (P = 0.05 %)	0.92	1.10	3.00	0.36	4.90	2.28	0.50	0.54	2.37	1.97	1.20	0.71

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Similar trend was observed in case of Mg uptake by cowpea crop. Within the treatments T₆ resulted in significantly higher uptake of Ca by leaves, haulm, seed and roots (19.50, 16.45, 9.97 and 6.31 kg ha⁻¹) and on par with T₁₃ (50 % P+ RD NK + FYM + PSB + VAM) 15.47, 13.38, 7.63 and 4.49 kg ha⁻¹ respectively. Lower Mg uptake was recorded in T₁ [RD NPK (150: 75: 40 kg ha⁻¹)] 4.19, 4.70, 1.13 and 1.64 kg ha⁻¹ respectively). Among the treatment inoculated treatment showed higher Mg uptake compared to uninoculated treatments.

The secondary nutrient uptake was significantly high in case of combined inoculation compared to uninoculated treatment may be due to high acquisition by microorganisms. Dual inoculation with AMF and rhizobacteria seemed to be the most effective treatment combination to improve plant nutrient uptake (Wu *et al.*, 2005).

4.4.4.3 Uptake of micronutrients by leaves haulm, seed, root and whole cowpea plant

The data pertaining to micronutrients uptake by different parts of cowpea crop differed significantly due to the residual effect of PSB, AMF, FYM and chemical fertilizers in soil with low available phosphorus (Tables 62 and 63).

Iron uptake by cowpea leaves, haulm, seed and root was significantly higher in treatment T₆ (528.52, 238.52, 140.92 and 158.56 g ha⁻¹ respectively) closely followed by T₁₃ (408.56, 227.72, 112.08 and 148.12 g ha⁻¹ respectively) and significantly lower iron uptake was observed in T₁ (171.52, 132.48, 27.40 and 63.60 g ha⁻¹ respectively). Among the treatment the iron uptake was more in inoculated treatment compared to uninoculated treatments.

Residual effect of PSB, AMF, and FYM, full dose P or 50 % P and NK fertilizer showed significant differences with respect to Mn uptake of cowpea crop. The Mn uptake in cowpea leaves, haulm, seed and root increased significantly in the treatments T₆ (101.28, 30.24, 156.12, and 8.80 g ha⁻¹ respectively) followed by T₁₃ (95.80, 29.08, 152.04 and 8.40 g ha⁻¹ respectively). Lower Mn uptake by leaves, haulm, seed and root was recorded in T₁ (29.08, 18.04, 95.44 and 5.12 g ha⁻¹) respectively. Among the different parts of cowpea roots showed low uptake of Mn compared to leaves, seed and root.

Uptake of zinc by cowpea leaves, haulm, seed and root was significantly higher in most of the treatments with dual inoculation compared to single and uninoculated treatment. In T₆ (RD NPK + FYM + PSB + VAM) uptake of zinc by leaves, haulm, seed and root was (21.48, 23.64, 12.12 and 5.40 g ha⁻¹ respectively) found to be on par with T₁₃ (18.92, 19.68, 10.04 and 5.24 g ha⁻¹ respectively). Significantly lower uptake of zinc by leaves, haulm, seed and root was recorded in T₁ (5.48, 7.20, 4.00 and 1.80 g ha⁻¹ respectively).

The uptake of Cu by cowpea leaves, haulm, seed and roots at harvest differed significantly in all the treatments compared to T₁ received RD NPK (150: 75: 40 kg ha⁻¹). The leaves, haulm, seed and root Cu uptake was significantly higher in

Table 62: Residual effect of phosphorus, PSB and VAM on Fe and Mn uptake (g ha⁻¹) by cowpea at harvest in low available phosphorus soil

Treatments	Fe (g ha ⁻¹)				Mn (g ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	171.52	132.48	27.40	63.60	29.08	18.04	95.44	5.12
T ₂ -FYM (10 t ha ⁻¹)	269.44	247.08	37.76	75.48	32.16	18.20	116.28	7.64
T ₃ -RD NPK + FYM	363.00	182.00	51.00	130.56	79.88	15.56	137.88	7.16
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	394.32	198.16	55.80	112.92	84.56	19.80	119.76	5.60
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	340.24	155.60	97.28	110.28	81.40	14.32	108.04	5.16
T ₆ -RD NPK + FYM + PSB + VAM	528.52	238.52	140.92	158.56	101.28	30.24	156.12	8.80
T ₇ -50 % P + RD NK + FYM	335.48	105.08	55.36	99.52	62.00	10.28	115.36	2.84
T ₈ -0 % P + RD NK + FYM	234.36	243.24	44.88	72.48	52.40	12.92	114.40	4.08
T ₉ -50 % P + PSB + RD NK + FYM	325.56	209.32	78.88	126.04	69.88	17.36	129.56	5.92
T ₁₀ -0 % P + PSB + RD NK + FYM	391.52	106.20	53.64	116.84	71.04	7.96	130.52	6.76
T ₁₁ -50 % P + VAM + RD NK + FYM	408.52	171.32	86.00	122.84	70.84	15.00	130.52	7.80
T ₁₂ -0 % P + VAM + RD NK + FYM	389.64	134.04	95.88	130.72	66.88	22.48	121.24	6.64
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	408.56	227.72	112.08	148.12	95.80	29.08	152.04	8.40
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	404.36	171.28	104.12	107.68	85.96	21.68	110.00	8.00
SEm±	12.76	13.00	6.56	5.92	4.04	0.92	4.44	0.32
CD (P = 0.05 %)	49.84	39.16	25.00	22.64	15.44	3.60	13.12	1.24

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

treatments T₆ (7.00, 12.48, 18.88 and 6.60 g ha⁻¹ respectively) and on par with T₁₃ (6.64, 11.40, 15.60 and 6.40 g ha⁻¹ respectively). Lower Cu uptake was recorded in T₁ (1.24, 3.16, 4.12 and 0.80 g ha⁻¹ respectively).

The micronutrients uptake was higher in case of dual inoculated treatments compared to single inoculated treatment, single inoculated treatments showed higher nutrient uptake compare to uninoculated treatments this may be due to the high solubility of micronutrient in soil through acid production which leads to higher uptake of these nutrients by plant. Gupta *et al.* (2006) noticed that the effect of bio-fertilizer inoculation and phosphorus fertilization on micronutrient uptake. The practice of seed inoculation with phosphorus solubilizing bacteria showed a significant increased in Fe, Cu, Mn and Zn uptake over uninoculated treatment. Phosphorus application also resulted in significant increase in N and P uptake in seed and straw. These findings are in accordance with those of Das *et al.* (2007) who had reported that the PSB and VAM with NK and FYM increased the micronutrient uptake by crop.

4.4.5 Correlation between yield, soil, pH, available NPK and different fractions of phosphorus in a residual crop of cowpea

The correlation between yield, available P, available nitrogen, available K, and different fractions of phosphorus was carried out (Table 64). There was significant positive correlation between yield of cowpea and saloid P, Ca- P and others, Yield was significantly correlated with available P ($r^2 = 0.565^*$), saloid P ($r^2 = 0.763^{**}$), Al-P ($r^2 = 0.605^*$) and organic- P ($r^2 = 0.647^*$) (Table 64).

pH was significantly negatively correlated with Fe-P ($r^2 = 0.566^*$) respectively. Available P was significantly positively correlated with available K ($r^2 = 0.569^*$), Ca- P ($r^2 = 0.646^*$) and organic P ($r^2 = 0.631^*$) respectively. The available K was positively correlated with other parameter.

Saloid P was significantly correlated with Ca-P ($r^2 = 0.763$). The Al-P was significantly correlated with Fe-P, Reductant – P, occluded – P and organic-P ($r^2 = 0.802^*$, $r^2 = 0.574^*$, $r^2 = 0.612^*$ and $r^2 = 0.814^*$) respectively. Fe- P was significantly correlated with reductant P, occluded – P and organic P ($r^2 = 0.811^*$, $r^2 = 0.790^*$ and $r^2 = 0.681^*$). Reductant P was significantly positively correlated with occluded P ($r^2 = 0.919^{**}$). Occluded P was positively correlated with Ca-P and organic P ($r^2 = 0.154$ and 0.374) respectively (Table 64).

There was a significant and positive correlation between different fractions of phosphorus. Shi *et al.* (2015) reported similar results on P fractions which were significantly correlated with other soil chemical properties and environmental conditions ($P = 0.005$). Changes in resin-P, NaOH-P_o, and HCl-P were positively correlated with CaM₃ and MgM₃, but negatively correlated with cumulative snowpack. Changes in NaHCO₃-Pi and NaOH-Pi fractions were positively correlated with the changes in TC and TN but negatively correlated with that in pH. Changes of NaHCO₃-P_o and residual P were positively correlated with cumulative snowpack and the changes in AlM₃, FeM₃, and KM₃. Root rhizosphere pH and root dry matter were found to be two of the most

Table 63: Residual effect of phosphorus, PSB and VAM on Zn and Cu uptake (g ha⁻¹) by cowpea at harvest in low available phosphorus soil

Treatments	Zn (g ha ⁻¹)				Cu (g ha ⁻¹)			
	Leaves	Haulm	Seed	Roots	Leaves	Haulm	Seed	Roots
T ₁ -RD NPK (150: 75: 40 kg ha ⁻¹)	5.48	7.20	4.00	1.80	1.24	3.16	4.12	0.80
T ₂ -FYM (10 t ha ⁻¹)	5.80	7.44	4.12	1.84	1.44	3.60	5.92	0.84
T ₃ -RD NPK + FYM	15.88	12.44	6.12	4.36	3.08	4.68	9.28	5.40
T ₄ -RD NPK + FYM + PSB (4 kg ha ⁻¹)	16.36	15.16	6.84	3.68	6.12	3.76	13.20	4.76
T ₅ -RD NPK + FYM + VAM (5 kg ha ⁻¹)	17.08	16.80	9.32	4.28	5.12	3.84	8.36	6.04
T ₆ -RD NPK + FYM + PSB + VAM	21.48	23.64	12.12	5.40	7.00	12.48	18.88	6.60
T ₇ -50 % P + RD NK + FYM	11.48	10.84	5.12	3.68	2.68	1.08	7.12	4.60
T ₈ -0 % P + RD NK + FYM	9.04	10.96	4.36	2.72	2.24	2.84	5.96	3.36
T ₉ -50 % P + PSB + RD NK + FYM	13.76	18.92	7.08	3.56	3.20	7.84	11.36	5.56
T ₁₀ -0 % P + PSB + RD NK + FYM	12.72	4.44	5.80	2.96	4.24	2.08	8.60	4.88
T ₁₁ -50 % P + VAM + RD NK + FYM	17.28	15.00	9.28	4.08	4.52	3.28	10.20	6.08
T ₁₂ -0 % P + VAM + RD NK + FYM	13.52	16.08	7.00	4.08	4.40	2.80	7.32	5.48
T ₁₃ -50 % P + PSB + VAM + RD NK + FYM	18.92	19.68	10.04	5.24	6.64	11.40	15.60	6.40
T ₁₄ -0 % P + PSB + VAM + RD NK + FYM	16.12	19.20	8.28	3.24	4.16	4.88	10.92	5.24
SEm±	0.76	0.68	0.40	0.20	0.28	0.24	0.56	0.28
CD (P = 0.05 %)	2.88	2.64	1.48	0.76	0.84	0.96	2.16	1.04

*RD: recommended dose, PSB: phosphorus solubilizing bacteria, VAM: vesicular arbuscular mycorrhizae, FYM: farm yard manure

Table 64: Correlation between soil phosphorus, nitrogen, potassium, different fractions of phosphorus and yield of cowpea as a residual crop in low available and high total phosphorus soil

	yield (q ha ⁻¹)	pH	Avail. - N	Avail. - P	Avail. - K	Saloid - P	Al - P	Fe - P	Reductant - P	Occluded - P	Ca - P	Organic- P
Yield q ha⁻¹	1											
pH	0.027	1										
Avail. - N	0.387	-0.085	1									
Avail. -P	0.565*	0.329	0.134	1								
Avail. - K	0.517	0.211	0.408	0.569*	1							
Saloid - P	0.763**	0.047	0.190	0.510	0.517	1						
Al - P	0.605*	-0.431	0.010	0.300	0.123	0.519	1					
Fe - P	0.165	-0.566*	-0.147	0.250	-0.027	0.287	0.802**	1				
Reductant - P	-0.043	-0.319	-0.507	0.287	-0.078	-0.051	0.574*	0.811**	1			
Occluded - P	0.011	-0.498	-0.497	0.091	-0.038	0.053	0.612*	0.790**	0.919**	1		
Ca - P	0.437	0.118	-0.122	0.646*	0.504	0.763**	0.326	0.296	0.169	0.154	1	
Organic - P	0.647*	-0.278	0.255	0.631*	0.326	0.425	0.814**	0.681**	0.488	0.374	0.373	1

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

important parameters influencing other root properties and seed yield. Near perfect linear relationship of P inflow rate and seed yield with root rhizosphere pH and RLD showed that differences in these parameters were associated with differences in root CEC and RLD (Mahanta *et al.*, 2014).

4.5 Phosphorus sorption study

Phosphorus adsorption was studied for two soils using Fox and Kamprath (1970) method. The graphical representation of equilibrium P concentration versus rate of P adsorbed on unit mass of soil was used to calculate the maximum sorption capacity of the soils and the affinity of the soil to hold P. The phosphorus sorption maxima was determined by fitting the equilibrium solution P concentration and adsorbed P values to Langmuir and Freundlich equations.

4.5.1 Langmuir isotherm

The equilibrium P concentrations and P adsorbed in two different soils varied from each other at different levels of P (Table 65 a). In two soils the equilibrium P concentration and rate of adsorption increased with increasing P levels. The equilibrium P concentration ranged from 0.12 to 46.20 and 0.011 to 44.12 $\mu\text{g ml}^{-1}$ in ZARS, GKVK and Virgin horticultural block, GKVK soils respectively. The rate of P adsorption ranged from 50.24 to 565.23 and 49.31 to 570.21 $\mu\text{g g}^{-1}$ in ZARS, GKVK and Virgin horticultural D-16 block GKVK soils respectively. The highest P sorption maxima followed the order Virgin horticultural block No. 24, GKVK > ZARS, GKVK.

4.2.2 Freundlich isotherm

The Freundlich adsorption isotherm constants are explained in Table 65b in ZARS, GKVK soil log C and log x/m values varied from 0 to 1.69 and 0 to 2.74 in 0 to 100 $\mu\text{g g}^{-1}$ P addition. In Virgin horticultural block, GKVK soil the log C and log x/m values varied from 0 to 1.68 and 0 to 2.83 in 0 to 100 $\mu\text{g g}^{-1}$ P addition.

P sorption data were fitted into Langmuir and Freundlich adsorption isotherm equations to determine various sorption constants namely, sorption maxima (smax) and bonding energy constants, Freundlich 'k' and 'n' of the soils and are given in the Table 65c. The Langmuir constant i.e. adsorption maxima was highest for Virgin horticultural block, GKVK (570.21 $\mu\text{g g}^{-1}$) and least for ZARS, GKVK (565.23 $\mu\text{g g}^{-1}$) soils. The bonding energy constants also followed the same trend wherein highest affinity of soil for P was found in Virgin horticultural block, GKVK (0.41) followed by ZARS, GKVK (0.39) soils respectively.

The Freundlich constants for two soils are illustrated in the Table (65c). The Freundlich 'k' value for ZARS, GKVK and Virgin horticultural block, GKVK soils were 115.6 and 119.4 $\mu\text{g g}^{-1}$ respectively, whereas the '1/n' values were 0.42 and 0.39 g ml^{-1} respectively. Phosphorus supply parameter of soil describes the potential of soil to release P in soil solution against depletion and is a outcome of the interaction among quantity, intensity and buffering capacity of the soil P. The supply parameter of two soils (Table 65c) varied with additions of phosphorus and the amount increased with increased P

levels. The supply parameter constant ranged from 285.36 to a minimum value of 0.51. The low supply parameter of soil samples indicates depletion in intensity and quantity factor due to P stress.

The adsorption isotherms or model describe the quantity - intensity relationship between solution and solid phosphorus phases for a given soil. The phosphate adsorption isotherm gave good fit adopting Langmuir ($r^2 = 0.95$ to 0.99) and Freundlich ($r^2 = 0.97$ to 0.99) in case of two soils. Similar results have been obtained by Zhang *et al.* (2005) they observed that the $S_{\max}$ value ranged from 34 to 500 mg kg^{-1} and was highly correlated with clay content ($r = 0.79$), organic C ($r = 0.80$), Al_{ox} ($r = 0.88$), and Fe_{ox} ($r = 0.83$). Soil pH was not correlated ($p > 0.05$) with $S_{\max}$. Path analysis showed significant direct effects ($p < 0.01$) between Al_{ox} and $S_{\max}$ and between Fe_{ox} and $S_{\max}$ but these relationships were highly influenced by indirect effects of Al_{ox} and Fe_{ox} . Multiple regression agreed well with path analysis and found that the combination of Al_{ox} and Fe_{ox} were the two most important soil properties related to $S_{\max}$ of the soils studied. Significant relationships existed between Al_{M3} ($r = 0.54$) and $S_{\max}$ and between Fe_{M3} ($r = 0.54$) and $S_{\max}$. Three P saturation indices studied were highly correlated ($p < 0.05$) with each other. Our results show that $S_{\max}$ of Oklahoma soils may be predicted with oxalate extractable Al and Fe or M3 extractable Al, Fe, and Ca. Pal *et al.*, (2009) studied the effect of land use pattern on P adsorption desorption in Terai soils of West Bengal. The different land use pattern used for the study was forest, orchard, cultivated land and tea garden. The results indicated that phosphorus adsorbed at 0.2 mg L^{-1} equilibrium solution P concentration in these land uses was low (40.2 to 67.6 mg kg^{-1}). The adsorption behaviour of these soils could be significantly correlated with Freundlich, Langmuir and Tempkin equations. The study revealed that phosphorus adsorption at 0.2 mg L^{-1} equilibrium solution P concentration was significantly correlated with organic carbon, CEC, free Fe_2O_3 and AEC, suggesting the role of these soil characteristics in P sorption process. Higher amount of added P was extracted during two successive desorption with 0.5 M NaHCO_3 (pH 8.5).

Egwu *et al.*, (2010) initiated a study to determine the P sorption characteristics and derive parameter estimates relevant in the prediction and management of P in major soils of the Nigerian savanna. The adsorption isotherms for the soils were gentle to steep, covered a wide range of P sorption characteristics. The Langmuir plots gave gentle curves in most cases, indicating that the assumptions on which the model was based were not fully satisfied. The Langmuir parameter estimates varied widely for the soils. The energy coefficient (K) ranged from 0.015 to $11.593 \text{ ml } \mu\text{g}^{-1}$ and was particularly high for soils of the Jos plateau with appreciable amounts of Fe oxides. The standard phosphate requirement (SRP) ranged from 2.87 - $1021 \mu\text{g g}^{-1}$, which implied that P amendment (fertilization) would be necessary for good crop growth in a good number of soils. P sorption parameters appreciably influenced by dithionite extractable Fe (Fed).

Generally, pH and CEC explained over 50 % of the variation in the sorption parameters in these savanna soils. In a study conducted by Mozaed *et al.*, (2010) to determine P sorption characteristics of five soil samples of southeastern Iran in a cropping system illustrated that Langmuir adsorption isotherm was much accurate for P

adsorption and had maximum r^2 . The adsorption of P was different for different soil due to the soil parameters like soil organic carbon (SOC), pH, exchangeable calcium, aluminium (Al) etc. results also indicated that SOC, and exchangeable Al are the major predictors of P sorption in these soils. Sediments from the canal and lake had the greatest native adsorbed P and the highest zero equilibrium P concentration. Sediment from the estuary had the highest P adsorption and followed by those from wetland and marine origins, respectively. Phosphorus de-sorption from sediments by replacing exchangeable P with Cl^- (20 mmol L^{-1} KCl) was obtained from an excellent fit of the data by an exponential growth model of desorption kinetics. The fractions of retained P ($P_{\text{ret}} = P_{\text{ads}} - P_{\text{des}}$) were as high as 85-98% in the studied sediments, which displayed strong P retention capacities by all these sediments reported by Qingren Wang and Yuncong Li, (2010).

Table 65a: Equilibrium P concentration and adsorption of P per unit soil in two type of soil by Langmuir isotherm

Soil type	P added (mg kg ⁻¹)	0	5	10	25	50	75	100
High available and Total P soil	C (µg ml ⁻¹)	0	0.12	0.73	5.66	13.99	29.66	46.2
	x/m(µg/g)	0	50.24	95.71	199.20	361.40	459.60	565.23
	C/x/m	0	0.00	0.01	0.029	0.04	0.07	0.09
Low available P and high Total P	C (µg ml ⁻¹)	0	0.11	0.67	5.54	12.10	28.41	44.12
	x/m(µg/g)	0	49.31	96.12	201.31	345.12	475.61	570.21
	C/x/m	0	0.001	0.02	0.031	0.03	0.06	0.08

Table 65b: Equilibrium soil solution, adsorbed P derived from Freundlich isotherm in two soils

Soil type	P added (mg kg ⁻¹)	0	5	10	25	50	75	100
High available and Total P soil	Log C	0	-1.0	-1.0	0.75	1.23	1.45	1.69
	Log x/m	0	1.68	2.11	2.31	2.67	2.73	2.74
Low available P and high Total P	Log C	0	-1.0	-0.15	0.81	1.01	1.43	1.68
	Log x/m	0	1.7	2.11	2.36	2.69	2.64	2.83

Table 65c: Equilibrium soil solution, adsorbed P derived from Freundlich isotherm in two soils

Soil type	Langmuir constants			Freundlich constant			Supply parameter			Maximum buffering capacity
	b (µg g ⁻¹)	k (ml µg ⁻¹)	r ²	k (µg g ⁻¹)	1/n (g ml ⁻¹)	r ²	r ²	K1	K2	
High available and Total P soil	565.23	0.39	0.97	115.6	0.42	0.99	0.91	264.51	0.51	90.12
Low available P and high Total P	570.21	0.41	0.95	119.4	0.39	0.97	0.97	285.36	0.52	93.45

V SUMMARY

The study was carried on two types of soil which were low and high in available phosphorus status by growing maize-cowpea cropping sequence, where cowpea grown as a residual crop. The results of the experiment are briefly summarized as under.

5.1 Field experiment: Effect of application of different levels of phosphorus, phosphorus solubilizers and FYM on performance of maize under maize - cowpea cropping system under high available and total phosphorus soils.

- The soil pH declined in many of the treatments at 60 DAS and at harvest of maize. 50 % P + PSB + RD NK + FYM recorded significantly higher EC (0.15 dS m^{-1}). However nutrient status of soil (major, secondary and micronutrients status) was significantly higher on application of RD NPK + FYM + PSB + VAM (T_6) and 50 % P + PSB + VAM + RD NK + FYM (T_{13}).
- The higher ratio of N:P in soil at tasseling stage and at harvest (6.21 and 5.07) was recorded in T_{12} (0 % P + VAM + RD NK + FYM). Higher ratio of P:K in soil at tasseling and at harvest was recorded in T_4 (RD NPK + FYM + PSB @ 4 kg ha^{-1}) (0.16 and 0.18), higher P:S ratio at harvest (2.14) was recorded in T_9 (50 % P + PSB + RD NK + FYM).
- The acid phosphatase activity was higher in T_6 and T_{13} (65.85 and $64.73 \text{ } \mu\text{g of PNP g}^{-1} \text{ soil hr}^{-1}$) respectively and lower activity was recorded in T_1 ($27.30 \text{ } \mu\text{g of PNP g}^{-1} \text{ soil hr}^{-1}$).
- Significantly higher plant height, maximum number of leaves, higher leaf area and leaf area index were recorded in T_6 (RD N P K + PSB + VAM + FYM). Significantly higher fresh weight, dry weight of maize leaf, stover weight and root weight were recorded in T_{14} (0 % P + PSB + VAM + RD NK + FYM).
- Yield parameters such as number of cobs plant⁻¹, number of rows per cob, number of seeds cob⁻¹ were significantly higher in T_{14} (0 % P + PSB + VAM + RD NK + FYM). Higher test weight (33.40 g) was recorded with application of 50 % P + PSB + VAM + RD NK + FYM (T_{13}) and T_6 (32.80g). Higher cob weight was recorded in T_{10} (0 % P + PSB + RD NK + FYM), whereas seed weight (g/cob) was higher at RD N P K + PSB + VAM + FYM.
- Maize grain yield (85.01 q ha^{-1}) and stover yield (97.70 q ha^{-1}) were significantly higher on application of RD NPK + PSB + VAM + FYM (T_6) and on par with T_{13} (50 % P RD N K + PSB + VAM + FYM).
- Major, secondary and micronutrients contents and uptake were higher in T_6 (RD N P K + PSB + VAM + FYM) and T_{14} (0 % P RD N K + PSB + VAM + FYM) treatments.
- Maize yield was positively correlated with available P (0.673**), saloid-P (0.908**), Ca-P (0.732**) and available nitrogen (0.569*). Available P was positively correlated

with saloid P (0.679**), Org-P (0.475), Ca-P (0.401) and reductant P (0.397). All the phosphorus fractions were positively correlated among each others.

5.2 Field experiment: Residual effect of different levels of phosphorus, phosphorus solublizers and FYM in high available and total phosphorus soils on performance of cowpea under maize - cowpea cropping system.

- Treatment T₃ (RD NPK) recorded significantly higher available nitrogen and phosphorus status at 60 DAS and at harvest. Higher available potassium at 60 DAS and at harvest were recorded in 0 % P + PSB + VAM + RD NK + FYM (291.23 and 275.32 kg ha⁻¹) respectively. Significantly higher exchangeable Ca (2.44 and 2.23 m.eq (100 g soil)⁻¹ and Mg (2.11 and 1.11 m.eq 100 g soil⁻¹) respectively at 60 DAS and at harvest were recorded in T₃ (RD NPK + FYM) 60 DAS. DTPA extractable micronutrients status in high available P soil was significantly higher in T₁₃ (50 % P + PSB + VAM + RD NK + FYM) at both the stages.
- The higher ratio of N:P in soil at 60 DAS and at harvest (6.52 and 5.92) respectively was recorded in T₁ (RD NPK alone). Significantly higher P:K ratio in soil at 60 DAS and at harvest was recorded in T₄ (PSB + RD NPK + FYM (0.15) and T₅ (RD NPK + FYM + VAM) (0.15). The higher P:S ratio in soil at 60 DAS and at harvest were recorded in T₆ (PSB + VAM + RD NPK + FYM (1.71 and 1.96 respectively) and T₄ (1.67 and 1.78 respectively). Treatment T₁₀ and T₄ recorded higher P:Zn ratio (9.16 and 9.01 respectively) at 60 DAS of cowpea soil and lower ratio was recorded in T₂ (FYM alone) (5.24). After harvest the P:Zn ratio was significantly higher in T₈ (0 % P + RD NK + FYM) (14.38) and lower in T₁₄ (0 % P + PSB + VAM + RD NK + FYM) (4.63).
- The acid phosphatase activity at 60 DAS and at harvest of cowpea soil was significantly higher in T₁₄ (0 % P + PSB + VAM + RD NK + FYM) (39.43 and 27.14 µg of PNP g⁻¹ soil hr⁻¹ respectively) and T₁₂ (0 % P + VAM + RD NK + FYM) at (37.34 and 26.26 µg of PNP g⁻¹ soil hr⁻¹ respectively).
- Total P content has decreased drastically in treatments with 0 % P or without P fertilizer + NK fertilizer + organic matter + biofertilizer treatments compared to treatments containing full dose of P fertilizer + NK + organic matter + biofertilizers.
- Significantly higher plant height, number of leaves, leaf area, leaf area index and fresh weight were recorded in RD NPK + FYM + PSB + VAM (T₆) and T₁₃ (50 % P + PSB + VAM + RD NK + FYM). At 60 DAS the fresh weight of leaf, haulm and root of cowpea were significantly higher in T₆ (12.80, 14.33 and 6.57 g plant⁻¹ respectively) followed by T₁₃ (12.53, 13.83 and 5.96 g plant⁻¹ respectively).
- Significantly higher dry weight of cowpea leaf at 60 DAS and at harvest was recorded in T₆ (PSB + VAM + RD NPK + FYM) (4.13 and 8.43 g plant⁻¹ respectively) and T₁₃ (50 % P + PSB + VAM + RD NK + FYM) (4.13 and 8.05 g plant⁻¹ respectively). Haulm weight, root weight and total dry matter of cowpea followed the similar trend.

- Yield attributes of cowpea such as higher number of pods plant⁻¹ (9.78 pods plant⁻¹), number of seeds pod⁻¹ (13.33), 1000 seeds weight (126.67 g), weight of pods (27.32) were observed in T₆ followed by T₁₃. Whereas T₁₃ recorded significantly higher seed weight (g per pod) of cowpea (8.43 g pod⁻¹) and was on par with T₆; 8.40 g pod⁻¹.
- Significantly higher grain and haulm yield of 13.73 and 19.23 q ha⁻¹ respectively was recorded in PSB + VAM + RD NPK + FYM followed by T₁₃ and T₉ (13.14 and 18.39 q ha⁻¹ respectively) and (12.83 and 17.97 q ha⁻¹ respectively). Significantly lower grain and haulm yield of 7.27 and 9.71 q ha⁻¹ was recorded in T₁ [RD NPK (150: 75: 40 kg ha⁻¹)].
- Higher major and secondary nutrients content in leaves, haulm and roots of cowpea were recorded in T₆ and T₁₃. Iron content in cowpea in different parts (leaves, haulm and roots) at 60 DAS was significantly higher in T₆ (PSB + VAM + RD NPK + FYM) and on par with T₁₃. T₈ recorded higher manganese content. Significantly higher copper and zinc content was recorded in T₆.
- Major, secondary and micro nutrients uptake by leaves, haulm, grain and roots of cowpea crop at harvest was significantly higher in T₆ (PSB + VAM + RD NPK + FYM).
- Yield of cowpea was positively correlated with saloid P ($r^2 = 0.564^*$), Ca- P ($r^2 = 0.583^*$) and available P ($r^2 = 0.127$). Saloid P was positively correlated with Ca-P ($r^2 = 0.762$). The Al-P was significantly correlated with Fe-P, Reductant – P, occluded – P and organic-P ($r^2 = 0.624^*$, 0.906^* , 0.697^* and 0.618^* respectively). Fe- P was significantly correlated with reductant P, occluded – P and organic P ($r^2 = 0.653^*$, 0.919^* and 0.745^* respectively). The fractions were positively correlated to each other.

5.3 Pot experiment: Effect of application of different levels of phosphorus, phosphorus solubilizers with FYM to low available and high total phosphorus soils on performance of maize under maize - cowpea cropping system and changes in soil properties and nutrient status at different growth stages of crop.

- ❖ Among the treatments at tasseling stage pH was declined in T₁₃ (50 % P +PSB + VAM + RD NK + FYM) (6.10).
- ❖ Major nutrient was increased in combined inoculation compared to single and uninoculated treatment declined compared to initial in all treatments except in T₆ where slightly increased.
- ❖ Significantly higher exchangeable Ca (5.50 and 4.61 m.eq 100 g soil⁻¹ respectively) and Mg (2.89 and 2.55 m.eq 100 g soil⁻¹ respectively) at tasseling and at harvest were noticed in T₆ (RD NPK + FYM + PSB + VAM).
- ❖ Significantly higher micronutrient content in soil was recorded in T₆ (NPK + FYM + PSB + VAM) namely Fe, Mn, Zn and Cu (32.94, 19.37, 1.16 and 3.59 mg kg⁻¹ respectively) at both stages.

- ❖ Higher saloid P and Ca-P content was recorded in T₆ (PSB + VAM + RD NPK + FYM) at tasseling and at harvest (12.37 and 7.58 mg kg⁻¹ respectively) but maximum decrement in Al-P, Fe-P, RS-P, total P and organic-P was recorded at harvest in T₁₄ (0 % P +PSB + VAM + RD NK + FYM) (288.30, 225.60, 187.90, 905.65 and 53.24 mg kg⁻¹ respectively).
- ❖ Plant height, leaf area and leaf area index fresh the plant height of maize were higher in T₆ (RD NPK + FYM + PSB + VAM). At tasseling and at harvest (189.0 and 214.50 cm) respectively, leaves area (2238.11 and 3197.3 cm²) respectively, leaf area index (2.49 and 1.78) respectively and fresh weight leaves, stover and roots (89.52, 188.94 and 59.10 g plant⁻¹).
- ❖ Yield attributes of maize under low available phosphorus soil were higher in T₆ (RD NPK + FYM + PSB + VAM) namely number of rows (13.75 per cob), number of seeds row⁻¹ (21.25), test weight (17.79 g) , cob weight (55.50 g), seed weight (36.45 g per cob), grain yield (36.45 g pot⁻¹) and stover (49.33 g pot⁻¹).
- ❖ Major nutrients and secondary nutrient content of maize at tasseling was significantly higher in T₆ (RD NPK + FYM + PSB + VAM) NPK.
- ❖ Iron content of maize was significantly higher in T₁₃ (50 % P +PSB + VAM + RD NK + FYM) but Mn, Zn and Cu were significantly higher in T₆ at tasseling stage of pot culture.
- ❖ Major nutrients uptake by maize at harvest were significantly higher in T₆ (RD NPK + FYM + PSB + VAM) and T₁₃ (50 % P + RD NK + FYM + PSB + VAM).
- ❖ Secondary and micro nutrients uptake by maize were higher at harvest in T₆ (RD NPK + FYM + PSB + VAM).
- ❖ Yield of maize positively and significantly correlated with available PNK (0.891**, 0.741**, 0.555**), saloid-P (0.802**) and Ca-P (0.589**). The available nitrogen positively and significantly correlated with available P (0.718*), saloid P (0.745**) and Ca-P (0.692*).
- ❖ Available P was positively and significantly correlated with available K (0.621*) saloid P (0.601*) and organic P (0.475). Saloid P was significantly and positively correlated with Ca-P (0.763**). Al-P was significantly and positively correlated with organic, Fe, occluded and Reductant P (0.855**, 0.802**, 0.612* and 0.574* respectively).

5.4 Pot experiment: Studies on the residual effect of different levels of phosphorus, phosphorus solubilizers with FYM to soil low in available P and high total phosphorus on performance of residual cowpea in maize - cowpea cropping system.

- The higher pH was noticed in T₄ (RD NPK + FYM + PSB) (6.47) and T₉ (50 % P +RD NK + FYM + VAM) recorded higher EC (0.349 ds m⁻¹).
- Available nitrogen in soil at 60 DAS was significantly higher in 50 per cent P + Mycorrhiza + RD NK & FYM (172.35 kg ha⁻¹), T₆ RD NPK + FYM + PSB +

Mycorrhiza recorded significantly higher available P_2O_5 (33.25 kg ha^{-1}) and significantly higher available K ($281.77 \text{ kg ha}^{-1}$) at 60 DAS was recorded in (T_8) 0 % P + Rec NK & FYM.

- At 60 DAS higher available S was observed in T_7 50 % P + Rec NK & FYM (20.61 mg kg^{-1}), RD NPK+FYM+Mycorrhiza recorded significantly higher exchangeable Ca content ($3.54 \text{ meq /100 g soil}$) . At harvest RD NPK+FYM+Mycorrhiza recorded significantly higher Mg content ($2.02 \text{ meq/100g soil}$)
- At 60 DAS T_4 recorded significantly higher Fe content (19.80 mg kg^{-1}) while at harvest of cowpea T_6 (RD NPK+FYM+PSB+Mycorrhiza) was recorded significantly higher manganese and Zn 9.24 and 2.95 mg kg^{-1} but significantly higher Cu content of 0.95 mg kg^{-1} was noticed on application of T_7 (50 % P +RD NK & FYM)
- Higher ratio of N:P in soil at 60 DAS of cowpea (12.45) was recorded in 0 % P + VAM + RD NK + FYM but at harvest it was higher (13.06) in 0 % P + PSB + RD NK + FYM. In case of P:K in soil of cowpea at 60 DAS was in T_6 (RD NPK+FYM+PSB+VAM) (0.10) and T_{10} (0.10) but in case of harvest T_3 (RD NPK+FYM) (0.10) showed higher P:K ratio.
- The highest P:S ratio in cowpea soil at 60 DAS and at harvest (0.65 and 0.52) and 0.57 and 0.51 were recorded in T_6 (RD N P K + PSB + VAM + FYM) and T_{10} (0 % P + PSB + RD NK + FYM). T_6 (RD NPK + FYM + PSB + Mycorrhiza) increased P:Ca significantly at 60 DAS of cowpea (0.018). After harvest the P:Zn ratio was significantly higher in T_3 , T_2 and T_5 (8.94 , 5.58 and 5.28 respectively).
- Saloid – P was significantly high in T_6 (RD NPK + FYM + PSB + VAM) 5.71 mg kg^{-1} . T_3 (RD NPK + FYM) $357.05 \text{ mg kg}^{-1}$) recorded significantly higher Al-P. The minimum Fe-P was recorded in 0 % P + PSB + VAM + RD NK + FYM ($211.63 \text{ mg kg}^{-1}$). Lower reductant soluble P was recorded in T_{14} ($174.85 \text{ mg kg}^{-1}$). Higher Ca-P was recorded in T_{14} (5.77). The maximum decrement in organic-P was recorded in T_1 (RD NPK) 43.48 mg kg^{-1} , the maximum increment was recorded in T_3 (66.59 mg kg^{-1}). RD NPK + FYM compared to initial ($1185.05 \text{ mg kg}^{-1}$).
- Significantly higher haulm height (74.08 cm), leaf area (61.75 cm^2) and leaf area index (0.49) was recorded at harvest in T_6 .
- Treatment T_6 (RD NPK + FYM + PSB + Mycorrhiza) resulted in higher number of pods plant^{-1} ($7.1 \text{ pods plant}^{-1}$), number of seeds pod^{-1} ($14.00 \text{ seeds pod}^{-1}$), seed weight (8.79 g pod^{-1}), grain and haulm yield of 21.60 and 29.73 g pot^{-1} respectively. T_3 (RD NPK & FYM) resulted in higher 1000 seeds weight (100.85 g).
- Total nitrogen and P content of cowpea increased with residual effect of RD NPK + FYM + PSB + VAM and K is higher in T_{13} .
- S, Ca and Mg and micronutrients content in cowpea were higher in RD NPK + FYM + PSB + VAM.
- Nitrogen, phosphorus, potassium, sulphur, calcium, magnesium and micronutrient uptake were significantly higher in RD NPK + FYM + PSB + VAM.

- There was significant and positive correlation between yield of cowpea and saloid P, Ca- P and others, Yield was significantly correlated with available P ($r^2 = 0.565^*$), saloid P ($r^2 = 0.763^{**}$), Al-P ($r^2 = 0.605^*$) and organic- P ($r^2 = 0.647^*$)
- Soil pH was significantly and negatively correlated with Fe-P ($r^2 = 0.566^*$). Available P was significantly positively correlated with available K ($r^2 = 0.569^*$), Ca- P ($r^2 = 0.646^*$) and organic P ($r^2 = 0.631^*$) respectively. The available K was positively correlated with other parameter.

5.5 Phosphorus sorption study

Langmuir isotherm

- The equilibrium P concentration ranged from 0.12 to 46.20 and 0.011 to 44.12 $\mu\text{g ml}^{-1}$ in ZARS GKVK and Virgin horticultural block GKVK soils, respectively. The rate of P adsorption ranged from 50.24 to 565.23 and 49.31 to 570.21 $\mu\text{g g}^{-1}$ in ZARS GKVK and Virgin horticultural block GKVK soils respectively. The highest P sorption maxima followed the order Virgin horticultural Block No. 24 GKVK > D-16 Block ZARS GKVK.

Freundlich isotherm

- The log C value for ZARS GKVK soil varied in D-16 Block ZARS, GKVK soil log C and log x/m values varied from 0 to 1.69 and 0 to 2.74 in 0 to 100 $\mu\text{g g}^{-1}$ P addition. In Virgin horticultural Block No. 24, GKVK soil the log C and log x/m values varied from 0 to 1.68 and 0 to 2.83 in 0 to 100 $\mu\text{g g}^{-1}$ P addition.
- The Langmuir constant i.e. adsorption maxima was highest for Virgin horticultural Block No. 24 GKVK (570.21 $\mu\text{g g}^{-1}$) and least for ZARS GKVK (565.23 $\mu\text{g g}^{-1}$) soils. The bonding energy constants also followed the same trend wherein highest affinity of soil for P was found in Virgin horticultural block GKVK (0.41) followed by ZARS GKVK (0.39) soils. The phosphate adsorption isotherm gave good fit adopting Langmuir ($r^2 = 0.95$ to 0.99) and Freundlich ($r^2 = 0.97$ to 0.99) in case of two soils.

Practical utility of the work

- An important practical outcome of the study is that 50 % of P can be saved without compromising on yield of crop and soil nutrient status in soil with high available P status.
- In case of soil with low available P status application of recommended dose of P to the first crop only would be sufficient. Thus saving on fertilizer to the second crop.
- Addition of lower P doses along with organic manures and P solubilizers to soil which may have high, medium or low P.

Future line of work

- ✓ It would be important to characterize the soils for available and total P in other parts of Karnataka under various crops and to work out the exact relation between available P and total P.
- ✓ A ready reckoner to be prepared in terms of quantity of P to be added to various types of soils and crops for achieving better P use efficiency.
- ✓ Similar studies need to be carried out on soils with variation in terms of amount, type of clay and organic matter content.

VI REFERENCES

- ABEKOE, M. K. AND SAHRAWAT, K. L., 2003, Long-term cropping effect on phosphorus fractions in an Ultisol of the humid forest zone in West Africa. *Comm. Soil Sci. Pl. Analy.*, **34**(3-4): 427-437.
- ADEDIRAN, J. A., TAIWO, L. B., AKANDE, M. O., SOBULO, R. A. AND IDOWU, O. J., 2004, Application of organic and inorganic fertilizer for sustainable maize and cowpea yields in Nigeria. *J. Pl. Nut.*, **27**(7): 1163-1181.
- ADNANE, B., MUSTAPHA, F., NEILA, A., MOHAMED, F., BOUAZIZ, S., JACQUES, D. J., CHERKAoui, I. M. AND CHERKI, G., 2012, Low soil phosphorus availability increases acid phosphatases activities and affects P partitioning in nodules, seeds and rhizosphere of *Phaseolus vulgaris*. *Agri*, **(2)**: 139-153.
- AKANDE, M. O., ADEDIRAN, J. A. AND OLUWATOYINBO, F.I., 2005, Effects of rock phosphate amended with poultry manure on soil available P and yield of maize and cowpea. *African J. Biotech.*, **4**(5): 444-448.
- ALOCIOUS ANU, 2009, Management of phosphorus in soils with high phosphorus status. *M.Sc. Thesis*, UAS,, GKVK, Bangalore Karnataka, India.
- AMRANI, M., WESTFALL, D. G. AND MOUGHLI, L., 1999, Evaluation of residual and cumulative phosphorus effects in contrasted Moroccan calcareous soils. *Nut. Cycl. Agroecosys.*, **55**: 231-238.
- ANDRADE, G., MIHARA, K.L., LINDERMAN, R.G. AND BETHLENFALVAY, G.J., 1997, Bacteria from rhizosphere and hydrosphere soils of different arbuscular mycorrhizal fungi. *Pl. Soil*, **192**: 71-79.
- ANNAHEIMA, K. E., DOOLETTE A. L., SMERNIK R. J., MAYER J., OBERSON A., FROSSARD E. AND BÜNEMANN, E. K., 2015, Long-term addition of organic fertilizers has little effect on soil organic phosphorus as characterized by ³¹P NMR spectroscopy and enzyme additions. *Geoderma*, **240**: 1-11.
- AULAKH, M. S., KABBA, B. S., BADDESHA, H. S., BAHL, GULSHAN, S. AND GILL M. P. S., 2003, Crop yields and phosphorus fertilizer transformations after 25 years of applications to a subtropical soil under groundnut-based cropping systems. *Field Crops Res.*, **83**: 283-296.
- BAIRVA, M., MEENA, S. S. AND MEHTA, R. S., 2012, Effect of bio-fertilizers and plant growth regulators on growth and yield of fenugreek (*Trigonella foenum-graecum* L.). *Int. J. Seed Spices*, **2**(1): 28-33.

- BALASUBRAMANIAN, V. AND RAJ, D., 1969, Study of the forms of soil phosphorus in Tamil Nadu. *Madras Agril. J.*, **56**: 790-793.
- BALEMI, T. AND NEGISHO, K., 2012, Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *J. Soil Sci. Pl. Nut.*, **12**(3): 547-561.
- BANERJEE, A., SANYAL, S. AND SEN, S., 2012, Soil phosphatase activity of agricultural land: A possible index of soil fertility. *Agric. Sci. Res. J.*, **2**(7): 412-419.
- BAPAT, M. V., PADOLE, G. C., TOLEY, N. G. AND BEDEKAR, U. G., 1965, Forms of phosphorus in Vidharbha soils. *J. Indian Soc. Soil Sci.*, **13**: 33-36
- BARROSO, C. B. AND NAHAS, E., 2005, The status of soil phosphate fractions and the ability of fungi to dissolve hardly soluble phosphates. *Appli. Soil Ecol.*, **29**: 73-83.
- BETTY, N., FITRIATIN, B. J. AND TOTO, S., 2008, The influence of organic phosphorous substrate on phosphatase activity of soil microbes. *Proc. Int. Sem. on Chem.* (Pp. 663).
- CARDOSO, I. M. AND KUYPER, T. W., 2006, Mycorrhizas and tropical soil fertility. *Agri. Ecosys. Environ.*, **116**(1-2): 72-84
- CHATTERJEE, D., DATTA, S. C. AND MANJAIAH, K. M., 2014, Fractions, uptake and fixation capacity of phosphorus and potassium in three contrasting soil orders. *J. Soil Sci. Pl. Nut.*, **14**(3): 640-656.
- CLARK, R. B., BALIGAR, V. C. AND ZOBEL, R. W., 2005, Response of mycorrhizal switchgrass to phosphorus fractions in acidic soil. *Comm. Soil Sci. Pl. Anal.*, **36**(9-10): 1337-1359.
- *CONTE, E., ANGHINONI, I. AND RHEINHEIMER, D. S., 2003, Phosphorus accumulation fractions in a clayey latosol (Oxisol) in relation to phosphate doses under no-tillage. *Revista Brasileira de Ciencia do Solo*, **27**(5): 893-900.
- DAROUB, S. H., ELLIS, B. G. AND ROBERTSON, G. P., 2001, Effect of cropping and low-chemical input systems on soil phosphorus fractions. *Soil Sci.*, **166**(4): 281-291.
- DAS, K., RAMAN, D., NARAYANAPPA, S. T. AND NAZIM SEKEROGLU, 2007, Comparative efficiency of bio- and chemical fertilizers on nutrient content and biomass yield in medicinal plant *Stevia rebaudiana* Bert. *Intern. J. Nature and Eng. Sci.* **1**(3): 35-39.

- DEVI, M. C. AND REDDY, M. N., 2002, Phenolic acid metabolism of groundnut (*Arachis hypogaea* L.) plants inoculated with VAM fungus and Rhizobium. *Pl. Growth Reg.*, **37**(2): 151-156.
- DICK, W. A., CHENG, L. AND WANG, P., 2000, Soil acid and alkaline phosphatase activity as pH adjustment indicators. *Soil Bio. Biochem.* **32**(13): 1915-1919.
- DODDAMANI, V. S. AND SHESHAGIRI RAO, T., 1988, Solubility criteria for the existence of solid phase phosphates in typical soils of Karnataka. *J. Indian Soc. Soil Sci.*, **36**: 666-670.
- DUTTA, D. AND BANDYOPADHYAY, P., 2009, Performance of chickpea (*Cicer arietinum* L.) to application of phosphorus and bio-fertilizer in laterite soil. *Archi. Agron. Soil Sci.*, **55**(2): 147-155.
- EGWU, G. N., UYOVBISERE, E. O. AND OKUNOLA, O. J., 2010, Phosphorus sorption isotherms and parameter estimates of soils of the savanna, and effect of soil properties on these parameters. *J. Env. Agril. Food Chem.*, **9**(5): 866-874.
- EKENLER, M. AND TABATABAI, M. A., 2003, Responses of phosphatase and arylsulphatase in soils to liming and tillage systems. *J. Pl. Nutr. Soil Sci.*, **166**(3): 281-290.
- FEN, G. S., YUBO, L., XIAO, L., WANG, H., ZHANG, F., SUO, T., CAI, X. AND RENGEL, Z., 2002, Histochemical visualization of phosphatase released by arbuscular mycorrhizal fungi in soil. *J. Pl. Nutr.*, **25**(5): 969-980.
- FENG, G., SONG, Y. C., LI, X. L. AND CHRISTIE, P., 2003, Contribution of arbuscular mycorrhizal fungi to utilization of organic sources of phosphorus by red clover in a calcareous soil. *App. Soil Eco.*, **22**(2): 139-148.
- FOX, R.L. AND KAMPRATH F.J., 1970, Phosphate sorption isotherms for evaluating the phosphate requirement of soil. *Soil Sci. Soc. Amer. Proc.*, **34**: 902-7.
- FOX, T.R. AND COMERFORD, N.B., 2002, Rhizosphere phosphatase activity and phosphatase hydrolysable organic phosphorus in two forested spodosols. *Soil Bio. Biochem.*, **34**: 1487-1494.
- *FULEKY, G., 2006, Phosphorus supply of typical Hungarian soils. *Agrokemia es Talajtan*, **55**(1): 117-126.
- GARG, S. AND BAHL, G.S., 2008, Phosphorus availability to maize as influenced by organic manures and fertilizer P associated phosphatase activity in soils. *Biores. Tech.*, **99**: 5773-5777.

- GHOSAL, P.K., BHATTACHARYA, B., BAGCHI, D.K. AND CHAKRABORTY, T., 2014, Direct and residual effect of rock phosphates on rice (*Oryza sativa* L.) productivity and soil phosphorus status in Alfisols of eastern Plateau of India. *Univ. J. Agric. Res.*, **1**(2): 35-40.
- GHOSH, P. K., DEVI DAYAL MANDAL, K. G., WANJARI, R. H. AND HATI, K. M., 2003, Optimization of fertilizer schedules in fallow and groundnut-based cropping systems and an assessment of system sustainability. *Field Crops Res.*, **80**(2): 83-98.
- GIRI, B., KAPOOR, R. AND MUKERJI, K. G., 2003, Influence of arbuscular mycorrhizal fungi and salinity on growth, biomass and mineral nutrition of *Acacia auriculiformis*. *Bio. Fert. Soil*, **38**: 170-175.
- GREEN, V. S., DAO, T. H., CAVIGELLI, M. A. AND FLANAGAN, D. C., 2006, Phosphorus fractions and dynamics among soil aggregate size classes of organic and conventional cropping systems. *Soil Sci.*, **171**(11): 874-885.
- GRYNDLER, M., LESTINA, J., MORAVEC, V., PRIKRYL, Z. AND LIPAVSKY, J., 1990, Colonization of maize roots by VAM fungi under conditions of long-term fertilization of varying intensity. *J. Agri. Eco. Env.*, **29**: 183-186.
- GUPPY, C. N., MENZIES, N. W., MOODY, P. W. AND BLAMEY, P. C., 2005, Competitive sorption reactions between phosphorus and organic matter in soil. *Australian J. Soil Res.*, **43**: 189-202.
- GUPTA, A, SHARMA, V. K., SHARMA, G. D. AND CHOPRA, P., 2006, Effect of biofertilizer and phosphorus levels on yield attributes, yield and quality of urdbean (*Vigna mungo*). *Indian J. Agron.*, **51**(2): 142-144.
- HALAJNIA A., HAGHNIA, G.H., FOTOVAT, A. AND KHORASANI, R., 2009, Phosphorus fractions in calcareous soils amended with P fertilizer and cattle manure. *Geoderma*, **150**:209-213.
- HALSTEAD, R. L. AND SOWDEN, F. J., 1986, Effect of long term of additions of organic matters on crop yields and soil properties in clay and sandy soils. *Canadian J. Soil Sci.*, **48**: 341-348.
- HANSEN, J. C., CADE-MENUN, B. J. AND STRAWN, D.G., 2004, Phosphorus speciation in manure amended alkaline soils. *J. Environ. Qual.*, **33**: 1521-1527.
- HARTONO, A., FUNAKAWA, S. AND KOSAKI, T., 2006, Transformation of added phosphorus to acid upland soils with different soil properties in Indonesia. *Soil Sci. Pl. Nutr.*, **52**(6): 734-744.

- HE, Z. Q., GRIFFIN, T. S. AND HONEYCUTT, C. W., 2004, Evaluation of soil phosphorus transformations by sequential fractionation and phosphatase hydrolysis. *Soil Sci.*, **169**(7): 515-527.
- HEMALATHA, S., RAO, PRAVEEN V., REDDY KUMAR PRATAP A. AND SURESH, K., 2013, A critical review on the influence of phosphorus on available nutrient status of soil in sunflower-groundnut crop sequence. *Intern. J. Pl. Animal Env. Scie.*, **3**(3): 165-167.
- *HENIRIQUEZ, C. AND KILLORN. R, 2005, Soil P forms and P uptake under intensive plant growth in the greenhouse. *Agronomia Costarricense*, **29**(2): 83-97.
- HESSE, P.R., 1994, *A Text Book of Soil Chemical Analysis*. CBS publishing House, New Delhi, India. pp. 720.
- HOCKING P. J., 2001, Organic acids exuded from roots on phosphorus uptake and aluminium tolerance of plants in acid soils. *Adv. Agron.*, **74**: 63-89.
- HOODA, P. S., RENDELL, A. R., EDWARDS, A. C., WITHERS, P. A., AITKEN, M. N. AND TRUESDALE V. W., 2000, Relating soil phosphorus indices potential phosphorus release to water. *J. Environ. Qual.*, **29**: 1166-1171.
- HUSSAIN, M. I., ASGHAR, H. N., AKHTAR, M. J. AND ARSHAD, M., 2013, Impact of phosphate solubilizing bacteria on growth and yield of maize. *Soil Environ.*, **32**(1): 71-78.
- HUSSAINI, M. A., OGUNLELA, V. B., RAMALAN, A. A. AND FALAKI, A. M., 2008, Mineral composition of dry season maize (*Zea mays* L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. *World J. Agril. Sci.*, **4**(6): 775-780.
- IBRIKCI, H., RYAN, J., ULGER, A. C., BUYUK, G., CAKIR, B., KORKMAZ, K., KARNEZ, E., OZGENTURK, G. AND KONUSKAN, O., 2005, Maintenance of phosphorus fertilizer and residual phosphorus effect on corn production. *Nutr. Cycl. Agroecosys.*, **72**: 279 -286.
- IYAMUREMYE, F. AND DICK, R. P., 1996, Organic amendments and phosphorous sorption by soils. *Adv. Agron.* **56**:139-185.
- JACKSON , M.L., 1973, *Soil Chemical Analysis*. Prentice Hall, New Delhi.
- JAKKERAL, S. A. AND KAJJIDONI, S. T., 2011, Root exudation of organic acids in selected genotypes under phosphorus deficient condition in blackgram (*Vigna mungo* L. Hepper). *Karnataka J. Agric. Sci.*, **24**(3): 316-319.

- JAT, R. S. AND AHLAWAT, I. P. S., 2006, Direct and residual effect of vermicompost, biofertilizers and phosphorus on soil nutrient dynamics and productivity of chickpea-fodder maize sequence. *J. Sus. Agric.*, **28**(1): 41-54.
- JENSEN, H., KAMALONGO, D., MYAKA, F. A. AND ADU GYANFI J. J., 2009, Multiple nutrient imbalances in ear leaves of on-farm unfertilized maize in eastern and southern Africa. *African J. Agril. Res.*, **4**(2): 107-112.
- JOHANSSON, J., PAUL, L.R. AND FINLAY, R.D., 2004, Microbial interactions in the mycorrhizosphere and their significance for sustainable agriculture. *FEMS Microbio. Eco.*, **48**: 1-13.
- JOHN, K., 2006, Variability and correlation studies in quantitative traits of finger millet (*Eleusine Coracana Gaertn*). *Agric. Sci. Digest.*, **26**(3): 166-169.
- JOSE, C. H., ANGELA M. H., MARCO, S. E. AND PATRICIA, M. C., 2011, Biological activity in a degraded Alfisol amended with sewage sludge and cropped with yellow serradela (*Ornithopus compressus* L.). *Chilean J. Agril. Res.*, **71**(1):164-172.
- KAHILUOTO, H., KETOJA, E., VESTBERG, M. AND SAARELA, I., 2001, Promotion of AM utilization through reduced P fertilization. *Pl. Soil*, **231**: 65-79.
- KALEESWARI, R. K., MEENA, S., LATHA, M. R., SARVANAPANDIAN, P., LATHA, N. AND R. INDRANI, 2007, Impact of organics and P solubilizing microorganisms on phosphate fertilizers under wet land eco- system. *Res. J. Agri. Biol. Sci.*, **3**(6): 577-580.
- KALEESWARI, R. K., 2007, Role of phosphatase enzymes in phosphorus nutrition of crops. *Agri. Rev.*, **28**(2): 149-153.
- KELLY, R. M., EDWARDS, D. G., THOMPSON, J. P. AND MAGAREY, R. C., 2001, Responses of sugarcane, maize, and soybean to phosphorus and vesicular-arbuscular mycorrhizal fungi. *Australian J. Agri.l Res.*, **52**(7): 731-743.
- KHALIL, S., ZIA, M. S. AND MAHMOOD, I. A., 2002, Biophos influence on P availability from rock phosphate applied to rice (*Oryza sativa* L.) with various amendments. *Int. J. Agri. Biol.*, **4**(2): 272-274.
- KHAN, A., GHULAM, J, MOHAMMAD SALEEM AKHTAR, SYED MUHAMMAD SAQLAN NAQVI, MOHAMMAD RASHEED, 2009, Phosphorus solubilizing bacteria: occurrence, mechanisms and their role in crop production. *J. Agric. Biol. Sci.*, **1**(1): 48-58.

- KLEINMAN, H. A., PETER J. A. AND LYNCH, JONATHAN P., 2009, Phosphorus runoff from a phosphorus deficient soil under common bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* L.) genotypes with contrasting root architecture. *Pl. Soil*, **317**: 1-16.
- KLOEPPER, J.W., RYU, C. and ZHANG, S., 2004, Induced systemic resistance and promotion of plant growth by *Bacillus* spp. *Phytopath.*, **94**: 1259-1266.
- KOGBE, J. O. S. AND ADEDIRAN, J. A., 2003, Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savanna zone of Nigeria. *African J. Biotech.*, **2**(10): 345-349.
- KOLAWOLE, G. O. AND TIAN, G., 2007, Phosphorus fractionation and crop performance on an Alfisol amended with phosphate rock combined with or without plant residues. *African J. Biotech.*, **6**(16):1972-1978.
- KOLAWOLE, G. O., ADIGUN C. O., AKINTADE, B. O., OPALEYE, O. A. AND LAWAL, B.A., 2013, Organic residues affect soil P availability, cowpea yield and nutrient uptake on a near neutral P-deficient Alfisol in south western Nigeria. *Intern. J. Applied Agric. Apic. Res.*, **9**(1 & 2): 81-90.
- KOTHANDARAMAN, G. V. AND KRISHNAMURTHY, K. R., 1979, Forms of inorganic phosphorus in Tamil Nadu soils. The phosphorus in soils, crops and fertilizers. *J. Indian Soc. Soil Sci.*, **65**: 516-521.
- LEMANOWICZ, J., 2011, Phosphatases activity and plant available phosphorus in soil under winter wheat (*Triticum aestivum* L.) fertilized minerally. *Polish J. Agron.*, **4**: 12-15.
- LEYTEM, A. B., BENJAMIN, L. TURNER, VICTOR RASOY AND KEVIN L. PETERSON, 2005, Linking manure properties to P solubility in calcareous soils. *Soil Sci. J.*, **69**: 1516-1524.
- LI, S.M., LI, L., ZHANG, F. S. AND TANG, C., 2004, Acid phosphatase role in chickpea - maize intercropping. *Ann. Bot.*, **94**: 297-303.
- LILIENFEIN, J., WILCKE, W., AYARZA, M. A., VILELA, L., LIMA, S., AND ZECH, W., 2000, Chemical fractionation of phosphorus, sulphur, and molybdenum in Brazilian savannah Oxisols under different land use. *Geoderma*, **96**(1-2): 31-46.
- LINDSAY, W. L. AND NORWELL, W.A., 1978, Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Sci. Soc. Amer. J.*, **42**: 421-428.
- LIU, Y., VILLALBA, G., AYRES, R.U. AND SCHRODER, H., 2008, Global phosphorus flows and environmental impacts from a consumption perspective. *J. Indust. Eco.*, **12**(2): 229-247.

- MAHALA, H. L., SHAKTAWAT, M. S. AND SHIVRAN, R. K., 2006, Direct and residual effects of sources and levels of phosphorus and farmyard manure in maize (*Zea mays*)-mustard (*Brassica juncea*) cropping sequence. *Indian J. Agron.*, **51**(1): 10-13.
- MAHANTA, D. and RAI, R. K., 2008, Effects of sources of phosphorus and biofertilizers on productivity and profitability of soybean (*Glycine max*)–wheat (*Triticum aestivum*) system. *Indian J. Agron.* **53**(4): 279-284.
- MAHANTA, D., RAI, R. K., MISHRA, S. D., RAJA, A., PURAKYASTH, T. J. AND VARGHESE, E., 2014, Influence of phosphorus and biofertilizers on soybean and wheat root growth and properties. *Field Crop Res.*, **166**: 1-9.
- MALIHA, R., SAMINA. K., NAJMA, A., SADIA, A. AND FAROOQ, L., 2004, Organic acids production and phosphate solubilization by phosphate solubilizing microorganisms under in vitro conditions. *Pak. J. Biol. Sci.*, **7**: 187-196.
- MANSKE, G. G. B., ORTIZ-MONASTERIO, J.I., GINKEL, M. VAN, GONZALEZ, R. M., FISCHER, R. A., RAJARAM, S. AND VLEK, P. L. G., 2001, Importance of P uptake efficiency versus P utilization on wheat yield in acid and calcareous soils in Mexico. *European J. Agron.*, **14**: 261-274.
- MARSCHNER, H., 1997, Mineral nutrition of higher plant 2nd edition, Academic Press, London. pp. 889.
- MCKEAGUE, J. A. AND DAY, J. H., 1966, Dithionite and oxalate Fe and Al as aids in differentiating various classes of soils. *Canadian J. Soil Sci.* **46**: 13-22.
- MEDINA, A., PROBANZA, A., GUTIERREZ MANERO, F. J. AND AZCON, R., 2003, Interactions of arbuscular-mycorrhizal fungi and *Bacillus* strains and their effects on plant growth, microbial rhizosphere activity (thymidine and leucine incorporation) and fungal biomass (ergosterol and chitin). *Appl. Soil Eco.*, **22**: 15-28.
- MEENA MARY, MATHEW, S. M. AND SHAHUL HAMEED, 2002, Effect of microbial inoculants and phosphorus levels on growth and phosphorus nutrition of vegetable cowpea. *J. Trop. Agri.*, **40**: 74-77.
- MEHTA, R. S., PATEL, B. S. AND BHAGIRATHRAM, 2012, Yield and nutrient uptake of fenugreek (*Trigonella foenumgraecum* L) as influenced by nitrogen, phosphorus and biofertilizers. *Ann. Agril. Res.*, **33**(1&2): 45-52.
- METHA, N. C., LEGG, J. O., GORING, C. A. I. AND BLAK, C. A., 1954, Determination of organic phosphorus in soil: I extraction method. *Soil Sci. Soc. Am. J.*, **18**: 443-449.

- MILLER, C. R., OCHOA, I., NIELSEN, K. L., BECK, D. AND LYNCH, J. P., 2003, Genetic variation for adventitious rooting in response to low phosphorus availability: potential utility for phosphorus acquisition from stratified soils. *Func. Pl. Biol.*, **30**: 973-985.
- MOHAMMAD, M. J., MALKAWI, H. I. AND SHIBLI, R., 2003, Effects of arbuscular mycorrhizal fungi and phosphorus fertilization on growth and nutrient uptake of barley grown on soils with different levels of salts. *J. Pl. Nutr.*, **26**(1): 125-137.
- MONGIA, A. D. AND BANDYOPADHYAY, A. K., 1996, Phosphate fractions and their relation to available phosphorus indices in soils of deciduous and mangrove forest of Andamans. *J. Indian Soc. Soil Sci.*, **44**(3): 514-516.
- MOZAED, H., HOSEINI, Y., NASERI, A. A. AND ABBASI, F., 2010, Determining P adsorption isotherm in soil and its relation to soil characteristics. *Int. J. Soil. Sci.*, **5**(3): 131-139.
- NATH R AND SAMANTA, R., 2012, Soil pH, microbial population, nitrate reductase and alkaline phosphatase activities of different environment of Dibrugarh district, Assam. *Adv. App. Sci. Res.*, **3**(3): 1772-1775.
- NHAMO, N., PAULINE, P. N. AND SHUMBA, D. B., 2014, Phosphorus application to maize-cowpea sequences in small holder farming systems of Zimbabwe. *Zimbabwe J. Agric. Res.*, **28**: 39-45.
- *NSANZABAGANWA, E., DAS, T. K., RANA, D. S. AND KUMAR, S. N., 2014, Nitrogen and phosphorus effects on winter maize in an irrigated agroecosystem in western Indo-Gangetic plains of India. *Maydica Electr. Publ.*, **59**: 152-160.
- NURUZZAMAN, M., HANS, L., MIKE D.A. BOLLAND AND ERIK J. VENEKLAAS, 2004, Grain legume crops increase soil phosphorus availability to subsequently grown wheat. *Proceedings of the 4th Intl Crop Sci. Cong. Brisbane, Australia*, 26 Sept - 1 Oct 2004.
- NYOKI. D, NDAKIDEMI. P. A., 2014, Influence of *Bradyrhizobium japonicum* and phosphorus on micronutrient uptake in cowpea. A case study of zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn). *Amer. J. Pl. Sci.*, **5**: 427-435.
- NZIGUHEBA, G., MERCKX, R. AND PALM, C. A., 2002, Soil phosphorus dynamics and maize response to different rates of phosphorus fertilizer applied to an Acrisol in western Kenya. *Pl. Soil*, **243**(1): 1-10.
- OLSEN, S.R. AND WATANABE, F.S., 1957, A method to determine phosphorus adsorption maxima of soils as measured by the Langmuir isotherm. *Soil Sci. Soc. Am. Proc.*, **21**: 144-149.

- OLUSEGUN, A. AND YEROKUN, 2008, Chemical characteristics of phosphorus in some representative benchmark soils of Zambia. *Geoderma*, **147**: 63-68.
- ONTHONG, J., SA GIMSANGUAN, ASHARA PENGNOO, CHAIRATANA NILNOND AND MITSURU OSAKI, 2014, Effect of pH and some cations on activity of acid phosphatase secreted from *Ustilago* sp. Isolated from acid sulphate soil. *Songklanakarin J. Sci. Technol.*, **29**(2): 275-286.
- ORTAS, I., ROWELL, D. L. AND HARRIS, P. J., 2004, Effect of mycorrhizae and pH change at the root-soil interface on phosphorus uptake by sorghum using a rhizocylinder technique. *Comm. Soil Sci. Pl. Anal.*, **35**(7-8): 1061-1080.
- PAL, S. R., SINGH, B. AND DHILLON, N. S., 2009, Phosphorus sorption parameters after 35 years of fertilization to maize-wheat cropping system. *J. Res.*, **46**(1&2): 27-3.
- PARAMASIVAM, P. AND UDAYASOORIAN, C., 1991, Phosphorus status and distribution of different forms of phosphorus in major soil series of Madhurai district of Tamil Nadu. *Mysore J. Agric. Sci.*, **25**: 44-48.
- PARFITT, R.L., 1978, Anion adsorption by soils and soil material. *Adv. Agron.* **30**:1–50.
- PELTOVUORI, T., UUSITALO, R. AND KAUPPILA, T., 2002, Phosphorus reserves and apparent phosphorus saturation in four weakly developed cultivated pedons. *Geoderma*, **110**(1-2): 35-47.
- PEREIRA, S. I. A. AND CASTRO, P. M. L., 2014, Phosphate-solubilizing rhizobacteria enhance *Zea mays* growth in agricultural P-deficient soils. *Ecol. Eng.*, **73**: 526–535.
- PETERSON, G. W. AND COREY, R. B., 1966, A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphate. *Soil Sci. Soc. Am. Proc.*, **30**: 563-564.
- PIOTROWSKA, A. AND WILCZEWSKI E., 2012, Effects of catch crops cultivated for green manure and mineral nitrogen fertilization on soil enzyme activities and chemical properties. *Geoderma*, **189**: 72-80.
- PIPER, C. S., 1966, *Soil and Plant Analysis*, Hans Publishers, Mumbai, India.
- PLAXTON, W.C., 2004, Plant responses: Biochemical adaptations to P-deficiency. In *Encyclopedia of Plant and Crop Science*. Marcel Dekkar, New York, pp. 976-980.
- PRADHAN, N. AND SUKLA, L. B., 2006, Solubilization of inorganic phosphates by fungi isolated from agriculture soil. *African J. Biotech.*, **5**(10): 850-854.

- PURNOMO, E., MURSYID, A., SYARWANI, M., JUMBERI, A., HASHIDOKO, Y., HESEGAWA, T., HONMA, S. AND OSAKI, M., 2005, Phosphorus solubilizing microorganisms in the rhizosphere of local rice varieties grown with no fertilizer on acid sulphate soils. *Soil Sci. Pl. Nutr.*, **51**(5): 679-681.
- QINGREN WANG AND YUNCONG LI, 2010, Phosphorus adsorption and desorption behavior on sediments of different origins. *J. Soils Sediments*, 10: 1159 - 1173.
- QURESHI, A.A., NARAYANASAMY, G., CHHONKAR, P.K. AND BALASUNDARAM, V.R., 2005, Direct and residual effect of phosphate rocks in presence of phosphate solublizers and FYM on the available P, organic carbon and viable counts of phosphate solublizers in soil after soybean, mustard and wheat crops. *J. Indian Soc. Soil Sci.*, **53**(1): 97-100.
- RAIESI, F. AND GHOLLARATA, M., 2006, Interactions between phosphorus availability and an AM fungus (*Glomus intraradices*) and their effects on soil microbial respiration, biomass and enzyme activities in a calcareous soil. *Pedobiologia*, **50**(5): 413-425.
- RAO, K.T., KRISHNA, I.S.R. AND REDDY, C.S., 2008, Biodiversity of Nallamalai hill ranges, Eastern Ghats, Andhra Pradesh. *Proceedings of National Seminar on Conservation of Eastern Ghats*. EPTRI, Hyderabad, 216-223.
- RAUSCH, C. AND BUCHER, M., 2002, Molecular mechanisms of phosphate transport in plants. *Planta*, **216**: 23–37.
- REDDY, D. D., RAO, S. A. AND MUNESHWAR SINGH., 2005, Changes in P fractions and sorption in an Alfisol following crop residues application. *J. Pl. Nutr. Soil Sci.*, **168**(2): 241-247.
- REYNOLDS, H. L., VOGELSANG, K. M., HARTLEY, A. E., BEVER, J. D. AND SCHULTZ, P. A., 2006, Variable responses of old-field perennials to arbuscular mycorrhizal fungi and phosphorus source. *Oecologia*, **147**(2): 348-358.
- RICHARDSON A. E. AND SIMPSON R J., 2011, Soil microorganisms mediating phosphorus availability. *Pl. Physio.*, **156**: 989-996.
- RICHARDSON, A. E., HADOBAS, P. A., HAYES, J. E., O'HARA, C. P. AND SIMPSON, R. J., 2001, Utilization of phosphorus by pasture plants supplied with *myo*-inositol hexaphosphate is enhanced by the presence of soil microorganisms. *Pl. Soil*, **229**: 47–56.
- ROBERTO, I. AND PAOLO, S., 2004, Phosphorus intensity – quantity relationships in soils highly contrasting in phosphorus adsorption properties. *Comm. soil sci. Pl. Analy.*, 35(1): 131-143.

- *ROCHA, A. T., DA DUDA, G. P., NASCIMENTO, C. W. A. AND RIBEIRO, M. R., 2005, Phosphorus fractionation and evaluation of available-P extractors in soils of Fernando de Noronha Island. *Revista Brasileira de Engenharia Agrícola e Ambiental*, **9**(2): 178-184.
- RODRIGUEZ, H. AND FRAGA, R. 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotech. Adv.*, **17**: 319-339.
- RODRIGUEZ, H., FRAGAR, R., GONZALEZ, T. AND BASHAN, Y., 2006, Genetics of phosphate solubilization and its potential applications for improving plant growth-promoting bacteria, *Pl. Soil.*, **287**: 15-21
- ROSSELLA, P., GIUSEPPE VALBOA, CARLO PIOVANELLI, GIORGIO BRANDI, 2007, Nitrogen and phosphorous in a loam soil of central Italy as affected by six years of different tillage systems. *Soil Till. Res.*, **92**: 175–180.
- ROY, R.N., SEETHARAMA, S. AND SINGH, R.N., 1978, Fertilizer use research in India. *Fert. News*, **23**: 22.
- SAHA, S., PRAKASH., V, KUNDU, S., KUMAR, N. AND MINA B. L., 2008, Soil enzymatic activity as affected by long term application of farm yard manure and mineral fertilizer under a rainfed soybean–wheat system in N-W Himalaya. *Euro. J. Soil Boil.*, **44**: 309–315.
- SAINI, V. K., BHANDARI, S. C. AND TARAFDAR, J. C., 2004, Comparison of crop yield, soil microbial C, N and P, N-fixation, nodulation and mycorrhizal infection in inoculated and non-inoculated sorghum and chickpea crops. *Field Crops Res.*, **89**(1) 39-47.
- SALTALI, K., KLC, K. AND KOCYIGIT, R., 2007, Changes in sequentially extracted phosphorus fractions in adjacent arable and grassland ecosystems. *Arid Land Res. Mgt.*, **21**(1): 81-89.
- SANGEETA, M., NARENDRA, K. P. AND RAJAN, R. A., 2006, Availability and uptake of phosphorus from organic manures in groundnut (*Arachis hypogea L.*)-corn (*Zea mays L.*) sequence using radio tracer technique. *Geoderma*, **133**: 225-230.
- *SARAPATKA, BORIVOJ, LENKA DUDOVA AND KRSKOVA MILENA, 2004, Effect of pH and phosphate supply on acid phosphatase activity in cereal roots. *Biologia, Bratislava*, **59**(1): 127-131.
- SCHROEDER, P. D. AND KOVAR, J. L., 2006, Comparison of organic and inorganic phosphorus fractions in an established buffer and adjacent production field. *Comm. Soil Sci. Pl. Anal.*, **37** (9-10): 1219-1232.

- SHARIF, M., BURNI, T., WAHID, F., KHAN, F., KHAN, S., KHAN, A. AND SHAH, A., 2013, Effect of rock phosphate composted with organic materials on yield and phosphorus uptake of wheat and mung bean crops. *Pak. J. Bot.*, **45**(4):1349-1356.
- SHEEBA. S. AND KUMARASWAMY, K., 2005, Effect of manure-fertilizer schedules on different forms of P in soil under intensive cropping. *J. Soils Crops*, **15**(1): 8-13.
- SHEN, J., LI, R., ZHANG, F., FAN, J., TANG, C., AND RENGEL, Z., 2004, Crop yields, soil fertility and phosphorus fractions in response to long-term fertilization under the rice monoculture system on a calcareous soil. *Field Crop Res.*, **86**: 225–238.
- SHI, Y. C., ZIADI, N., MESSIGA, A. J., LALANDE, R. AND HU, Z. Y., 2015, Soil phosphorus fractions change in winter in a corn-soybean rotation with tillage and phosphorus fertilization. *Pedosphere*, **25**(1): 1-11.
- *SILVA, M. A., DA NOBREGA, J. C. A., CURI, N., SIQUEIRA, J. O., SAE MELO MARQUES, J. J. G. AND DE MOTTA, P. E. F., 2003, Phosphorus fractions in Oxisols. *Pesquisa Agropecuaria Brasileira*, **38**(10): 1197-1207.
- *SILVEIRA, M. M. L., DA ARAUJO, M., DO S. B., SAMPAIO, E. V. AND DE S. B., 2006, Phosphorus distribution in different soil orders in the semi-arid states of Paraíba and Pernambuco, Brazil. *Revista Brasileirade Ciencia do Solo*, **30**(2): 281-291.
- SINGARAM, P. AND KAMALAKUMARI, K., 1995, Long term effect of FYM and fertilizers on enzyme dynamics of soil. *J. Indian Soc. Soil Sci.*, **43**: 378-381.
- SINGH, A., BAOULE, A. L., AHMED, H. G., DIKKO, A. U., ALIYU, U., SOKOTO, M. B., ALHASSAN, J., MUSA, M. AND HALIRU, B., 2011b, Influence of phosphorus on the performance of cowpea (*Vigna unguiculata* L. Walp.) varieties in the Sudan savanna of Nigeria. *Agril. Sci.*, **2**: 313-317.
- SINGH, B. AND PANDEY, R., 2003, Differences in root exudation among phosphorus starved genotypes of maize and green gram and its relationship with phosphorus uptake. *J. Pl. Nutr.*, **26** (12): 2391–2401.
- SINGH, S.R., NAJAR, G.R., SINGH, UMMED AND SINGH, J.K., 2011 a, Phosphorus management in maize-onion cropping sequence under rainfed temperate conditions of Inceptisol. *J. Indian Soc. Soil Sci.* **59**(4): 355-361.
- SMITH, L. H. S. E., HOLLOWAY, R. E. AND SMITH, Z. Y. F. A., 2006, Arbuscular mycorrhizal fungi contribute to phosphorus uptake by wheat grown in a phosphorus-fixing soil even in the absence of positive growth responses. *New Phytologist*, **172**(3): 536-543.

- SPERBER, J. I., 1957, Solution of mineral phosphates by soil bacteria. *Nature*, **180**: 994-995.
- SRINIVAS, A. AND RAJU, M. S., 1996, Rainy season maize-based cropping systems in Andhra Pradesh. *Indian J. Agron.*, **43**(4):576-579.
- *STAMTFORD, N. P., SANTOS, P. R., SANTOS, C. E. S., FREITAS, A. D. S., DIAS, S. H. L., LIRA J. M. A., 2007, Agronomic effectiveness of biofertilizers with phosphate rock, sulphur and *Acidithiobacillus* for yam bean grown on a Brazilian tableland acidic soil. *Biores. Tech.*, **98**:1311-1318.
- SUBBAIAH, B.V. AND ASIJA, G.L., 1956, A rapid procedure for the estimation of the available nitrogen in soil. *Curr. Sci.*, **25**: 259-260.
- SUBBARAO, 1986, Dual inoculation with *Rhizobium* sp. and *Glomus fasciculatum* enhances nodulation, yield and nitrogen fixation in chickpea (*Cicer arietinum* L.). *Pl. Soil*, **95**: 351-359.
- SUNDRARAJ, N., NAGRAJU, S., VENKATARAMU, M.N. AND JAGANNATH, M. K., 1977, *Design and Analysis of Field Experiments*. University Press, UAS, Bangalore, India.
- SURENDRA, S. T. AND SHARANAPPA, 2000, Integrated management of nitrogen and phosphorus in maize (*Zea mays*) and their residual effect on cowpea. *Indian J. Agril. Sci.*, **70**: 119-121.
- SURI, V. K., CHOUDHARY, A. K. AND KUMAR ANIL, 2013, VAM fungi spore populations in different farming situations and their effect on productivity and nutrient dynamics in maize and soybean in Himalayan acid Alfisol. *Comm. Soil Sci. Pl. Anal.*, **44**: 3327-3339.
- SURI, V. K., CHOUDHARY, A. K., CHANDER, G., VERMA, T. S., GUPTA M. K. AND DUTT, N., 2011, Improving phosphorus use through co-inoculation of Vesicular Arbuscular Mycorrhizal Fungi and phosphate-solubilizing bacteria in maize in an acidic Alfisol. *Commn. Soil Sci. Pl. Anal.*, **42**: 2265-2273.
- SURI, V. K., G. CHANDER, A. K. CHOUDHARY, AND T. S. VERMA. 2006. Co-inoculation of VAM and phosphate solubilizing bacteria (PSB) in enhancing phosphorus supply to wheat in Typic Hapludalf. *Crop Res.*, **31**: 357-361.
- SUSHMA, A. R., 2005, Residual effect of coir pith based compost with other organics and inorganics on ragi crop yield and soil properties. *M.Sc. Thesis*, UAS, Bangalore, Karnataka, India.

- SZOTT, L. T. AND MELENDEZ, G., 2001, Phosphorus availability under annual cropping, alley cropping, and multistrata agroforestry systems. *Agrofor. Sys.*, **53**(2): 125-132.
- TABATABAI, M.A AND BREMNER, J.M., 1972, Assay of urease activity in soils. *Soil Bio. Bioch.*, **4**: 479-487.
- TARAFDAR, J.C., 2013, Phosphorus – A bright future ahead. 40th Dr. R.V. Tamhane memorial lecture. *Proc. 78th Ann. Conv. Indian Soc. Soil Sci. Jodhpur.*
- TIRADO, R. AND ALLSOPP, M., 2012, Phosphorus in agriculture problems and solutions. *Greenpeace Res. Lab. Techn. Report.*
- VANCE, C. P., UHDE-STONE, C. AND ALLAN, D. L., 2003, Phosphorus and use: Critical adaptations by plants securing a non-renewable resource. *New phytologist*, **157**: 423-457.
- VASANTHI, B. G., NAGRAJ, M. S., BIPPIN, R. A AND RAGHAVENDRA, 2000, Phosphate sorption characteristics of some acidic soil of hilly zone Karnataka. *National sem. Dev. Soil Sci.2000, NBSS &LUP Nagpur.*
- VASUKI, N., SHETTY, Y. V., RUDRAMURTHY, H. V. AND VAGEESH, T. S., 2002, Rescheduling of phosphorus application to FCV tobacco grown on phosphorus build up soils of KLS region. Report on Network research project (tobacco), Zonal Agricultural Research Station Navile, Shimoga.
- VISHWANATH, J. AND DODDAMANI, V. S., 1991, Distribution of phosphorus fractions in Vertisols. *J. Indian Soc. Soil Sci.*, **39**: 441-445.
- WALKLEY, A. AND BLACK, C.A., 1934, A method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Sci.*, **37**: 29-38.
- WANG, X., LESTER, D. W., GUPPY, C. N., LOCKWOOD, P. V. AND TANG, C., 2007, Changes in phosphorus fractions at various soil depths following long-term P fertiliser application on a Black Vertisol from south-eastern Queensland. *Australian J. Soil Res.*, **45**(7): 524-532.
- WATANABE, F. S. AND OLSEN, S. R., 1965, Test of an ascorbic acid method for determining phosphorus in water and NaHCO₃ extracts. *Soil Sci. Soc. Am. Proc.*, **29**: 677-678.
- WAUGH, D. L. AND FITTS J. W., 1966, Soil test interpretation studies. Laboratory and potted plants. *Bull. Int. Soil Testing Series 3, North Carolina State Univ., Raleigh, U.S.A.* PP. 334-339.

- WHITELAW, M. A., 2000, Growth promotion of plants inoculated with phosphate solubilizing fungi. *Adv. Agron.*, **69**: 99-151.
- WU, S. C., CAO, Z. H., LI, Z. G., CHEUNG, K. C. AND WONGA, M. H., 2005, Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: A greenhouse trial. *Geoderma*, **125**: 155-166.
- YADAV, R. S. AND TARAFDAR, J. C., 2001, Influence of organic and inorganic phosphorus supply on the maximum secretion of acid phosphatase by plants. *Biol. Fertil. Soils*, **34**:140–143.
- YANG, J. E., JONES, C. A., KIM, H. J. AND JACOBSEN, J. S., 2002, Soil inorganic phosphorus fractions and Olsen-P in phosphorus-responsive calcareous soils: Effects of fertilizer amount and incubation time. *Comm. Soil Sci. Pl. Analy.*, **33**(5-6): 855-871.
- YAWALKAR, K. S., AGRAWAL, J. P. AND BOKDE, S., 1992, Bulky organic manures. (In) *Manures and Fertilizers*, Edn 7, Pp. 49.
- YE, D., LI, T., YU, H., CHEN, G., ZHENG, X., ZHANG, Z. AND LI, J., 2015, P accumulation of *Polygonum hydropiper*, soil P fractions and phosphatase activity as affected by swine manure. *Appl. Soil Ecol.* **86**: 10 -18.
- YOUSEFI, A. A., KHAVAZI, K., MOEZI, A. A., FARHAD, R. AND NADIAN, H. A., 2011, Phosphate solubilizing bacteria and arbuscular mycorrhizal fungi impacts on inorganic phosphorus fractions and wheat growth. *World Appl. Sci. J.*, **15**(9): 1310-1318.
- ZAIDI, A., KHAN, M. S., AHMAD, M., OVES, M., WANI, P. A., 2009, Recent advances in plant growth promotion by phosphate-solubilizing microbes. In: KHAN M S *et al* (Eds) microbial strategies for crop improvement. Springer-Verlag, Berlin Heidelberg, pp 23-50.
- ZHANG, H., SCHRODER, J. L., FUHRMAN, J. K., BASTA, N. T., STORM, D. E. AND PAYTON, 2005, Path and multiple regression analyses of phosphorus sorption capacity. *Soil Sci. Soc. Am. J.* **69**: 96 - 106.
- ZHANG, Q., WANG, G. H., FENG, Y. K., SUN, Q. Z., WITT, C. AND DOBERMANN, A., 2006, Changes in soil phosphorus fractions in a calcareous paddy soil under intensive rice cropping. *Pl. Soil*, **288**(1-2): 141-154.
- ZHU, J., KAEPLER, SHAWN M. AND LYNCH, JONATHAN P., 2005, Topsoil foraging and phosphorus acquisition efficiency in maize (*Zea mays*). *Func. Pl. Biol.*, **32**:749-762.

ZORNOZA, R., GUERRERO, C., MATAIX-SOLERA, J., ARCENEGUI, V., GARCIA-ORENES, F., MATAIX BENEYTO, J., 2006, Assessing air drying and rewetting pre-treatment effect on some soil enzyme activities under Mediterranean conditions. *Soil Biol. Biochem.*, **38**(8): 2125-2134.

* Originals not seen.

Enhancing P Utilization in Soil High in P Status Through Inorganic Nutrients and Microbial Management

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ABSTRACT

A field experiment was conducted at ZARS, GKVK, Bangalore to utilize the high P content in soil (Alfisol, Oxic Haplaustalf) by providing a combination of inorganic fertilizer (urea, single super phosphate and muriate of potash) and P solubilizing microorganisms in a maize – cowpea cropping sequence. The results revealed that there was positive impact of PSB and VAM on maize grain and stover yield (85.01 and 97.70 q ha⁻¹ respectively) on addition (T₆) Rec.NPK + FYM + PSB + VAM followed by T₁₃ 50% P+PSB + VAM + Rec. NK & FYM (84.62 and 97.22 q ha⁻¹ grain and stover yield respectively) similar results were also recorded in case of cowpea. After the harvest of cowpea, lower NK and a build-up of available phosphorus was recorded in all the treatments except in T₈ and T₁ (58.27 and 62.62 kg P₂O₅ ha⁻¹ respectively) as compared to initial (63.94 kg P₂O₅ ha⁻¹). The study indicated that phosphorus could be saved upto 50% by utilizing the P contained in soil using P solubilizer.

APPLIED phosphorus is subjected to various soil reactions which limit its availability to crops. Further phosphatic inputs are costly and hence call for judicious P management. An attempt was made to utilize the high P in soils by providing inorganic and P mobilizers such as PSB and VAM.

The experiment was conducted at GKVK, Bangalore on an Alfisol (Oxic Haplaustalf) Vijayapura series with high available and total P. The soil was slightly acidic (pH 5.42), with high phosphorus, potassium, calcium, magnesium and organic carbon which recorded 63.94 kg ha⁻¹, 364.48 kg ha⁻¹, 3.35, 2.50 meq 100 g soil⁻¹ and 1.26 per cent respectively, whereas available nitrogen was medium 258.22 kg ha⁻¹, DTPA extractable micronutrients Fe, Mn, Zn and Cu were in sufficient range (49.21, 30.83, 2.59 and 1.97 mg kg⁻¹ respectively). Maize was grown during *kharif* 2013 followed by cowpea during *rabi* season. Fourteen treatments with organic manures and different combination of microbial inoculants *viz.* PSB and VAM at different doses of phosphorus fertilizers were tried adopting the RCBD design.

Field experiments indicated positive impact of PSB and VAM on maize yield which was significant (85.01 q ha⁻¹) and stover (97.70 q ha⁻¹) on application of Rec. NPK + PSB + VAM + FYM (T₆) followed by T₁₃ (84.62 and 97.22 q ha⁻¹ grain and stover

respectively to which recommended PSB, VAM, NK and FYM was applied without P. PSB and VAM together were capable of mobilizing soil P (Gryndler *et al.*, 1990) (Table I). Treatments T₄ (Rec.NPK+FYM+PSB) and T₅ (Rec. NPK +FYM +VAM) recorded on par (82.35 and 82.12 q ha⁻¹) maize yield respectively. However, least yield (50.85 and 58.47 q ha⁻¹ of maize grain and stover) was recorded in T₂ (FYM alone) (Table I). This indicates that with dual inoculation of efficient VAM strain and PSB along with 50 per cent P₂O₅ dose, 50 per cent of fertilizer P can be saved without impairing the yield of maize in an acidic Alsol (Suri *et al.*, 2011).

Similar results were recorded in case of cowpea (residual crop). The grain (13.73 q ha⁻¹) and haulm (19.23 q ha⁻¹) was significantly higher on application of (Rec.P+PSB+VAM+Rec.NK & FYM) (T₆) which was closely followed by T₁₃ (grain 13.14 and haulm 18.39 q ha⁻¹) (50 % +FYM +Rec.NK +PSB+VAM) and T₄ (grain 12.50 and haulm 17.50 q ha⁻¹) (Rec. NPK + FYM + PSB) which is attributed to the residual effect of FYM, phosphorus fertilizer and PSM (Table I). PSB and VAM lead to increased mobilization of phosphorus from soil thus an increased grain and haulm yield (Meena *et al.*, 2002 and Amrani *et al.*, 1999). After harvest of maize the soil indicated a P build up whereas other nutrients decreased. The available nitrogen decreased significantly irrespective

TABLE I

Influence of phosphorus, PSB and VAM application on yield of maize and cowpea ($q\ ha^{-1}$) in high available phosphorus soil

Treatments	Maize ($q\ ha^{-1}$)		Cowpea ($q\ ha^{-1}$)	
	Grain	Stover	Grain	Stover
T ₁ - Rec. NPK (150: 75: 40 $kg\ ha^{-1}$)	66.01	75.89	8.63	12.09
T ₂ - FYM (10 t ha^{-1})	50.85	58.47	8.87	12.41
T ₃ - Rec. NPK + FYM	76.31	87.64	10.57	14.79
T ₄ - Rec. NPK + FYM + PSB (4 $kg\ ha^{-1}$)	82.35	94.61	12.50	17.50
T ₅ - Rec. NPK + FYM + VAM (5 $kg\ ha^{-1}$)	82.12	94.29	11.83	16.57
T ₆ - Rec. NPK + FYM + PSB + VAM	85.01	97.70	13.73	19.23
T ₇ -50% P + Rec. NK & FYM	75.42	86.80	7.27	10.17
T ₈ -0% P + Rec. NK & FYM	72.72	83.73	6.93	9.71
T ₉ -50% P + PSB + Rec. NK & FYM	80.07	91.94	12.83	17.97
T ₁₀ -0% P + PSB + Rec. NK & FYM	79.87	91.82	9.97	13.95
T ₁₁ -50% P + VAM + Rec. NK & FYM	80.47	92.37	10.73	15.03
T ₁₂ -0% P + VAM + Rec. NK & FYM	79.91	91.79	9.73	13.63
T ₁₃ -50% P + PSB + VAM + Rec. NK & FYM	84.62	97.22	13.14	18.39
T ₁₄ -0% P + PSB + VAM + Rec. NK & FYM	78.53	90.27	9.50	13.30
CD (P=0.05)	4.35	4.71	2.72	3.81
SEm±	1.50	1.62	0.94	1.31

of treatment compared to initial value of 258.22 $kg\ ha^{-1}$. Treatment T₁₃ recorded higher 167.66 $kg\ N\ ha^{-1}$ followed by T₁₂ (163.62 $kg\ N\ ha^{-1}$) and lowest was recorded in T₂ (131.50 $kg\ N\ ha^{-1}$) to which FYM alone was applied and all the other treatments were on par. Build-up of available phosphorus was observed in all the treatments compared to initial content of (63.94 $kg\ P_2O_5\ ha^{-1}$) T₁₃ (50%P+PSB+VAM+Rec.NK+FYM) recorded 114.46 $kg\ P_2O_5\ ha^{-1}$ followed by T₁₄ (0%P+PSB+VAM+Rec.NK+FYM) 101.20 $kg\ P_2O_5\ ha^{-1}$ and the least 70.82 $kg\ ha^{-1}$ in (T₂) (Table II). The treatments with a combination of recommended fertilizer and microbial culture were on par with respect to P which is indicative of solubilisation of native phosphorus by micro-organisms (Suri, *et al* 2011).

The available potassium decreased compared to initial in all treatments. T₁₃ and T₁₄ recorded higher

K₂O (282.69 and 282.68 $kg\ ha^{-1}$ respectively) followed by other treatments. Whereas the content of sulphur decreased compared to initial content except T₁₃ which recorded (17.59 ppm) on par value followed by other treatments. Similarly exchangeable Ca and Mg too recorded significant build-up compared to initial content 3.35 and 2.50 m.eq 100g soil⁻¹ except T₁, T₇ and T₁₁ which recorded low calcium and magnesium compared to initial. Treatment T₁₃ recorded significantly higher DTPA extractable Fe, Mn, Zn and Cu (38.38, 29.51, 4.92 and 1.46 $mg\ kg^{-1}$ respectively) and all the other treatments were on par (Table II).

At harvest of cowpea all the treatments recorded a significant rise in pH and EC compared to the initial, whereas available N, P, S, K, Ca, Mg Fe Mn, Zn, Cu, decreased (Table III). The available nitrogen decreased significantly irrespective of treatment

TABLE II
Influence of P, PSB and VAM application on soil nutrient status after harvest of maize in soil with high available phosphorus

Treatments	pH	EC dSm ⁻¹	N	P ₂ O ₅ kg ha ⁻¹	K ₂ O	S ppm	Ca m.eq (100 g soil) ⁻¹		DTPA micronutrients (mg kg ⁻¹)			
									Fe	Mn	Zn	Cu
T ₁	6.32	0.06	141.40	78.12	232.21	8.06	2.96	2.03	20.20	16.97	2.46	0.76
T ₂	6.85	0.06	131.50	70.82	219.98	7.32	3.98	2.10	32.32	21.82	4.10	1.31
T ₃	5.44	0.07	141.40	97.71	232.00	10.26	3.15	2.18	35.35	24.24	4.10	1.21
T ₄	5.59	0.08	139.38	90.73	224.10	7.33	3.33	1.77	25.25	24.24	1.64	1.02
T ₅	6.58	0.05	138.37	94.22	262.45	10.99	3.54	2.24	34.34	16.97	3.28	0.97
T ₆	6.47	0.05	143.42	103.29	275.60	11.72	3.61	2.25	39.39	24.24	2.46	1.31
T ₇	6.39	0.05	151.50	76.77	274.59	10.26	2.53	1.77	25.25	24.24	2.96	1.00
T ₈	5.9	0.05	133.32	76.77	252.99	8.79	3.11	1.70	23.23	16.97	1.64	0.92
T ₉	6.2	0.15	143.42	87.24	227.45	13.19	3.47	1.84	33.33	21.82	2.96	0.82
T ₁₀	5.25	0.14	151.50	101.20	214.58	10.26	3.25	2.26	27.27	29.09	2.46	1.13
T ₁₁	5.66	0.11	141.40	83.75	243.61	12.46	2.70	2.24	35.35	26.66	1.64	1.11
T ₁₂	6.1	0.13	163.62	80.26	263.91	13.19	3.27	2.32	36.36	29.09	3.28	1.16
T ₁₃	5.97	0.12	167.66	114.46	282.69	17.59	3.05	1.92	38.38	29.51	4.92	1.46
T ₁₄	6.35	0.13	156.55	101.20	282.68	14.60	3.19	1.74	36.36	29.36	4.10	1.31
Initial	5.42	0.10	258.22	63.94	364.48	18.10	3.35	2.50	49.21	30.83	2.59	1.97
CD (P=0.05)	0.45	0.02	12.41	10.64	13.39	2.68	0.25	0.24	3.13	1.58	0.34	0.15
SEm ±	0.15	0.01	4.56	3.73	4.61	0.91	0.09	0.08	1.03	0.53	0.11	0.05

T₁-Rec. NPK (150: 75: 40 kg ha⁻¹), T₂-Rec. FYM (10 tonne), T₃-Rec. NPK + FYM, T₄-Rec. NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-Rec. NPK + FYM + Mycorrhiza (VAM@ 5 kg ha⁻¹), T₆-Rec. NPK + FYM + PSB + Mycorrhiza, T₇-50% P₂O₅ + Rec. NK & FYM, T₈-0% P₂O₅ + Rec. NK & FYM, T₉-50% P₂O₅ + PSB + Rec. NK & FYM, T₁₀-0% P₂O₅ + PSB + Rec. NK & FYM, T₁₁-50% P₂O₅ + Mycorrhiza + Rec. NK & FYM, T₁₂-0% P₂O₅ + Mycorrhiza + Rec. NK & FYM, T₁₃-50% P₂O₅ + PSB + Mycorrhiza + Rec. NK & FYM, T₁₄-0% P₂O₅ + PSB + Mycorrhiza + Rec. NK & FYM

TABLE III
Influence of P, PSB and VAM application on soil nutrient status after harvest of cowpea in soil with high available phosphorus

Treatments	pH	EC dSm ⁻¹	N	P ₂ O ₅ kg ha ⁻¹	K ₂ O	S ppm	Ca Mg m.eq (100 g soil) ⁻¹				DTPA micronutrients (mg kg ⁻¹)			
											Fe	Mn	Zn	Cu
T ₁	6.34	0.26	100.49	62.62	205.50	7.75	2.10	1.25			23.14	14.03	0.91	0.60
T ₂	7.28	0.25	96.49	67.59	192.92	9.21	2.40	1.68			22.19	16.42	0.95	0.53
T ₃	6.11	0.23	100.86	87.45	210.09	10.76	2.50	1.50			24.08	18.59	0.93	0.59
T ₄	6.05	0.34	99.85	70.50	212.00	10.18	2.27	1.56			22.58	18.57	1.62	0.56
T ₅	7.25	0.26	98.85	74.86	254.63	11.31	2.51	1.67			23.10	14.82	1.01	0.58
T ₆	6.55	0.29	103.45	90.08	260.93	11.31	2.70	1.50			26.04	18.81	1.83	0.63
T ₇	7.14	0.22	118.22	68.78	248.01	9.15	2.43	1.21			21.13	17.00	1.92	0.51
T ₈	6.35	0.25	98.44	58.27	236.06	8.04	2.41	1.23			16.07	14.97	1.02	0.61
T ₉	6.30	0.32	104.50	68.95	213.31	8.40	2.10	1.36			22.62	17.16	1.18	0.67
T ₁₀	6.25	0.30	120.82	75.74	214.20	9.86	2.53	1.62			27.70	20.58	0.86	0.77
T ₁₁	5.67	0.32	101.20	71.32	202.01	9.21	2.27	1.19			29.93	19.38	1.30	0.54
T ₁₂	6.54	0.32	138.80	70.14	196.59	8.24	2.38	1.12			29.84	20.48	1.23	0.63
T ₁₃	6.40	0.32	143.84	96.42	264.91	11.96	2.86	1.70			36.61	21.83	1.51	0.56
T ₁₄	6.24	0.32	121.75	73.40	238.43	11.96	2.51	1.58			32.76	21.42	1.42	0.59
Initial	5.42	0.100	258.22	63.94	364.48	18.10	3.35	2.50			49.21	30.83	2.59	1.97
CD (P=0.05)	0.22	0.03	13.68	12.47	19.12	1.23	0.16	0.16			2.42	2.76	0.22	0.09
SEm ±	0.07	0.01	4.71	4.29	6.58	0.43	0.06	0.05			0.83	0.95	0.08	0.03

T₁-Rec. NPK (150: 75: 40 kg ha⁻¹), T₂-Rec. FYM (10 tonne), T₃-Rec. NPK + FYM, T₄-Rec. NPK + FYM + PSB (PSB @ 4 kg ha⁻¹), T₅-Rec. NPK + FYM + Mycorrhiza (VAM@ 5 kg ha⁻¹), T₆-Rec. NPK + FYM + PSB + Mycorrhiza, T₇-50% P₂O₅ + Rec. NK & FYM, T₈-0% P₂O₅ + Rec. NK & FYM, T₉-50% P₂O₅ + PSB + Rec. NK & FYM, T₁₀-0% P₂O₅ + PSB + Rec. NK & FYM, T₁₁-50% P₂O₅ + Mycorrhiza + Rec. NK & FYM, T₁₂-0% P₂O₅ + Mycorrhiza + Rec. NK & FYM, T₁₃-50% P₂O₅ + PSB + Mycorrhiza + Rec. NK & FYM, T₁₄-0% P₂O₅ + PSB + Mycorrhiza + Rec. NK & FYM

compared to initial (258.22 kg ha⁻¹). Treatment T₁₃, T₁₂ and T₁₄ recorded higher 143.84, 138.80 and 121.75 kg N ha⁻¹ and lower N was recorded in T₂, T₈ and T₅ (96.49, 98.44 and 98.85 kg N ha⁻¹) all other treatments indicated on par results. Build-up of available phosphorus was observed in all the treatments except in T₈ and T₁ (58.27 and 62.62 kg P₂O₅ ha⁻¹) respectively compared to initial (63.94 kg P₂O₅ ha⁻¹). It may be due to the residual effect of bio-fertilizer and organic manure. Combination of 50 per cent P with biofertilizers significantly increased the soil phosphorus (Mahanta and Rai, 2008). The treatments with combination of recommended fertilizer and microbial culture recorded significantly high available P due to the residual effect and solubilisation of native phosphorus by micro-organisms which added to soil phosphorus pool (Suri, *et al* 2011) and combined inoculation of AMF and PSM at lower phosphorus levels enhanced their growth, phosphorus content and residual phosphorus of the soil (Meena *et al.*, 2002).

The available potassium content after residual cowpea crop decreased compared to initial in all treatments. T₁₃ recorded highest K₂O (264.91 kg ha⁻¹) followed by other treatments. The content of S decreased, while in T₁₃ and T₁₄ high sulphur was recorded compared to all other treatment (11.96 and 11.96 ppm) lower sulphur was recorded in T₁ (7.75 ppm). Magnesium and calcium recorded significant decline compared to initial 3.35 and 2.50 m.eq 100g soil⁻¹ and T₁₃ recorded significantly higher Ca and Mg (2.82 and 1.70 m.eq 100g soil⁻¹). Treatment T₁₃ recorded significantly higher DTPA extractable Fe 36.61 mg kg⁻¹ but Mn, Zn and Cu declined compared to the initial (Table III).

The combination of inorganic source of nutrients with organic and microbial cultures favoured

solubilisation of native phosphorus leading to increase in available pool and thus contributing to increased yield.

The study clearly indicates that in soil with inherent high available and total phosphorus the dosage of P can be reduced. The proof to this is provided by the mobilization of native P by the microorganism both VAM and PSB. Thus combinations of organics and microbes could maximize P use efficiency which could save on phosphorus without affecting yield.

REFERENCES

- AMRANI, M., WESTFALL, D. G. AND MOUGHILI, L., 1999, Evaluation of residual and cumulative phosphorus effects in contrasted Moroccan calcareous soils. *Nut. Cycling Agroecosys.*, **55**: 231-238.
- GRYNDLER, M., LESTINA, J., MORAVEC, V., PRIKRYL, Z. AND LIPAVSKY, J., 1990, Colonization of maize roots by VAM fungi under conditions of long-term fertilization of varying intensity. *J. Agri. Eco. Env.*, **29**:183-186.
- MAHANTA, D. AND RAI, R. K., 2008, Effects of sources of phosphorus and biofertilizers on productivity and profitability of soybean (*Glycine max*)-wheat (*Triticum aestivum*) system. *Indian J. Agron.* **53**(4): 279-284.
- MEENA MARY, MATHEW, S. M. AND SHAHUL HAMEED, 2002, Effect of microbial inoculants and phosphorus levels on growth and phosphorus nutrition of vegetable cowpea. *J. Trop. Agri.*, **40**: 74-77.
- SURI, V. K., CHOUDHARY, A. K., CHANDER, G., VERMA, T. S., GUPTA M. K. AND DUTT, N., 2011, Improving phosphorus use through co-inoculation of Vesicular Arbuscular Mycorrhizal Fungi and phosphate-solubilizing bacteria in maize in an acidic alfisol. *Commn. Soil Sci. Plant Anal.*, **42**: 2265-2273.