SOIL AND NUTRIENT MANAGEMENT FOR SUPPRESSION OF FUSARIUM WILT DISEASE OF YARD LONG BEAN

(*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)

By

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(2016 - 11 - 094)

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE & AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522
KERALA, INDIA

2018

DECLARATION

I, hereby declare that this thesis entitled **"SOIL AND NUTRIENT MANAGEMENT FOR SUPPRESSION OF FUSARIUM WILT DISEASE OF YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani
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CERTIFICATE

Certified that this thesis entitled **"SOIL AND NUTRIENT MANAGEMENT FOR SUPPRESSION OF FUSARIUM WILT DISEASE OF YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)"** is a record of research work done independently by **Mr. Sooraj R. S.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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ACKNOWLEDGEMENT

I feel immense pleasure to express my profound and heartfelt thankfulness to Dr. Biju Joseph, Assistant Professor, Department of Soil science and Agricultural Chemistry and the Chairperson of my Advisory Committee for his patience, support, inspiring guidance and constant encouragement throughout the course of investigation and preparation of thesis. This work would not have been possible without his valuable help and support.

I wish to express my sincere gratitude to Dr. Sudharmaidevi C.R., Professor and Head, Department of Soil science and Agricultural Chemistry, College of Agriculture, Vellayani and member, advisory committee for her constant encouragement, support, critical suggestions and timely help throughout the research work and course of study.

I express my heartfelt gratitude to Dr. R. Gladis, Assistant Professor, Department of Soil science and Agricultural Chemistry, College of Agriculture, Vellayani and member of advisory committee for her timely suggestions and kind guidance throughout the course programme. I express my heartfelt gratitude to Dr. Babu Mathew P., Professor (Agronomy) and member of advisory committee for his support, valuable and positive advices and instructions which were always informative and helpful to me throughout the course of investigation.

I express my deepest and sincere thanks to Dr. A. Sajeena, Assistant Professor (Plant Pathology), Cropping Systems Research Centre, Karamana and member of advisory committee for providing all essential directions and valuable support for the conduct of research work.

I express my gratitude to all the teaching and non teaching staff of the department of Soil Science and Agricultural Chemistry, for their help and support during the study period.

I owe my sincere thanks to Geethu Jacob, Lakshmi S., Sreelakshmi M.M., Parvathy P.J., Shamsidha P. and Nibinettan, Dhaneshettan and chechiez (Shreya, Priya and Rakhi) for their help extended to me during the study period.

I owe my special thanks to Ananthuvettan, Ajmal, Faseeh, Ajeesh, Latheef, Rahul, Naveen, Gokul, Akhil, Fallu, Abhinav, Ajil, Arjun, Avinash, Shahiba, Chacko, Divya, Merin, Elizebeth, Mathew, Anaswasra and Shilpa for their support and help during the course of my study.

I am thankful to my seniors, colleagues, junior students and research assistants for their help during my research work.

I wish to acknowledge with gratitude the award of fellowship by the Kerala Agricultural University during the tenure of the M. Sc. (Ag.) programme. I am most indebted to my Amma, Achan and Jithu for their affection, constant encouragement and support without which I would not have completed this work and above all, for the attention focused and facilities arranged to carry forward my studies. I bow before the God almighty for all the bountiful blessings showered on me at each and every moment without which this study would never have seen light.

SOORAJ R. S.

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LIST OF ABBREVIATIONS

%	-	Per cent
@	-	at the rate of
°C	-	Degree celsius
B	-	Boron
BCR	-	Benefit / cost ratio
Ca	-	Calcium
CD	-	Critical difference
CEC	-	Cation exchange capacity
Cm	-	Centimeter
Cu	-	Copper
DAS	-	Days after sowing
dSm^{-1}	-	deci Siemens per meter
EC	-	Electrical conductivity
et al.	-	And others
Fe	-	Iron
Fig.	-	Figure
FYM	-	Farm yard manure
g	-	Gram
H	-	Hydrogen
ha^{-1}	-	Per hectare

LIST OF ABBREVIATIONS CONTINUED

K	-	Potassium
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
l	-	Litre
LR	-	Lime requirement
m	-	Meter
Mg	-	Magnesium
mg kg^{-1}	-	milligram per kilogram
ml	-	Milli litre
mm	-	Milli meter
Mn	-	Manganese
Mo	-	Molybdenum
MOP	-	Muriate of Potash
N	-	Nitrogen
No.	-	Number
NS	-	Non significant
P	-	Phosphorus
pH	-	Soil reaction

LIST OF ABBREVIATIONS CONTINUED

POP	-	Package of Practices
ppm	-	parts per million
S	-	Sulphur
Si	-	Silicon
SE	-	Standard error
RDF	-	Recommended dose of Fertilizers
Rs.	-	Rupees
t ha^{-1}	-	Tonnes per hectare
viz.	-	namely
Zn	-	Zinc

Introduction

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1. INTRODUCTION

Yard long bean (*Vigna unguiculata* subsp. *sesquipedalis (L.)* Verdcourt) or vegetable cowpea is an important leguminous vegetable crop of India and is well adapted to wide range of agro-climatic conditions. It is also referred as long podded cowpea, snake bean, pea bean or Chinese long bean, '*Kurutholapayar*', '*Pathinettumaniyan*', '*Achingapayar*', and 'Vallipayar' in the traditional vernaculars used in Kerala. Area under cultivation of vegetable cowpea in Kerala is 6714 hectare and for other pulses, it is 2989 hectare (GOK, 2015). Yard long bean plays a major role in human diet, mostly in poorer countries. It is a rich and inexpensive source of vegetable protein and the pods are highly nutritive containing 23 to 26% digestible protein and high dietary fibre (Ano and Ubochi, 2008). The ability to fix atmospheric nitrogen makes the crop agriculturally important and hence, the crop is considered as an important component of crop rotation systems.

The climatic conditions in Kerala are well suited for the production of vegetable cowpea. However, the crop is highly prone to various pest and disease infestations. Among them, *Fusarium* wilt is one of the serious fungal disease which reduces the yield and quality of the produce drastically. Raghunath *et al.* (1995) reported that the use of chemical fungicides is not much effective against controlling the *Fusarium* wilt disease in vegetable cowpea. Moreover, excessive use of agrochemicals has caused serious environmental and health problems including loss of biodiversity and human disorders. This indicates a need of alternative disease management practices in vegetable cowpea production, which are more safe and economic.

The acidic nature of soils provides a favorable soil reaction for the growth of soil fungal pathogens (Jones *et al.*, 1990). The hostile soil pH and calcium deficiency can be corrected by the addition of liming sources into the soil. The lime recommendation for yard long bean is 250 kg ha^{-1} applied as basal (KAU, 2016). This is inadequate in highly acidic soils while liming rate calculated based on the lime requirement of soil will be more realistic. Field observations have indicated that *Fusarium* wilt disease of vegetable cowpea manifests at the flowering stage of the crop (Senthil, 2003). The possibility of applying lime in splits (basal and at flowering) has to be considered in this context. Alternate liming sources like dolomite can also be evaluated.

Nutrients can affect the disease tolerance or resistance of plants to pathogens. Managing and exploiting soil environmental conditions as part of an integrated control strategy can make a significant contribution to agricultural sustainability and environmental quality. Application of organic matter and practices which increase the total microbial activity in the soil might enhance general suppression of pathogens by increasing competition for nutrients (Kaewchai *et al.*, 2009).

Fusarium wilt in yard long bean has also been linked with the application of organic manure mostly cow dung which may contain the inoculum of the fungus (Smith *et al.,* 1988). Enrichment of cow dung with *Trichoderma* and neem cake can help to reduce the inoculum load of *Fusarium* in the manure (Sreeja, 2014).

Balanced nutrition is important for the proper health of the crop and to develop resistance against diseases. It also helps in the better utilization of nutrients both applied and native to soil thereby maximizing the benefit-cost ratio. Supply of secondary and micronutrients in the optimum quality and in the right stage of the crop is important. There is widespread deficiency of secondary and micronutrients like Ca, Mg and B in Kerala soils (KSPB, 2013). High rainfall, low base saturation, low organic matter content and continuous removal of nutrients without replenishment through fertilizers or organic manures are the main factors contributing to the deficiency of these elements. The inadequate supply of these nutrients may be a major factor which makes the crop susceptible to fungal diseases.

There is a dynamic interrelation between the nutritional status of plants with pathogen and abiotic environment, and hence, proper management of nutrients in cultivated crops can effectively decline the severity of most diseases. The morphological or histological characteristics of the host plants are also governed by their nutritional status, which, in turn, regulates the pathogen entry, its penetration, and spreading of infection to the unaffected plant parts. Healthy plants with optimum nutrition can suppress diseases to a permissible level or to a level which can further be controlled by pesticides or other conventional practices that are more successful, cost-effective and environment friendly.

Hence, the present investigation was undertaken with the following objectives;

- To assess the impact of liming practices, organic manure addition and nutrient management on the release of nutrients in acid soil.
- To study the effect of soil amendments and *Trichoderma* enriched cowdung on the management of *Fusarium* wilt disease of yard long bean.
- To compare the effectiveness of soil amendments and nutrient management on growth, yield and quality parameters of the crop.

Review of Literature

2. REVIEW OF LITERATURE

Leguminous crops are normally considered to be acidifying plants due to fixation of nitrogen which provides an encouraging soil reaction to the growth of soil fungal pathogens in the rhizosphere. Yard long bean is a vegetable pulse crop which is widely cultivated throughout the world and the most important legume grown in Kerala. A group of diseases affects the crop at various stages of its growth, of which *Fusarium* wilt disease (also known as vascular wilt) has emerged as a major concern. Protective measures must be carried out before cultivation because very few counter actions are available after the development of diseases. Some soils suppress soil-borne diseases despite the presence of a high population density of pathogens. If the suppression of soil against soil borne diseases may be improved for crop fields, it may be possible to minimize the labor and cost associated with excessive disinfection practices. In the present study, combinations of soil amendments, were evaluated along with organic manures to suppress the pathogen population, increase soil available nutrients and to reduce the yield reduction caused in the field.

The literature related to severity and extent of yield loss due to *Fusarium* wilt, soil acidity and fungal pathogens, effect of soil amendments and foliar fertilization on plant disease suppression as well as soil nutrient release pattern and quality-yield parameters are reviewed and presented here.

2.1. INCIDENCE, SEVERITY AND EXTENT OF YIELD LOSS DUE TO FUSARIUM WILT DISEASE

Govil and Rana (1994) observed that symptoms of Fusarium wilt are extreme under dry and hot conditions which may cause up to eighty percent plant mortality. Infected plants have brown vascular tissue in the roots and stems and show wilting of the stem tips. The causal organism (*F. oxysporum*) is a soil borne fungus and has been reported to affect a number of pulse crops. The damage due to the infection varied with the stage at which it occurred, and the control of diseases caused by pathogen is very hard. Fusarium wilt epidemics can be critical to individual crops and under favorable condition, the wilt infection can harm the crop completely and cause total crop failure (Halila and Strange, 1997).

Orton (1902) reported the incidence of Fusarium wilt disease in cowpea from USA, while Singh and Sinha (1955) reported the disease incidence in India. The vascular wilt of cowpea was noticed in farmer's field in Thiruvananthapuram district of Kerala since 1995 - 96 (Raghunath *et al*., 1995). Losses in seed yield due to Fusarium wilt ranged from 9.11 to 80.30% in cowpea in North-eastern Brazil (Assucao *et al*., 2003).

Cortes *et al*. (1998) reported that Fusarium wilt was the most important soil borne disease of chickpea particularly in the Indian sub continent, the Mediterranean Basin and California. Severe infestation of the pathogen resulted in considerable losses in the production. Annual yield losses in the chickpea due to Fusarium wilt were estimated at 10 % in India and Spain and 40 % in Tunisia. Similarly in pigeon pea, gross yield failure due to wilt and root rot disease was 97000 t year $^{-1}$ in India (Saxena *et al*., 2002).

Nelson *et al*. (1997) observed immediate loss of soybean crop caused by *Fusarium spp.* which includes decay of root, excessive leaf abscission, chlorosis and empty pod formation. Yield losses from soybean root rot ranged nearly 50 % and probably due to continuous cropping, root rot disease became more and more severe in crop, distressing the yield as well as quality (Li *et al*., 2010).

Clarkson (1978) observed that several *Fusarium spp*. are associated with the root rot of field pea. The symptoms of vascular wilt complex disease may not be able to be seen until the flowering stage and it may be easily confused with root rot caused by other soil borne pathogens. Severe incidence of *Fusarium oxysporum* complex caused a yield loss of 13.9 - 95 % in pea fields (Maheswari *et al.*, 1981) and also became a problem for the production of lentil crop in north India (Chaudhary and Amarjit, 2002). Sivaprasad *et al.* (2013) conducted study regarding incidence of various fungal diseases in black gram and reported that the fraction yield loss due to various biotic factors was of 50%, out of which the fungal pathogen *F. oxysporum* causing vascular wilt alone accounted for 10 - 25 %.

Fusarium is capable of producing macro-conidia, micro-conidia and chlamydospores. Fungal chlamydospores of *F. oxysporum* can stay alive in soil up to six years without any host plants (Haware *et al.*, 1996). The species of *Fusarium* are also capable of producing mycotoxins, which contaminate agricultural crops, mostly cereals, and the food produced out of them (Dean *et al.*, 2012).

2.2. SOIL AND NUTRIENT MANAGEMENT FACTORS AND FUSARIUM WILT DISEASE INCIDIENCE

2.2.1. Soil acidity

As a general rule fungal growth is highly adapted to acidic pH and the association of *Fusarium spp.* with acidic soil reaction was given by Jones *et al.* (1990) and Sharma *et al.* (2005).

Papendick and Cook (1973) reported that application of ammoniacal nitrogen fertilizers (NH_4) decreases the soil pH and increasing the prevalence and extent of damage with the fungal root rot caused by *Fusarim spp.*, although nitrate nitrogen (NO_3) fertilizers decline the disease. Parallel results are obtained for Smiley *et al.* (1996) and they also concluded that the Fusarium rot incidence was minimum at soil pH above 5.3. Moreover, experiments of Alhussaen (2012) assured the possibility of pH level being used to reduce plant disease severity and reproduction.

Bonanomi *et al.* (2010) analyzed an extensive data set of 2,423 studies to identify the characteristics of organic amendments to soil related to suppressiveness against soil-borne diseases. They found that the most useful features showing positive correlations with the disease suppression of *Fusarium* spp. were total bacterial population, the C to N ratio and soil pH.

Deficiency of Ca and Mg is predominant in acid soils with higher rainfall, and are critical for upholding the plant vitality from fungal disease incidence (Huber, 1989). In a greenhouse study conducted by Fukui *et al.* (1994), soil sample drawn from *pythium spp.* infected rhizosphere of wheat and the pH was adjusted to a range from 4.3 to 7.6 using sulfuric acid (H_2SO_4) or lime ($CaCO_3$). Among the various soil samples analyzed, pH more than 6.5 showed minimal disease activity.

In vitro studies conducted by Jaruhar and Prasad (2011), revealed that the acidic pH is optimum for growth as well as sporulation of the *Fusarium oxysporum* which was isolated from the rhizosphere of lentil. However, chlamydospore sporulation was found best in the pH level 4.5 and further increases in the pH level showed retarding effect on mycelial mat accumulation, and sporulation (Tyagi and Paudel, 2014).

2.2.1.1. Constraints regarding the nutrient availability in acidic soils

The soils of Kerala are highly weathered latarite soils (Ultisols) which are mostly acidic with excessive deposition of sesquioxides. Babu (1981) reported that such soils are deficient in available nutrients due to leaching out of exchangeable bases and fixation of nutrients under hydrated as well as amorphous oxides of Fe and Al. Laterization of soil has been resulted in higher fixation of applied phosphorus in the soil under tropical areas (Perur, 1996; West *et al.*, 1997), and are extensively distributed in the humid tropics of India (Velayutham and Pal, 2004). These soils are deficient in zinc and possess a high zinc fixing capacity.

Coleman and Thomas (1967) observed that in extremely weathered tropical acid soil, exchangeable Al^{3+} was the principal cation contributing to soil acidity more than any other ions. It causes a significant portion of the independent negative charge, which is contributed by Al^{3+} and H^{+} ions (exchangeable acidity).

Tadano and Yoshida (1978) reported that the availability of Fe and Al caused reduction in the Zn uptake in strongly acid soils and it also resulted in the nutrient imbalance and limited availability of P, K, Ca, and Mg in several crops (Yoshida, 1981; Fageria *et al.*, 1981; Olaleye *et al.*, 2001). Studies conducted in the laterite soils of Kerala revealed that the nutrient availability in the surface and sub soil reduced with the excessive aluminum present, which can be managed with the addition of soil amendments (Aloka, 2016).

Soil acidity is an important yield reducing factor which restricts the profitable crop production.

In Indian sub-continent, acid soils widely distributed up to 49 million hectare area, of which 26 m ha has pH less than 5.5 and 23 m ha has pH between 5.6 and 6.5 (Panda, 1979). Acid soils make up approximately 30% of the world's whole land area and more than 50% of the world's potentially arable lands, principally in the tropics and subtropics. Low soil pH restricts the nutrient availability in the soil and results in poor plant productivity. It may be also correlated with the existence of toxic elements such as Al, Fe, Mn and hydrogen in higher level (Meena and Yadav, 2014).

2.2.1.2. Liming practice for the amelioration of soil acidity

The inherent acidic nature of soils of Kerala warrants a regular liming practice as part of the soil fertility management strategies to augment food production (GOK, 2013). Productivity of acid soils is low due to the impaired environment of acidic soil, which induces deficiency and toxicity of mineral nutrients. In view of lime requirement (LR) of different groups of acid soils, farmers seldom follow standard recommendations. Therefore, in recent years the dose of lime has been substantially reduced and commonly applied to the tune of 1/5th to 1/10th of the LR (Barman *et al*., 2014). The recommendation of lime and dolomite for yard long bean is 250 kg/ha and 400 kg/ha respectively (KAU, 2016). Leguminous and oilseed crops are showing more response with the lime addition in comparison with other crops.

2.2.2. Organic matter addition

Organic manures can act as a source of fungal pathogens. Hence, all relevant measures should be taken to minimize contamination in the organic manure from outside and within the farm to control the disease infestations. The enrichment of farm yard manure with *Trichoderma* is found very useful for preventing the growth of Fusarium wilt complex in the manure. Moreover, the application of neem cake - cow dung mixture enriched *Trichoderma* are effective to suppress the soil born plant pathogens causing the diseases like quick wilt of pepper, rhizome rot of cardamom and rhizome rot of ginger (KAU, 2009).

Lazarovits *et al*. (2001) reported that the incorporation of organic amendments decreased the incidence of soil born fungal diseases in comparison with the non treated plants. The decomposition of organic manure can lethally affect the pathogen activity through the production of fatty acids as a result of the decomposition which could have regulated the soil pH, nitrification rate, organic matter content and buffering capacity of soil. Moreover, the studies of Kouki *et al*. (2012) exposed the chances of fungal disease incidence as a result of poor quality organic manure application to the crop.

2.2.3. Nutrient management

Fusarium wilt disease in cowpea is not effectively controlled by application of chemical fungicides (Raghunath, 1995). However, it can be managed by enhancing the host plant resistance with proper nutrient management as a proven strategy. Disease resistance of any plant is mainly genetically controlled but has a close association with the nutritional status of the plants or pathogens; and thus, nutrient management has always been an important regulator for plant diseases (Dordas, 2008). There is a dynamic interrelation between the nutritional status of plants with pathogen and abiotic environment, and hence, proper management of nutrients in cultivated crops can effectively decline the severity of most diseases.

Mineral nutrition can affect plant defense either by formation of mechanical barriers, primarily through the development of thicker cell walls, or synthesis of natural defense compounds, such as phytoalexins, antioxidants, and flavanoids, that provide protection against pathogens (Bhaduri *et al.*, 2014). Moreover, addition of nutrients indirectly enhances the pathogen inactivity, thus increasing the yield of crops.

2.3. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON PLANT BIOMETRIC CHARACTERS

2.3.1. Liming

Rajashree and Pillai (2001) observed that application of 250 kg ha^{-1} lime increased the plant height, number of leaves per plant, number of branches per plant and LAI in fodder legumes in summer rice fallows.

Geetha (2015) reported that in a field experiment in rice with three doses of lime, in which the lime applied as per SMP buffer method, soil test based application of fertilizers along with cow dung at the rate of 5 t ha^{-1} resulted in the highest tiller production, number of productive tillers per plant, thousand grain weight and number of grain per panicle than lime applied according to POP recommendations.

A study conducted in pepper revealed that the incorporation of the liming materials such as lime, gypsum and dolomite showed a significant increase in all the biometric characters including plant height, number of leaves, inter nodal length and leaf area and the root characters such as fresh, dry root weight and length of longest root per plant over control without the addition of any liming materials (Aloka, 2016). However, Santos *et al.* (2017) observed that among the various limestone doses applied to cabbage, lime applied @ 4.0 Mg ha^{-1} performed superior with respect to the plant flowering characteristics, shoot development and root volume over all other treatments which received lime @ 0, 1 and 2 Mg ha^{-1}.

2.3.2. Organic manure addition

Band *et al.* (2007) observed that the FYM along with the addition of chemical fertilizers recorded significantly higher crop duration and leaf area index in French bean over control which receiving the recommended dose of fertilizers. Similarly, the studies of Sowmya (2014) in cowpea revealed that the RDF along with FYM at 5 t ha^{-1} recorded highest productive duration, plant height, number of branches per plant and leaf area index to all other treatments including the plot which receiving the sole application of chemical fertilizers.

2.3.3. Foliar fertilization

Foliar application of nutrients during their critical growth stages resulted in higher nutrient uptake by green gram and recorded higher growth and yield parameters (Anandhakrishnaveni *et al.*, 2004).

Foliar nutrition of N and micronutrients resulted in shortest days for flowering, maximum leaf area index and total dry matter content over control in several genotypes of mung bean (Mondal *et al.*, 2011).

The studies conducted by Jose (2015) revealed that foliar fertilization of $MgSO_4$ and borax resulted in the shortest days for first flowering and increased the productive crop duration, number of primary branches and leaf area index of yard long bean laterite soils of Kerala.

Rajitha (2016) reported that the foliar application of one per cent each of secondary and micronutrients recorded the highest biometric as well as yield attributes in groundnut. The attributes like plant height, leaf area, crop duration, number of nodules, and seed yield were increased in green gram with the foliar supplementation of K and micronutrients along with recommended dose of fertilizers (Dhamak, 2017).

2.4. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON YIELD AND YIELD ATTRIBUTES

2.4.1. Liming

Samonte (1985) obtained maximum yields in acidic soils when the pH was raised above 6 under mung bean and soybean cultivation. Parvathappa *et al.* (1995) observed that the application of lime resulted in an increase in yield per plant, harvest index and total dry matter production of cowpea and sunflower over control.

Dutta *et al.* (1998) reported that liming up to 25 per cent LR and 50 per cent LR increased significantly the yield attribute characters, pod yield and oil content of groundnut. Filho *et al.* (2000) studied the response of bean to six rates of lime (0, 3, 6, 9, 12 and 15 ton ha^{-1}) and found that liming increased yield up to 37 per cent over control.

Addition of graded levels of basic slag *viz.,* 500, 750 and 1000 kg ha^{-1} significantly increased grain and straw yield of rice (Mohandas and Appavu, 2000).

Vongvilay *et al.* (2009) studied the effect of lime application on soybean production on two acid upland soils. The highest grain yields of 2,206 and 2,102 kg ha^{-1} were obtained from lime treated Bachieng and Hoythakoune sites as compared with the control treatment (1,462 and 962 kg ha^{-1}, respectively). Moreover, Oluwatoyinbo *et al.* (2009) reported the highest yield of 4.4 Mt ha^{-1} by okra crop with application of 5 Mt ha^{-1} lime.

Sudharmaidevi *et al.* (2012) investigated the effect of liming on nutrient availability and yield of cowpea in ultisols of Southern Kerala. Results showed significant increase in yield and availability of nutrients by liming.

In a field experiment, Mesfin *et al.* (2014) evaluated response of the haricot bean to varied rates of chemical fertilizer and lime on acidic soils. The results revealed that seed yield, dry matter accumulation and harvest index of bean were improved by the liming and subsequent fertilizer application.

The results of Mamatha (2015) revealed that the higher seed and haulm yield in cowpea was obtained by the treatment receiving the recommended dose of fertilizers along with the addition of liming materials over control.

A field study conducted on banana crop in Wayanad district revealed that the addition of lime on the basis of SMP buffer method in acidic soil with a pH of 5.3 resulted in increasing the yield characters such as number of hands, fingers and bunch weight and also obtained a maximum bunch yield of 14.63 kg compared to11.38kg in zero liming plot (Abraham *et al.*, 2015).

Results of the field experiment by Geetha (2015) on rice crop revealed that lime applied as per SMP buffer method, soil test based application of fertilizers along with cow dung at the rate of 5 t ha^{-1} resulted in the highest grain and straw weight, dry matter production and harvest index than lime applied according to POP recommendations.

Meena and Varma (2016) conducted a field experiment to understand the influence of NPK and lime levels under acidic soil conditions for the sustainable mungbean production. Results of the study demonstrated a significant improvement in seed (622 kg ha^{-1}) and biological (2145 kg ha^{-1}) yield with 100 % RDF plus lime @ 200 kg ha^{-1}.

Santos *et al.* (2017) reported that fresh weight, total root dry weight and inflorescence fresh weight and diameter were found significantly increased in cabbage crop which was affected with club root disease caused by *Plasmodiophora brassicae*.

2.4.2. Organic manure addition

Subbarayappa *et al.* (2009) revealed that the application of full dose of recommended dose of fertilizers along with the organic manure incorporation to cowpea increased the pod length, seed weight, per plant yield, total dry matter production and harvest index compared to control.

Application of organic manure to green gram observed makeable increase in seed yield, number of pods per plant, dry matter accumulation as compared to the treatment which didn't received any organic manure source (Shete *et al.*, 2010). Moreover, studies of Sharma and Abraham (2010) revealed that the incorporation of FYM @ 10 t ha^{-1} in combination with N and Zn fertilizer sources recorded significantly higher yield per plant, dry matter accumulation and harvest index in black gram over the sole addition of fertilizers.

Trichoderma has a positive impact on plant growth as it produces different kinds of secondary metabolites which are important for plant growth regulation (Vinale *et al.,* 2009). The application of various organic substrates enriched with *Trichoderma* recorded higher plant height, pods per plant and seed yield over untreated control in chickpea (Talukdar *et al.*, 2017).

2.4.3. Foliar fertilization

Revathy *et al.* (1996) reported that pod weight, number of pods per plant and per plant yield of groundnut was highest with two foliar applications of magnesium. The application of $MgSO_4$ increased yield attributes such as yield, 100 seed weight, total dry matter, leaf dry weight, number of branches per plant and harvest index of soybean (Saad *et al.*, 2000). Ashoub *et al.* (2003) found that foliar application of 1% $MgSO_4$ in sunflower had the uppermost yield characteristics as well as oil, protein and carbohydrate content. The foliar supplementation of $MgSO_4$ and borax in fortnightly intervals increased the pod length, pod weight, yield, number of harvests, bhusa yield, total dry matter production and harvest index yield in yard long bean (Jose, 2015).

The study conducted by Beg and Ahmad (2012) revealed that foliar supplementation of K at one kg ha^{-1} at flowering in mung bean recorded higher plant height, length of petiole, leaf area, dry matter production, yield per plant and harvest index. Shruthi and Vishwanath (2018) found that foliar fertilization of water soluble NPK fertilizers (19:19:19) increased the growth and yield parameters such as plant hight, crop productive duration, pod yield, seed yield, haulm yield and dry matter production in lima bean.

2.5. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON SOIL PROPERTIES AND NUTRIENT AVAILABILITY

2.5.1. Liming

2.5.1.1. Soil pH

The application of liming materials in soybean crop showed increased soil pH and decrease in toxic concentrations of Al and Mn (Raij *et al.*, 1997). Tripathy *et al.* (1982) reported that the lime applied in higher doses results in losses by leaching from the top soil because of their low exchange capacity. Attempts were made to reduce the dose of lime to one fourth to one-half of lime requirement and apply in split doses (Prasad *et al.*, 1983; Pradhan and Misra, 1985).

Mathur *et al.* (1991) observed that liming at split doses increased the soil pH and was found most profitable and sufficient to meet the Ca requirement of crops. The split dose application of lime on the surface 1.5 Mg ha^{-1} recorded the highest pH of 5.6 in the soil which was higher than the single basal application of lime, where the treatment without lime incorporation resulted in the lowest value of 4.8 in control (Caires *et al.*, 2006).

The pot culture studies conducted by Barman *et al.* (2014) in sunflower reported that application of lime at 0 (without lime), 1/3 rd, 2/3 rd and 1 LR improved the soil pH from 5.66 to 7.11, 7.25 and 7.36 respectively.

Treatment with organic fertilizer and $CaCO_3$ increased soil pH and lowered the *R. solanacearum* population nearly 100 times and increased the Ca^{2+} content in tobacco significantly compared to treatments without $CaCO_3$ (He *et al.*, 2014).

Santos *et al.* (2017) observed that the application the limestone doses (0 Mg ha^{-1}, 1.0 Mg ha^{-1}, 2.0 Mg ha^{-1} and 4.0 Mg ha^{-1}) remarkably increased the soil pH from 5.2 and a maximum value of 6.1 was obtained in response to the limestone incorporated @ 4.0 Mg ha^{-1}. The application of lime alleviated the toxicity due to Al present in the soil and enhanced the available nutrients in soil.

2.5.1.2. EC and organic carbon status

Parvathappa *et al.* (1995) reported that the application of lime from 0 to 2.5 t ha^{-1} significantly increased the electrical conductivity from 0.11 dS m^{-1} to 0.16 dS m^{-1} and organic carbon status from 0.32 % to 0.44 %.

Application of different rates of lime by Kumar *et al.* (2014) resulted a non significant variation in electrical conductivity where the organic carbon status was increased from 0.95 % to 1.18 % by lime @ 600 kg ha^{-1} over zero lime amended plot, while Geetha (2015) obtained a positive correlation for both EC and organic carbon in soil. However, Mamatha (2015) reported that the EC and organic carbon status in soil did not have any significant influence with the incorporation of liming materials.

2.5.1.2. Macro nutrients

Smyth and Sanchez (1980) conducted greenhouse and laboratory experiments to study the effect of lime and phosphorus application to an oxisol on phosphorus sorption and iron retention. They reported that $CaCO_3$ and previous P application decreased P fixation and improved cation exchange properties in the soil. Liming ameliorated soil acidity to a favourable limit and substantially augmented calcium plus magnesium status and lime potential in soil (Raji *et al.*, 1982).

Parvathappa *et al.* (1995) reported that the available N, P, S and exchangeable Ca and Mg in soils were increased when lime was applied to a red sandy clay loam acid soil (Oxic Haplustalf) for five years. Application of lime reduced soil acidity and increased organic carbon. Liming stimulates microbial activity leading to mineralization of organic N and fixation of atmospheric nitrogen (Raychaudhuri *et al.*, 1998).

The results of the experiments conducted by Blaszcyk *et al.* (1986) and Nakayama *et al.* (1987) proposed that application of lime significantly increased calcium, magnesium and potassium concentration in the soil over untreated control.

Helyar and Anderson (1974) demonstrated that calcium carbonate application increased exchangeable Ca and decreased exchangeable Al and Mn but had little effect on the exchangeable levels of other cations. Moreover, increase in Ca levels in the soil enhanced the root penetration of soybean in to the deeper layers and also induced the normal distribution of nodules on the root by *Rhizobium* (Balatti *et al.*, 1991).

Tripathi *et al.* (1997) observed that the application of lime materials such as burnt lime or quick lime, slaked lime, calcite, dolomite and limestone increased the nutrients availability of calcium and phosphorus in the soil solution.

Addition of graded levels of basic slag *viz.,* 500, 750 and 1000 kg ha^{-1} significantly increased soil available P, Ca, Mg, Fe and Si (Mohandas and Appavu, 2000).

Raychoudhary *et al.* (1998) reported that liming @ 2.5 t ha^{-1} increased the efficiency of phosphate solublizing micro organism and increased the available P content of an acid hilly Ultisol of Manipur by 25.9 per cent. Application of various liming material were studied by Caires *et al*. (2002) in wheat crop and reported that the basal incorporation of dolomite improved the available Mg status of the soil and increased concentration in the leaves. Tariq and Mott (2006) observed that the higher dose of liming caused enhanced release of Ca^{2+} into the soil solution and in turn that increases Mg in soil which may be correlated with the replacement of Mg from the exchangeable sites. The reduction in the Mg content was observed with the liming due to its displacement by the mass action of calcium in the soil (Fageria *et al*., 2007).

Field experiments conducted by Geetha (2015) on aerobic and flooded systems of rice in which three doses of lime, soil test based application of chemical fertilizers and cow dung at the rate of 5 t ha^{-1} were applied to study the nutrient dynamics revealed that lime applied as per SMP buffer method resulted in higher EC, OC and available nutrients (N, P, K, Ca, Mg and S) than lime applied according to POP recommendations.

The study conducted in Wayanad revealed that the incorporation of the liming materials such as lime, gypsum and dolomite showed a significant increase in pH and available N, P, K status of the soil over untreated control (Aloka, 2016).

2.5.1.3. Micro nutrients

Abruna *et al.* (1964) reported that exchangeable Mn content of humid tropical soils was sharply decreased by liming. The application of lime materials such as burnt lime or quick lime, slaked lime, calcite, dolomite and limestone may reduce solubility of Fe and Mn in the soil (Tripathi *et al.,* 1997).

Sinha and Singh (1987) reported a lowering of water soluble B upon liming as well as its uptake by soybean and groundnut plants. It appears that the major boron fixing inorganic compounds (hydroxides of Fe and Al) increases with a rise in pH and facilitates boron adsorption in high pH soils.

Haynes and Ludecke (1981) reported that liming resulted in an increase in exchangeable Ca and per cent base saturation with concomitant decreases in levels of exchangeable Al, Fe and Mn.

Study carried out from Wayanad district revealed that incorporation of lime at the rate of 3.11 kg/plant on the basis of SMP buffer method in acidic soil with a pH of 5.3 registered higher available copper (6.36 ppm), zinc (2.35 ppm) and boron (0.68 ppm) content in the soil over zero limed treatment (4.85, 1.78 and 0.37 ppm) and thereby maximizing the productivity (Abraham *et al.*, 2015).

Geetha (2015) conducted field experiments on aerobic and flooded systems of rice in Palakkad with three doses of lime. The lime applied as per SMP buffer method resulted in lower available Fe, Mn and Al in soil than lime applied according to POP recommendations.

Mamatha (2015) conducted an experiment under the cowpea rhizosphere with various liming materials. The availability of primary and micronutrients viz; N, P, K, Ca, Mg, S, Zn, Cu, Fe and Si content of soil were found to be high in the treatments receiving basic slag and lime as liming source.

2.5.2. Organic manure addition

A decrease in bulk density by the addition of organic matter residues over long time was observed by Rasmussen and Collins (1991). Organic manure addition into the soil enhanced the physico-chemical properties, organic carbon status and exchangeable nutrients in soil solution which are supportive for plant growth (Heather *et al.*, 2006). Sowmya (2014) observed that the application of RDF along with FYM at 5 t ha^{-1} into the soil resulted in an increase in the availability of nitrogen, phosphorus and potassium after harvest of the crop in comparison with the plot which receiving the sole application of chemical fertilizers under the cowpea rhizosphere.

Thenmozhi and Paulraj (2009) observed that the availability of N, P, K, Ca, Mg, S and micronutrients were increased significantly with the incorporation of organic manure fortified *Trichoderma viride* composts each along with 75 % of the RDF. The microbial enriched compost added into soil act as storehouse for several nutrients and increase biological activities through beneficial microbes, which enhances nutrient dynamics in soil and thereby recover the soil fertility that are contributing to plant growth. The nutrients of different composts were enhanced in litter compost with cow dung slurry and *Trichoderma spp.* over its individual addition, which may be due to the increased rate of decomposition (Wagh and Gangurde, 2015).

2.5.3. Foliar fertilization

Shruthi and Vishwanath (2018) also observed that the application of water soluble NPK fertilizers (19:19:19) did not have any marked influence with respect to the soil properties as well as available nutrients in soil.

2.6. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON CONTENT AND UPTAKE OF NUTRIENTS IN PLANT

2.6.1. Liming

Samonte (1985) obtained optimum yields in mung bean and soybean cultivation due to the higher N status obtained in plants by lime application. The importance of liming for soybeans is due to its effect on the increasing the soil reaction and improving the uptake of N, P, K and S by plant (Quaggio *et al*., 1993).

Parvathappa *et al*. (1995) reported that the liming increased the grain yield, content and uptake of N, P, K, Ca, Mg and S in the grain in cowpea and sunflower over untreated plots.

Filho *et al.* (2000) studied the response of bean to six rates of lime (0, 3, 6, 9, 12 and 15 ton ha^{-1}) and found that the liming caused a higher uptake of N, P, K, Ca, Mg and Cu in the plant.

Liming alone increased the nodule weight per plant (71%), pod (36%) and haulm yield (37%) and their respective N uptake (51% and 91%) and P uptake (49% and 50%) respectively in pod and haulm (Raychoudhary *et al.*, 1998).

Whalen *et al*. (2002) revealed that the uptake of N, K, S, Ca and Mg in Canola grain and straw was greater from soils receiving lime and manure than fertilized soils.

Caires *et al.* (2002) reported that the basal incorporation of dolomitic lime stone increased the Mg concentration in the in leaves of the wheat crop while the addition of gypsum increased the uptake of Ca and S.

Sarker *et al.* (2014) determined the effect of varied levels of lime and phosphorus on the growth and nutrient uptake by Indian spinach (*Basella alba* L.). Application of 2000 kg ha^{-1} lime along with the application of the 150 kg P ha^{-1} resulted in higher uptake of N, K and Ca and better morphological characters in comparison with other treatments.

Mamatha (2015) conducted an experiment in cowpea and reported a higher uptake of N, P and K into the seed and haulm by the treatment receiving the recommended dose of fertilizers along with the addition of liming materials over control.

The study conducted by Aloka (2016) in pepper revealed that the higher content of total N, P, K, Ca and S in leaf with treatments received lime addition and lowest was recorded by control without receiving any liming materials in all stages of plant growth.

Meena and Varma (2016) conducted a field experiment in Vindhyan region of India to understand the influence of NPK and lime levels under acidic soil conditions for the sustainable mung bean production. The study revealed that the total NPK uptake was increased from 53.85 kg/ha to 96.68 kg/ha.

2.6.2. Organic manure addition

Sharma *et al.* (2002) reported that the incorporation of organic manure residues along with various fertilizers improved the content and uptake of primary, secondary and micronutrients by cowpea at harvest. Akbari *et al.* (2002) observed that application of organic manure at 10 t ha^{-1} significantly improved organic carbon, available ‘P’, ‘K’ and ‘S’ status in soil after harvesting ground nut. The uptake of primary nutrients was improved due to the addition of full dose of recommended dose of fertilizers along with organic manure incorporation in chickpea (Subbarayappa *et al.*, 2009).

2.6.3. Foliar fertilization

Superiority was observed in the pod nutrient content and whole plant uptake for N, P, Ca, Mg, S and B in yard long bean with the foliar fertilization of $MgSO_4$ and borax (Jose, 2015). The combined foliar supplementation of Mg, S and micronutrients along with recommended packages for the groundnut improved the nutrient content and uptake of nutrients over ordinary recommended dose (Rajitha, 2016). The foliar K and micronutrient fertilization along the recommended dose of fertilizers (RDF) in green gram resulted in the synergistic effect on concentration and uptake of other nutrients (N, P, Fe, Zn, Cu, Mn) over the plants which received only RDF (Dhamak, 2017).

Shruthi and Vishwanath (2018) reported that foliar fertilization of water soluble NPK fertilizers (19:19:19) improved the uptake of the primary nutrients in lima bean.

2.7. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON QUALITY PARAMETERS

2.7.1. Liming

Parvathappa *et al.* (1995) observed that liming increased grain yield, nutrient uptake and protein concentration of cowpea grain. The studies regarding the response of bean to different rates of lime (0, 3, 6, 9, 12 and 15 ton ha^{-1}) revealed that the protein content and keeping quality were significantly improved by the lime added at the rate of 15 ton ha^{-1} (Filho *et al.*, 2000).

Chatterjee *et al.* (2005) worked on the effect of lime on yield, quality and nutrient uptake by 6 groundnut varieties in the acid soils of Konkan and reported that the application of lime at the rate of lime requirement increased the protein content by 32 per cent over no lime application.

A field trial established by Caires *et al.* (2006) evaluated grain yield and soybean quality based on oil, protein and nutrient content, after liming and the results revealed that the incorporation of lime at the rate of 1.5 M t ha^{-1} showed a higher protein (346.1 g kg^{-1}) and decreased the oil content (166.9 g kg^{-1}) in comparison with the zero limed control. Mamatha (2015) conducted an experiment in cowpea with various liming materials and reported a higher crude protein content of seed in the treatment which receiving basic slag and lime as liming source

2.7.2. Organic manure addition

Nanthakumar and Veeragavatham (2001) observed an increased yield and quality parameters in brinjal due to the incorporation of organic manures. Protein and mineral content of okra fruit was increased when organic manures are added to the soil (Bhadoria *et al.*, 2002). The addition of organic manure @ 2.5 t ha^{-1} in addition with $3/4^{th}$ of recommended dose of chemical fertilizers enhanced the crude protein content in black gram seed from 14.7 to 18.7 per cent (Vasanthi and Subramanian, 2004).

2.7.3. Foliar fertilization

Ram and Bose (2000) observed that foliar fertilization of Mg and micronutrients improved the TSS, total sugar content, reducing sugars and fruit acidity in mandarin orange. Similarly, foliar magnesium application enhanced the vegetative growth and thereby high quality produce (Moretti, 2002; Moustafa and Omran, 2006; Azizi *et al.*, 2011).

The proein content was increased with the foliar application of $MgSO_4$ and borax at fortnightly intervals while keeping quality and fiber content were unaffected (Jose, 2015). Results of Rajitha (2016) suggested that the combined foliar application of Mg, S and micronutrients along with recommended packages for the groundnut improved the protein, oil content and other quality parameters over ordinary recommended dose. Shruthi and Vishwanath (2018) reported that foliar fertilization of water soluble NPK fertilizers (19:19:19) in lima bean increased the protein content of seeds where fiber and fat remained non significant.

2.8. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON DISEASE SUPPRESSION

2.8.1. Liming

Experiments conducted by Everett and Blazquez (1967) to evaluate the effect of lime on the severity of Fusarium wilt of watermelons revealed that plant stand was 6.2%, 53.0%. 62.0% and 85.5% and the soil pH 4.6, 5.5, 6.0 and 6.5 for the no lime, 3,000, 6,000 and 9,000 pounds of lime per acre, respectively.

Jones and Woltz (1967) discovered that the hydrated lime amendments (1,000 and 2,000 lbs/A) reduced the incidence and the rate of development of Fusarium wilt of tomato caused by race 2 of *Fusarium oxysporum* f. *lycopersici*. Marketable yields were increased by both lime rates by approximately 8.76 t ha^{-1}.

The soil fungal population is highly adapted to the acidic pH. The sporulation and mycelia growth were showed maximum values with acidic medium (Jones *et al.*, 1990; Sharma *et al.*, 2005).

The lab studies revealed that the crown rot disease in tomato caused by the pathogen *Fusarium oxysporum* was more severe with the lower lime rate with N source and supplemental addition of the NaCI (Woltz *et al.*, 1992).

Sugimoto *et al.* (2008) evaluated several calcium compounds against Phytophthora stem rot caused by *Phytophthora sojae*i in soybean (*Glycine max*) and observed that the extent of disease reduction was related to increased calcium uptake by plants, suggesting that calcium was the effective element in reducing Phytophthora stem rot.

Niwa (2008) reported that increased calcium levels may suppress the resting spore germination and reduce the pathogenic activities. Soil acidity and calcium deficiency is conducive to the plant disease development.

Application of $CaCO_3$ reduced disease incidence which may be due to the decreased pectinase activity with increase of calcium content and uptake by plants (He *et al.*, 2014).

In a field experiment conducted by Santos *et al.* (2017) the use of the bio-fungicide (*T. harzianum*) in combination with the limestone doses (0 Mg ha^{-1}, 1.0 Mg ha^{-1}, 2.0 Mg ha^{-1} and 4.0 Mg ha^{-1}) was evaluated against the club root disease caused by *Plasmodiophora brassicae*. The results revealed that the increased yield and reduced diseased root volume in response to the limestone doses was obtained and disease reduction was not significant with the use of the biofungicide. The effect of liming probably derives from both its beneficial action on the neutralization of Al and its phytotoxic effect on root development.

2.8.2. Organic manure addition

Cotxarrera *et al.* (2002) studied the effect of vegetable waste compost and animal waste compost to suppress the incidence of *Fusarium oxysporum* f.sp. *lycopersici* in tomato and observed 90 % decrease in wilt disease.

Mallesh *et al.* (2009) reported that soil amended with FYM showed 62.5 % reduction in disease severity of root rot of sage caused by *F. solani* and *R. solani*.

Yadav *et al.* (2010) studied the suppressive action of *Trichoderma harzianum*, FYM and vermicompost separately and in combination under field conditions against Alternaria leaf spot disease of cabbage. Seedling treatment with *T. harzianum* and its application along with vermicompost recorded the highest disease reduction (62.5%).

Saadi *et al.* (2010) evaluated the impact of compost (tomato plant and cow manure) against *Fusarium oxysporum* in melon and in turn 83 % disease reduction was obtained over control.

Results of experiment conducted in yellow soil (ultisols) and *kuroboku* soils (andisols) revealed the benefits of addition of organic amendments increased suppressiveness against spinach wilt disease (*F. oxysporum* f. sp. *Spinaciae*) and against lettuce root rot disease (*F. oxysporum* f. sp. *lactucae*) in Japan (Mituboshi *et al.*, 2018).

The several approaches are conducted to control the soil born phytopathogens such as *F. oxysporum* f. sp. *ciceri, R. solani,* and *S. rolfsii* with cultural or chemical methods but these measures alone were uneconomical and complicated since the soil and seed-borne nature of the pathogen (Ahmad *et al.*, 2010). *Trichoderma* enriched organic manures can be used as an effective organic manure source for plant growth and suppression of plant pathogenic soil borne fungi especially the *Fusarium sp. Trichoderma* fortified compost is very effective in controlling different soil-borne pathogen as well as increasing growth and yield of many crops (Kaewchai *et al.*, 2009; Rahman, 2013).

2.8.3. Foliar fertilization

Application of foliar KNO_3 considerably reduced the mean disease incidence, severity and leaf shedding in the Alternaria leaf blight affected cotton (Bhuiyan *et al.*, 2007). Kashyap and Dhiman (2009) found that foliar fertilization of K salts to cauliflower leaves suppressed alterneria blight (*Alterneria brassicola)* by developing induced protection against the pathogen. Narmadhavathy (2016) observed the efficiency of NPK foliar spray as 19:19:19 (0.5%) in controlling anthracnose leaf spot disease *(Colletotrichum fructicola)* of culinary melon where application of $CaNO_3$ was less effective.

Boron (B) can suppress the penetration of pathogen infection since it promotes the integrity and permeability of the plasma membrane (Dordas, 2008). By affecting phenolics and lignin synthesis, B can also suppress penetration of pathogens. Moreover, *in vitro* studies of Sanjeev and Eswaran (2008) exposed the efficacy of borax against *Fusarium oxysporum* causing Panama wilt of banana.

Nayana (2015) observed that the banana Sigatoka leaf spot was effectively controlled by foliar application of Mg, Zn and B along with fungicides or bio-control agent. Similarly, foliar fertilization of liquid micronutrient formulations to *Kokkan* virus affected banana plants have been shown reduction in the external disease symptoms, virus titre values and shown improvement in yield (Sangeetha, 2015).

2.9. EFFECT OF SOIL AND NUTRIENT MANAGEMENT ON ECONOMICS OF PRODUCTION

2.9.1. Liming

Kumar *et al.* (2014) applied different rates of lime in ricebean and obtained an increase of Rs. 16034 ha^{-1} in gross returns by the lime application @ 600 kg ha^{-1} over zero lime amended plot. The benefit cost ratio calculated was 2.01 and 2.29 with the application of lime @ 0 kg ha^{-1} and 600 kg ha^{-1} respectively.

Nazrul and Shaheb (2016) carried out an experiment to evaluate the integrated method of liming and fertilizer addition in cauliflower. The benefit cost ratio of 2.91 was obtained for the treatments without lime, where 3.32 achieved through liming @ 2 t ha^{-1}.

2.9.2. Organic manure addition

The organic amendments are potential source of beneficial microorganisms which can antagonize the soil born plant pathogen and in turn are able to assure economic crop production under unhealthy field conditions. Mallesh *et al.* (2009) reported that application of FYM resulted in higher net income and benefit cost ratio through the suppression of root rot disease. Addition of organic amendments increased the net returns in the field affected with spinach wilt disease (Mituboshi *et al.*, 2018).

2.9.3. Foliar fertilization

Nayana (2015) observed that foliar fertilization of Mg, Zn and B along with fungicides significantly controlled the banana Sigatoka leaf spot disease, which was more economical than the application of fungicides alone. Similar studies conducted by Sangeetha (2015) exposed the efficiency of liquid micronutrient formulations in reducing the yield loss due to the *Kokkan* virus in banana plants and thereby increased the net income obtained. Shruthi and Vishwanath (2018) obtained an additional benefit of Rs. 33850 ha^{-1} by the foliar fertilization of 19:19:19 over control. The BCR obtained was 4.8 with foliar fertilization in comparison to 3.7 obtained in control which received soil fertilization alone.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation titled "Soil and nutrient management for suppression of *Fusarium* wilt disease of yard long bean *(Vigna unguiculata* subsp. *sesquipedalis (L.)* Verdcourt)" was carried out at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during February to May, 2017. The primary objective of the study was to assess the impact of liming practices, organic manure addition and nutrient management on the management of *Fusarium* wilt disease of yard long bean. The experimental details with special reference to the materials used and methods adopted are described in this chapter.

3.1. EXPERIMENTAL SITE

3.1.1. Location

The experiment was conducted in the D block of the Instructional Farm attached to the College of Agriculture, Vellayani. The farm is situated at 8^0 25' 52'' N latitude and 76^0 59' 15'' E longitude at an altitude of 29 m above mean sea level (MSL).

3.1.2. Soil

The soil of the examination site was sandy clay loam. Initially, the samples were collected, air dried and sieved through 2 mm sieve and analyzed for pH, EC, CEC, organic carbon and available nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B) as per standard procedures (Table 1). The physical and chemical properties of the soil are furnished in Table 2.

3.1.3. Crop and Variety

Vegetable cowpea (variety Vellayani Githika) variety released from the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani was selected for the study. The variety is trailing type with intermediate climbing growth habit. Pods are long, thick, green fleshy with reddish brown colour seeds.

Table 1. Analytical methods followed in soil analysis

Sl. No	Parameter	Method	Reference
1	Bulk density	Core sampler	Black *et al*. (1965)
2	Texture analysis	International pipette method	Robinson (1992)
3	pH	pH meter (Soil: water - 1:2.5)	Jackson (1973)
4	Lime requirement	SMP buffer method	Shoemaker *et al*. (1961)
5	Electrical conductivity	Conductivity meter	Jackson (1973)
6	Organic carbon	Walkley and black rapid titration method	Walkley and Black (1934)
7	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
8	Available P	Bray's extraction and photoelectric colorimetry	Jackson (1973)
9	Available K	Flame photometry	Pratt (1965)
10	Available Ca	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
11	Available Mg	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
12	Available S	Photoelectric colorimetry	Massouni and Comfield (1963)
13	Available Fe	Atomic absorption Spectroscopy	Sims and Johnson (1991)
14	Available Mn	Atomic absorption Spectroscopy	Sims and Johnson (1991)
15	Available Zn	Atomic absorption Spectroscopy	Emmel *et al.* (1997)
16	Available Cu	Atomic absorption Spectroscopy	Emmel *et al.* (1997)
17	Available B	Hot.water.extraction.and estimation.by.Azomethine-H colorimetry..using spectrophotometer	Binghum (1982)

Table 2. Physico-chemical properties of the soil

Sl. No	Physicochemical properties	Status	Rating
Physical properties			
	Bulk density (Mg/m3)	1.40	
Mechanical composition			
1	Coarse sand	15.8%	
2	Fine sand	32.60%	
3	Silt	26.04%	
4	Clay	25.85%	
5	Texture	Sandy clay loam	
Chemical properties			
1	pH	4.97	Very strongly acidic
2	EC	0.05 dS m-1	Normal
3	Organic Carbon	0.79 %	Medium
4	CEC	6.98 cmol kg-1	
5	Available nutrients		
(a)	N	316.2 kg ha-1	Medium
(b)	P	58.4 kg ha-1	High
(c)	K	365.7 kg ha-1	High
(d)	Ca	240 mg kg-1	Deficient
(e)	Mg	126 mg kg-1	Sufficient
(f)	S	4.61 mg kg-1	Deficient
(g)	Fe	36.82 mg kg-1	Sufficient
(h)	Mn	29.6 mg kg-1	Sufficient
(i)	Zn	0.77 mg kg-1	Deficient
(j)	Cu	1.85 mg kg-1	Sufficient
(k)	B	0.09 mg kg-1	Deficient

3.1.4. Source of Seed material

The seeds for the study were obtained from the Instructional Farm of College of Agriculture, Vellayani.

3.1.5. Cropping history of the field

The same crop variety was cultivated in the experimental field during the previous season and it was severely affected with Fusarium wilt disease, caused by the fungus *Fusarium oxysporum* f.sp. *solani*

3.1.6. Season

The experiment was conducted during February to May 2017.

3.1.7. Weather conditions

A warm humid tropical climate prevailed over the experimental area. The data on various weather parameters *viz.* maximum and minimum temperature, relative humidity (RH) and rainfall during the cropping period were collected from the Agro Meteorology Observatory attached to RARS (Southern zone), at College of Agriculture, Vellayani.

3.2. EXPERIMENTAL DESIGNS

3.2.1. Design and layout

The experiment was laid out in Randomized Block Design comprising of 13 treatment combinations replicated thrice. The details of the experiment are given below:

Design of Experiment: RBD		Spacing	: 2 x 2 m
Crop	: Vegetable cowpea	Plot size	: 6 x 6 m
Variety	: Githika	No. of Treatments: 13	

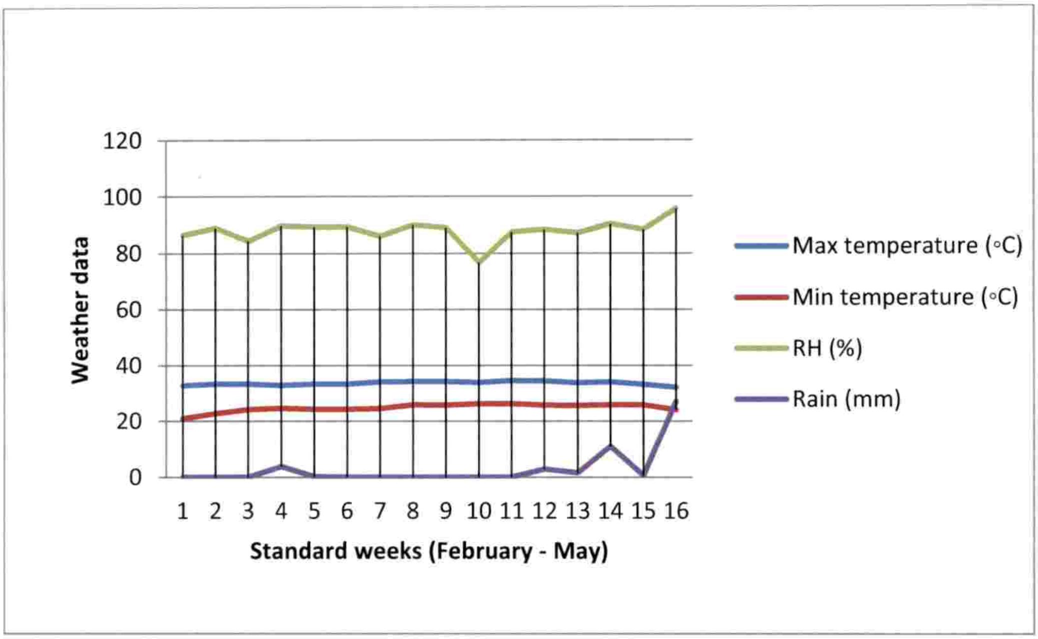


Fig. 1. Weather data for the cropping period

3.2.2. Treatments

T_1 : Soil test based Package of Practices Recommendations of KAU except lime and cow dung

T_2 : T_1 + Foliar application of 19:19:19 NPK (0.5%), KNO_3 (0.3%), $MgSO_4$ (1%) and borax (0.5%) at fortnightly interval

T_3 : Organic package (cow dung 20 t ha^{-1} as basal followed by additional dose of 1.5 t ha^{-1} poultry manure + 50 kg ha^{-1} rock phosphate as 4 equal splits at fortnightly intervals)

T_4 : Fortified thermal organic fertilizer (4 t ha^{-1} as basal, followed by 5 top dressings @ 50g/plant at fortnightly interval)

T_5 : Integrated disease management package developed by KAU (Seed treatment with carbendazim @ 2g/kg seed + burning of pits prior to sowing + soil incorporation of *Trichoderma* enriched neem cake organic manure mixture @ 1 kg/pit at twinning stage + mancozeb and carbendazim (0.3%) at 20, 40 and 50 DAS)

T_6 : T_2 + Lime 250 kg ha^{-1} (POP) + cow dung 20 t ha^{-1}

T_7 : T_2 + Lime 250 kg ha^{-1} (POP) + *Trichoderma* enriched cow dung 20 t ha^{-1}

T_8 : T_2 + Lime @ lime requirement (basal) + cow dung 20 t ha^{-1}

T_9 : T_2 + Lime @ lime requirement (basal) + *Trichoderma* enriched cow dung 20 t ha^{-1}

T_{10} : T_2 + Lime @ lime requirement (2 equal splits - basal and at flowering) + cow dung 20 t ha^{-1}

T_{11} : T_2 + Lime @ lime requirement (2 equal splits - basal and at flowering) + *Trichoderma* enriched cow dung 20 t ha^{-1}

T_{12} : T_2 + Dolomite 400 kg ha^{-1} + cow dung 20 t ha^{-1}

T_{13} : T_2 + Dolomite 400 kg ha^{-1} + *Trichoderma* enriched cow dung 20 t ha^{-1}

All cultural practices as per Package of Practices Recommendations of KAU were followed.

3.3. DETAILS OF OPERATIONS DURING FIELD EXPERIMENT

3.4.1. Land preparation

The experimental site was ploughed and leveled thoroughly. Weeds were removed. The field was laid out into three blocks each with thirteen plots (6 m x 6 m) according to the orientation of the land. Lime and dolomite as per the treatments were incorporated into the pits and mixed well 10 days before sowing.

3.4.2. Manure and Fertilizer application

Organic manures were applied as basal and as top dressing as per the treatments. The fertilizers were applied as per the package of practices recommendations (POP) of KAU (2016). Foliar application of nutrients was given at fortnightly intervals as per the treatments.

3.4.3. Chemical analysis of liming materials

The ameliorants used for the study namely lime ($CaCO_3$) and Dolomite [$CaMg(CO_3)_2$] were analyzed for total Ca, Mg and heavy metals (Al, Pb, Hg, Cd, As, Ni and Cr) as per standard procedures (Table 3).

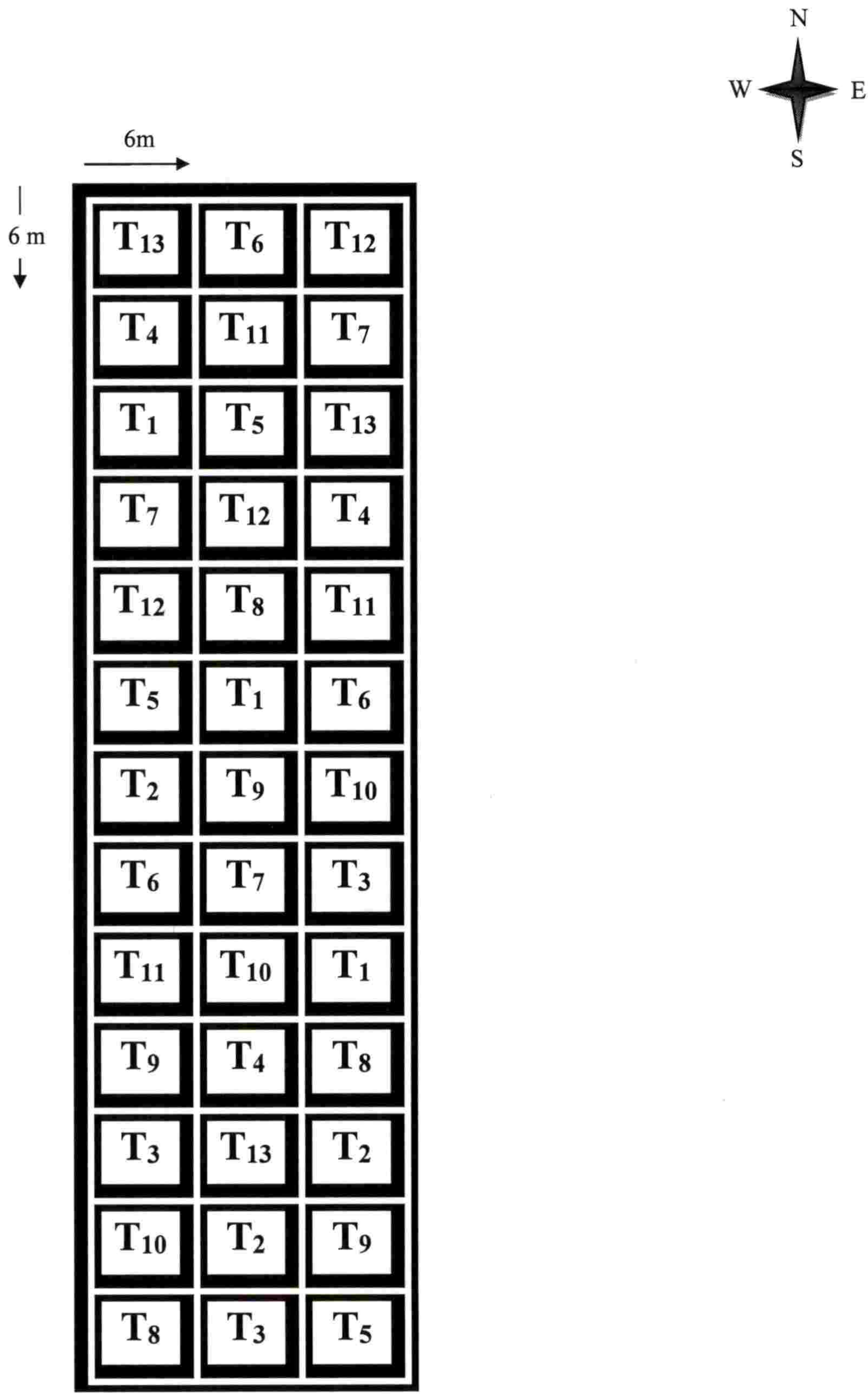


Fig.1: Layout of the field experiment

Table 3. Analytical methods followed for analysis of soil amendments

Sl No.	Parameter	Method	Reference
1	Total Al	Atomic absorption Spectroscopy	Emmel *et al*. (1977)
2	Total Pb	Atomic absorption Spectroscopy	Page and Ganje (1970)
3	Total Hg	Atomic absorption Spectroscopy	Perkin-Elmer (1979)
4	Total Cd	Atomic absorption Spectroscopy	Issac and Kerber (1971)
5	Total As	Atomic absorption Spectroscopy	Issac and Kerber (1971)
6	Total Ni	Atomic absorption Spectroscopy	Piper (1966)
7	Total Cr	Atomic absorption Spectroscopy	Emmel *et al*. (1977)
8	Total Ca and Mg	Atomic absorption Spectroscopy	Issac and Kerber (1971)

3.4.4. Sowing

The seeds of Yard long bean were sown on 7th February 2017 with the application of organic manure and the required quantity of basal dose of fertilizers as per the treatments. Seeds were sown on slightly raised beds with a spacing of 2 m x 2 m.

3.4.5. Plant protection

Quinalphos @ 2 ml l^{-1} was applied for the management of *Aphis craccivora*, when the pest incidence was noticed.

3.4.6. Harvesting

Harvesting commenced from 47 DAS. Subsequent harvests of green pods were done on alternate days. Fresh weight of pods from observation plants were recorded separately.

3.5. OBSERVATIONS

3.5.1. Biometric observations

3.5.1.1. Days for first flowering

Number of days taken for flowering was recorded for each observational plant and mean value was worked out.

3.5.1.2. Crop duration

The duration of the crop from sowing up to the end of the cropping period ie., till crop yield came below economic level was recorded and expressed in days.

3.5.1.3. Leaf Area Index (LAI)

The leaf area of observational plants was measured by graph paper method. LAI was calculated by dividing with spacing of the crop.

3.5.2. Yield characters

3.5.2.1. Pod length

Length of the pod was measured as the distance from pedicel attachment of the pod to the apex using twin and scale. Average of the pod length from observational plants at peak harvesting time was taken and expressed in centimeters.

3.5.2.2. Pod weight

The pods from the observational plants were weighed separately and averages were worked out and expressed in grams.

3.5.2.3. Number of pods per plant

The pods obtained from each of the observational plants were counted and the average was worked out.

3.5.2.4. Yield per plant

The pods from the observational plants were weighed separately and per plant total yield was calculated.

3.5.2.5. Yield per plot

The pods obtained from each of the plots were weighed separately and recorded in kilograms.

3.5.2.6. Total dry matter production

At final harvest, the observation plants were uprooted carefully without damaging the roots, dried under shade and oven dried at 80 ± 5 ^{0}C until two constant weights were obtained. The final weight were recorded and expressed in grams.

3.5.2.7. Harvest Index

Harvest index was calculated using the formula:

$$\text{Harvest index} = \frac{\text{Economic yield (g plant}^{-1})}{\text{Biological yield (g plant}^{-1})} \quad \text{(Donald, 1962)}$$

3.5.3. Collection and analysis of soil samples

Soil samples were drawn from the rhizosphere of the observation plants at flowering stage for analysis of soil pH.

Soil samples were also collected at the end of crop from 0-15 cm depth from different spots in each plot and composite samples were prepared by quartering method. The samples were shade dried, ground, and passed through 2 mm sieve and stored in air tight containers. The processed samples were analyzed for pH, EC, CEC, organic carbon and soil available nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B) as per analytical procedures given in Table 1.

3.5.4. Plant analysis and nutrient uptake studies

3.5.4.1. Index leaf tissue concentration of nutrients

Fourth fully matured leaf samples from the top were collected at 45 DAS for analysis of the N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B concentration.

3.5.4.2. Pod analysis

The pods from observational plants were harvested separately and were dried in a hot air oven at 70 °C until constant weight was obtained, ground and used for analysis. Single acid digestion method using H_2SO_4 was adopted for nitrogen estimation and diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) was employed for all

Table 4. Chemical composition of amendments

Sl. No.	Parameter	Amendments	
		Lime	Dolomite
1	Total Ca (%)	45.23	22.07
2	Total Mg (%)	-	11.59
	Heavy metals		
3	Al (mg kg^{-1})	15	10
4	Pb (mg kg^{-1})	1.1	1.2
5	Hg (mg kg^{-1})	0.1	0.1
6	Cd (mg kg^{-1})	0.8	1.2
7	As (mg kg^{-1})	1.6	1.8
8	Ni (mg kg^{-1})	0.1	0.1
9	Cr (mg kg^{-1})	14	13

Table 5. Analytical methods followed for plant analysis

Sl. No	Parameter	Methods	Reference
1	Nitrogen	Microkjedhal distillation after digestion in sulphuric acid	Jackson (1973)
2	Phosphorus	Nitric – perchloric acid (9:4) digestion and colorimetry making use of vanadomolybdate phosphoric yellow colour method	Jackson (1973)
3	Potassium	Nitric – perchloric acid (9:4) digestion and flame photometry.	Jackson (1973)
4	Calcium and Magnesium	Versanate titration method	Issac and Kerber (1971)
5	Sulphur	Turbidometric method	Bhargava and Raghupathy (1995)
6	Iron, Manganese, Copper and Zinc	Atomic absorption spectroscopy	Lindsay and Norvel (1978)
7	Boron	Azomethine – H colorimetric method	Wolf (1971)

other nutrients. The analytical procedures for index leaf tissue and pod analysis are given in Table 5.

3.5.4.3. Nutrient Uptake

The nutrient uptake in pod was calculated by multiplying the content of the respective nutrient in pod with the dry weight of the pod and expressed as kg ha^{-1}.

3.5.5. Analysis of quality parameters

3.5.5.1. Protein

The protein content in the fresh pod samples was estimated by Lowry method (Sadasivam and Manickam, 1992).

3.5.5.2. Crude Fiber

The crude fibre content in the fresh pod samples was estimated by gravimetric method (Sadasivam and Manickam, 1992).

3.5.5.3. Keeping quality

The harvested pods were kept under ordinary room condition to study the shelf life. The number of days, up to which the pods remained fresh for consumption without loss of colour and glossiness, were recorded.

3.5.6. Disease scoring for Fusarium wilt disease

3.5.6.1. Percentage incidence

Percentage incidence under natural epiphytotic condition (Singh, 2002) was calculated by using the formula

$$\text{PDI} = \frac{\text{Number of affected plants}}{\text{Total number of plants}} \times 100$$

3.5.6.2. Disease index

Based on the extent of damage caused by the disease, standard score chart with pictorial diagram was developed for assessing the severity (disease index) due to Fusarium wilt disease in cowpea (Singh, 2002). Data on the severity of Fusarium wilt in cowpea was recorded following the 0 – 4 (Plate 1) rating scale (Senthil, 2003) where,

0 – Healthy plants

1 – Slight yellowing of leaves

2 – Yellowing and necrosis of leaves, initiation of basal swelling

3 – Basal swelling, yellowing and necrosis of leaves

4 – Basal swelling, distortion, yellowing and necrosis. Total wilting

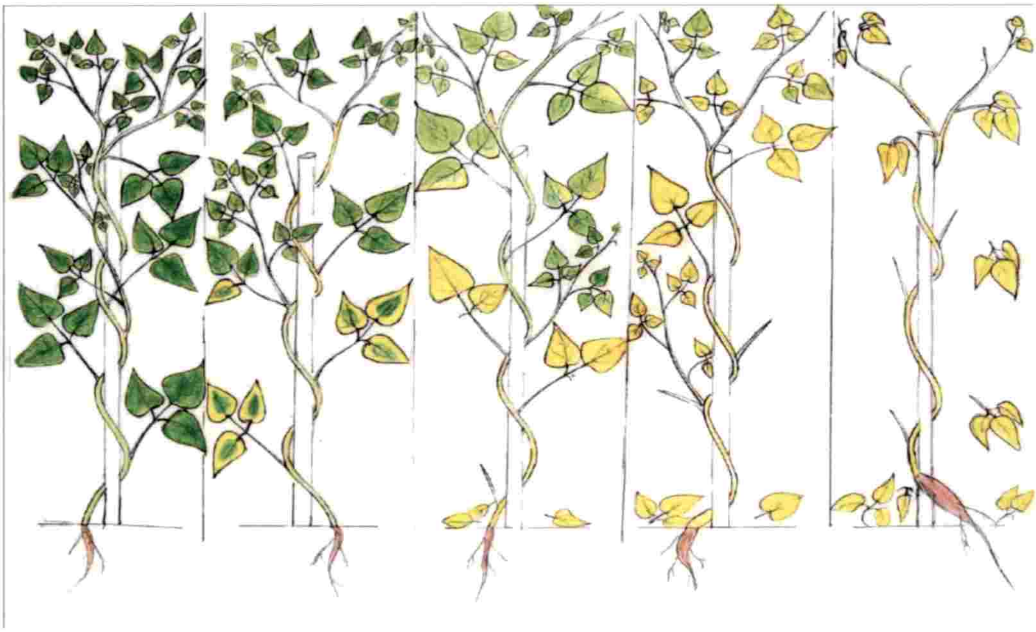
Based on the scores assigned to each diseased plant/leaf, severity (disease index) was worked out using the formula described by McKinney (1923).

$$\text{Disease index} = \frac{\text{Sum of individual ratings}}{\text{Total number of plants/ leaves observed}} \times \frac{100}{\text{Maximum grade}}$$

3.6. ECONOMICS OF CULTIVATION

Based on the cost of cultivation and prevailing price of produce, the economics of cultivation was determined and expressed in terms of benefit: cost ratio (BCR).

$$\text{Benefit Cost ratio} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$



0 1 2 3

4

Plate 1. Standard area diagram for assessing the severity of Fusarium wilt in cowpea

3.7. STATISTICAL ANALYSIS

The data generated from the experiment were statistically analyzed using the technique of Analysis of Variance for Randomised Block Design (Cochran and Cox, 1965) and the significance was tested using F test. Wherever the F values were found significant, critical difference was calculated at five per cent probability level.

Plate 2. General view of the field experiment

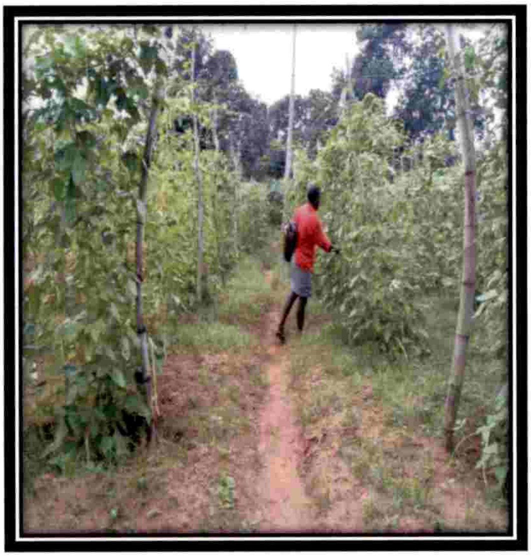


Plate 3. Foliar application of nutrients in the field and the changes observed

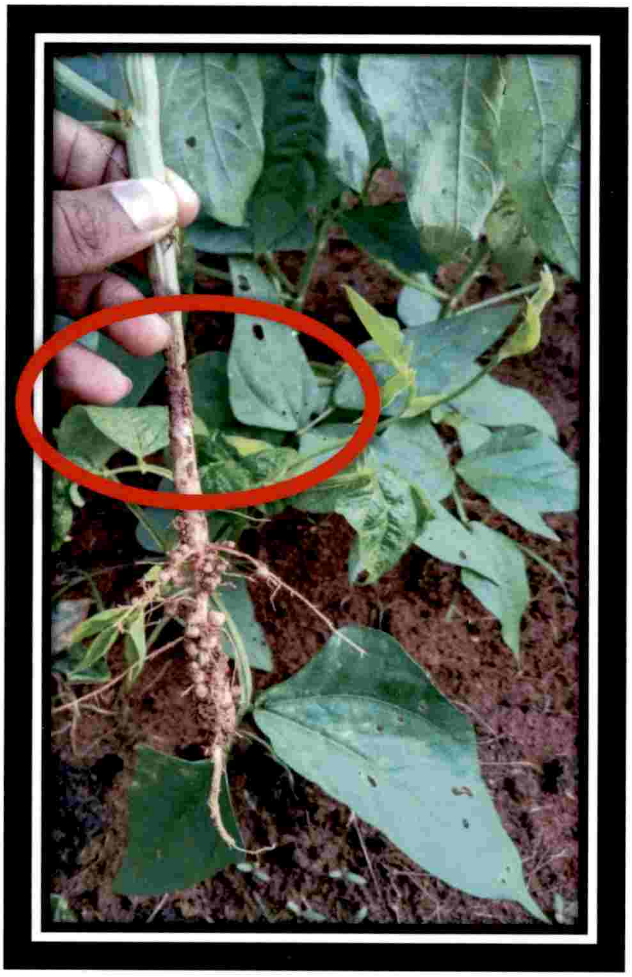


Plate 4. The *Fusarium* wilt disease at initial stage

Results

4. RESULTS

The study entitled "Soil and nutrient management for the suppression of Fusarium wilt disease of yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was carried out to assess the impact of liming, organic manure addition and nutrient management on the suppression of *Fusarium* wilt disease of yard long bean. The results generated from the investigation are presented in this chapter.

4.1. BIOMETRIC OBSERVATIONS

4.1.1. Days to first flowering

The data on the influence of treatments on the number of days to first flowering is presented in Table 6. The treatments resulted in a significant reduction in the number of days to first flowering. Minimum number of days for first flowering was observed in the treatments T_8 and T_9 (32 days) which received application of lime @ LR at basal dose and organic manure as cow dung (20 t ha^{-1}) and *Trichoderma* enriched cow dung (20 t ha^{-1}) respectively. This was followed by T_{11} (33.66 days), T_{12} (34 days), T_{13} (34.33 days), T_6 (34.33 days), T_7 (34.33 days) and T_{10} (34.33 days) which were on par. The organic package (T_3) recorded the maximum number of days for first flowering (36.33) which was on par with the treatments T_1 and T_2 which received POP recommendations without lime and cow dung (35.66 days). Basal incorporation of dolomite at the rate of 400 kg ha^{-1} (T_{12} and T_{13}) was equally effective as lime applied as 250 kg ha^{-1} (T_{10} and T_{11}).

4.1.2. Crop duration

The duration of the crop was significantly influenced by the treatments. The maximum crop duration of 95.33 days was observed in the treatments receiving foliar fertilization, lime @ lime requirement as 2 splits and cow dung at 20 t ha^{-1} (T_{10}) which was on par with T_{11} (94.66 days). The lowest crop duration was recorded in the fortified organic

Table 6. Effect of soil and nutrient management on biometric observations of yard long bean

Treatments	Days to first flowering	Crop duration (days)	Leaf Area Index (LAI)
T_1	35.66	86.33	0.36
T_2	35.66	87.00	0.38
T_3	36.33	85.66	0.37
T_4	35.00	85.33	0.37
T_5	34.66	87.33	0.41
T_6	34.33	89.66	0.38
T_7	34.33	89.66	0.39
T_8	32.00	91.66	0.39
T_9	32.00	93.00	0.38
T_{10}	34.33	95.33	0.41
T_{11}	33.66	94.66	0.42
T_{12}	34.00	92.00	0.40
T_{13}	34.33	92.33	0.40
CD (0.05)	**0.893**	**2.589**	**0.027**

fertilizer treatment T_4 (85.33 days) which was on par with T_3 (85.66 days), T_2 (87 days) and T_1 (86.33 days).

4.1.3. Leaf area index (LAI)

The treatments significantly influenced the leaf area index of the plants. The treatment T_{11} (soil test based POP recommendation with 2 split doses of lime @ lime requirement and *Trichoderma* enriched cow dung + foliar spray of nutrients at fortnightly intervals) recorded the highest leaf area index of 0.42 which was on par with T_{10} (0.41), T_5 (0.41), T_{12} (0.40) and T_{13} (0.40). Treatment T_1 recorded the lowest leaf area index (0.36) and it was on par with T_2 and organic treatments (T_3 and T_4).

4.2. YIELD AND YIELD ATTRIBUTES

4.2.1. Pod length

The results on pod length of yard long bean as influenced by various treatments are presented in Table 7. Highest pod length of 51.10 cm was recorded in the treatment T_{11} (soil test based POP recommendation with modified split doses of lime @ lime requirement and *Trichoderma* enriched cow dung @ 20 t ha^{-1} + foliar spray of nutrients at fortnightly intervals) which was on par with T_8 (50.63 cm), T_9 (51.06 cm) and T_{10} (50.30 cm). Application of lime @ LR as basal dose (T_8) recorded a pod length of 50.63 cm which was significantly higher than the pod length in the treatment receiving POP recommendation of lime (T_6). Split application of lime didn't influence pod length with T_8 (50.63 cm) and T_{10} (50.30 cm) being on par. Enrichment of cow dung with *Trichoderma* also did not influence the pod length. Dolomite when applied at 400 kg ha^{-1} (T_{12} and T_{13}) performed on par with the treatments receiving lime at 250 kg ha^{-1} (T_6 and T_7).

4.2.2. Pod weight

The results of pod weight of yard long bean are presented in Table 7. There was a significant influence of the treatments on pod weight. The highest pod weight of 19.69 g

Table 7. Effect of soil and nutrient management on yield and yield attributes of yard long bean

Treatments	Pod length (cm)	Pod weight (g)	Number of pods per plant	Yield per plant (g)	Yield per plot (t ha^{-1})
T_1	45.76	15.49	58	898.42	8.98
T_2	46.13	15.63	59	922.17	9.22
T_3	44.80	14.79	56	828.24	8.28
T_4	44.70	14.67	56	821.52	8.21
T_5	45.10	16.04	59	946.36	9.46
T_6	46.70	16.89	61	1030.29	10.30
T_7	47.50	17.34	63	1057.74	10.57
T_8	50.63	17.66	64	1175.58	11.75
T_9	51.06	18.75	65	1212.80	12.12
T_{10}	50.30	19.54	65	1263.62	12.63
T_{11}	51.10	19.69	65	1286.35	12.86
T_{12}	47.50	17.12	60	1032.34	10.32
T_{13}	48.06	18.23	61	1050.20	10.50
CD (0.05)	2.506	1.625	2.709	39.340	0.54

was recorded in the treatment T_{11} (lime @ LR in 2 split doses along with *Trichoderma* enriched cow dung) which was on par with T_{10} (19.54 g), T_9 (18.75 g) and T_{13} (18.23 g). The treatments receiving lime at 250 kg ha^{-1} (T_6 and T_7) performed on par with the treatments receiving lime @ lime requirement. Split application of lime resulted in significant increase in pod weight with T_{10} (19.54 g) being superior to T_8 (17.66 g). Enrichment of cow dung with *Trichoderma* did not significantly influence pod weight (T_8 was on par with T_9 and T_{10} was on par with T_{11}). The treatments receiving lime at 250 kg ha^{-1} (T_6 and T_7) were on par with the treatments receiving dolomite at 400 kg ha^{-1} (T_{12} and T_{13}).

4.2.3. Number of pods per plant

The treatments had a significant effect on number of pods per plant. Highest value was noticed in the treatments T_{11} (65), T_{10} (65) and T_9 (65) which was on par with T_8 (64) and T_7 (63). Number of pods per plant increased with the incorporation of liming materials in comparison with the organic manure applied treatments (T_3 and T_4) and control plot (T_1). Application of lime as per lime requirement (T_8) resulted in significantly higher number of pods per plant (64) in comparison to treatments receiving lime at 250 kg ha^{-1} (T_6). Split application of lime didn't influence the number of pods. Dolomite performed on par with lime with respect to number of pods.

4.2.4. Yield per plant

The treatments significantly influenced the yield per plant of cowpea (Table 7). The highest yield was obtained in T_{11} (1286.35 g) which received lime as per lime requirement in 2 splits and organic manure as *Trichoderma* enriched cow dung at 20 t ha^{-1}. However, this was on par with T_{10} (1263.62 g) where the organic manure used was cow dung. Application of lime as per lime requirement (T_8 and T_9) significantly increased the yield per plant in comparison with lime applied at the rate of 250 kg ha^{-1} (T_6 and T_7). Enrichment with *Trichoderma* didn't significantly influence yield per plant as indicated by the on par values obtained between T_6 and T_7, T_8 and T_9 and T_{10} and T_7. Dolomite performed on par with lime application (T_6 is on par with T_{12}, T_7 is on par with T_{13}). The lowest yield per plant was recorded in T_4 – fortified organic fertilizer (821.52 g) which was on par with T_3 – organic package (828.24 g)

4.2.5. Yield per plot

The trend of results for yield per plot was similar to that of yield per plant (Table 7). The maximum mean yield per plot was obtained in T_{11} (12.86 t ha^{-1}) which was on par with T_{10} (12.63 t ha^{-1}) and were significantly superior to all other treatments. Application of lime as per lime requirement (T_8 and T_9) significantly influenced the yield per plot in comparison to application of lime at 250 kg ha^{-1} (T_6 and T_7). Application of *Trichoderma* enriched cow dung (T_7, T_9 and T_{11}) produced on par results for yield per plot in comparison to organic manure applied as cow dung (T_6, T_8 and T_{10}). Application of dolomite @ 400 kg ha^{-1} (T_{12} and T_{13}) produced on par results with the treatments receiving lime at 250 kg ha^{-1} (T_6 and T_7). The treatment receiving organic package T_3 (8.28 t ha^{-1}) was on par with fortified organic fertilizer T_4 (8.21 t ha^{-1}).

4.2.6. Total dry matter production

The result on total dry matter production (t ha^{-1}) as influenced by treatments is presented in Table 8. The highest dry matter production was associated with the treatment T_{11} (2.72 t ha^{-1}) which was on par with T_{10} (2.64 t ha^{-1}). The lowest value was obtained in T_4 (1.91 t ha^{-1}) which was on par with T_3 (1.94 t ha^{-1}). Lime application as per lime requirement (T_8 and T_9) significantly influenced total dry matter production in comparison to the application of lime at 250 kg ha^{-1} (T_6 and T_7). Split application of lime at basal and flowering stages (T_{10} and T_{11}) significantly increased total dry matter production in comparison to lime applied as single basal dose (T_8 and T_9). There was no significant influence of application of *Trichoderma* enriched cow dung (T_7, T_9 and T_{11}) and application of cow dung (T_6, T_8 and T_{10}). Liming material did not influence total dry matter production with dolomite treatments (T_{12} and T_{13}) performing on par with lime applied treatments.

Table 8. Effect of soil and nutrient management on total dry matter production and harvest index of yard long bean

Treatments	Total dry matter production (t ha^{-1})	Harvest Index
T_1	2.03	0.573
T_2	2.16	0.579
T_3	1.94	0.559
T_4	1.91	0.556
T_5	2.25	0.575
T_6	2.28	0.580
T_7	2.32	0.587
T_8	2.50	0.596
T_9	2.57	0.606
T_{10}	2.64	0.614
T_{11}	2.72	0.620
T_{12}	2.28	0.593
T_{13}	2.33	0.589
CD (0.05)	**0.117**	**0.0093**

Table 9. Effect of soil and nutrient management on soil pH, electrical conductivity and soil organic carbon

TREATMENTS	Soil pH @ flowering stage	Soil pH @ harvest	EC (dS m^{-1})	Organic carbon (%)
T_1	4.85	4.80	0.08	0.98
T_2	4.89	4.82	0.08	0.93
T_3	5.69	5.41	0.11	1.15
T_4	5.13	5.10	0.10	1.16
T_5	6.28	5.83	0.12	1.22
T_6	6.31	5.78	0.11	1.17
T_7	6.28	5.72	0.09	1.22
T_8	6.54	6.36	0.12	1.25
T_9	6.43	6.31	0.15	1.23
T_{10}	6.74	6.56	0.17	1.25
T_{11}	6.69	6.53	0.19	1.23
T_{12}	6.33	5.79	0.11	1.17
T_{13}	6.25	5.72	0.08	1.19
CD (0.05)	**0.258**	**0.346**	**NS**	**NS**

4.2.7. Harvest Index

There was a significant influence of treatments on harvest index of yard long bean (Table 8). The highest harvest index was associated with T_{11} (0.620) which was on par with T_{10} (0.614) followed by T_9 (0.606) which were on par. The lowest harvest index was associated with the organic treatments T_4 (0.556) and T_3 (0.559).

4.3. ELECRO-CHEMICAL PROPERTIES AND ORGANIC CARBON STAUS OF SOIL

4.3.1. Soil reaction (pH)

The effect of treatments on soil reaction is presented in Table 9. Treatments significantly increased the pH of the soil and the mean values ranged from 4.85 to 6.74 at flowering stage. The highest soil pH was noticed in T_{10} (6.74) which was on par with T_{11} (6.69) and T_8 (6.54). Application of lime @ LR as 2 splits resulted in an increase in the soil pH. However, the effects were not statistically significant. There was no significant variation between the lime amended @ 250 kg ha^{-1} treatments T_6 (6.31) and T_7 (6.28) and the dolomite applied treatments at 400 kg ha^{-1} T_{12} (6.33) and T_{13} (6.25). The lowest pH was registered in T_1 followed by T_2 with a mean value of 4.85 and 4.89 respectively.

There was a decrease in soil pH from flowering stage to harvest in all the treatments. However, maximum soil reaction at harvest of the crop was recorded in T_{10} (6.56), which were on par with T_{11} (6.53), T_8 (6.36) and T_9 (6.31). The treatments without the addition of any liming materials viz. T_1 and T_2 registered significantly lower pH values (4.80 and 4.82) in comparison with the lime amended treatments.

4.3.2 EC

The EC of soil ranged from 0.08 (T_1) to 0.19 (T_{11}) dSm^{-1}. There was no significant difference between treatments with respected to soil electrical conductivity.

4.3.3. Organic carbon

The results on organic carbon status of soil as influenced by various treatments is presented in table 9. It ranged from 0.93 per cent (T_2) to 1.25 per cent (T_8 and T_{10}). However there was no significant difference between the treatments, with respect to the organic carbon.

4.4. AVAILABLE NUTRIENT STATUS OF SOIL

4.4.1 Primary nutrients

The results pertaining to the available nutrient status of soil for primary nutrients at harvest stage of the crop is presented in Table 10.

4.4.1.1. Available Nitrogen

The treatments had a positive influence on the available N content of soil at harvest. The available nitrogen was effectively improved in all treatments in comparison to the initial status of 316.2 kg ha^{-1}. The values ranged from 301.64 kg ha^{-1} (T_3) to 380.76 kg ha^{-1} (T_{11}). The highest mean value was observed in the treatment T_{11} (381 kg ha^{-1}), where lime @ lime requirement was applied as 2 split doses along with *Trichoderma* enriched cow dung @ 20 t ha^{-1}. This was on par with the treatments T_{10} (375 kg ha^{-1}), T_9 (361 kg ha^{-1}) and T_8 (360 kg ha^{-1}). The lowest mean value was registered in the organic treatment T_3 (302 kg ha^{-1}) which was on par with T_4 (302 kg ha^{-1}), T_2 (321 kg ha^{-1}) and T_1 (322 kg ha^{-1}).

4.4.1.2 Available Phosphorous

The mean values for available phosphorus ranged from 59.07 kg ha^{-1} to 80.23 kg ha^{-1}. The highest content was recorded in the treatment T_9 (80.23 kg ha^{-1}) with lime applied as per lime requirement (full dose at basal) followed by the incorporation of *Trichoderma* enriched cow dung which was on par with available P status in T_{11}, T_{10}, T_{13}, T_8, T_7 and T_5. Lime and dolomite amended plots such as T_6 (68.53 kg ha^{-1}), T_7 (70.32 kg ha^{-1}), T_8 (78.63

Table 10. Effect of soil and nutrient management on availability of primary nutrients in soil after harvest, kg ha^{-1}

Treatments	N	P	K
T_1	322	64.61	374
T_2	321	66.61	368
T_3	302	60.24	370
T_4	302	59.07	372
T_5	340	72.99	374
T_6	344	68.53	373
T_7	348	70.32	369
T_8	360	78.63	375
T_9	361	80.23	371
T_{10}	375	76.88	387
T_{11}	381	79.89	391
T_{12}	337	68.50	373
T_{13}	346	74.63	357
CD (0.05)	27.14	10.95	NS

kg ha^{-1}), T_{12} (68.50 kg ha^{-1}) and T_{13} (74.63 kg ha^{-1}) significantly improved the available P status over control plot T_1 (64.61 kg ha^{-1}).

4.4.1.3 Available potassium

The available K status of soil at harvest of the crop didn't differ significantly due to the treatments. Maximum value was recorded in T_{11} (391 kg ha^{-1}) and minimum value in T_2 (368 kg ha^{-1}).

4.4.2. Secondary nutrients

The results on available secondary nutrients status in soil at harvest stage of the crop is presented in Table 11.

4.4.2.1. Calcium

The effect of treatments was found to be significant with respect to available calcium in soil. The highest value was observed in T_{11} (304.12 mg kg^{-1}) which received lime @ lime requirement in 2 splits and *Trichoderma* enriched cow dung @ 20 t ha^{-1}. The lowest value was noticed in T_2 (229.53 mg kg^{-1}) which was on par with control plot T_1 (234.98 mg kg^{-1}), T_3 (248.30 mg kg^{-1}) and T_4 (243.54 mg kg^{-1}). It was also observed that the available calcium status of soil in T_1 and T_2 were lower than the initial calcium status of the experimental field (240 mg kg^{-1}).

4.4.2.2. Magnesium

The available magnesium status of soil was significantly influenced by the treatments (Table 11). The highest mean value of 206.05 mg kg^{-1} was recorded in T_{13} (dolomite at 400 kg ha^{-1} + *Trichoderma* enriched cow dung @ 20 t ha^{-1}) and it was on par to T_{12} (196.01 mg kg^{-1}) which received the application of dolomite at 400 kg ha^{-1} + cow dung @ 20 t ha^{-1}. The lowest mean value was registered in T_2 (119.50 mg kg^{-1}) and it was on par with the control plot T_1 (125.77 mg kg^{-1}). All the treatments with incorporation of

Table 11. Effect of soil and nutrient management on availability of secondary nutrients in soil at harvest, kg ha^{-1}

Treatments	Ca	Mg	S
T_1	235	126	4.38
T_2	230	120	4.45
T_3	248	156.	4.61
T_4	244	160	4.57
T_5	279	166	4.85
T_6	280	152	4.72
T_7	279	168	4.80
T_8	293	156	5.09
T_9	287	167	5.24
T_{10}	293	175	5.20
T_{11}	304	163	5.43
T_{12}	281	196	4.68
T_{13}	280	206	4.75
CD (0.05)	**21.909**	**34.238**	**0.260**

agricultural lime as per lime requirement such as T_8, T_9, T_{10} and T_{11} recorded significantly higher available magnesium status over control.

4.4.2.3. Sulphur

It was observed that the treatments showed significant influence on the available sulphur content at harvest of the crop. Highest mean values were obtained by the treatment T_{11} (5.43 mg kg^{-1}) followed by T_9 (5.24 mg kg^{-1}) and T_{10} (5.20 mg kg^{-1}) which were on par. The lowest available sulphur content was recorded in the control plot T_1 (4.38 mg kg^{-1}).

4.4.3. Available micronutrient status

The results pertaining to the available nutrient status of soil for micronutrients at harvest of yard long bean are presented in Table 12.

4.4.3.1. Iron

The treatments resulted in a significant reduction in available Fe status of soil. The highest available iron content was noticed in T_2 (41.95 mg kg^{-1}) which received POP recommendation along with foliar fertilization and the lowest iron content was noticed in T_{11} (29.03 mg kg^{-1}) with split doses of lime @ lime requirement along with *Trichoderma* enriched cow dung @ 20 t ha^{-1}. The control plot T_1 (39.40 mg kg^{-1}) also recorded a significantly higher available iron content which was on par with T_2, T_3 and T_4. Application of lime @ LR (T_8 and T_9) did not significantly influence the available Fe in soil compared to lime application at 250 kg ha^{-1}(T_6 and T_7). Application of dolomite @ 400 kg ha^{-1} (T_{12} and T_{13}) performed on par with the treatments receiving lime at 250 kg ha^{-1} (T_6 and T_7).

4.4.2.2. Manganese

The results on available Mn status of soil indicated that there was a significant reduction in available Mn content in soil with the application of liming materials, organic manures and foliar fertilizers. The mean values for available manganese ranged from 25.03

Table 12. Effect of soil and nutrient management on availability of micronutrients in soil at harvest mg kg^{-1}

Treatments	Fe	Mn	Zn	Cu	B
T_1	39.40	28.32	0.87	2.16	0.09
T_2	41.95	30.78	0.83	2.06	0.10
T_3	35.08	28.07	1.12	2.25	0.12
T_4	38.46	32.63	1.09	2.28	0.13
T_5	35.93	28.08	1.16	2.32	0.13
T_6	34.85	26.33	1.20	2.18	0.14
T_7	34.72	26.21	1.18	2.20	0.13
T_8	34.36	26.65	1.24	2.37	0.15
T_9	34.73	26.34	1.27	2.46	0.12
T_{10}	30.46	25.03	1.35	2.63	0.11
T_{11}	29.03	25.16	1.39	2.68	0.13
T_{12}	34.60	26.65	1.09	2.07	0.15
T_{13}	35.06	28.00	1.13	2.14	0.14
CD (0.05)	**3.826**	**4.793**	**0.092**	**0.106**	**NS**

mg kg^{-1} to 32.63 mg kg^{-1}. The highest mean value was noticed in T_4 which is on par with T_2 (30.78 mg kg^{-1}), T_1 (28.32 mg kg^{-1}), T_3 (28.07 mg kg^{-1}) and T_{13} (28.00 mg kg^{-1}). The lowest mean value was noticed in T_{10} which was on par with all the lime amended plots.

4.4.2.3. Zinc

The incorporation of various liming materials and organic manures were found to have a significant effect on available zinc of the soil. The highest available zinc content was noticed in T_{11} (T_2 + split doses of lime @ lime requirement + *Trichoderma* enriched cow dung) with mean value of 1.39 mg kg^{-1} which was on par with T_{10} (1.35 mg kg^{-1}) while the lowest was noticed in T_2 (0.83 mg kg^{-1}) which was on par with T_1 (0.87 mg kg^{-1}).

4.3.2.4 Copper

As indicated in Table 12, the available copper content in the soil was significantly influenced by all the treatments. Mean values for available copper in different treatments ranged from 2.06 mg kg^{-1} to 2.68 mg kg^{-1}. The highest available copper content was observed in T_{11} (2.68 mg kg^{-1}) which was on par with T_{10} (2.63 mg kg^{-1}) while the lowest was noticed in T_2 (2.06 mg kg^{-1}) and it was on par with the control plot T_1 (2.16 mg kg^{-1}).

4.3.2.5. Boron

The available boron content of soil ranged from 0.09 mg kg^{-1} (T_1) to 0.15 mg kg^{-1} (T_{12} and T_8). There was no significant difference between the treatments with respect to available boron content of soil.

4.5. INDEX TISSUE CONCENTRATION OF NUTRIENTS

The data pertaining to the index leaf tissue concentration of nutrients as influenced by various treatments are presented in Table 13 to 15.

4.5.1. Nitrogen

The index tissue concentration of nitrogen differed significantly due to the application of soil amendments and organic manures (Table 13). The highest nitrogen content was observed in T_{11} (2.65 %) which received lime @ lime requirement in 2 splits and organic manure as *Trichoderma* enriched cow dung at 20 t ha^{-1}, followed by T_{10} (2.58 %) where the organic manure used was cow dung which were on par. The minimum value was observed in T_1 (2.04 %) which was on par with organic package T_3 (2.19 %). All the lime and dolomite amended treatments showed significant higher nitrogen content in index leaf tissue over control T_1.

4.5.2. Phosphorus

As indicated in Table 13, the total phosphorus content in index leaf tissue was significantly influenced by the treatments. The highest phosphorus content in index leaf was obtained in T_{11} (0.37 %) which received lime @ lime requirement in 2 splits and organic manure as *Trichoderma* enriched cow dung @ 20 t ha^{-1}. However, this was on par with T_{10} (0.35 %) where the organic manure used was cow dung @ 20 t ha^{-1}. The lowest phosphorus content in index leaf was registered by the fortified fertilizer applied plants T_4 (0.22 %) and it was on par with the organic package T_3 (0.24 %) and control T_1 (0.26 %). Dolomite when applied at 400 kg ha^{-1} (T_{12} and T_{13}) performed on par with the treatment receiving lime at 250 kg ha^{-1} (T_6 and T_7).

4.5.3. Potassium

The potassium concentration in the index leaf tissue of yard long bean was not significantly influenced by the treatments. However, the highest potassium content was recorded in T_{11} (2.35 %) and the lowest was registered in T_4 (2.02 %).

Table 13. Effect of soil and nutrient management on content of primary nutrients in index leaf tissue, %

Treatments	N	P	K
T_1	2.04	0.26	2.23
T_2	2.32	0.28	2.20
T_3	2.19	0.24	2.07
T_4	2.23	0.22	2.02
T_5	2.35	0.28	2.27
T_6	2.28	0.27	2.25
T_7	2.30	0.26	2.28
T_8	2.39	0.30	2.30
T_9	2.44	0.29	2.29
T_{10}	2.58	0.35	2.33
T_{11}	2.65	0.37	2.35
T_{12}	2.28	0.25	2.26
T_{13}	2.33	0.26	2.23
CD (0.05)	**0.163**	**0.041**	**NS**

4.5.4. Calcium

The calcium content in index leaf tissue was significantly influenced by the treatments (Table 14). Application of lime @ LR in 2 split doses (T_{10}) resulted in maximum calcium content of 1.66 %. This was followed by T_{11} (1.65 %), which was on par with all the lime amended treatments. Treatments receiving lime at 250 kg ha^{-1} T_6 (1.43 %) and T_7 (1.45 %) performed on par to treatments receiving dolomite at 400 kg ha^{-1} (T_{12} and T_{13}). The lowest calcium content in index leaf was registered by T_4 (0.72 %) and it was on par with the T_2 (0.80 %) and T_1 (0.76 %).

4.5.5. Magnesium

As indicated in Table 14, the magnesium concentration in index leaf tissue was significantly influenced by the treatments. The superior values were associated with the treatments T_{12} (1.34 %) and T_{13} (1.28 %) which received dolomite at 400 kg ha^{-1} and it was on par with the treatments received split application of lime @ LR (T_{10} and T_{11}). However, treatments receiving dolomite at 400 kg ha^{-1} (T_{12} and T_{13}) gave significantly higher magnesium per cent in leaves than the treatments which received lime at 250 kg ha^{-1} (T_6 and T_7).

4.5.6. Sulphur

The sulphur content in index leaf tissue was significantly influenced by the application of various treatments (Table 14). Highest value of 0.27 % was recorded in the treatments T_{11} and T_{13} which were on par with all the treatments which received liming material or organic manure as soil amendment. The organic package (T_3) and fortified organic fertilizer (T_4) registered a sulphur content of 0.22 % in index leaf tissue which was on par with the T_1 (0.18 %).

Table 14. Effect of soil and nutrient management on content of secondary nutrients in index leaf tissue, %

Treatments	Ca	Mg	S
T_1	0.76	0.69	0.18
T_2	0.80	1.25	0.26
T_3	1.02	0.52	0.22
T_4	0.72	0.67	0.22
T_5	1.31	0.97	0.26
T_6	1.43	0.89	0.24
T_7	1.45	0.94	0.25
T_8	1.58	1.02	0.25
T_9	1.61	1.05	0.26
T_{10}	1.66	1.15	0.25
T_{11}	1.65	1.05	0.27
T_{12}	1.36	1.34	0.26
T_{13}	1.38	1.28	0.27
CD (0.05)	**0.216**	**0.303**	**0.054**

4.5.7. Micronutrients

Results of the micronutrient concentration (Fe, Mn, Zn, Cu and B) in index leaf tissue of yard long bean as influenced by treatments are presented in Table 15.

4.5.7.1. Iron

The iron concentration of index leaf tissue ranged from 94.83 mg kg^{-1} (T_{10}) to 127.23 mg kg^{-1} (T_3). There was no significant difference between the treatments with respect to the iron concentration in the index leaf.

4.5.7.2. Manganese

Similar to the results for iron, the manganese concentration of index leaf was also not significantly influenced by the treatments. The values ranged from 66.33 mg kg^{-1} (T_{10}) to 76.93 mg kg^{-1} (T_3).

4.5.7.3. Zinc

The zinc concentration of index leaf tissue was significantly influenced by different treatments. Application of lime @ LR in two splits and *Trichoderma* enriched cow dung @ 20 t ha^{-1} resulted in the highest zinc concentration of 29.93 mg kg^{-1} (T_{11}). However, it performed on par with T_9 (28.46 mg kg^{-1}) and T_{10} (27.32 mg kg^{-1}). Split application of lime (T_{10} and T_{11}) was on par to lime application as single basal dose (T_8 and T_9). Application of *Trichoderma* enriched cow dung (T_7, T_9 and T_{11}) increased the zinc concentration in index leaves over application of cow dung (T_6, T_8 and T_{10}). However, the increase was not significant. The lowest zinc content was obtained by the treatment T_1 (20.44 mg kg^{-1}).

4.5.7.4. Copper

The copper content in index leaf tissue ranged from 3.67 mg kg^{-1} (T_{13}) to 4.78 mg kg^{-1} (T_{10}). However, the differences were not statistically significant.

Table 15. Effect of soil and nutrient management on content of micronutrients in index leaf tissue, mg kg^{-1}

Treatments	Fe	Mn	Zn	Cu	B
T_1	116.00	74.06	20.44	4.23	25.75
T_2	109.56	76.80	21.42	4.45	28.85
T_3	127.23	76.93	22.77	4.45	23.36
T_4	122.86	74.90	23.54	3.91	24.69
T_5	118.80	75.66	25.60	4.34	23.30
T_6	111.47	69.66	24.47	4.00	26.95
T_7	104.80	68.50	24.68	4.29	29.61
T_8	98.24	68.30	26.40	4.45	30.25
T_9	106.26	74.66	28.46	4.34	31.47
T_{10}	94.83	66.33	27.32	4.78	30.36
T_{11}	102.25	70.36	29.93	4.56	32.32
T_{12}	107.63	68.15	23.96	3.78	29.53
T_{13}	114.03	72.40	23.66	3.67	27.73
CD (0.05)	**NS**	**NS**	**3.406**	**NS**	**4.325**

4.5.7.5. Boron

The boron concentration in index leaf tissue was significantly influenced by the various treatments (Table 15). The highest boron concentration of index leaf was observed in T_{11} (32.32 ppm) which receiving the application of lime @ LR and organic manure as cow dung enriched with *Trichoderma* @ 20 t ha^{-1}. It was on par with the boron concentration obtained in treatments which receiving the application of lime (T_{10}, T_9, T_8 and T_7) and dolomite (T_{12}). The lowest boron concentration of 23.30 mg kg^{-1} was obtained in IDM package (T_5).

4.6. NUTRIENT CONTENT AND UPTAKE IN POD

4.6.1. Primary nutrients

The data pertaining to the nutrient concentration and uptake of N, P and K in pod are presented in Table 16.

4.6.1.1. Nitrogen

The N content of pod was significantly influenced by treatments. The highest value of 3.39 % was associated with the treatment T_{10} which received lime as per LR in 2 split doses as soil amendment and cow dung @ 20 t ha^{-1} as organic manure source. However, it was on par with all the foliar fertilized treatments except T_6 and T_{12}. The lowest N content was obtained in T_4 (2.79 %) which was on par with T_3 (2.82 %) and control T_1 (2.84 %).

The treatments significantly influenced the N uptake in pod. The highest uptake was obtained in the treatment T_{11} where lime @ LR was applied in 2 splits along with *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure source. Application of lime as per LR significantly increased the N uptake. The treatments receiving lime @ LR namely T_8, T_9, T_{10} and T_{11} were superior to all other treatments.

Table 16. Effect of soil and nutrient management on content and uptake of primary nutrients in pod

Treatments	% N	Uptake (kg ha^{-1})	% P	Uptake (kg ha^{-1})	% K	Uptake (kg ha^{-1})
T_1	2.84	51.87	0.47	9.11	2.58	47.28
T_2	3.30	53.45	0.56	9.39	3.10	49.87
T_3	2.82	49.63	0.47	8.43	2.60	45.81
T_4	2.79	50.12	0.46	8.26	2.61	46.92
T_5	3.12	51.98	0.54	9.67	2.89	46.66
T_6	3.08	56.99	0.53	9.92	2.93	54.46
T_7	3.17	58.75	0.54	10.16	2.98	55.34
T_8	3.24	69.76	0.55	12.03	3.02	65.12
T_9	3.21	68.90	0.57	12.27	3.10	66.77
T_{10}	3.39	72.89	0.55	11.89	3.13	67.35
T_{11}	3.34	75.26	0.55	12.49	3.04	68.50
T_{12}	3.09	54.37	0.55	12.08	2.90	63.02
T_{13}	3.15	56.80	0.56	11.96	3.06	64.53
CD (0.05)	**0.273**	**11.322**	**0.095**	**2.912**	**0.260**	**9.345**

4.6.1.2. Phosphorus

The phosphorus content in pod was significantly influenced by the treatments. The highest phosphorus content in pod was obtained in T_9 (0.57 %) and lowest was registered in T_4 (0.46 %). Dolomite when applied at 400 kg ha^{-1} (T_{12} and T_{13}) performed on par with the treatment receiving lime at 250 kg ha^{-1} (T_6 and T_7).

The uptake of phosphorus in pods was significantly influenced by the treatments. All the treatments receiving soil amendments were on par.

4.6.1.3. Potassium

The potassium content in pod was significantly influenced by the treatments. The highest potassium content of 3.13 % was recorded in the treatments T_{10} which was on par with lime and dolomite amended treatments T_5, T_6, T_7, T_8, T_9, T_{11}, T_{12} and T_{13}. The lowest value was registered in T_1 (2.58 %) and it was on par with the organic treatments (T_3 and T_4).

All treatments with incorporation of agricultural lime as per lime requirement namely as T_8 (65.12), T_9 (66.77), T_{10} (67.35) and T_{11} (68.50) and dolomite at 400 kg ha^{-1} (T_{12} and T_{13}) produced significantly higher K uptake over other treatments.

4.6.2. Secondary nutrients

The results on the content and uptake of secondary nutrients in pod are presented in the Table 17.

4.6.2.1. Calcium

The calcium content in pod was significantly influenced by the treatments. Split application of lime @ LR (T_{10} and T_{11}) recorded highest value of 1.38 mg kg^{-1} and it was on par to the treatments T_8 and T_9 which received lime @ LR at single basal dose. Application of lime @ POP recommendation (T_6 and T_7) resulted in significantly lower calcium content in pod in comparison to the treatments received lime @ LR (T_8 and T_9) which were in turn on par with the treatments receiving dolomite at 400 kg ha^{-1} (T_{12} and T_{13}).

The uptake of calcium in pod was significantly influenced by various treatments. The highest uptake was obtained in the treatment T_{10} (28.59 kg ha^{-1}) where lime @ LR was applied in 2 splits along with cow dung @ 20 t ha^{-1} as organic manure source. However, it was on par with T_8 (26.34 kg ha^{-1}), T_9 (24.31 kg ha^{-1}), T_{11} (24.04 kg ha^{-1}) and T_{13} (22.51 kg ha^{-1}). The dolomite applied treatment T_{12} and T_{13} performed on par with T_5, T_6 and T_7.

4.6.2.2. Magnesium

The magnesium content in pod was not significantly influenced by the treatments. The values ranged from 0.74 mg kg^{-1} (T_5) to 1.18 mg kg^{-1} (T_{12}).

The uptake of magnesium in pod was significantly influenced by various treatments. The highest value of 26.03 kg ha^{-1} was registered in treatment T_{11} (T_2 + lime @ LR in 2 splits + *Trichoderma* enriched cow dung @ 20 t ha^{-1}) and it was on par with the treatments T_8, T_9, T_{10}, T_{12} and T_{13}. The dolomite treatments (T_{12} and T_{13}) performed on par with the treatments receiving lime at LR rate (T_8, T_9, T_{10} and T_{11}). The lowest uptake of magnesium in pod was obtained in treatment T_1 (8.76 kg ha^{-1}) which was on par with T_3 and T_4.

4.6.2.3. Sulphur

The suphur content in pod was significantly influenced by the treatments. The highest sulphur content in pod was obtained in the treatments T_9 and T_{11} (0.41 mg kg^{-1}) which were on par with T_7, T_8, T_{10}, T_{12} and T_{13}. The lowest sulphur content was registered by control T_1 (0.24 mg kg^{-1}) which was significantly lower than all other treatments.

The uptake of suphur in pod was significantly influenced by various treatments. Highest value of 9.44 kg ha^{-1} was obtained in the treatments T_{11} and it was on par with the

Table 17. Effect of soil and nutrient management on content and uptake of secondary nutrients in pod

Treatments	Ca (mg kg^{-1})	Uptake (kg ha^{-1})	Mg (mg kg^{-1})	Uptake (kg ha^{-1})	S (mg kg^{-1})	Uptake (kg ha^{-1})
T_1	0.48	8.77	0.80	8.76	0.24	4.51
T_2	0.53	9.89	0.86	15.89	0.31	5.80
T_3	0.74	13.06	0.80	13.07	0.31	5.45
T_4	0.69	12.48	0.83	12.48	0.33	6.09
T_5	0.95	16.79	0.74	16.79	0.35	6.27
T_6	1.01	18.81	0.89	18.81	0.34	6.38
T_7	1.05	18.80	0.86	18.93	0.37	6.96
T_8	1.35	26.34	0.89	24.34	0.39	8.50
T_9	1.33	24.31	0.92	23.79	0.41	8.86
T_{10}	1.38	28.59	0.86	24.88	0.40	8.76
T_{11}	1.38	24.04	0.99	26.03	0.41	9.44
T_{12}	1.01	21.76	1.18	21.76	0.40	8.81
T_{13}	0.92	22.51	1.05	22.51	0.40	8.41
CD (0.05)	**0.262**	**6.581**	**NS**	**6.258**	**0.046**	**1.245**

treatments receiving lime as per LR (T_8 and T_9) and treatments receiving dolomite at 400 kg ha^{-1} (T_{12} and T_{13}). The treatment T_1 (4.51 mg kg^{-1}) obtained lowest uptake of S which was on par to the organic package T_3 (5.45 mg kg^{-1}).

4.6.2. Micronutrients

The data pertaining to the content and uptake of micronutrients in pod are presented in the Table 18 and 19.

4.6.2.1. Iron

The content of Fe in pod was not significantly influenced by the treatments. However, the values ranged from 97.6 mg kg^{-1} (T_9) to 112 mg kg^{-1} (T_1).

The iron uptake in pod was also not significantly influenced by various treatments. The highest iron uptake in pod was observed from T_{11} (0.225 kg ha^{-1}) and the lowest was recorded from T_3 and T_6 (0.191 kg ha^{-1}).

4.6.2.2. Manganese

There was no significant difference between the treatments with respect to Mn content of pod. However, the values ranged from 44.66 mg kg^{-1} (T_9) to 52.66 mg kg^{-1} (T_2).

The uptake of Mn in pod was significantly influenced by various treatments. The highest uptake obtained from the treatment T_{12} (0.106 kg ha^{-1}) which received dolomite at 400 kg ha^{-1}. It was on par to all other treatments except with T_3 (0.080 mg kg^{-1}) and T_4 (0.085 mg kg^{-1}).

4.6.2.2. Zinc

The content of Zn in pod was significantly influenced by the treatments. The application of lime @ LR and cow dung enriched with *Trichoderma* @ 20 t ha^{-1} recorded highest zinc content of 32 mg kg^{-1} (T_9 and T_{11}) and it performed on par with the treatments

Table 18. Effect of soil and nutrient management on content and uptake of Fe, Mn and Zn in pod

Treatments	Fe (mg kg^{-1})	Uptake (kg ha^{-1})	Mn (mg kg^{-1})	Uptake (kg ha^{-1})	Zn (mg kg^{-1})	Uptake (kg ha^{-1})
T_1	112	0.205	50.66	0.092	25.33	0.462
T_2	109.3	0.205	52.66	0.097	26.00	0.478
T_3	109.0	0.191	45.66	0.080	24.00	0.424
T_4	110.0	0.197	48.00	0.085	24.33	0.436
T_5	101.6	0.201	46.66	0.092	26.00	0.570
T_6	105.0	0.198	46.33	0.096	28.33	0.526
T_7	103.3	0.191	48.66	0.090	28.00	0.518
T_8	99.0	0.213	48.33	0.104	30.33	0.652
T_9	97.6	0.209	44.66	0.096	32.00	0.660
T_{10}	98.0	0.210	45.00	0.096	31.66	0.758
T_{11}	100.0	0.225	45.00	0.101	32.00	0.795
T_{12}	101.3	0.218	49.33	0.106	27.66	0.601
T_{13}	103.6	0.218	47.66	0.100	27.34	0.621
CD (0.05)	**NS**	**NS**	**NS**	**0.018**	**4.288**	**0.114**

T_6, T_7, T_8 and T_{10}. The lowest Zn content in pod was recorded in organic package treatment T_3 (24 mg kg^{-1}).

The uptake of zinc in pod was also significantly influenced by various treatments. Split application of lime @ LR along with organic manure as cow dung enriched with *Trichoderma* @ 20 t ha^{-1} recorded highest Zn uptake of 0.795 kg ha^{-1} (T_{11}) and it performed on par with the treatment T_{10} which receiving the application of 2 split doses of lime @ LR along with organic manure as cow dung @ 20 t ha^{-1}. The lime applied @ LR showed significantly higher uptake of zinc in pod compared to the treatments which receiving soil test based recommendation of fertilizers without lime and cow dung (T_1 and T_2).

4.6.2.3. Copper

The content of copper in pod was not significantly influenced by the treatments (Table 19). However, the Cu content ranged from 7.43 mg kg^{-1} (T_{13}) to 8.80 mg kg^{-1} (T_2).

The uptake of Cu in pod was significantly influenced by various treatments. All the treatments receiving lime as per LR recorded significantly higher uptake of copper in pod in comparison to other treatments. All the remaining treatments were on par.

4.6.2.4. Boron

The boron content in pod was significantly influenced by the treatments (Table 19). Dolomite application at 400 kg ha^{-1} and cow dung @ 20 t ha^{-1} as organic manure source recorded highest B content of 19.43 mg kg^{-1} (T_{12}) which was on par to the treatments which received lime as per LR in 2 split doses (T_{10} and T_{11}). The lowest content of B in pod was registered by control treatment T_1 (11.89 mg kg^{-1}) which was significantly lower than all the treatments which received foliar fertilization.

The uptake of B in pod was significantly influenced by various treatments. The values ranged from 0.021 kg ha^{-1} (T_1) to 0.041 kg ha^{-1} (T_{12}). The treatments receiving lime

Table 19. Effect of soil and nutrient management on content and uptake of Cu and B in pod

Treatments	Cu (mg kg^{-1})	Uptake (kg ha^{-1})	B (mg kg^{-1})	Uptake (kg ha^{-1})
T_1	8.66	0.158	11.89	0.021
T_2	8.80	0.162	15.77	0.029
T_3	8.70	0.153	14.83	0.027
T_4	8.46	0.152	14.51	0.025
T_5	8.70	0.160	13.61	0.027
T_6	8.23	0.152	15.47	0.026
T_7	8.20	0.151	15.65	0.029
T_8	8.23	0.177	15.12	0.032
T_9	8.33	0.178	15.74	0.033
T_{10}	8.63	0.185	16.52	0.033
T_{11}	8.30	0.187	17.50	0.039
T_{12}	7.66	0.165	19.43	0.041
T_{13}	7.43	0.156	17.38	0.037
CD (0.05)	**NS**	**0.021**	**3.518**	**0.009**

@ lime requirement (T_8, T_9, T_{10} and T_{11}) and dolomite @ 400 kg ha^{-1} (T_{12} and T_{13}) showed significantly higher uptake of boron compared to other treatments.

4.7. QUALITY PARAMETERS

The data on quality parameters of yard long bean as influenced by various treatments are presented in Table 20.

4.7.1. Protein

The protein content in pod was significantly influenced by the treatments. The highest value was recorded in the treatment T_{11} (6.35 %) which receiving lime as per lime requirement in 2 split doses as soil amendment, *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure source and foliar fertilization of nutrients. However, it was on par to the treatments T_7 (6.18 %), T_8 (6.25 %), T_9 (6.30 %), T_{10} (6.34 %), T_{12} (6.27 %) and T_{13} (6.29 %). The lowest protein content was recorded by control T_1 (5.36 %) which was on par to T_2 (5.49 %), T_3 (5.42 %) and T_4 (5.43 %).

4.7.2. Fiber content

The fiber content in pod was not significantly influenced by various treatments. The values ranged from 12.14 % (T_{12}) to 12.53 % (T_5).

4.7.3. Keeping quality

The treatments did not significantly influence the keeping quality of pods. However, the values ranged from 3 days (T_1 and T_2) to 4 days (T_7, T_9 and T_{10}).

4.9. FUSARIUM WILT DISEASE INCIDENCE

The data pertaining to the influence of treatments on incidence and severity of Fusarium wilt disease of yard long bean are presented in Table 21.

Table 20. Effect of soil and nutrient management on protein, crude fiber and keeping quality of yard long bean

Treatments	Protein (%)	Fiber content (%)	Keeping quality (days)
T_1	5.36	12.21	3.0
T_2	5.49	12.51	3.0
T_3	5.42	12.42	3.3
T_4	5.43	12.51	3.3
T_5	5.51	12.53	3.6
T_6	5.93	12.21	3.6
T_7	6.18	12.24	4.0
T_8	6.25	12.16	3.6
T_9	6.30	12.41	4.0
T_{10}	6.34	12.43	4.0
T_{11}	6.35	12.35	3.6
T_{12}	6.27	12.14	3.6
T_{13}	6.29	12.15	3.6
CD (0.05)	**0.250**	**NS**	**NS**

Plate 5. The *Fusarium* wilt disease incidence observed at 60 DAS

Plate 6. Suppression of *Fusarium* wilt disease observed in treatments T_{11} and T_9

4.9.1. Percentage Disease Incidence (PDI)

Percentage disease incidence at natural field conditions was significantly influenced by the treatments. There was no disease incidence in the treatments T_5 (IDM package) and T_{11} (Split doses of lime @ LR along with *Trichoderma* enriched cow dung @ 20 t ha^{-1}). However, they were on par with T_8 (11.10 %), T_9 (11.82 %) and T_{10} (5.55 %). All the treatments which received lime @ LR (T_8, T_9, T_{10} and T_{11}) performed on par. The highest disease incidence was observed in the control treatment T_1 (55.55 %) followed by T_2 (38.88 %), T_3 (38.88 %) and T_4 (44.44 %) which were significantly higher than all the lime added treatments.

4.9.1. Disease index (DI)

The disease index (DI) was also significantly influenced by treatments under natural field conditions. Zero value for disease index was recorded in the IDM package treatment (T_5) and treatment receiving split doses of lime @ LR along with *Trichoderma* enriched cow dung (T_{11}) as organic manure and were significantly lower than all other treatments. The highest value of disease index was registered in control T_1 (45.83).

4.10. ECONOMICS OF CULTIVATION AS INFLUENCED BY TREATMENTS

The data on economics of cultivation of yard long bean as indicated by Benefit Cost Ratio (BCR) is presented in Table 22. The highest benefit cost ratio was obtained by the treatment T_{11} (2.58) which received the application of lime @ LR in 2 splits along with cow dung enriched with *Trichoderma* @ 20 t ha^{-1} as organic manure source, which was on par with T_{10} (2.54). Lime applied @ LR as basal (T_8 and T_9) was significantly superior to the treatments which receiving lime as per POP recommendations (T_6 and T_7). Treatments receiving dolomite @ 400 kg ha^{-1} (T_{12} and T_{13}) recorded a BCR on par with the treatments receiving lime @ 250 kg ha^{-1} (T_6 and T_7). The lowest BCR was obtained in the treatment T_4 (1.68).

Table 21. Effect of soil and nutrient management on Percentage Disease Incidence (PDI) and Disease Index (DI) of Fusarium wilt disease in yard long bean

Treatments	Disease Incidence (%)*	Disease index *
T1	55.55 (48.24)	45.83 (42.48)
T2	38.88 (38.35)	27.08 (30.88)
T3	38.88 (38.35)	22.91 (28.45)
T4	44.44 (41.75)	13.88 (21.26)
T5	0.00 (0.82)	0.00 (0.82)
T6	24.99 (29.78)	12.49 (20.65)
T7	16.66 (19.26)	11.80 (19.97)
T8	11.10 (16.33)	6.24 (12.14)
T9	11.82 (16.37)	6.29 (12.20)
T10	5.55 (8.58)	2.77 (6.14)
T11	0.00 (0.82)	0.00 (0.82)
T12	22.22 (28.03)	13.19 (21.10)
T13	19.44 (22.03)	11.80 (19.97)
CD (0.05)	**22.207 (18.415)**	**11.863 (10.072)**

* Values in parenthesis are arc sine converted

Table 22. Effect of soil and nutrient management on the economics of production (BCR) of yard long bean

Treatments	Gross Income (Rs. ha^{-1})	Benefit: Cost ratio
T_1	359368	2.29
T_2	368868	2.15
T_3	331296	1.87
T_4	328608	1.68
T_5	378544	2.01
T_6	412116	2.13
T_7	423096	2.18
T_8	470232	2.36
T_9	485120	2.43
T_{10}	505440	2.54
T_{11}	514540	2.58
T_{12}	412936	2.14
T_{13}	420080	2.15

Discussion

5. DISCUSSION

The results emanating from the present investigation entitled "Soil and nutrient management for the suppression of Fusarium wilt disease of yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" are discussed in this chapter.

5.1. BIOMETRIC CHARACTERS

The biometric characters of yard long bean like days to first flowering, crop duration and leaf area index were showed a marked influence with respect to various treatments.

The number of days to first flowering was significantly reduced by the treatments (Fig. 3). The minimum number of days for first flowering was observed in the treatments T_8 (lime @ LR as basal dose, cow dung @ 20 t ha^{-1}, soil test based fertilizer application and foliar fertilization of nutrients at fortnightly intervals) and T_9 (lime @ LR as basal, *Trichoderma* enriched cow dung @ 20 t ha^{-1}, soil test based fertilizer application and foliar fertilization of nutrients at fortnightly intervals). The earlier flowering of cowpea associated with these treatments might be attributed to the amelioration of soil acidity due to the higher rate of lime applied (900 kg ha^{-1}) which could have resulted in better nutrient release in soil. The results are in line with the findings of Barman *et al.* (2014). The early flowering noticed in the foliar fertilized treatments can also be attributed to the foliar supplementation of B and Mg which are important for pollen production. Similar results have been reported by Jose (2015).

Soil and nutrient management through the application of soil amendments, organic manure and foliar fertilization significantly increased the crop duration of yard long bean (Fig. 4). Treatment receiving lime @ LR (900 kg ha^{-1}) as 2 splits, cow dung at 20 t ha^{-1} and foliar fertilization at fortnightly intervals (T_{10}) was superior,

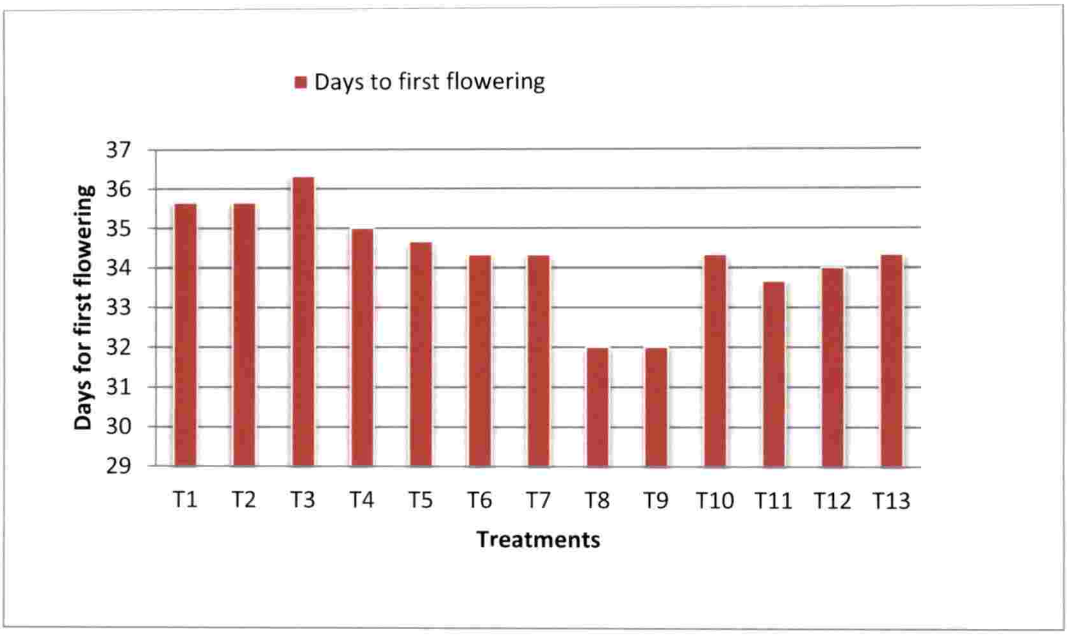


Fig. 3. Effect of soil and nutrient management on days to first flowering in yard long bean

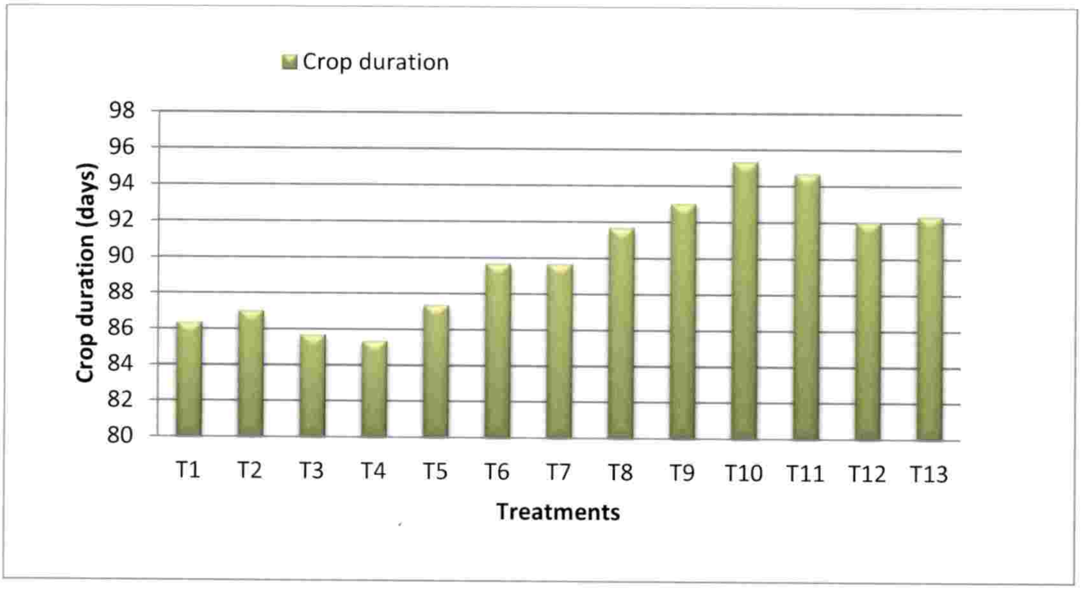


Fig. 4. Effect of soil and nutrient management on crop duration of yard long bean

which was on par with the treatment where organic manure source used was *Trichoderma* enriched cow dung @ 20 t ha^{-1} (T_{11}). It was also observed that the treatments where lime was added @ 900 kg ha^{-1} (as per LR) performed superior to the treatments where lime was added @ 250 kg ha^{-1} (as per POP recommendations) irrespective to the organic manure source used. Application of lime at higher dose increased the soil pH, availability and uptake of essential nutrients (except Fe and Mn) and decreased the concentration of Fe and Mn, which might have led to beneficial conditions for higher crop growth (Sumner *et al.,* 1986). This was in accordance with the results obtained by Geetha (2015) in rice, who observed that the treatment with lime applied as per SMP buffer method performed superior to the treatment where lime was applied as per POP.

The incorporation of liming materials, organic manure and application of foliar fertilizers showed marked increase in leaf area index over control (Fig. 5). The highest leaf area index of 0.42 associated with the treatment T_{11} (lime @ LR in 2 split doses, *Trichoderma* enriched cow dung @ 20 t ha^{-1}, soil test based fertilizer application and foliar fertilization of nutrients at fortnightly intervals) may be due to the increased nutrient uptake of Ca and Mg with the incorporation of sufficient quantity of liming materials or due to the application of foliar fertilizers at fortnightly intervals. Calcium is a structural component of cell walls and Ca supply through liming in the present study could have had a profound effect on crop foliage growth which is in agreement with the findings of Havlin *et al*., (2013). Similar results were also obtained by Rajitha (2016) in groundnut.

5.2. YIELD AND YIELD ATTRIBUTES

The yield attributes (pod length, pod weight, number of pods per plant), yield per plant, yield per plot, total dry matter production and harvest index were significantly influenced by the application of liming materials, organic manures and foliar fertilization (Figures 6 to 11). Application of lime @ LR (900 kg ha^{-1}) in 2

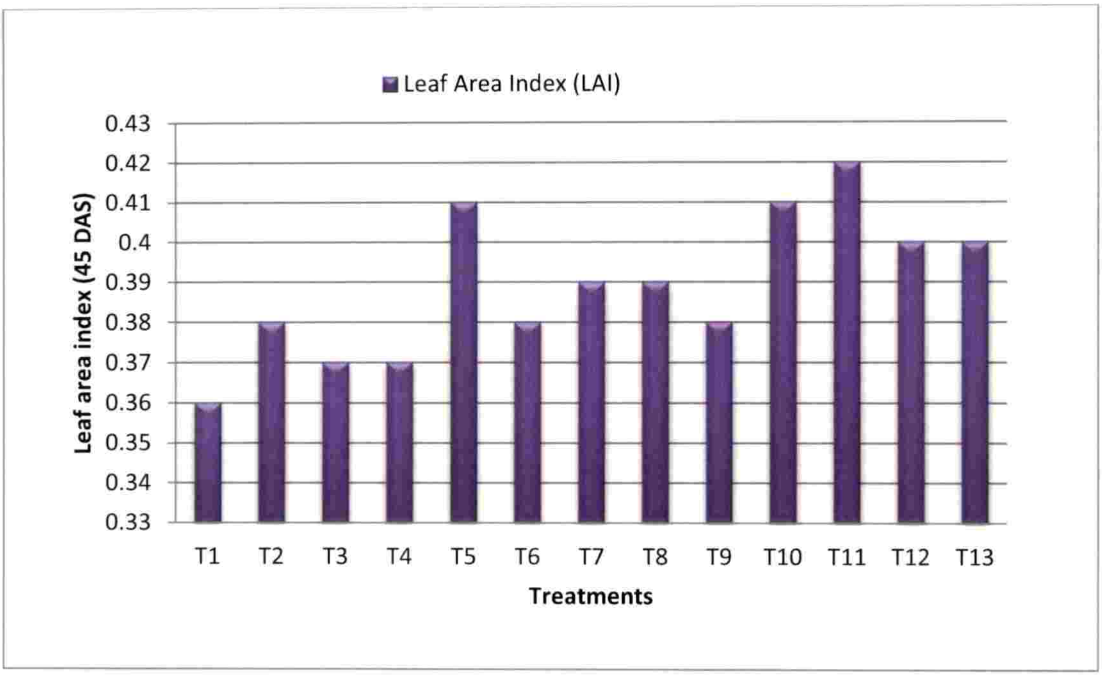


Fig. 5. Effect of soil and nutrient management on leaf area index of yard long bean

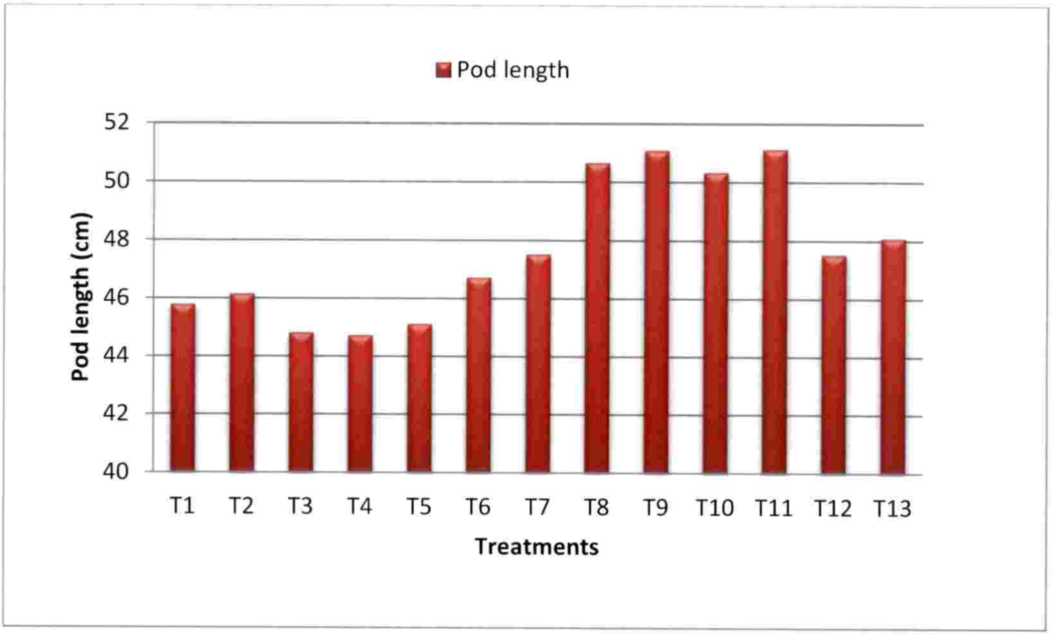


Fig. 6. Effect of soil and nutrient management on pod length of yard long bean

splits, *Trichoderma* enriched cow dung @ 20 t ha^{-1}, soil test based fertilizer application and foliar fertilization of nutrients at fortnightly intervals (T_{11}) was superior with respect to all yield and yield attributes. The positive influence on yield and yield attributes may be attributed to the influence of lime incorporation at sufficient rate which would have sequentially caused an increased nutrient availability, microbial activity and nutrient transformation. This is evident from the results of available N, P, Ca, Mg and S in soil associated with the treatment which received lime @ 900 kg ha^{-1} (T_8, T_9, T_{10} and T_{11}). The results were in accordance with the findings of Meena and Varma (2016) who observed that liming along with foliar fertilization resulted in increased nutrient uptake and seed yield in mung bean which was cultivated under acid soils of Vindhya region. Similar results were also reported by Singh *et al.* (2004), Kumar *et al.* (2014) and Patil and Ananthanaryana (1989).

It should be noted that there was a 43.17 % increase in yield in the treatment T_{11} (split doses of lime @ 900 kg ha^{-1} in 2 equal splits, basal incorporation of *Trichoderma* enriched cow dung @ 20 t ha^{-1}, foliar fertilization at fortnightly intervals and soil test based fertilizers) over control which received only the application of soil test based chemical fertilizers. In similar studies Parvathappa *et al.* (1995) reported an increase in per plant yield of 30.5 % over control by applying lime @ 2.5 t ha^{-1} as basal in cowpea along with recommended dose of fertilizers, while Kumar *et al.* (2014) obtained 54 % increase in yield due to the incorporation of lime @ 600 kg ha^{-1} in ricebean. The increased yield and yield attributes observed in the study may be due to synergistic effect of liming materials, organic manure and foliar fertilization on nutrient availability, uptake and dry matter production.

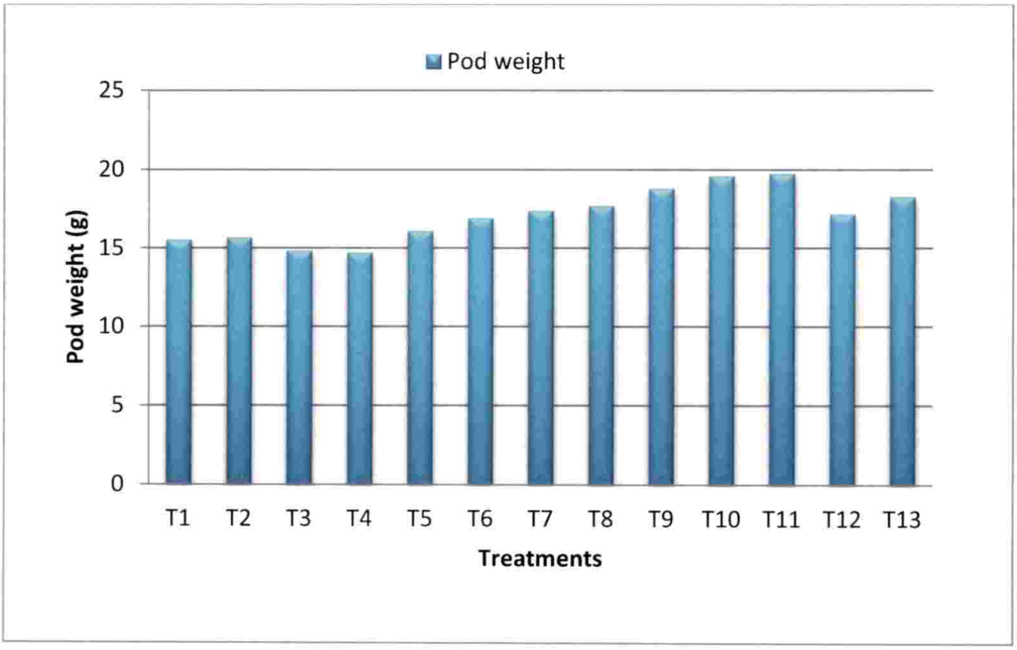


Fig. 7. Effect of soil and nutrient management on pod weight of yard long bean

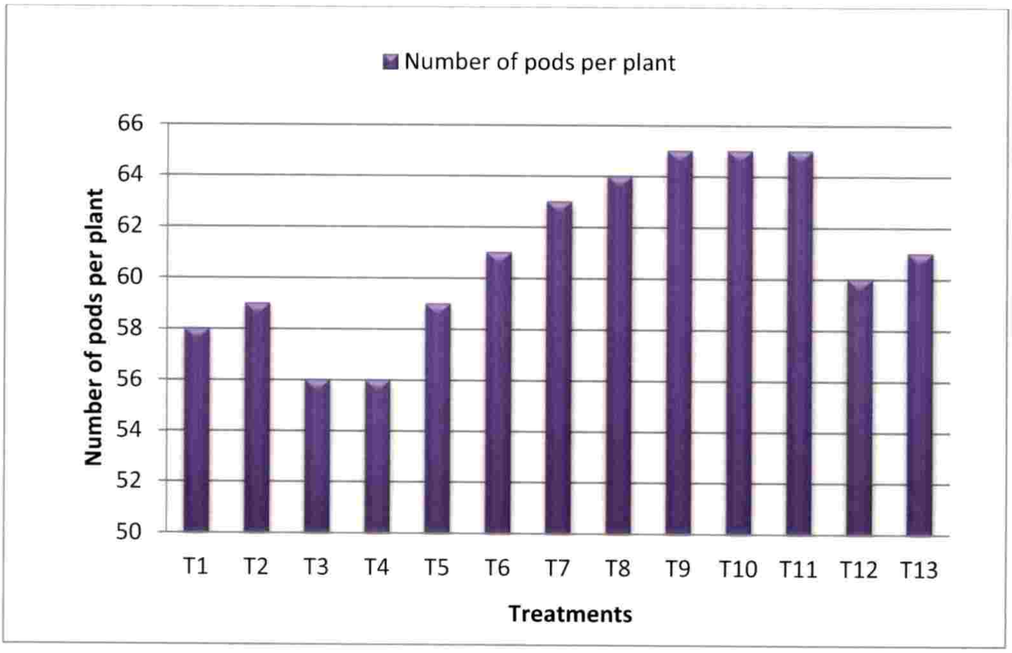


Fig. 8. Effect of soil and nutrient management on number of pods per plant of yard long bean

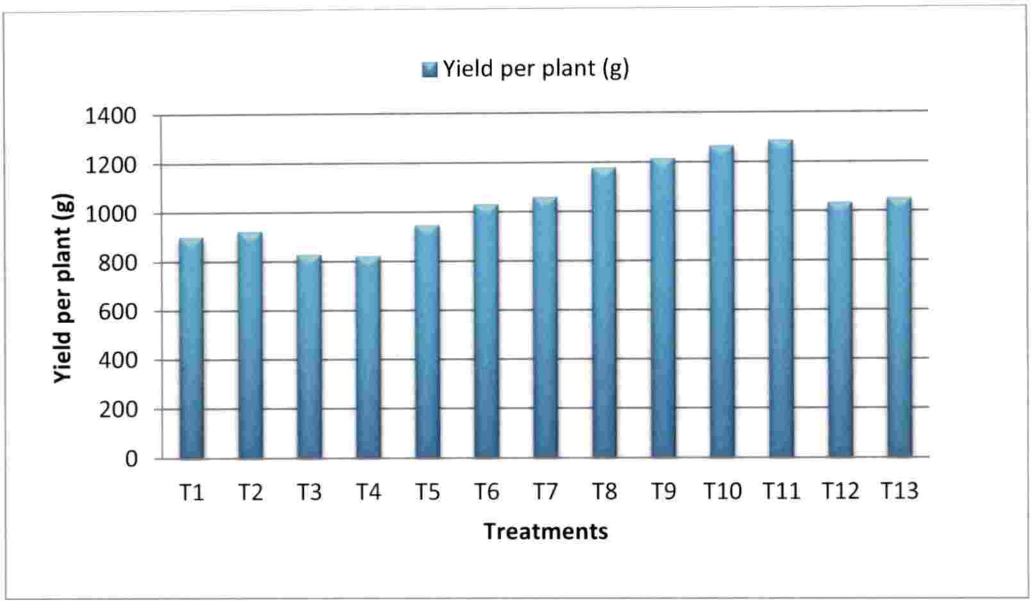


Fig. 9. Effect of soil and nutrient management on yield per plant of yard long bean

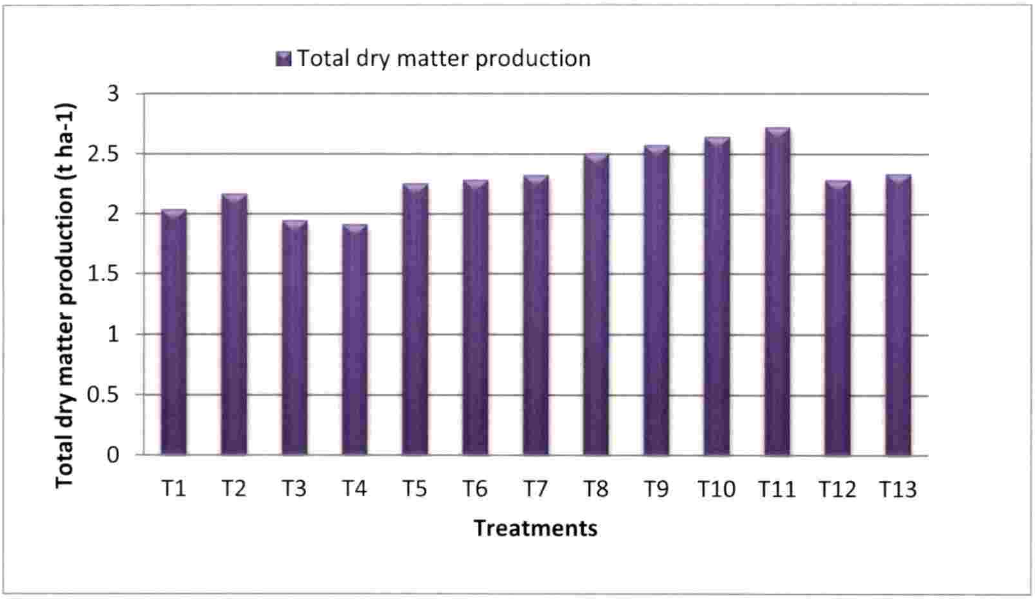


Fig. 10. Effect of soil and nutrient management on total dry matter production of yard long bean

5.3. PHYSICO CHEMICAL CHARACTERS OF SOIL

5.3.1. Soil reaction (pH)

The treatments resulted in a significant increase in soil pH at flowering and plant harvest stages (Fig. 12). The highest soil pH in both stages observed in T_{10} which received lime @ LR (900 kg ha^{-}) in 2 split doses, cow dung @ 20 t ha^{-1} as organic manure and foliar fertilization at fortnightly intervals.

Significantly lower soil pH was obtained in T_1 (4.85) and T_2 (4.89) which received the sole application of chemical fertilizers. Similar results were reported by Nakayama *et al.* (1987), Caires *et al.* (2006), He *et al.*, 2014 and Santos *et al.*, 2017 who observed decrease in soil acidity and subsequent yield reduction due to sole incorporation of chemical fertilizers in comparison with lime added plots.

The marked improvement in the soil reaction during flowering stage must have been contributed by the incorporation of sufficient quantity of liming materials. There was a reduction in soil pH from flowering stage to harvest in all the treatments. Split application of lime was found effective than basal which might be due to reduced leaching losses as concluded by Tripathy *et al.* (1982).

The increase in soil pH with the incorporation of lime and organic manure observed in the present study indicates that the amelioration of soil acidity might be due to the release of Ca and Mg which would have replaced the excessive concentration of aluminum and iron in the soil solution as suggested by Sinha and Singh (1987), Haynes and Ludecke (1981). This is also established from the significantly lower values for available Fe and Mn in soil obtained in the present study.

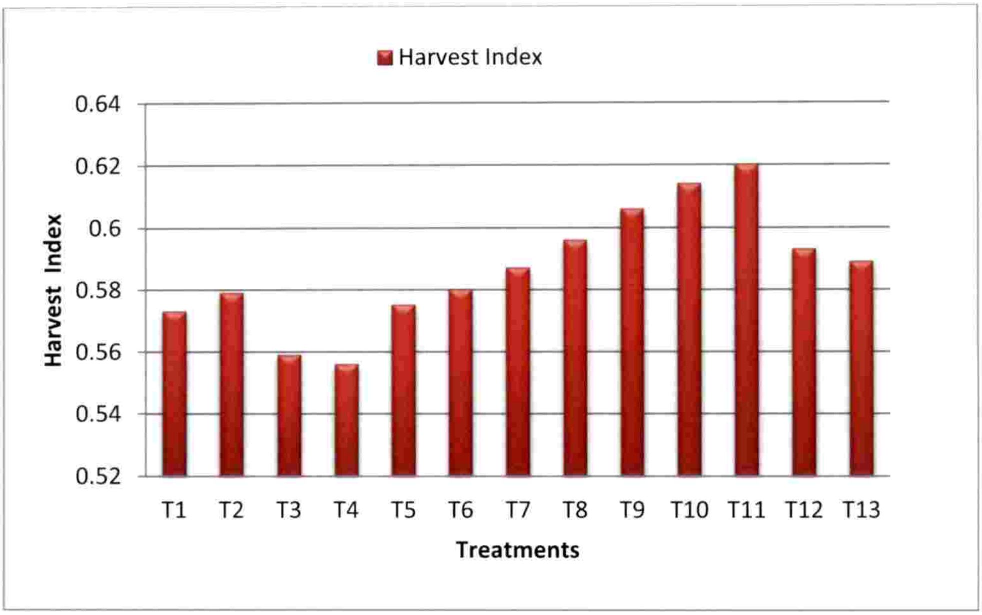


Fig. 11. Effect of soil and nutrient management on harvest index of yard long bean

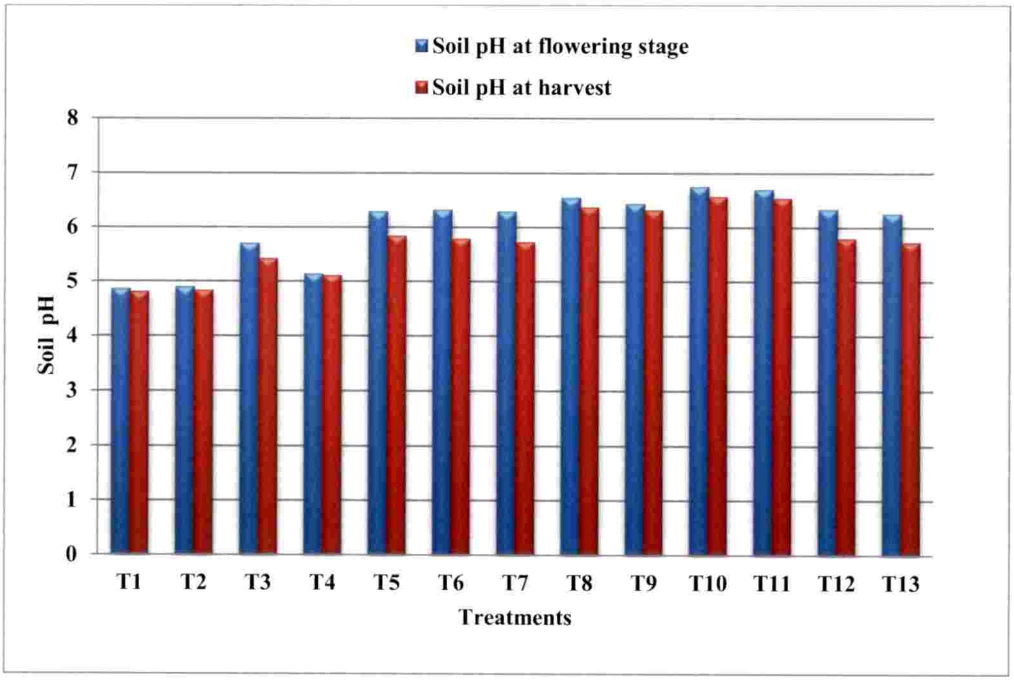


Fig. 12. Effect of soil and nutrient management on soil pH at flowering and harvest

4.3.2. EC

There was no significant difference between treatments with respected to soil electrical conductivity. Similar results have been reported by Mamatha (2015).

4.3.3. Organic carbon

The organic carbon content of the soil was not significantly influenced by the treatments. The results are in line with the findings of Mamatha (2015).

5.4. AVAILABLE NUTRIENT STATUS OF POST HARVEST SOIL

5.4.1. Available Nitrogen

The treatments had a positive influence on the available N content of soil at harvest (Fig. 13). The highest mean value was observed in the treatment T_{11} (380.76 kg ha^{-1}), where lime @ LR was applied as 2 equal split doses along with *Trichoderma* enriched cow dung @ 20 t ha^{-1}, soil test based fertilizer application and foliar fertilization of nutrients at fortnightly intervals. This was on par with the treatments which received lime as per LR which emphasized the importance of proper liming. In spite of the enhanced removal of N for increased dry matter production observed in this treatment, there was an increase in $KMnO_4$ – N in soil. This may be due to the positive effect of liming at appropriate quantity and organic manure addition on N availability since in the present study appreciable increase in pH was noticed by the application of lime @ LR (900 kg ha^{-1}). These findings are in line with Ranjit *et al.* (2007) who reported that application of $CaCO_3$ increased the soil pH, accelerated the process of mineralization of nitrogen and promoted the uptake of nitrogen. Similar observations were also reported by Patil and Ananthanarayana (1989), Raychoudhary *et al.* (1998) and Halim *et al.* (2014).

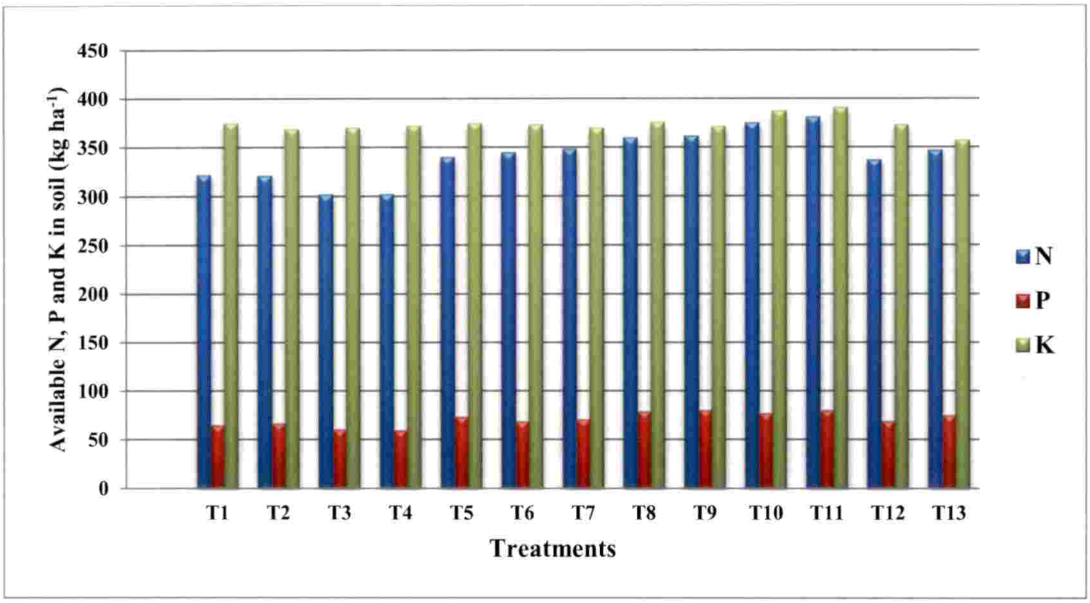


Fig. 13. Effect of soil and nutrient management on availability of primary nutrients in soil after the harvest

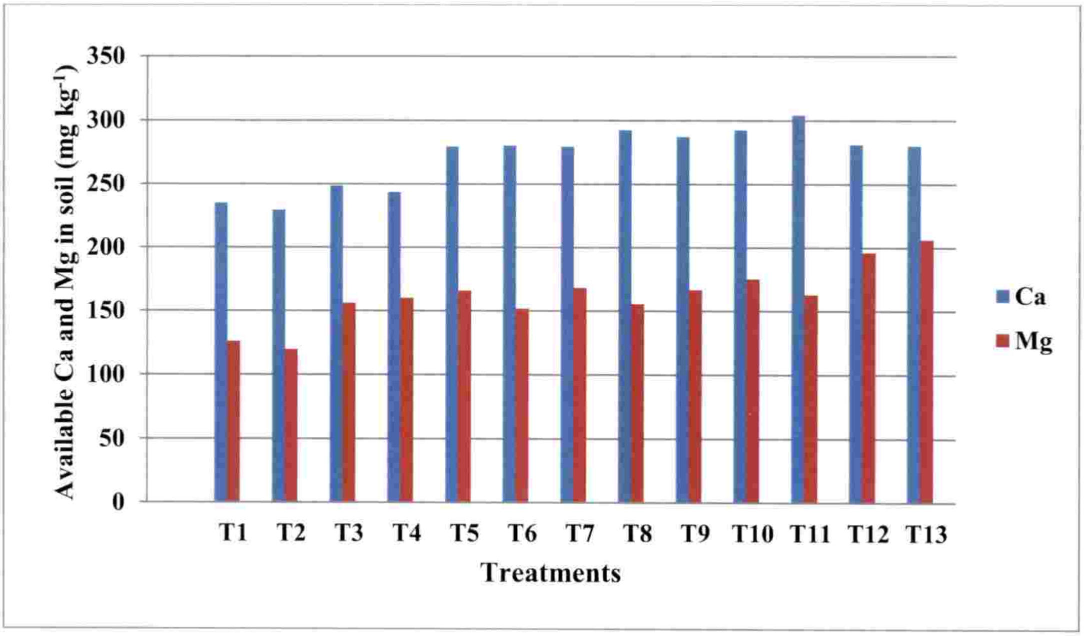


Fig. 14. Effect of soil and nutrient management on availability of Ca and Mg in soil after the harvest

5.4.2. Available Phosphorous

The available P status of soil was significantly influenced by various treatments (Fig. 13). The highest value was recorded in the treatment T_9 (80.23 kg ha^{-1}) with lime applied @ LR as basal followed by the incorporation of *Trichoderma* enriched cow dung @ 20 t ha^{-1} which was on par with available P status in T_{11}, T_{10}, T_{13}, T_8, T_7 and T_5. Lime and dolomite amended plots significantly improved the available P status over control plot T_1 (64.61 kg ha^{-1}). The positive effect of liming on P availability may be due to the increase in soil pH which would have resulted in the dissociation of Al and Fe phosphates resulting in a increase in liable P. The increased soil pH would have improved the soil microbial activity resulting in increased mineralization of organic matter. The organic acids produced by the organic manure added would have also contributed to the favorable phosphorus transformation. This result is in agreement with the finding of Ali and Shahram (2007), Mandal *et al.* (1975) and Patil and Ananthanarayana (1989).

5.3.3. Available potassium

The available K status of soil at harvest of the crop did not differ significantly due to the treatments. Similar results were also reported by Bheemaiah and Ananthanarayana (1984) and Ali *et al.* (2012).

5.3.4. Available Calcium

The available calcium status in soil was significantly influenced by the treatments (Fig. 14). The maximum value was recorded in T_{11} (304.12 mg kg^{-1}) which received lime @ LR (900 kg ha^{-1}) in 2 equal split doses and *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure source. It was on par to the treatments which received lime @ LR as either basal or split dose incorporation. The lowest value was noticed in T_2 (230 mg kg^{-1}) which was on par with the treatments which did not receive any liming materials (T_1, T_3 and T_4). In a similar study in sunflower Barman *et al.* (2014) observed that the basal incorporation of lime @ 2/3 of LR and full dose as pre LR increased the available Ca in soil from 333 mg kg^{-1} in control to 647 and 867 mg kg^{-1}, respectively. The lesser variation obtained under the present study might be due to the increased uptake of applied Ca in yard long bean under the field conditions and due to the leaching loss of calcium. Similar findings were also reported by Caires *et al.* (2006), Tariq and Mott (2006) and Geetha (2015).

5.3.5. Available Magnesium

The available Mg status of soil was significantly influenced by the treatments. The highest available magnesium was observed in T_{13} which received dolomite incorporation @ 400 kg ha^{-1} and organic manure as *Trichoderma* enriched cow dung @ 20 t ha^{-1} along with the soil test based fertilizer application and foliar fertilization of nutrients at fortnightly intervals (Fig. 14). This was on par to the treatments which received lime @ LR (T_8, T_9, T_{10} and T_{11}). This is in line with the findings of Caires *et al.* (2002) who reported that the application of dolomite to soil can directly contribute to the soil Mg fraction. The higher Mg availability noticed in the treatments where lime was applied @ LR (900 kg ha^{-1}) can be attributed to the release of Mg with the replacement by calcium (Blaszcyk *et al.*, 1986). Similar results were also obtained by Tariq and Mott (2006), Geetha (2015) and Aloka (2016).

5.3.6. Available Sulphur

The treatments showed a marked increase on the available sulphur content at harvest of the crop (Fig. 15). A superior available S status in soil was registered in the treatment T_{11} (5.43 mg kg^{-1}) followed by T_{10} and T_9 all of which received lime @ LR (900 kg ha^{-1}) along with the organic manure addition @ 20 t ha^{-1}. The results were parallel to the reports given by Parvathappa *et al.* (1995) who reported that the available S in soil was increased when lime was added to the soil. Similar studies conducted by Brunner and Blaser (1989) revealed that the marked improvement in extractable S content with liming of soil may be due to the increase in soil pH and microbial activity followed by faster mineralization of added organic manure source. The favorable soil pH would have increased the biochemical attack of organic matter sequentially resulting in the release of more SO_4 form of sulphur as observed by Ericksen *et al.* (1995) and (Geetha, 2015).

5.3.7. Available Micronutrients

The results from the present investigation revealed that there was a significant reduction in HCl extractable Fe content in soil with the application of liming sources and organic manures (Fig. 16). The lowest available iron content was noticed in T_{11} (29.03 mg kg^{-1}) which received the split addition of lime @ LR along with *Trichoderma* enriched cow dung @ 20 t ha^{-1}. Significantly lower value was registered where lime was applied @ 900 kg ha^{-1} (T_{10} and T_{11}) in 2 split doses. Decrease in exchangeable Fe content in soil might be attributed to the reduced activity of iron under the higher pH condition which was resulted by liming (Barman *et al.*, 2014). Similar studies conducted by Geetha (2015) revealed that the addition of lime @ lime requirement based on SMP buffer method significantly reduced the excessive iron concentration in soil in comparison with POP recommendations. It should be noted that the significant decrease in available iron content of soil did not affect the iron nutrition of crop as indicated by the absence of any significant decrease in iron uptake. Higher crop yield attributes were also associated with this treatment indicating that the reduced available iron has benefited the crop.

Similar to available Fe in soil, available Mn also showed a decrease with the addition of liming materials (Fig. 16). The lowest HCl extractable Mn was observed in T_{10} (25.03 mg kg^{-1}) which was on par with all the lime amended treatments. The increase in soil pH observed in these treatments would have reduced the availability of Mn. However, it did not affect the Mn nutrition of yard long bean since there was

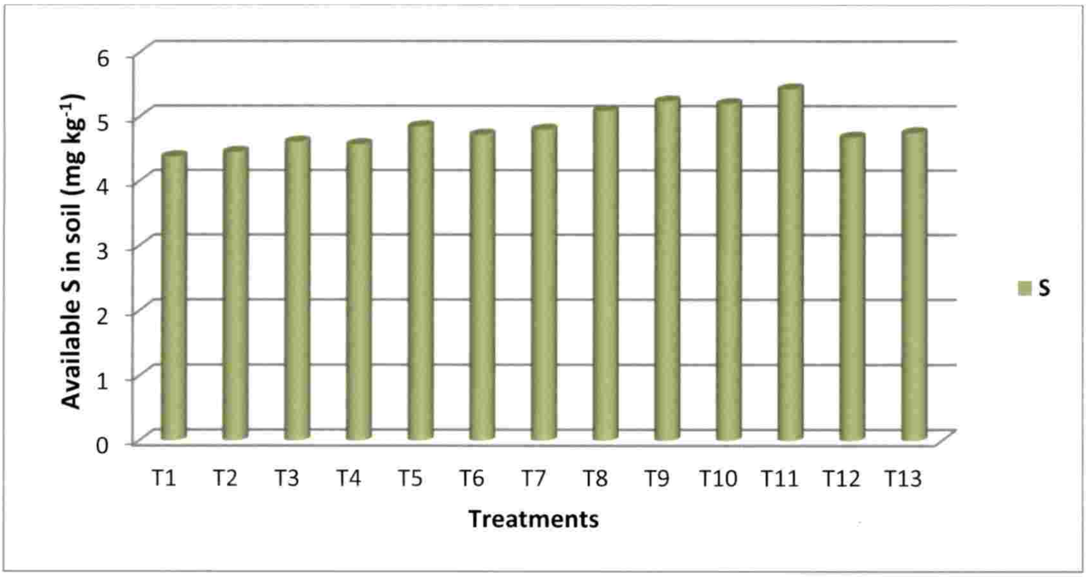


Fig. 15. Effect of soil and nutrient management on availability of sulphur in soil after the harvest

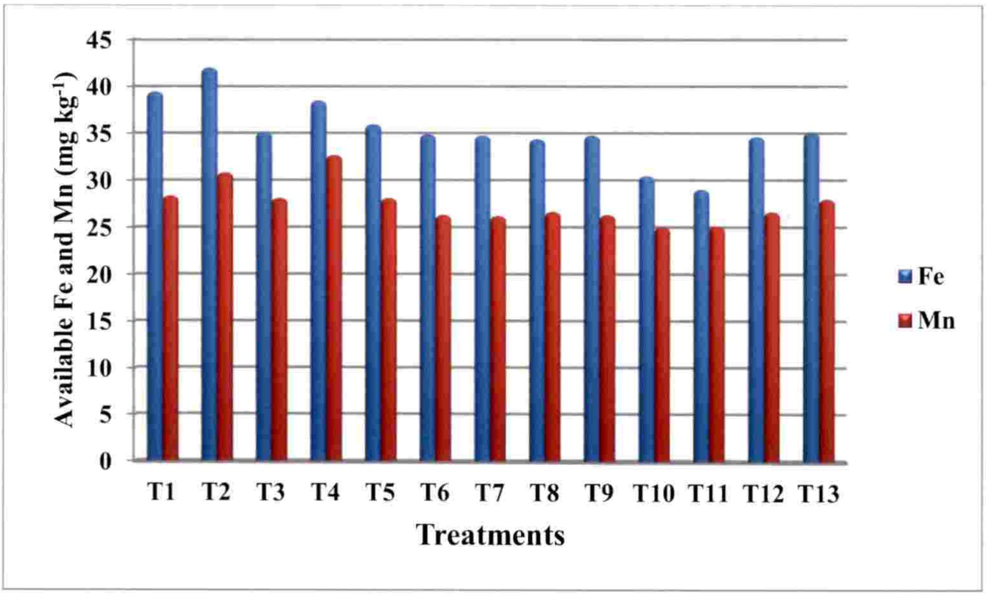


Fig. 16. Effect of soil and nutrient management on availability of Fe and Mn in soil after the harvest

no reduction in Mn uptake in this treatment. These results are in line with the findings of Tariq and Mott (2006) and Barman *et al.* (2014).

The available Zn status in soil showed a marked increase with the application of organic manures and liming materials. The highest available zinc was observed in the treatment T_{11} (1.39 mg kg^{-1}) and it performed on par with T_{10} (1.35 mg kg^{-1}). The combined application of liming materials and organic manure resulted in higher values of HCl extractable Zn which might be attributed to the increased rate of mineralization (Abraham *et al.*, 2015). Also the decrease in available Fe and Mn in these treatments would have caused an increase in Zn content in soil due to antagonistic relationship between Fe and Zn.

The available copper content in the soil showed a marked increase with the application of soil amendments into the soil. The highest available copper was observed in T_{11} (2.06 mg kg^{-1}) followed by T_{10} and it was significantly higher than the treatments T_2 and T_1 which did not receive any soil amendments. The results are in concurrence with the findings of Jaskulska *et al.* (2014) who observed a comparable increase in the available copper content in soil through liming.

Application of liming materials and organic manures failed to show any significant influence on hot water extractable boron content in soil.

5.5. INDEX LEAF TISSUE CONCENTRATION OF NUTRIENTS

The data on nutrient content in index leaf tissue of yard long bean as influenced by various treatments are presented in Figures 17 to 22.

5.5.1. Primary nutrients

As presented in Fig. 17 and 18, the nitrogen and phosphorus concentration of index leaf tissue of yard long bean showed a marked increase with liming, organic manure addition and application of foliar fertilizer at fortnightly intervals along with

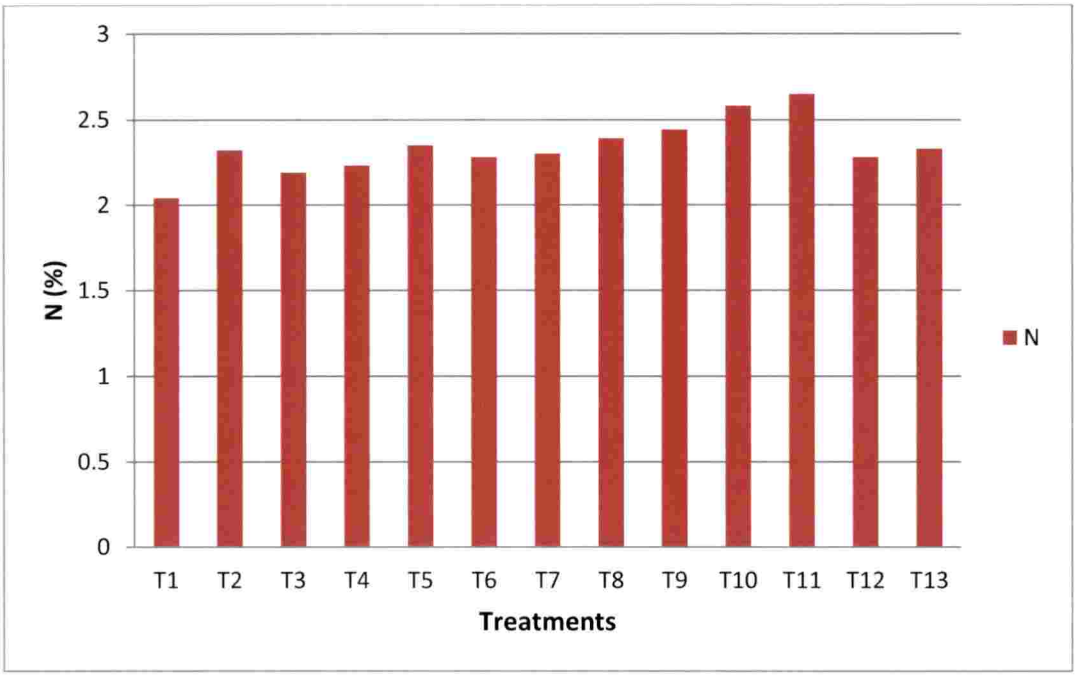


Fig. 17. Effect of soil and nutrient management on index leaf tissue concentration of N

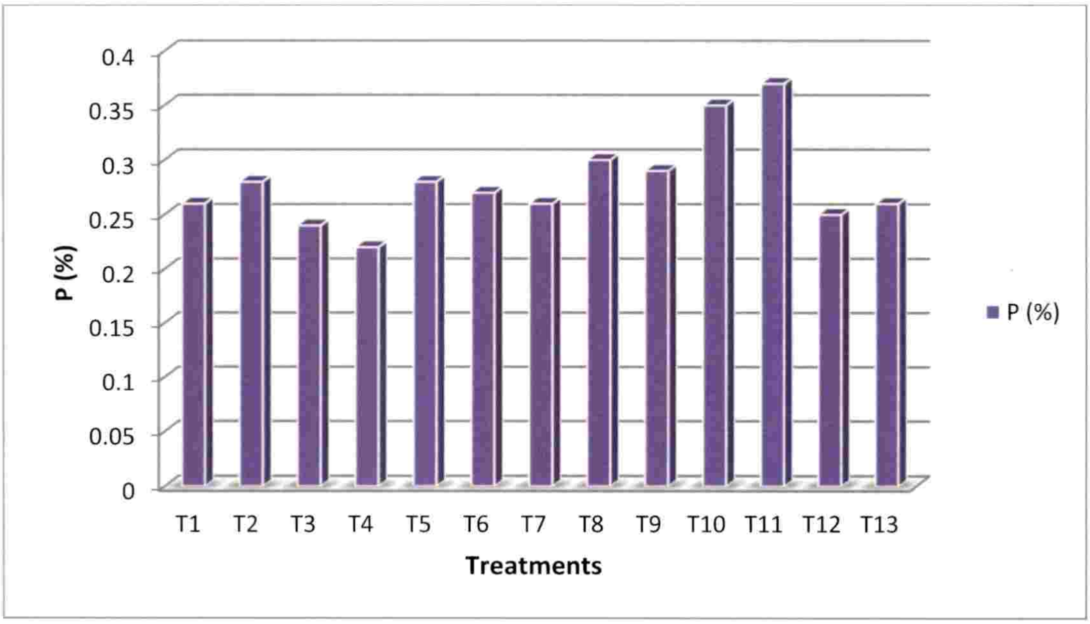


Fig. 18. Effect of soil and nutrient management on index leaf tissue concentration of P

the soil test based dose of fertilizers. The highest N (2.65 %) and P (0.37 %) content were recorded by T_{11} which received split application of lime @ LR along with the incorporation of *Trichoderma* enriched cow dung @ 20 t ha^{-1} and it was on par with T_{10} where cow dung @ 20 t ha^{-1} was used as organic manure source. The alkaline $KMnO_4$ – N and Bray – P content in soil were also high for the above treatments. This might have naturally resulted in enhanced absorption of N and P by the crop ultimately leading to higher N and P content in index leaf tissue. The N and K supplied by foliar fertilization would have also contributed to the higher tissue concentration of these elements. The observation was in accordance with the findings of Mamatha (2015) who suggested that the soil acidity management with liming materials improve the root growth in cowpea through proper Ca nutrition and increases the availability and uptake of all essential nutrients. Similar results were also reported by Shruthi and Vishwanath (2018) who obtained the increase of N and P concentration in leaves.

However, the potassium content in the index leaf tissue was not significantly influenced by the treatments.

5.5.2. Secondary nutrients

The index leaf tissue concentration of calcium and magnesium showed a substantial improvement with the application of soil amendments and foliar fertilization as presented in Fig. 19. The highest content of Ca was recorded in T_{10} which received the addition of lime @ LR (900 kg ha^{-1}) in 2 equal splits along with cow dung @ 20 t ha^{-1} while superior Mg concentration was obtained by the dolomite amended treatments (T_{12} and T_{13}). Addition of lime supplies Ca^{2+} into the soil which might have enhanced the concentration of Ca in plant (Moreira and Fageria, 2010). Similarly, the application of dolomite into the soil as liming material possibly contributed sufficient Mg^{2+} in plant since it is a main component of dolomite (Caires *et al.*, 2002; Aloka, 2016).

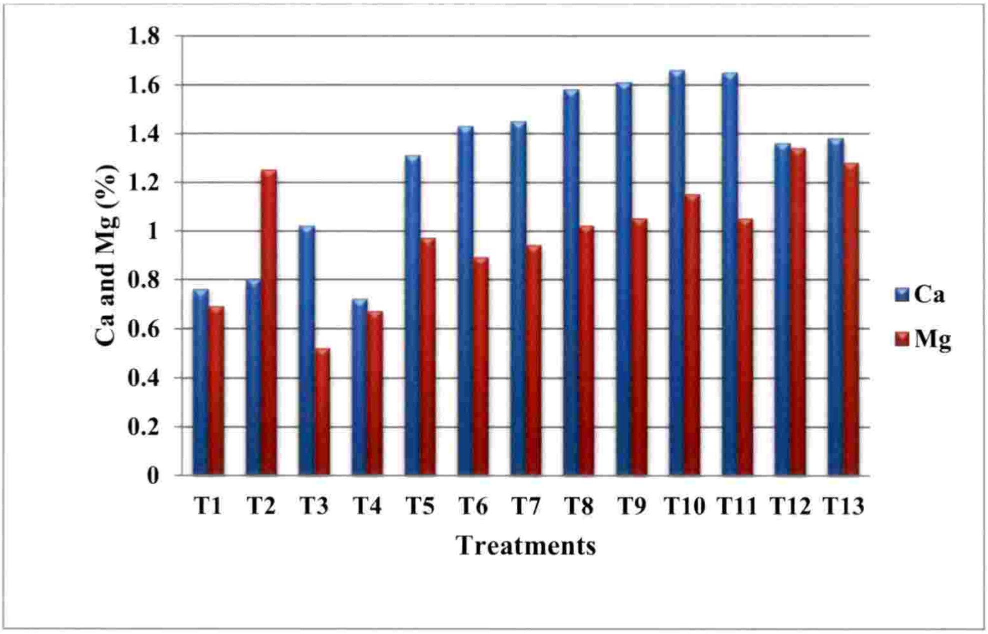


Fig. 19. Effect of soil and nutrient management on index leaf tissue concentration of Ca and Mg

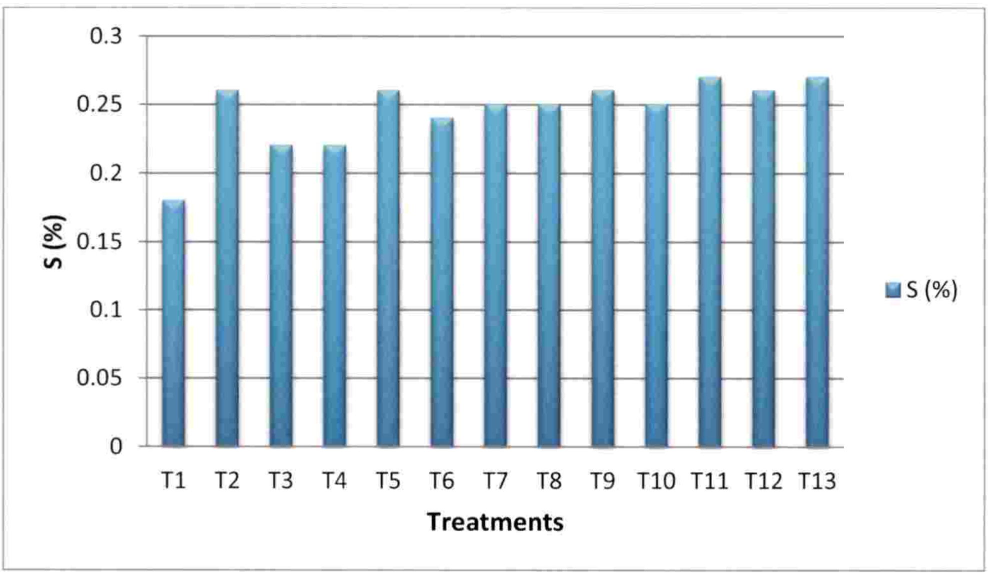


Fig. 20. Effect of soil and nutrient management on index leaf tissue concentration of S

The foliar fertilization of $MgSO_4$ (1 %) at fortnightly intervals would have also contributed to the higher Mg content. The S content in index leaf tissue was significantly influenced by the treatments (Fig. 20). The highest S content was observed in T_{13} and T_{11} (0.27 %) which was on par with all the treatments that received foliar fertilization and the organic treatments. The organic manure applied in these treatments and the sulphur from the $MgSO_4$ foliar spray applied would have contributed to the significant increase in S in plant tissue. Parvathappa *et al.* (1995) also reported that liming increased the content and uptake of S in cowpea and sunflower over untreated plots. Similar results were also observed by Jose (2015) who reported that the foliar fertilization with $MgSO_4$ significantly improves the Mg and S content of leaves in yard long bean.

5.5.3. Micronutrients

The concentration of Fe and Mn in the index leaf tissue of yard long bean was not significantly influenced by the treatments while the zinc concentration showed a substantial improvement over control. Application of lime @ LR in two equal splits and *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure source resulted in the highest zinc concentration of 29.93 mg kg^{-1} (T_{11}) in index leaf tissue while the lowest zinc content was obtained by the treatment T_1 (20.44 mg kg^{-1}) which received the sole addition of soil test based fertilizers (Fig. 21). The application of lime and organic manure might have enhanced the mineralization process in soil which in turn would have contributed to the Zn in soil, followed by the uptake by plants (Srivastava and Gupta, 1996; Sharma *et al.*, 2005 and Tariq and Mott, 2006). Similar observations were also obtained by Barman *et al.* (2014) and Abraham *et al.* (2015).

There was no significant influence of treatments on the index leaf concentration of copper. However, the content of boron in index leaf tissue was significantly influenced by the treatments. The highest boron content was observed in T_{11} (32.32 mg kg^{-1}) which received lime @ LR in 2 equal splits as liming material

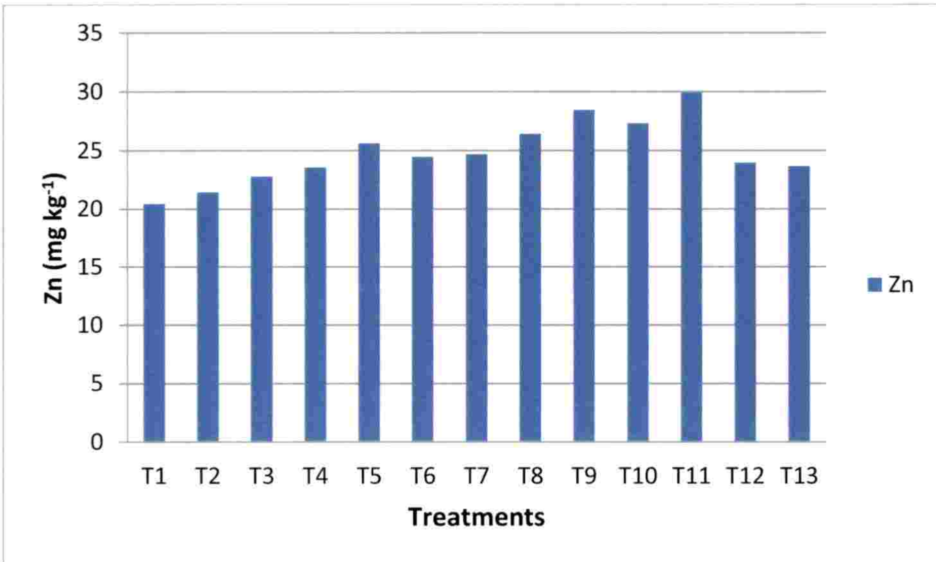


Fig. 21. Effect of soil and nutrient management on index leaf tissue concentration of Zn

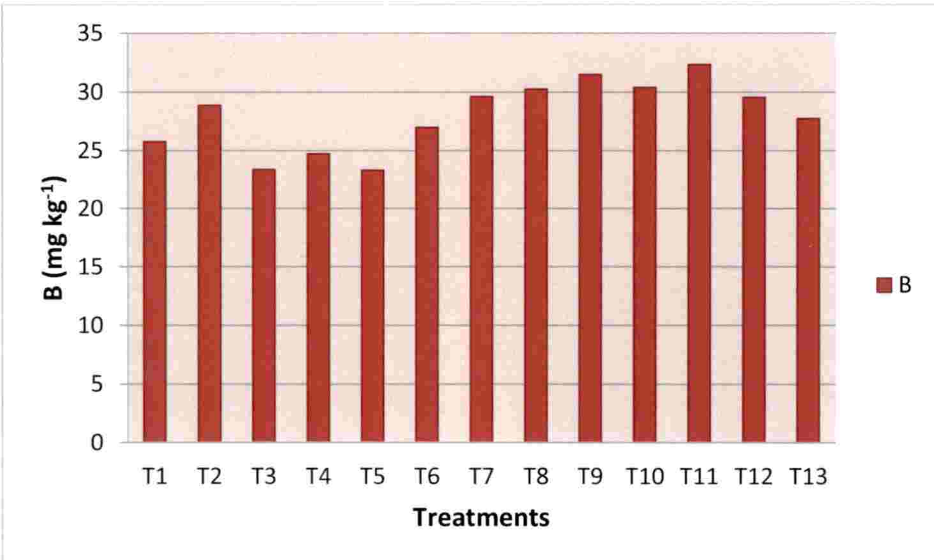


Fig. 22. Effect of soil and nutrient management on index leaf tissue concentration of B

and *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure along with foliar fertilization (Fig. 22). Application of liming material would have promoted the uptake of Ca^{2+} in plants which might have subsequently increased the need for B due to similarity in their function as suggested by Golakya and Patel (1986). Hence the increased uptake of calcium as a result of liming may be the probable reason behind the higher concentration of B obtained in the index leaf of yard long bean. Moreover, the foliar fertilization of borax (0.5 %) might have also contributed to the increase in B concentration in the index leaf tissue which was suggested by Jose (2015) who observed a significantly higher content and uptake of boron with the foliar fertilization of borax in fortnightly intervals.

5.6. NUTRIENT CONTENT AND UPTAKE IN POD

The data pertaining to the concentration and uptake of nutrients in pod are presented in Figures 23 to 31.

5.6.1. Primary nutrients

The content and uptake of N, P and K in pods of yard long bean were significantly influenced by treatments (Fig. 23 and 24). Liming @ LR along with the application of organic manure @ 20 t ha^{-1} and foliar fertilization of nutrients along with soil test based fertilizers showed a marked increase in the content and uptake of primary nutrients. The appreciably higher available N, P and K in soil observed in these treatments might be the probable reason for the concurrent increase in the concentration and uptake of these nutrients into the pod. The higher rate of lime applied (900 kg ha^{-1}) would have also promoted biological nitrogen fixation as reported by Raychaudhuri *et al.* (1998) who observed a 71 % increase in nodule weight per plant over zero limed control. In addition, Mohandas and Appavu (2000) observed increased efficiency of phosphate solublizing micro organism through the incorporation of liming materials resulting in enhanced availability of P in soil. The higher mineralization of added organic manure as well as substitution of K by Ca^{2+} as

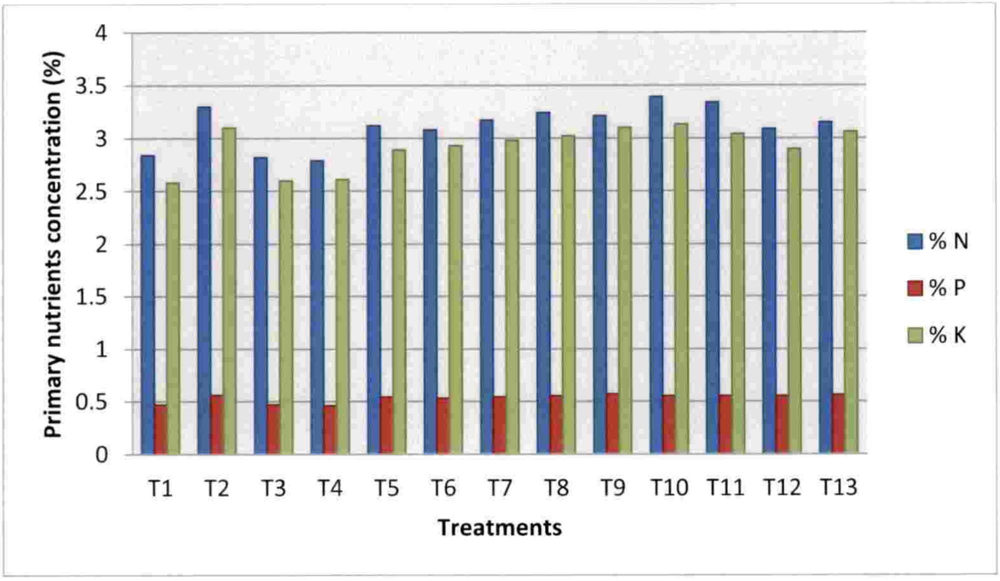


Fig. 23. Effect of soil and nutrient management on content of primary nutrients in pod

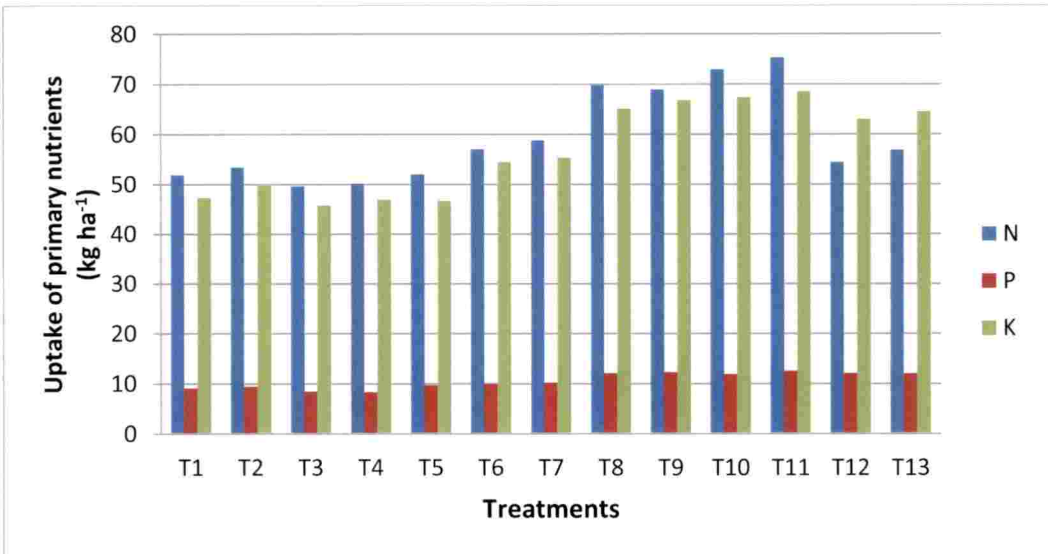


Fig. 24. Effect of soil and nutrient management on uptake of primary nutrients in pod

a result of the incorporation of liming materials might be the probable reason behind the significant increase in the uptake of potassium. The results of the present investigation were in accordance with the finding of Parvathappa *et al.* (1995), Geetha (2015) and Meena and Varma (2016).

The increased concentration of N, P and K in pod can also be attributed to the foliar supplementation of 19:19:19 (0.5 %) at fortnightly intervals. Similar conclusions were also reported by Shruthi and Vishwanath (2018) who found that foliar fertilization of water soluble NPK fertilizers (19:19:19) increased the content and uptake of primary nutrients.

5.6.2. Secondary nutrients

The results from the current investigation revealed a significant increase in content and uptake of Ca and Mg in pod while there was no significant difference in content of Mg. However, the uptake of Mg in pod varied significantly. Application of lime @ LR in 2 equal splits recorded superior uptake of Ca, Mg and S and it was found on par with single basal incorporation of lime @ LR as evidenced from Fig. 26. The increased Ca nutrition through liming as suggested by Moreira and Fageria (2010) might be the probable reason behind the appreciable increase in the uptake of nutrients over control (T_1) which did not receive any of the soil amendments. Positive impact of liming on the content and uptake of K in plants may be interrelated with the synergistic interaction between K and Ca, where sufficient supply of Ca might boost up the requirement by crops (Barman, 2014).

Positive correlation between liming and S uptake in pod obtained under the present investigation was in agreement with the reports of Mamatha (2015) who obtained an increase in the uptake of sulphur in seed and haulm of cowpea.

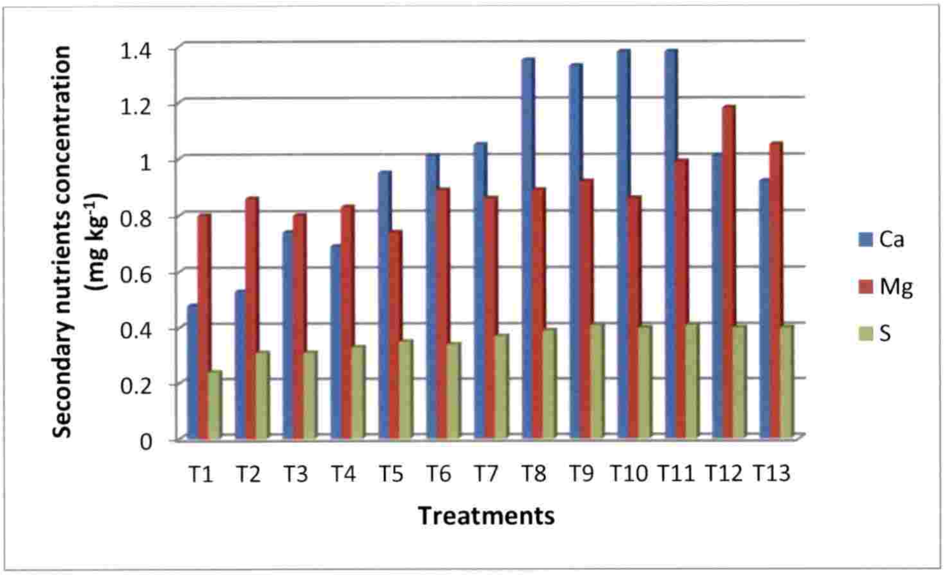


Fig. 25. Effect of soil and nutrient management on content of secondary nutrients in pod

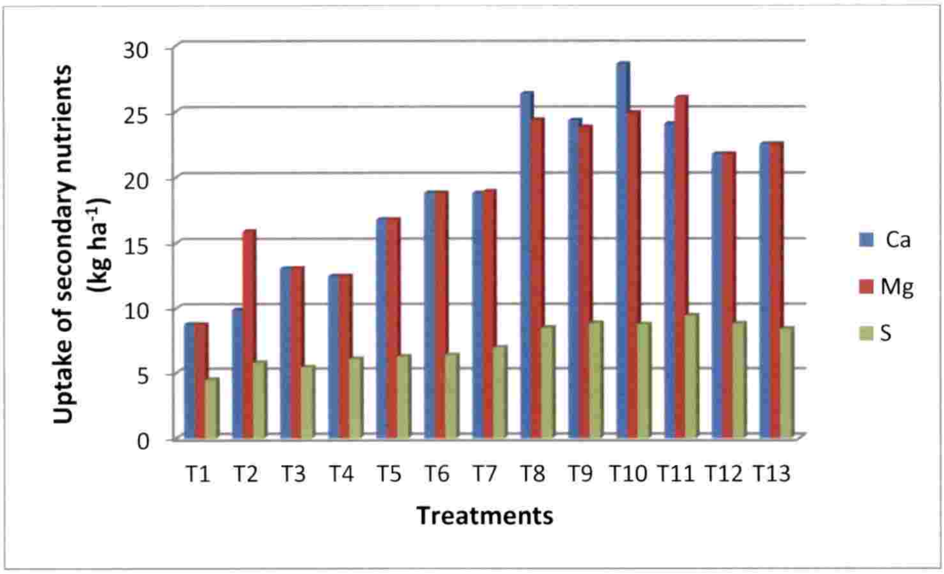


Fig. 26. Effect of soil and nutrient management on uptake of secondary nutrient in pod

The increased content and uptake of Mg and S might be due to the foliar supplementation of $MgSO_4$ (0.5 %) received at fortnightly intervals which was in concurrence with the reports given by Jose (2015).

5.6.3. Micronutrients

The content and uptake of Fe and Mn in pod of yard long bean was not significantly influenced by treatments. Similar result was also obtained with respect to the Mn content in pod. However, the uptake of Mn in pod was significantly increased with the application of liming materials except the organic treatments (Fig. 27 and Fig. 28). The highest uptake was observed in the treatment T_{12} (0.106 kg ha^{-1}). This might be due to the higher yield and dry matter accumulation associated with this treatment.

As evidenced from Fig. 27 and 28, the content and uptake of Zn showed a appreciable increase with the addition of lime @ LR, organic manure and soil test based application of chemical fertilizers over the sole application of chemical fertilizers. The marked increase in the available Zn in soil obtained in the treatments which received liming @ LR under the present investigation might have directed its subsequent increase in the content and uptake in pod. Similar results were also reported by Sharma *et al.* (2005) and Tariq and Mott (2006).

The content of copper in pod was not significantly influenced by the treatments. However, the uptake of Cu in pod was significantly influenced (Fig. 31). The highest uptake was associated with the treatment T_{11} (0.187 kg ha^{-1}). The available Cu in soil was also highest in this treatment. This coupled with the higher yield and dry matter production in the above treatment would have contributed to the higher uptake of Cu in pod. Similar results were also reported by Geetha (2015).

Both the content and uptake of boron in pod was significantly influenced by the treatments. The treatment T_{12} which received dolomite @ 400 kg ha^{-1} as liming

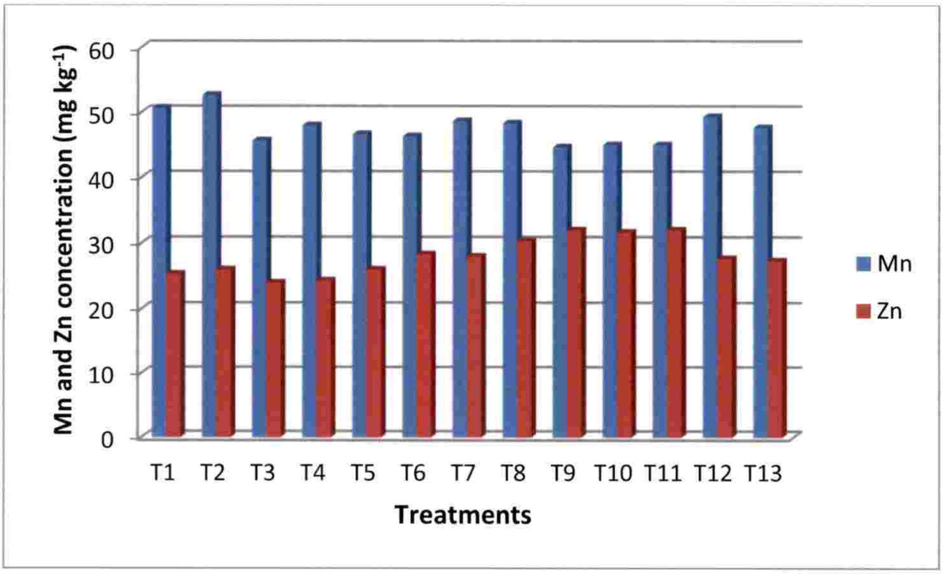


Fig. 27. Effect of soil and nutrient management on content of Mn and Zn in pod

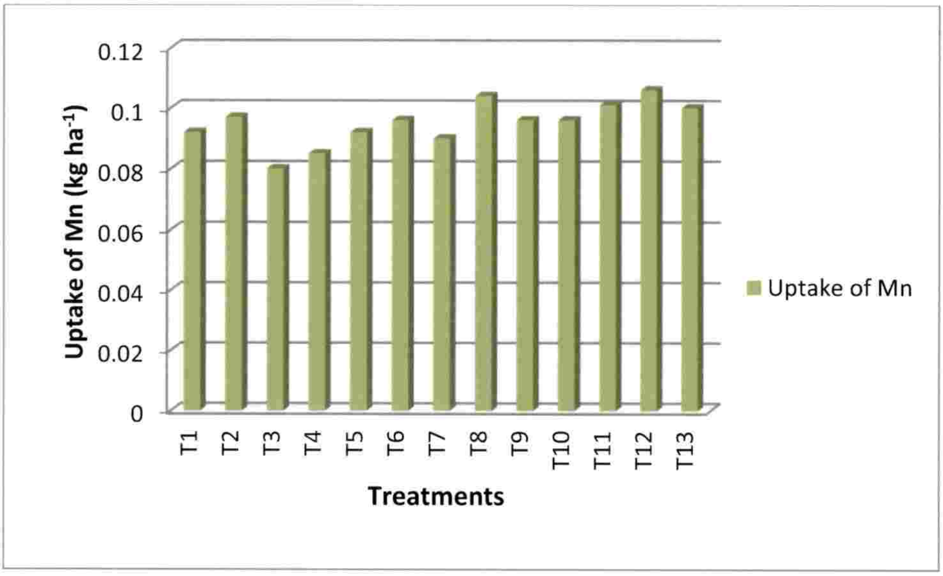


Fig. 28. Effect of soil and nutrient management on uptake of Mn in pod

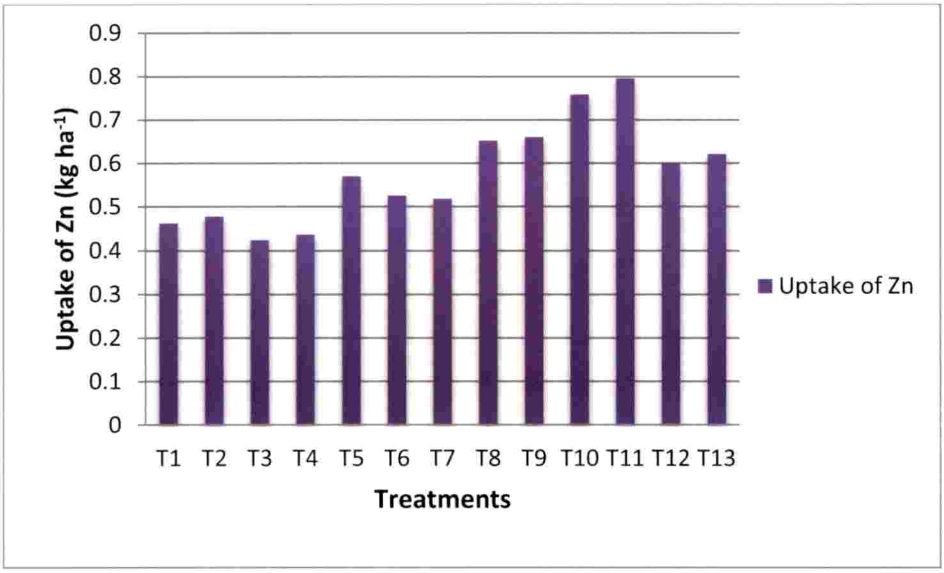


Fig. 29. Effect of soil and nutrient management on uptake of Zn in pod

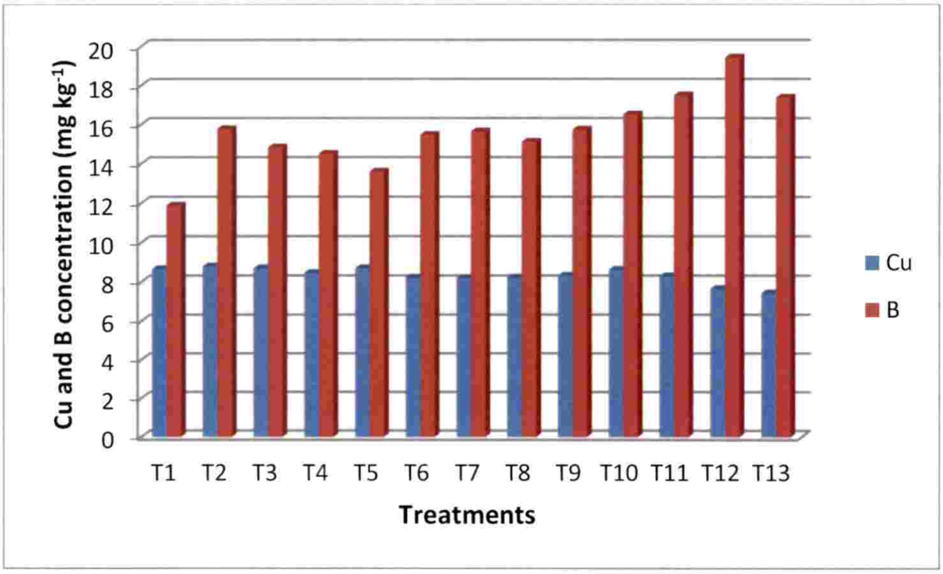


Fig. 30. Effect of soil and nutrient management on content of Cu and B in pod

material, *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure source and foliar fertilization recorded the highest content and uptake of boron. Since the available B content in soil did not show any significant variation with respect to the treatments in the present investigation, the increase in uptake might be attributed to the better absorption of boron through leaves as a result of the foliar supplementation of borax (0.5 %) at fortnightly intervals. Similar interpretation was also done by Jose (2015).

5.7. QUALITY PARAMETERS

Among the quality parameters, protein content in pod was significantly influenced by the treatments (Fig. 32). The highest protein content was obtained in the treatment T_{11} (6.35 %) which received lime as per LR (900 kg ha^{-1}) in 2 split doses as soil amendment, *Trichoderma* enriched cow dung as organic manure source and foliar fertilization of nutrients. The results are in concurrence with the findings of Caires *et al.* (2006) who observed that the incorporation of lime showed a higher protein content in comparison with the zero limed control. Increased protein content with the liming may be due to the positive impact of liming on the enhanced nitrogen availability through increased nitrification. The available N content of soil, index leaf tissue concentration of N and uptake of N in pod were also highest in this treatment. Similar findings were also reported by Kumar *et al.* (2014).

The improvement of protein under the present study can be also associated with the proper Mg, B and S nutrition received through the foliar fertilization of borax and $MgSO_4$ at fortnightly intervals. The significant rise in protein is probably due to the vital role that B plays in protein and nucleic acid metabolism as suggested by Debnath and Gosh (2011). The role of Mg as a cofactor for several enzymes must also be remembered which might have also contributed to the biosynthesis of protein.

The application of soil amendments, organic manure and foliar fertilization did not exert any significant effect on the fibre content and keeping quality of pod.

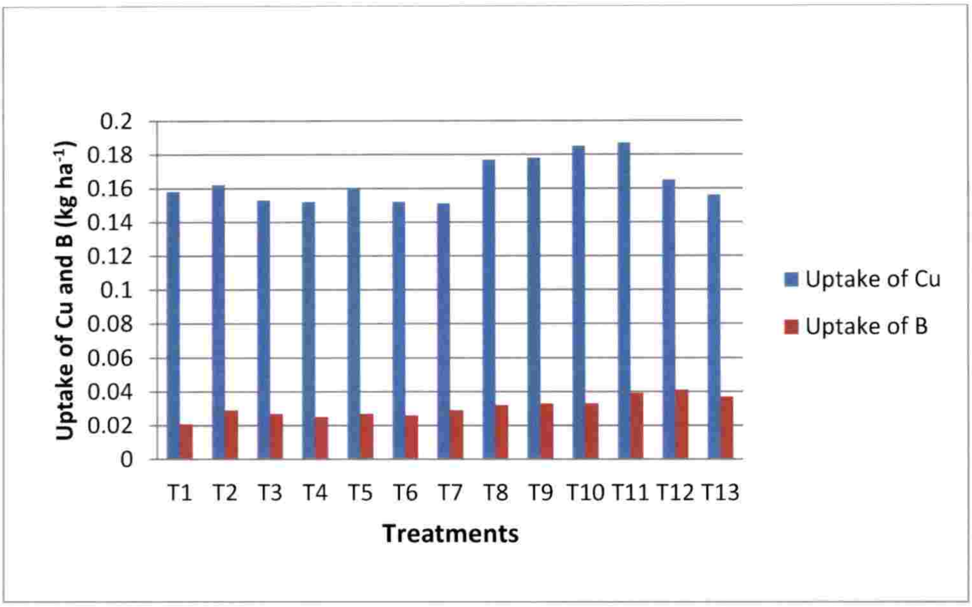


Fig. 31. Effect of soil and nutrient management on uptake of Cu and B in pod

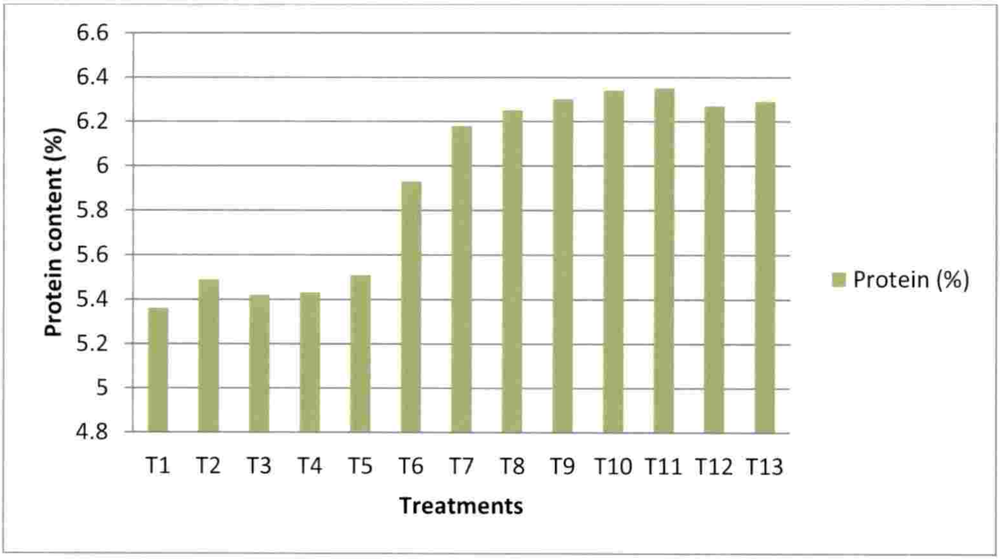


Fig. 32. Effect of soil and nutrient management on protein content in pod of yard long bean

The genetic and environmental factors might have exerted greater influence in comparison to the effect produced by the treatments. Similar explanations were also given by Jose (2015).

5.8. DISEASE SCORING FOR FUSARIUM WILT

The data pertaining to the incidence and severity of Fusarium wilt disease of yard long bean are presented in Fig. 33 and 34.

The field experiment conducted to evaluate the influence of soil and nutrient management for the suppression of Fusarium wilt disease of yard long bean under natural field conditions revealed that the application of lime @ LR (900 kg ha^{-1}) as 2 splits at basal and at flowering, basal incorporation of *Trichoderma* enriched cow dung @ 20 t ha^{-1} and foliar supplementation of nutrients at fortnightly intervals along with the addition of soil test based fertilizers (T_{11}) resulted in zero disease incidence and severity of disease which was same as the result obtained in IDM package which received seed treatment with carbendazim @ 2g/kg seed, burning of pits prior to sowing, soil incorporation of *Trichoderma* enriched neem cake organic manure mixture @ 1 kg per pit at twinning stage along with the application of mancozeb and carbendazim (0.3%) at 20, 40 and 50 DAS. The suppression effect generated through the lime application might be attributed to the increase in the soil pH as suggested by Everett and Blazquez (1967) who evaluated different doses of lime against the severity of Fusarium wilt disease of watermelons in which the soil was artifically infested with races 1 and 2 of *Fusarium oxysporum* and obtained 85.5% plant stand with 9000 pounds of lime per acre. Parallel studies conducted by Jones and Woltz (1967) discovered that the hydrated lime amendments reduced the incidence and the rate of development of Fusarium wilt of tomato caused by race 2 of *Fusarium oxysporum* f. *lycopersici*. The significant reduction obtained through liming may also be due to the proper calcium nutrition of the crop which was in agreement with the findings of Sugimoto *et al.* (2008). The increased calcium levels may suppress the

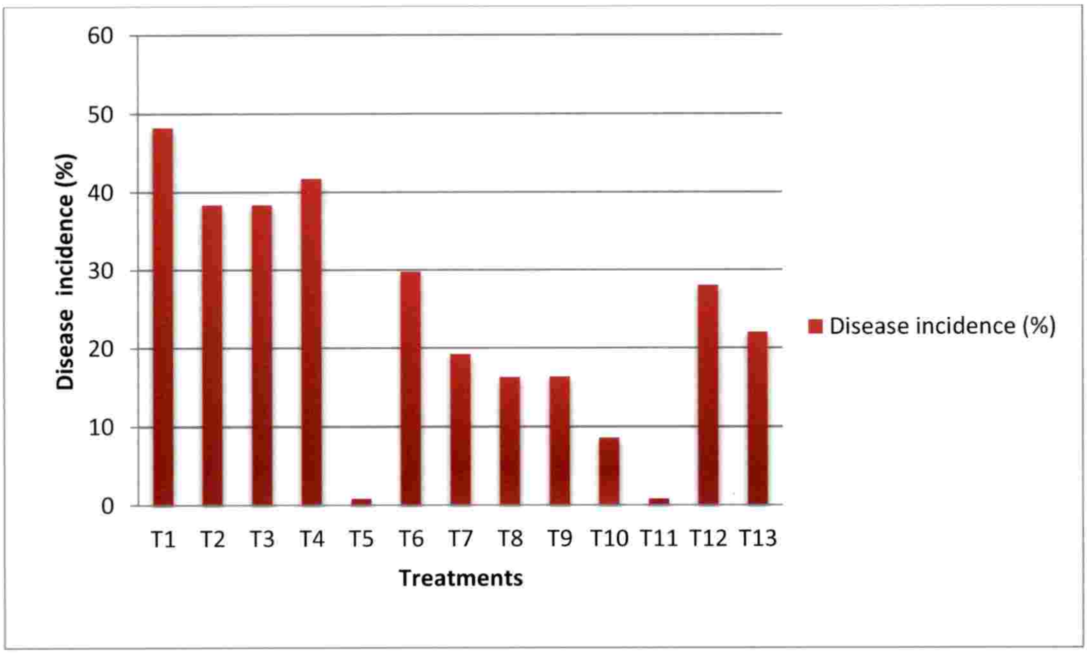


Fig. 33. Effect of soil and nutrient management on incidence of Fusarium wilt disease in yard long bean under *in vivo* conditions

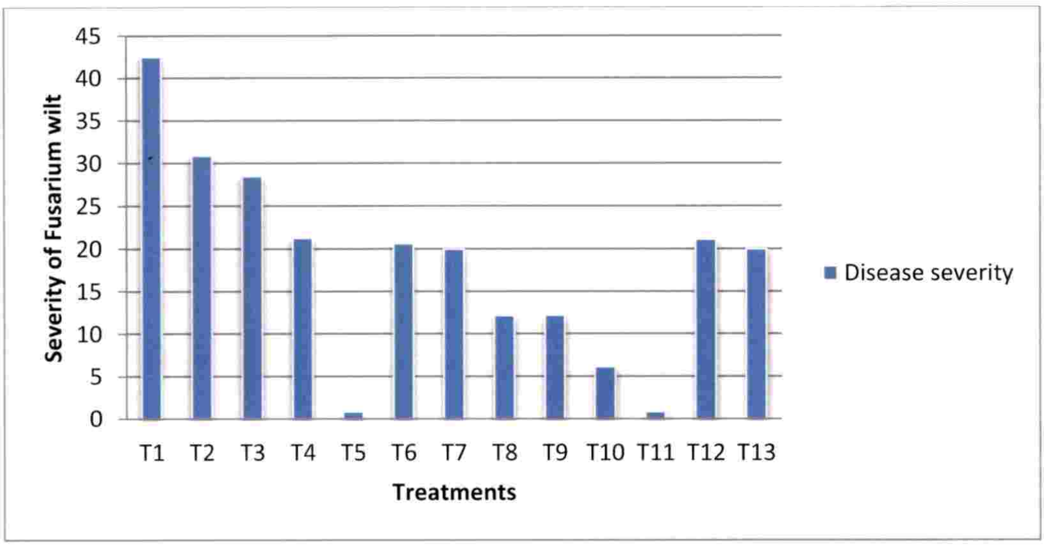


Fig. 34. Effect of soil and nutrient management on the severity (disease index) of Fusarium wilt disease in yard long bean under *in vivo* conditions

resting spore germination followed by reduction in the pathogenic activity. Higher calcium content in plant also decrease pectinase activity which will in turn reduce the disease incidence (He *et al*., 2014).

The treatments receiving *Trichoderma* enriched cow dung performed on par with the corresponding cow dung incorporated treatments which may be due to the incompatibility of bio-control agent with the higher dose of lime. Similar reports were given by Santos *et al.* (2017) who used the bio-fungicide (*T. harzianum*) in combination with the limestone doses against club root disease which revealed that the increased yield and reduced diseased root volume in response to the limestone doses and disease reduction was not significant with the use of the biofungicide.

5.9. ECONOMICS OF PRODUCTION

The economics of cultivation of yard long bean as indicated by Benefit Cost Ratio (BCR) as influenced by treatments is presented in Figure 35. Split dose incorporation of lime @ LR (900 kg ha^{-1}) along with the cow dung enriched with *Trichoderma* @ 20 t ha^{-1} as organic manure source (T_{11}) showed remarkable increase in BCR which was higher than the treatments receiving lime @ POP recommendations. The net return was increased with the liming and organic manure addition in comparison to the sole application of fertilizers. The higher BCR obtained might be attributed to the concurrent increase in the growth and yield of yard long bean through better nutrition and suppression of Fusarium wilt disease.

The profitable production of vegetable cowpea obtained in *Fusarium* prone field conditions by the application of soil amendments can be attributed to the enhanced plant vigor, healthy soil nutrient management and the better uptake of nutrients which was probably also favored by the foliar supplementation. Moreover proper liming might have positively influenced the nutrient use efficiency by correcting the soil reaction, which in turn would have promoted the economic production of yard long bean.

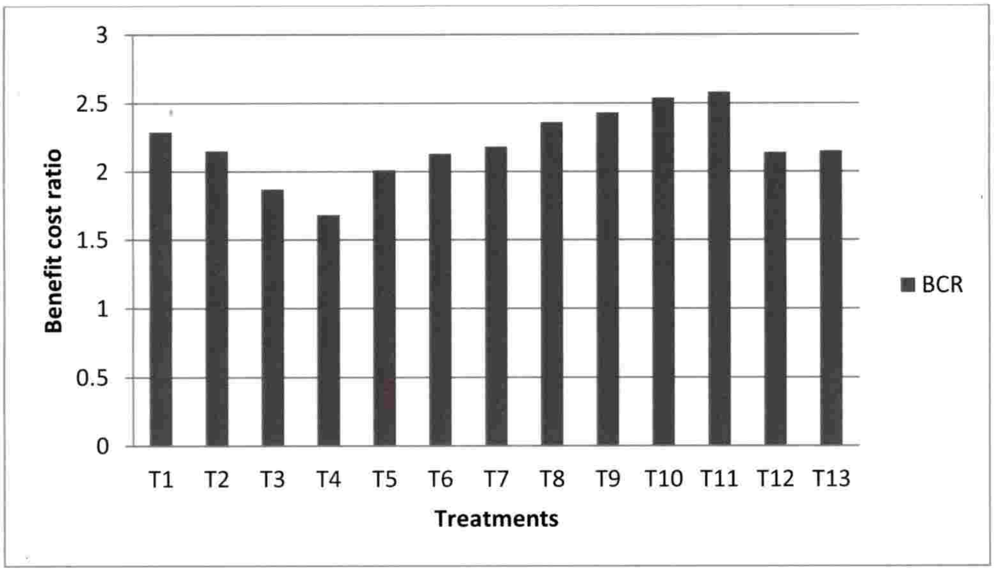


Fig. 35. Effect of soil and nutrient management on the economics of production (BCR) of yard long bean

Summary

6. SUMMARY

The salient findings obtained from the study on "Soil and nutrient management for the suppression of Fusarium wilt disease of yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" are summarized in this chapter.

A field experiment was conducted to assess the impact of liming, organic manure addition and nutrient management on the suppression of *Fusarium* wilt disease of yard long bean (variety Githika).

The experiment was laid out in RBD with thirteen treatments and three replications and the treatments were T_1 - soil test based POP (control), T_2 - T_1 + foliar fertilization of 19:19:19 (0.5%), KNO_3 (0.3%), $MgSO_4$ (1%) and borax (0.5%) at fortnightly interval, T_3 - organic package (cow dung 20 t ha^{-1} as basal followed by additional dose of 1.5 t ha^{-1} poultry manure + 50 kg ha^{-1} rock phosphate as 4 equal splits at fortnightly intervals), T_4 - fortified organic fertilizer (4 t ha^{-1} as basal, followed by 5 top dressings @ 50g/plant at fortnightly interval), T_5 - IDM package (Seed treatment with carbendazim @ 2g/kg seed + burning of pits prior to sowing + soil incorporation of *Trichoderma* enriched neem cake organic manure mixture @ 1 kg/pit at twinning stage + mancozeb and carbendazim (0.3%) at 20, 40 and 50 DAS), T_6 - T_2 + lime 250 kg ha^{-1} + cow dung 20 t ha^{-1}, T_7 - T_2 + lime 250 kg ha^{-1} + *Trichoderma* enriched cow dung 20 t ha^{-1}, T_8 - T_2 + lime @ LR (basal) + cow dung 20 t ha^{-1}, T_9 - T_2 + lime @ LR (basal) + *Trichoderma* enriched cow dung 20 t ha^{-1}, T_{10} - T_2 + lime @ LR (2 equal splits – basal and at flowering) + cow dung 20 t ha^{-1}, T_{11} - T_2 + lime @ LR (2 equal splits – basal and at flowering) + *Trichoderma* enriched cow dung 20 t ha^{-1}, T_{12} - T_2 + dolomite 400 kg ha^{-1} + cow dung 20 t ha^{-1} and T_{13} - T_2 + dolomite 400 kg ha^{-1} + *Trichoderma* enriched cow dung 20 t ha^{-1}.

From the results of the investigation, the following conclusions were derived.

- The addition of lime @ LR (900 kg ha^{-1}) as basal recorded significantly lower number of days to first flowering in comparison with lime @ POP.
- The duration of the crop was significantly influenced by the treatments. The treatment T_{10} which received lime @ LR (900 kg ha^{-1}) as 2 splits, cow dung @ 20 t ha^{-1} and foliar fertilization at fortnightly intervals was superior.
- Application of liming materials, organic manure and foliar fertilization showed marked increase in LAI of yard long bean. The highest LAI was resulted with the treatment T_{11} (0.42).
- The yield attributes (pod length, pod weight, number of pods per plant), yield per plant, yield per plot, total dry matter production and harvest index of yard long bean were significantly influenced by the application of liming materials, organic manures and foliar fertilizers. T_{11} (Application of lime @ LR (900 kg ha^{-1}) in 2 equal splits, cow dung enriched with *Trichoderma*, foliar fertilization at fortnightly intervals) was superior with respect to all yield and yield attributes.
- There was 43.17 % increase in yield in T_{11} over control (T_1) which received only the application of soil test based chemical fertilizers.
- The treatments resulted in a significant increase in soil pH at flowering and after harvest. The highest soil pH was observed in T_{10} in both stages of the crop.
- There was no significant difference between treatments with respect to soil EC.
- The organic carbon content of soil was significantly influenced by the treatments.
- The treatments improved the available N content of soil at harvest. T_{11} (380.76 kg ha^{-1}) recorded the highest value and it was on par with all the treatments which received the lime @ LR (900 kg ha^{-1}).
- The highest available P in soil was observed in treatment T_9 where lime @ LR was applied as basal followed by incorporation of *Trichoderma* enriched cow dung @ 20 t ha^{-1} and foliar fertilization.

- The treatments did not influence the available K status of the soil.
- The available Ca status of soil was significantly influenced by the treatments. The highest value was observed in T_{11} which was on par with T_8, T_9, and T_{10}.
- The highest available Mg in soil was observed in the treatment T_{13} which received dolomite incorporation @ 400 kg ha^{-1}.
- The treatments significantly increased the available S content in soil. The highest value was observed in T_{11} followed by T_{10} and T_9.
- There was a significant reduction in the content of HCl extractable Fe and Mn with the addition of soil amendments, and the lowest values were recorded by the treatments T_{11} and T_{10} respectively.
- The incorporation of various liming materials and organic manures significantly increased the available Zn and Cu content in soil. The highest available Zn (1.39 mg kg^{-1}) and Cu (2.68 mg kg^{-1}) content was noticed in T_{11} (1.39 mg kg^{-1}) and it was on par to the treatment T_{10}.
- The available B status was not significantly influenced by the treatments.
- Analysis of index tissue concentration of nutrients indicated significantly higher content of N (2.65 %) and P (0.37 %) in T_{11} which received lime as per lime requirement in 2 splits and organic manure as *Trichoderma* enriched cow dung at 20 t ha^{-1}. The N and P concentration of index leaf tissue showed a marked increase with the application of soil amendments and foliar fertilizers, while the content of K was unaffected.
- The index leaf tissue concentration of Ca, Mg and S showed a substantial improvement with the application of soil amendments and foliar fertilization. Highest values were recorded by the treatments T_{10} (3.66%), T_{12} (1.34%) and T_{13} (0.27%) respectively.
- The concentration of Fe, Mn and Cu in the index leaf tissue of yard long bean was not significantly influenced by the treatments while the Zn and B concentration showed a substantial improvement over control (T_1).

- Application of lime @ LR was registered maximum content of Zn and B in index leaves. The treatment T_9 (28.46 mg kg^{-1}) registered the maximum content of Zn in T_{11} (32.32 mg kg^{-1}) recorded the highest B.
- The content and uptake of N, P and K in pods of yard long bean were significantly influenced by treatments. Liming @ LR along with the application of organic manure @ 20 t ha^{-1} and foliar fertilization of nutrients along with soil test based fertilizers performed best in comparison with other treatments.
- The highest content of N, P and K was recorded in the treatments T_{10} (3.39 %), T_9 (0.57 %) and T_{10} (3.13 % %) respectively, which received the incorporation of lime @ lime requirement irrespective of the organic manure source applied.
- A significant increase in content and uptake of Ca and Mg in pod was observed while there was no significant difference in content of Mg
- The lime applied as per POP recommendation resulted in significantly lower Ca content in pod in comparison with lime @ LR. The highest S content in pod was obtained in the treatments T_9 and T_{11} (0.41 mg kg^{-1}).
- Application of lime @ LR in 2 equal splits recorded superior uptake of Ca (28.59 mg kg^{-1}), Mg (26.03 kg ha^{-1}) and S (9.44 kg ha^{-1}) and it was found on par to basal incorporation of lime @ LR.
- The content and uptake of Fe, Mn and Cu in pod of yard long bean was not significantly influenced by treatments. Nevertheless, the uptake of Mn and Cu in pod was appreciably increased with the application of liming materials except in the organic treatments.
- The content and uptake of Zn and B showed a appreciable increase with the addition of lime @ LR, organic manure addition @ 20 t ha^{-1} and foliar fertilization over control.
- The application of lime and dolomite significantly increased protein content in pod and highest was registered by T_{11} (6.35 %). However, the fiber content and keeping quality were not significantly influenced by the treatments.

- The incidence and severity of Fusarium wilt disease of yard long bean at natural field conditions was significantly influenced by the treatments.
- There was no Fusarium wilt disease incidence in treatment T_{11} (Split doses of lime @ LR along with *Trichoderma* enriched cow dung) which could achieve the equal results to T_5 (Seed treatment with carbendazim @ 2g/kg seed + burning of pits prior to sowing + soil incorporation of *Trichoderma* enriched neem cake organic manure mixture @ 1 kg/pit at twinning stage + mancozeb and carbendazim (0.3%) at 20, 40 and 50 DAS). The highest disease incidence was observed in the control treatment T_1 (55.55 %) which did not receive any soil amendments and foliar supplementation of nutrients.
- The data on economics of production revealed that the highest BCR was obtained by the treatment T_{11} (2.58) which received the application of lime as per LR in 2 splits along with cow dung enriched with *Trichoderma* as organic manure source, which was on par with T_{10} (2.54).
- Lime applied @ LR as basal (T_8 and T_9) recorded significantly higher BCR over lime @ POP recommendations.

Based on the study, it can be concluded that the increased growth and yield of yard long bean through the management of Fusarium wilt disease can be achieved by the basal application of *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure, lime application @ LR (900 kg ha^{-1}) in 2 splits (basal and flowering stage) as soil amendment and soil test based recommended dose of fertilizers as soil application along with foliar fertilization of 19:19:19 NPK (0.5 %), KNO_3 (0.3 %), $MgSO_4$ (1 %) and borax (0.5 %) at fortnightly intervals.

Future line of work

- The evaluation of microbial parameters in relation to liming and *Trichoderma* enriched organic amendment addition in soil should be studied

- The combined effect of liming materials and bio-control agents on growth and yield of different crops are to be assessed under Fusarium inoculated and natural field conditions
- The interrelation between disease resistance and nutrient management be studied in relation to the accumulation of secondary metabolites and defence related compounds in plants

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SOIL AND NUTRIENT MANAGEMENT FOR SUPPRESSION OF FUSARIUM WILT DISEASE OF YARD LONG BEAN

(*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)

by

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(2016 - 11 - 094)

ABSTRACT

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE & AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

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KERALA, INDIA

2018

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ABSTRACT

The study entitled "Soil and nutrient management for suppression of *Fusarium* wilt disease of yard long bean *(Vigna unguiculata* subsp. *sesquipedalis (L.)* Verdcourt)" was conducted at Instructional Farm, College of Agriculture, Vellayani during February to May 2017 with the objective to assess the impact of liming practices, organic manure addition and nutrient management on the suppression of *Fusarium* wilt disease of yard long bean.

The experiment was laid out in RBD with thirteen treatments and three replications. The treatments were T_1 - soil test based POP (control), T_2 - T_1 + foliar fertilization of 19:19:19 (0.5%), KNO_3 (0.3%), $MgSO_4$ (1%) and borax (0.5%) at fortnightly interval, T_3 - organic package (cow dung 20 t ha^{-1} as basal followed by additional dose of 1.5 t ha^{-1} poultry manure + 50 kg ha^{-1} rock phosphate as 4 equal splits at fortnightly intervals), T_4 - fortified organic fertilizer (4 t ha^{-1} as basal, followed by 5 top dressings @ 50g/plant at fortnightly interval), T_5 - IDM package (Seed treatment with carbendazim @ 2g/kg seed + burning of pits prior to sowing + soil incorporation of *Trichoderma* enriched neem cake organic manure mixture @ 1 kg/pit at twinning stage + mancozeb and carbendazim (0.3%) at 20, 40 and 50 DAS), T_6 - T_2 + lime 250 kg ha^{-1} + cow dung 20 t ha^{-1}, T_7 - T_2 + lime 250 kg ha^{-1} + *Trichoderma* enriched cow dung 20 t ha^{-1}, T_8 - T_2 + lime as per LR (basal) + cow dung 20 t ha^{-1}, T_9 - T_2 + lime as per LR (basal) + *Trichoderma* enriched cow dung 20 t ha^{-1}, T_{10} - T_2 + lime as per LR (2 equal splits – basal and at flowering) + cow dung 20 t ha^{-1}, T_{11} - T_2 + lime as per LR (2 equal splits – basal and at flowering) + *Trichoderma* enriched cow dung 20 t ha^{-1}, T_{12} - T_2 + dolomite 400 kg ha^{-1} + cow dung 20 t ha^{-1} and T_{13} - T_2 + dolomite 400 kg ha^{-1} + *Trichoderma* enriched cow dung 20 t ha^{-1}.

The results revealed that the growth attributes of the crop were significantly influenced by the treatments. The minimum number of days for flowering was

observed in T_8 and T_9 (32 days) and the maximum crop duration of 95.33 days was observed in the treatment T_{10}. The treatment T_{11} recorded the highest leaf area index of 0.42. The yield and yield attributes namely pod length (51.10 cm), pod weight (19.69 g), number of pods per plant (65), yield per plant (1286.35 g), yield per plot (12.86 t ha^{-1}), total dry matter production (2.72 t ha^{-1}) and harvest index (0.62) were the highest in treatment T_{11}. The highest soil pH was observed in the treatment T_{10} (6.74) which received lime as per lime requirement in 2 equal splits at basal and at flowering stage which was on par with T_{11} (6.69) and T_8 (6.54). The EC and organic carbon status of soil were not significantly influenced by the treatments.

There was a significant influence of the treatments on the available N and P status of soil at harvest of the crop with T_{11} (304.12 kg ha^{-1}) and T_9 (80.23 kg ha^{-1}) recording the highest values respectively. The highest available Ca was registered by T_{11} (304.12 mg kg^{-1}) while the lowest value was noticed in T_2 (229.53 mg kg^{-1}). The highest available Mg was observed in T_{13} (206.05 mg kg^{-1}) which received dolomite @ 400 kg ha^{-1}. The treatments improved the available S status of soil with T_{11} (5.43 mg kg^{-1}) recording the highest value. The available Fe and Mn were significantly reduced in the treatments receiving lime. The incorporation of various liming materials and organic manures significantly increased the available Zn and Cu, while the available B status was unaffected.

Analysis of index tissue concentration of nutrients indicated significantly higher content of N (2.65 %) and P (0.37 %) in T_{11}. The content of secondary nutrients Ca, Mg and S were significantly influenced by the treatments with T_{10}, T_{12} and T_{13} recording the highest values of 3.66 %, 1.34 % and 0.27 % respectively. The content of Zn and B were also significantly increased with T_9 (28.46 mg kg^{-1}) and T_{11} (32.32 mg kg^{-1}) recording the highest values respectively. All the treatments receiving lime @ LR along with foliar fertilization improved the uptake of N, P, K, Ca, Mg, S, Zn, Cu and B.

The highest disease incidence of 55.51 % and disease index of 45.84 % were obtained in the control treatment T_1 which was on par with T_2, T_3 and T_4. The treatment T_{11} resulted in zero disease incidence and disease index which was on par with the IDM package treatment (T_5). Analysis of economics of production in various treatments revealed that the highest BCR was obtained in the treatment T_{11} (2.58) which was on par with T_{10} (2.54).

From the study it can be concluded that increased growth and yield of yard long bean through the suppression of Fusarium wilt disease can be achieved by the basal application of *Trichoderma* enriched cow dung @ 20 t ha^{-1} as organic manure, lime @ LR in 2 splits at basal and flowering stage as soil amendment and soil test based dose of fertilizers as soil application along with foliar fertilization of 19:19:19 (0.5 %), KNO_3 (0.3 %), $MgSO_4$ (1 %) and borax (0.5 %) at fortnightly interval as nutrient source.

Appendix

APPENDIX –I

Weather data during the cropping period (February 2017 to May 2017)

Standard weeks	Max temperature (◦C)	Min temperature (◦C)	RH (%)	Rain (mm)
7	32.7	20.9	86.4	0
8	33.3	22.7	88.9	0
9	33.3	24.1	84.3	0
10	32.8	24.6	89.6	3.8
11	33.3	24.3	89.3	0.2
12	33.3	24.3	89.3	0
13	34	24.5	86	0
14	34.2	25.8	90	0
15	34.2	25.7	89	0
16	33.8	26.2	76.6	0
17	34.5	26.2	87.4	0
18	34.4	25.7	88.3	2.9
19	33.7	25.6	87.1	1.5
20	34.1	25.8	90.3	11
21	33.2	25.8	88.3	0.6
22	32.1	24	95.7	27.1