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Influence of Intercropping Systems, Mycorrhizal Inoculation and Fertilizer Levels on Root Colonization, Root Attributes and Yield of Hybrid Maize

T. Ananthi* and M. Mohamed Amanullah
Department of Agronomy
Tamil Nadu Agricultural University, Coimbatore - 641 003

A Field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore during winter 2011-12 to study the influence of maize *(Zea mays)* under different intercropping systems, mycorrhizal inoculation and fertilizer levels on root growth and grain yield of hybrid maize under irrigated condition. The experiment was laid out in split – split plot design. The results revealed that the root parameters such as root length, root volume, root dry mass, root- shoot ratio and root colonization were higher under sole maize, inoculation of mycorrhiza and fertilizer levels. Regarding the treatment combinations, 100% RDF along with mycorrhizal inoculation recorded significantly better root parameters. With regard to the yield, sole maize recorded the highest grain and stover yield (8,531 and 12,560 kg ha^{-1}, respectively). Also mycorrhizal inoculated treatments recorded the highest grain and stover yield (8,892 and 12,849 kg ha^{-1}, respectively). Regarding the treatment combinations, sole maize along with mycorrhizal inoculation and 125% RDF recorded significantly higher yield parameters and yield. However, the yield was comparable with maize + cowpea intercropping along with mycorrhizal inoculation and application of 100% RDF.

Key words: Hybrid maize, Intercropping systems, *Glomus intraradices,* Fertilizer levels, Root morphology.

Maize (*Zea mays* L.) is one of the most versatile crops and can be grown in diverse environmental conditions and has diversified uses as human food and animal feed. The productivity of any crop is the ultimate result of its growth and development. Plant population, inorganic and organic fertilization are the important prime factors that determine the yield of maize crop. Among the plant nutrients, primary nutrients such as, nitrogen, phosphorus and potassium play a crucial role in deciding the growth and yield. The nitrogen use efficiency can be improved with the use of hybrids, soil application of arbuscular mycorrhiza and application of fertilizers coinciding with peak need by the crop.

Phosphorus is known to stimulate early and extensive development of root systems, which enables rapid maize growth and to mature early (Sankaran *et al.,* 2005). Enhancement of P uptake by mycorrhizal hyphae can also be indirectly attributed to the faster uptake rate of P by the hyphae and the disturbance of the solution solid P equilibrium, which will increase the sorption of absorbed phosphate into soil solution.

The initial slow growth of the maize crop roots introduction of legume as intercrop in the inter row space and such a system will also enhance the productivity. Most of research work and approaches to develop production technologies for maize in the past, but now there is need to work with cropping systems that farmers can practice to exploit location specific agro-climatic conditions for enhanced production. Considering the limited net sown area, it will be necessary to raise the cropping intensity so as to grow more crops on the same piece of land. The initial slow growth of the maize crop roots offers a choice for introduction of legume as intercrop in the inter row space and such a system will also enhance the productivity. Hence, an attempt was made to study the yield of hybrid maize as influenced by different intercropping systems, mycorrhizal inoculation and fertilizer levels during winter seasons.

*Corresponding author email: ananthu12@gmail.com

Materials and Methods

Field experiments were conducted at Tamil Nadu Agricultural University Farm, Coimbatore during winter 2011-12 to study the influence of maize under different intercropping systems, mycorrhizal inoculation and fertilizer levels on root growth and grain yield of hybrid maize under irrigated condition. The experiment was laid out in a split-split design with three replications. Three intercropping systems *viz.,* sole maize, maize+cowpea and maize + green gram were the treatments under main plot. Two mycorrhizal treatments *viz.,* no mycorrhizal inoculation (control) (M_-) and inoculation of mycorrhiza (M_+) were included under sub plot. Three fertilizer levels *viz.,* 75% RDF (F_1), 100% RDF (F_2), and 125 % RDF (F_3) were studied under sub-sub plot. The soil of the experimental field was sandy clay loam in texture belonging to *Typic Ustropept*. The nutrient status of soil was low in available nitrogen (234 kg ha^{-1}), medium in available phosphorus (14.6 kg ha^{-1}) and high in available potassium (612.0 kg ha^{-1}). Maize hybrid, NK 6240, a high yielding single cross hybrid released by syngenta private ltd, India was chosen for the study.

Seeds of maize hybrids were sown on the flat beds by adopting a spacing 60 x 25 cm along with vermiculite based mycorrhizal inoculum at a depth of 5 cm below the seeds. The mycorrhizal inoculum (*Glomus intraradices* TNAU-03-08) used in this study was purchased from the Department of Agricultural Microbiology, Tamil Nadu Agricultural University. This strain was cultured in maize plants and propagules comprised of infected root bits and spores were blended in sterile vermiculite. The inoculum with the spore density of 10 spores g^{-1} was applied as a thin layer beneath the seeds one week after sowing @ 100 kg ha^{-1}. Seeds were dibbled at the rate of one seed $hill^{-1}$.

As an intercrop, cowpea CO (CP) 7 and greengram (CO 6) were raised as per the treatments with spacing of 30 x 10 cm and a seed rate of 10 kg ha^{-1}. One row of intercrop was sown in between the rows of main cop as additive series. Adjacent to the treatment plots, sole cowpea and greengram were also raised in dummy plots with same management practices to calculate the yield advantages.

Well-decomposed farmyard manure at the rate of 12.5 t ha^{-1} was applied uniformly over the field before last ploughing. $ZnSO_4$ @ 37.5 kg ha^{-1} was applied uniformly as basal to all the plots. The recommended fertilizer dose followed for maize was 150:75:75 kg NPK ha^{-1}. As per the treatment schedule, nitrogen as urea was applied in three splits *viz*., 25: 50: 25 per cent as basal and on 25 and 45 DAS, respectively. The entire dose of phosphorus as single super phosphate was applied basally. The potassium as muriate of potash was applied in two equal split doses *viz*., basal and at 45 DAS.

The root and shoot samples were collected at 45 and 60 DAS. The root architecture of mycorrhizal and non mycorrhizal plants was observed in terms of root length, root volume, and root dry mass.

Plant mycorrhizal colonization

The root colonization of maize plants was favorably influenced by intercropping systems, mycorrhizal inoculation and fertilizer levels. Mycorrhizal colonization was assessed in AM treated and untreated plants at 45 and 60 DAS (Fig 1). The beneficial effects of intercropping are, at least in pat, due to the contribution of AM fungal hyphae. Intercropping with legume improved mycorrhizal fungal colonization of roots of both maize and intercrops.

The results in this study showed that intercropping maize with cowpea and greengram could promote colonization on the roots of both maize and legumes by *Glomus intraradices*. In general, many factors such as root density, root exudates and nutrient status of the rhizosphere, contribute to regulate colonization by AMF (Smith and Read, 1997). Similar finding was also reported by Harinikumar *et al.* (1990) in maize and soybean intercropping system.

The intercropping system did not significantly increase root density in this study, however, the diffusion of root exudates to the adjacent maize roots was relatively free in this treatments. Since root exudates govern signalling between AMF and their host plants (Hause and Fester 2005), the additional exudates from intercropped roots would stimulate the establishment of AMF symbiosis. Moreover, the small difference in colonization between maize and legume roots in this study suggests that traversed AM hyphae could possibly multiply the infection rates in the intercropping system.

In this study, the percentage of colonization was found to be higher (30-60%) in AM treated plants than untreated plants (20-30%) at 60 DAS when compared to 45 DAS. The plants in the non mycorrhizal treatment were also colonized by AM fungi, which indicated that indigenous AM fungi occurred in the soils, a few of AM fungal species belonging to the genera *Glomus* and *Acaulospora* were found but at a low spore density and with a limited species. AM fungi can colonize the roots of maize, mycorrhizal colonization rates were lower relative to the mycorrhizal inoculation. The reasons may be the propagules in the soils were far lower than those in mycorrhizal inoculation, so the overall effect was probably lower in non mycorrhizal soil under field conditions (Wang *et al.,* 2006).

A significant increase in the proportion of mycorrhizal colonization in arbuscular mycorrhiza inoculated roots (M_+) from non-inoculated (M_-) maize plants at all the fertilizer levels were noticed. The higher proportion of mycorrhizal colonization in the M_+ maize plants was consistent across mycorrhizal structures such as arbuscules, vesicles and external mycelium, and across time of sample collection (45 and 60 DAS).

The development of mycorrhizal structures such as arbuscules and vesicles had significant changes at varying fertilizer levels, but the growth of external mycelium was decreased at higher levels of fertilizer application in AM_+ plants. Monocots like grasses with rapidly developing roots are the ideal stock plants for AM, but any host plant which is readily colonized by AM and which can be easily grown in the greenhouse can also serve as the stock plant

(Ferguson and Woodhead, 1982). The reduction of mycorrhizal infection in the presence of added phosphorus is owing to a self regulatory mechanism of plant discarding the mycorrhizal fungus when its phosphorus requirement is more than that satisfied (Hayman, 1982) . Similar results were reported by Mehraban *et al.* (2009) and Albert *et al.* (2009) in sorghum.

The fertilizer level significantly increased root colonization in this study. Inoculation of *Glomus intraradices* increased the percentage of colonization at both the stages even at lower levels of fertilizer application i.e. 75% RDF. In contrast, higher level 125%RDF caused a slight inhibitory effect on colonization.

Root morphology

Root morphological features such as length, volume, root dry mass and root – shoot ratio were significantly increased by intercropping systems, mycorrhizal inoculation and fertilizer levels at 45 and 60 DAS (Table 1).

Table 1. Effect of intercropping systems, mycorrhizal inoculation and fertilizer levels on root parameters of maize hybrid at 45 and 60 DAS during winter 2011-12

Treatment	Root length (cm)		Root volume (cc plant^{-1})		Root dry mass (kg ha^{-1})		Root-shoot ratio	
	45 DAS	60 DAS	45 DAS	60 DAS	45 DAS	60 DAS	45 DAS	60 DAS
Intercropping systems (I)								
I_1 - Sole maize	21.55	27.23	88.35	147.2	546	1142	0.140	0.158
I_2 - Maize + Cowpea	20.74	27.27	83.18	136.8	525	1059	0.139	0.154
I_3 - Maize + Green gram	20.20	26.12	77.36	133.6	509	1010	0.137	0.152
SEd	0.35	0.31	0.89	1.8	10	26	0.001	0.002
CD (P=0.05)	0.96	0.87	2.47	5.1	27	73	0.002	0.004
Mycorrhizal inoculation (M)								
M_- - Uninoculated	19.26	25.23	73.71	127.5	483	940	0.137	0.148
M_+ - Inoculated with AMF	22.40	28.52	92.21	150.9	570	1202	0.139	0.161
SEd	0.37	0.44	1.25	1.7	7	16	0.001	0.001
CD (P=0.05)	0.91	1.09	3.07	4.1	17	40	0.002	0.002
Fertilizer levels (F)								
F_1 - 75% RDF	19.42	25.55	79.10	135.6	508	1001	0.137	0.152
F_2 - 100% RDF	21.48	27.34	83.84	140.3	531	1100	0.139	0.155
F_3 - 125% RDF	21.59	27.73	85.95	141.7	541	1111	0.139	0.156
SEd	0.44	0.44	1.90	1.9	7	16	0.001	0.002
CD (P=0.05)	0.91	0.91	3.92	3.9	15	33	0.002	0.003
Interaction	Sig	Sig	NS	Sig	Sig	Sig	NS	Sig

Root length

Root length which represents the time trend of growth was recorded at different phenophases of maize.

Regarding the intercropping systems, the highest root length (21.55 and 27.27 cm at 45 and 60 DAS, respectively) was associated with sole maize followed by maize + cowpea intercropping and both were comparable with each other. Mycorrhizal inoculated treatments recorded higher root length (22.40 and 28.52 cm at 45 and 60 DAS, respectively), than the non mycorrhizal treatments.

Regarding the fertilizer treatments, higher root length (21.59 and 27.73 cm at 45 and 60 DAS,

Table 2. Interaction effect of mycorrhizal inoculation and fertilizer levels on root length (cm) of maize hybrid at 45 and 60 DAS during winter 2011-12

Mycorrhizal inoculation	Fertilizer levels							
	Root length @ 45 DAS				Root length @ 60 DAS			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
M_- -Uninoculated (control)	18.50	19.21	20.07	19.26	24.47	24.95	26.26	25.23
M_+- Inoculated with AMF	20.34	23.75	23.11	22.40	26.63	29.73	29.20	28.52
Mean	19.42	21.48	21.59		25.55	27.34	27.73	
		SEd	CD (5%)			SEd	CD (5%)	
	M at F	0.63	1.37		M at F	0.67	1.47	
	F at M	0.68	1.38		F at M	0.77	1.57	

respectively) was associated with 125% RDF followed by 100% RDF but both were comparable. The interaction between fertilizer levels and mycorrhizal inoculation was significant. Increased root length was observed under 100 % RDF along with mycorrhizal inoculation (23.75 and 29.73 cm at 45 and 60 DAS, respectively) and was comparable with 125% RDF with mycorrhizal inoculation and (M_+ F_3) fertilizer level 75 % RDF without mycorrhizal inoculation (M_-F_1) recorded the least root length (Table 2).

Root volume (cc plant^{-1})

In general, intercropping systems, fertilizer levels and mycorrhiza influenced root volume significantly. Among the intercropping system, higher root volume (88.4 and 147.2 cm at 45 and 60 DAS, respectively) was associated with sole maize followed by maize intercrop with cowpea. Among mycorrhizal treatments, mycorrhizal inoculation recorded higher root volume (92.2 and 150.9 cm at 45 and 60 DAS, respectively), than the non mycorrhizal inoculation. Regarding the fertilizer treatments, the higher root volume (86.0 and 141.7 cm at 45 and 60 DAS, respectively) was associated with 125% RDF followed by 100% RDF and both were comparable among themselves.

The interaction between fertilizer levels and mycorrhizal inoculation was significant at 60 DAS only. Increased root volume was observed under 100 % RDF along with mycorrhizal inoculation (154.2 cm at 60 DAS) and was comparable with 125% RDF with mycorrhizal inoculation (M_+F_3) and 75 % RDF without mycorrhizal inoculation (M_- F_1) recorded the least root volume (Table 3).

Table 3. Interaction effect of mycorrhizal inoculation and fertilizer levels on root volume (cc plant^{-1}) and root-shoot ratio of maize hybrid at 60 DAS during winter 2011-12

Mycorrhizal inoculation	Fertilizer levels Root Volume				Fertilizer levels Root shoot ratio			
	F_1	F_2	F_3	M ean	F_1	F_2	F_3	Mean
M_- -Uninoculated (control)	122.9	126.5	133.2	127.5	0.134	0.136	0.140	0.137
M_+- Inoculated with AMF	148.3	154.2	150.3	150.9	0.143	0.148	0.143	0.146
Mean	135.6	140.3	141.7		0.139	0.142	0.1432	
		SEd	CD (5%)			SEd	CD (5%)	
	M at F	2.7	6.0		M at F	0.003	0.007	
	F at M	3.0	6.1		F at M	0.004	0.008	

Root dry mass

The root dry mass increased with the age of the crop and reached the highest at harvest. Regarding the intercropping systems, higher root dry mass (546 and 1142 kg at 45 and 60 DAS, respectively) was associated with sole maize followed by maize cowpea intercropping and both were comparable with each other at 45 DAS. Inoculation of mycorrhiza had substantial effect on root dry mass. Mycorrhizal inoculated plants recorded higher root dry mass (570 and 1202 kg at 45 and 60 DAS, respectively), than the non mycorrhizal plants.

Regarding the fertilizer treatments, the highest root dry mass (531 and 1100 kg at 45 and 60 DAS, respectively) was associated with 125% RDF followed by 100% RDF but it was comparable with 100% RDF. The fertilizer level 75 % recorded the least root length at all the stages.

Table 4. Interaction effect of mycorrhizal inoculation and fertilizer levels on root dry mass (kg ha^{-1}) of maize hybrid at 45 and 60 DAS during winter 2011-12

Mycorrhizal inoculation	Fertilizer levels							
	Root dry mass @ 45 DAS				Root dry mass @ 60 DAS			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
M_- -Uninoculated (control)	465	478	507	483	893	935	992	940
M_+- Inoculated with AMF	551	585	574	570	1110	1265	1231	1202
Mean	508	531	541		1001	1100	1111	
		SEd	CD (5%)			SEd	CD (5%)	
	M at F	11	23		M at F	25	54	
	F at M	12	25		F at M	28	58	

The interaction between fertilizer levels and mycorrhizal inoculation was significant. Increased root dry mass was observed under 100 % RDF along with mycorrhizal inoculation (585 and 1265 at 45 and 60 DAS, respectively) and was comparable with 125% RDF with mycorrhizal inoculation (F_3M_+). The treatment combination 75 % RDF without mycorrhizal inoculation (F_1M_-) recorded the least root dry mass (Table 3).

Root-shoot ratio

The root – shoot ratio declined from 45 DAS to 60 DAS. Regarding the intercropping systems, higher root – shoot ratio (0.140 and 0.158 at 45 and

60 DAS, respectively) was associated with sole maize followed by maize cowpea intercropping and both were comparable with each other at all the stages (Table 1) . Inoculation of mycorrhiza had substantial effect on root – shoot ratio. Mycorrhizal inoculated plants recorded higher root – shoot ratio (0.140 and 0.161 at 45 and 60 DAS, respectively), than the non mycorrhizal plants. Regarding the fertilizer treatments, the higher root – shoot ratio of 0.139 at 45 DAS was associated with 100% RDF followed by 125% RDF and both were comparable. At 60 DAS, the higher root – shoot ratio of 0.156 was recorded with 125% RDF.

The root length is an important morphological parameter involved in improving water and nutritional status of the plant. Knowledge about the root system of a crop is a pre-requisite for understanding many problems related to crop production. Root characters such as length and distribution and especially root volume help in divulging the pattern of water use and nutrient uptake by the crop. In general, the root characters such as root length, volume and its dry weight showed a gradual increase from 45 to 60 DAS.

Among the intercropping systems, sole maize recorded higher root length (6.3 and 4.1 %), root volume (12.4 and 9.2%) and root dry mass (6.8 and 11.6%), in comparison with maize + greengram intercropping at both 45 and 60 DAS, respectively. This might be due to better utilization of spacing, nutrients, light and moisture.

In the case of fertilizer levels, 125% RDF increased the root length (10.1 and 7.9 %), root volume (8.0 and 4.3 %) and root dry mass (6.1 and 9.9 %) in comparison with 75% RDF level of fertilizers at both 45 and 60 DAS. With regard to the N and P application, the root characters such as total root length and root volume increased with increasing fertilizer levels in the present investigation. This is in corroboration with the findings of Dhurandher and Tripathi (1999). Deeper root system might play an important role not only for continuous water uptake, but also for nutrient uptake under suboptimal water availability.

With regard to mycorrhiza, the measurements of root architecture variables *viz.,* root length, root volume, root dry mass and root/shoot ratio in the mycorrhizal plants were significantly higher than non-mycorrhizal (M-) plants. The increase in root architecture measurements in mycorrhizal inoculated (M+) plants was found in both the root samples collected at 45 and 60 DAS. The extensive root growth of AM plants might be attributed to the improved P nutrition of host plants. The enhanced supply of P by mycorrhizal symbiosis has been unequivocally demonstrated (Hetrick *et al*., 1996; Smith and Read, 1997; Subramanian *et al*., 2006). At early stage of crop growth, AM fungal inoculated plants showed an increase in root mass while the shoot masses were similar. This may be attributed to the utilization of carbon for establishment of functional symbiosis as reported by Jakobsen and Rosendahl (1990).

In the case of fertilizer levels, 125% RDF increased the oot length (10.1and 7.9%), root volume (8.0 and 4.3%) and root dry mass (6.1 and 9.9%) in comparision with 75% RDF level of fertilizers at both 45 and 60 DAS. With regard to the N and P application, the root characters such as total root length and root volume increased with increasing fertilizer levels in the present investigation. This is in corroboration with the findings of Dhurandher and Tripathi (1999) and Ananthi *et al.* (2011a). Deeper root system might play an important role not only for continuous water uptake, but also for nutrient uptake under suboptimal water availability.

Grain and stover yield (Table 5)

The maize grain yield was significantly influenced by intercropping systems, mycorrhizal inoculation and fertilizer levels.

Table 5. Effect of intercropping, mycorrhiza and fertilizer levels on grain and stover yield (kg ha^{-1}) of maize hybrid during winter 2011-12

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
Intercropping systems (I)	8531	12560
I_1 - Sole maize	8455	12223
I_2 - Maize + Cowpea	8323	12205
I_3 - Maize + Green gram	54	83
SEd	151	231
Mycorrhizal inoculation (M)		
M_- - Uninoculated (control)	7981	11810
M_+ - Inoculated with AMF	8892	12849
SEd	73	67
CD (P=0.05)	179	164
Fertilizer levels (F)		
F_1 - 75% RDF	8176	12051
F_2 - 100% RDF	8561	12444
F_3 - 125% RDF	8572	12494
SEd	90	113
CD (P=0.05)	185	232
Interaction	**Sig**	**Sig**

Effect of intercropping systems

Among the intercropping systems, sole maize recorded the highest grain yield of 8531 kg ha^{-1} but was comparable with maize intercropped with cowpea. The yield reduction due to intercropping cowpea was negligible (0.89 per cent) comparing the sole maize yield. Higher yield under sole maize was due to zero competition for sunlight, space, water and nutrients compared to intercropping which might have curtailed efficient utilization of natural resources and restrict growth of maize from initial stages to harvest resulting in yield competition in intercrop (Yilmaz *et al.,* 2008). Similar findings were also obtained by Haque *et al.* (2008) and Choudhary *et al.* (2012).

Effect of mycorrhizal inoculation

Mycorrhizal inoculation recorded higher grain yield (8892 kg ha^{-1}) than no inoculation (7981 kg ha^{-1}) and reduction in yield being 10.25 per cent. Mycorrhiza had positive influence on grain yield of maize crop. The improved nutritional status of AM fungus -inoculated plants resulted in higher grain yield in comparison to uninoculated treatments. This yield gain in mycorrhizal treatments was mainly caused by the intense flow of minerals and metabolites from the leaf to the developing kernel. The increased yields of AM fungus inoculated treatments thus suggest that significant amounts of P and N were translocated from the source to the sink to support kernel development and grain yield (Subramanian and Charest, 1997). A higher yield of maize due to mycorrhizal inoculation has been reported previously by Subramanian *et al. (*2008) and Ananthi *et al.* (2011b).

Effect of fertilizer levels

Comparing the yield of maize grain obtained under different fertilizer levels, 125 % RDF recorded the highest grain yield of 8572 kg ha^{-1} and was comparable with 100% RDF. Fertilizer level of 75% RDF recorded lower grain yield and was 4.7 per cent and 4.5 per cent lesser than 125% and 100% RDF.

Table 6. Interaction effect of mycorrhizal inoculation and fertilizer levels on grain yield (kg ha^{-1}) and stover yield (kg ha^{-1}) of maize hybrid during winter 2011-12

Mycorrhizal inoculation	Grain yield (kg ha^{-1})				Stover yield (kg ha^{-1})			
	Fertilizer levels				Fertilizer levels			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
M_- -Uninoculated (control)	7804	7964	8175	7981	11657	11732	12041	11810
M_+- Inoculated with AMF	8548	9157	8970	8892	12445	13155	12947	12849
Mean	8176	8561	8572		12051	12444	12494	
		SEd	CD (5%)			SEd	CD (5%)	
	M x F	127.0	276.0		M x F	146.0	318.0	
	F x M	134.0	275.0		F x M	140.0	286.0	

This increase in yield was probably due to effective utilization of applied nutrients, increased sink capacity and nutrient uptake by crop. The yield potential of maize is mainly governed by the growth and yield components. The positive and significant improvement in yield attributes and nutrient uptake would have resulted in enhanced grain yield. The present findings are in line with the findings of Maddonni *et al*. (2006). The positive responses of hybrid maize upto 250 kg N ha^{-1} as reported by Srikanth *et al*. (2009) lend support to the present findings.

Since N is the major structural constitute of cells, as N level increased, the rate of vegetative and reproductive growth also increased in plants due to increase in assimilating surface of plants as well as total photosynthesis. In physiological terms, the grain yield of maize is largely governed by source (photosynthesis) and sink (grain) relationship which is directly related to N. These resulted in more grain yield when N was higher.

Interaction effect

The interaction between mycorrhizal inoculation and fertilizer levels on maize grain yield was significant. The highest grain yield (9157 kg ha^{-1}) was recorded under the treatment combination mycorrhizal inoculation with 100% RDF (M_+F_2) followed by 125% RDF and was comparable with each other (Table 6).

The interaction between intercropping systems, mycorrhizal inoculation and fertilizer levels on maize grain yield was significant. The treatment combination sole maize with 125% RDF along with mycorrhizal inoculation ($I_1F_3M^+$) recorded significantly higher yield (8561 kg ha^{-1}) (Fig 2). In sole maize, there was no competition for various resources except intra-species competition and the immediate supply of nutrients due to the addition of inorganic fertilizers and the significant amounts of P and N were translocated from the source to the sink in mycorrhizal inoculated maize plants, might be the reason for increase in growth and yield parameters which would have increased the yields in the treatments mentioned.

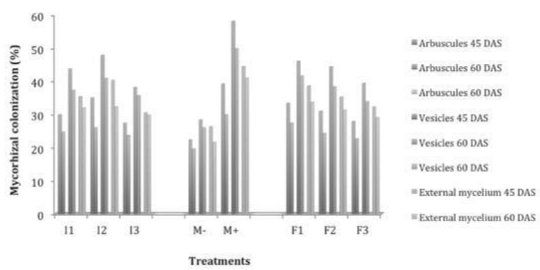

Fig.1. Effect of intercropping systems, mycorrhizal inoculation and fertilizer levels on mycorrhizal colonization of maize hybrid at 45 and 60 DAS during winter 2011-12

Even though maize intercropped with cowpea and 100% RDF along with mycorrhizal inoculation ($I_2F_2M^+$) recorded lesser yield than the $I_1F_3M^+$, the yield reduction was not significant. The reduction of maize yield was probably due to intercrop competition between maize and cowpea. However, additional yield from cowpea not only compensated the deficit, but also gave extra income. This finding is in conformity with that of Quayyum and Maniruzzaman (1995), Uddin *et al.* (2003) and Pandey *et al.* (2003). Under maize + cowpea intercropping systems, 100% RDF with mycorrhizal inoculation produced higher yield. This might be due to mycorrhizal fungi increased the root efficiency to absorb nutrient and in nutrient depleted soil, mycorrhizal fungi develop strand in the soil and absorb phosphorus through the root hairs, thereby increase nodulation and nitrogen, this character of the fungi enhanced plant growth and yield Muok, *et al*. (2009). Mycorrhizal inoculum significantly increased the growth and yield of maize and cowpea resulting from the interaction between mycorrhizal fungi and *rhizobia.*

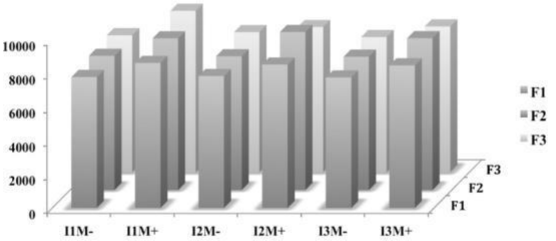

Fig 2. Interaction effect of intercropping, mycorrhiza and fertilizer levels on grain yield (kg ha-1) of maize hybrid during winter 2011-12

Stover yield did exhibit similar trend as that of grain yield. Regarding intercropping systems, sole maize recorded the highest stover yield (12560 kg ha-1) followed by maize intercropped with cowpea which was comparable with sole maize. This might be due to higher plant height, LAI and DMP in sole maize and also there is no inter plant competition. Mycorrhizal inoculated plants recorded significantly higher (12849 kg ha-1) stover yield, which might be due to increase in plant height, leaf area index and total biomass as evidenced in the present investigation. Similar results of increase in stover yield due to mycorrhizal inoculation were also reported earlier by Lauzon and Miller (1997) in maize.

Increasing the fertilizer levels increased the stover yield significantly. Fertilizer level of 125% RDF recorded higher stover yield (12494 kg ha-1) followed by100% RDF. The positive and significant improvement in LAI and DMP at different stages and higher nutrient uptake due to higher dose of fertilizer would have resulted in enhanced stover yield. These results are in conformity with the findings of Srikanth *et al*. (2009).

The interaction between mycorrhizal inoculation and fertilizer levels was significant. The treatment combination mycorrhizal inoculation with 100% RDF (M_+F_2) recorded higher stover yield (13155 kg ha-1) followed by mycorrhizal inoculation with 125% RDF (M_+F_3) and both were comparable with each other (Table 6).

Conclusion

Finally, it can be concluded that the root parameters *viz.,* root length, root volume, root dry mass and root- shoot ratio and root colonization were higher under sole maize, mycorrhizal inoculation and fertilizer level of 125% RDF at both 45 and 60 DAS. Root colonization was higher under maize/cowpea intercropping among intercropping systems, mycorrhizal inoculation among the mycorrhiza treatments and 75% RDF among the fertilizer levels. Among the intercropping systems, sole maize recorded higher grain and stover yield. With respect to mycorrhiza, mycorrhiza inoculated treatments and among fertilizer levels 125% RDF recorded higher grain and stover yield.

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