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Growth, yields and nitrogen use of open pollinated and hybrid maize (*Zea mays* L) as affected by organic matter and its placement in minor seasons of Asia

Ravi Sangakkara*[1], Danushka Wijesinghe[1], Prasanna Amarasekera[1], Siril Bandaranayake[1], Peter Stamp[2]

[1]Faculty of Agriculture, University of Peradeniya, 20400, Sri Lanka
[2]Institute of Agricultural Sciences, ETH Zentrum, 8092 Zurich, Switzerland
*Corresponding author: E-mail: ravisangakkara@sltnet.lk

Abstract

Sustainable maize (*Zea mays* L) production in smallholder cropping systems of South Asia require combinations of organic matter and mineral fertilizers, especially nitrogen, when the crop is subjected to water stress in the minor seasons. As the cultivation of hybrid maze is being promoted in these nations, field studies over two minor seasons evaluated the impact of three types of common organic materials and their method on incorporation on root growth, seeds yields and nitrogen use patterns of an open pollinated (OPV) and a hybrid variety of maize. The growth and yields of the OPV were higher than those of the hybrid, illustrating the greater adaptability of this variety to the drier conditions of minor seasons. The least beneficial impact of organic matter on growth, yield and nitrogen use was with rice straw, a low quality organic matter, while Tithonia leaves promoted root growth. Application of Gliricidia leaves produced the highest yields followed by the use of Tithonia. N use patterns were enhanced to similar extents by the addition of Tithonia and Gliricidia leaves, and the beneficial impact was greater than when rice straw was used. Incorporation enhanced the benefits of the organic matter, especially in the hybrid, which produced lower yields, which is considered less adaptable to the environments of this season. The benefits of using good quality organic matter and its incorporation on maize growth, productivity and the utilization patterns of nitrogen in the minor dry seasons of South Asia was evident in this field study.

Keywords: maize varieties, organic matter placement, minor seasons, yields, N use, Asia

Introduction

Smallholder highland rainfed agricultural systems of the world cover over 1.132 billion hectares and provide some 60% of the food and nutritional needs of the world's population (Biradar et al, 2009). These systems are principally found in tropical Asia and Africa, and provide a major proportion of food for the peoples of these nations. Hence their values in food production and their future sustainability issues are vital for the food security of these nations (Beddington, 2011; Anthony and Ferroni, 2012). As quoted by Vanlauwe et al (2011) for Africa, such a sustainability policy for Asia, the most populous region of the world, will help to provide food and food security to the rural peoples of these developing nations, and also assist in breaking the cycle of poverty.

Rural smallholder highland farming systems of South Asia, as found in Sri Lanka are characterized by low soil fertility (de Costa and Sangakkara, 2006), due to low organic matter contents in the soils (Lal, 2009). Thus addition of organic matter brings about both short and long term benefits by enhancing the soil carbon pool, improving soil physical, chemical and biological properties and also providing some nutrients (Kumar and Goh, 2003; de Costa and Sangakkara, 2006). The inclusion of mineral fertilizers, especially nitrogen, which is the most limiting nutrient in tropical soils (Moser et al, 2006; Widowati et al, 2011), along with organic matter helps to improve the fertility of these soils and develop sustainable systems (Fageria and Baligar, 2005). Furthermore, as nitrogen, a nutrient that is rapidly lost from cropping systems (Widowati et al, 2011), is the most commonly used mineral fertilizer in Asia (Shindo, 2012), its optimal use becomes vital in these smallholder highland farming systems to maintain productivity, especially as prices of this commodity are increasing in these nations (Gerpacio and Pingali, 2007).

The supply of organic matter in tropical smallholder farming systems is limited in choice, quantity and quality, and their use is determined by availability due to other competing uses (Mapfumo and Giller, 2001; Amusan et al, 2011), Thus they do not provide the required nutrients to crops grown in these smallholdings, although they do help improve soil quality. An optimal solution is the combination of organic matter with mineral fertilizers, especially nitrogen, as studies in Africa (e.g., Chivenge et al, 2011a) and Asia (Sangakkara et al, 2008a) illustrate the benefits of combining these two fertilizer sources for highland rainfed crop production and increasing fertilizer use efficiencies under field conditions.

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Maize is the most popular highland cereal grown in most South Asian nations (FAO, 2010), and traditionally, open pollinated varieties (OPV's) were grown in the smallholder farms under rainfed conditions, due to their better adaptability to stress conditions. With the advent of hybrid maize, smallholder highland farmers began growing hybrids using techniques adopted for the traditional OPV's (Gerpacio, 2003). Furthermore, hybrid varieties are more susceptible to changes in the environment than OPV's, especially drought, as found in the smallholder highland farms in minor seasons of South Asia (Azeez et al, 2005). Although organic matter and mineral fertilizers could increase yields of hybrid maize as in the case of OPV's (Vanlauwe et al, 2011), maize production in the tropics suffer from suboptimal mineral and organic fertilizer management, especially for nitrogen (Pasuquin et al, 2012). Thus studies of Sangakkara et al (2003; 2008a,b) report the benefits of previous cropping systems and incorporating organic matter to improve nitrogen use efficiencies and yields of OPV maize in major and minor seasons of South Asia. However a comparison of the yields and nitrogen use efficiencies of OPV and hybrid maize varieties as affected by different organic materials have not been reported for Asia, especially under conditions of the minor seasons, when crops are generally subjected to water stress (Domros and Ranatunga, 1993). As water stress and N fertility are the most important stress factors for maize in the tropics (Campos et al, 2004), this study was carried out under field conditions over two minor seasons to evaluate the nitrogen use efficiencies and yields of a popular OPV and hybrid variety of maize as affected by the methods of placement of three types of common organic materials used by smallholder farmers of South Asia.

Materials and Methods

This field study was carried out on adjacent sites at the Experimental station of the University of Peradeniya (8°N 81°E, 418m above sea level) in the mid country intermediate climatic zone of Sri Lanka, in two minor seasons (late April – August) of 2006 and 2007, which corresponds to the Southwest Monsoon (Domros and Ranatunga, 2003). The soil of the site is an Ultisol (Rhododhult) (Panabokke, 1996), with a sandy clay loam texture. The important chemical characteristics of the soil were – pH (1:2.5 H_2O) 6.84 (± 0.25); and total Nitrogen, available Phosphorus and Potassium contents of 26.51 (± 3.22) mg g^{-1}, 8.2 (± 0.09) mg g^{-1} and 9.7 (± 0.84) mg g^{-1} respectively. The CEC was 42.05 ± 2.11 m eq 100 g^{-1} soil and the soil organic matter content was 0.91% ± 0.04% in the top 40 cm of soil, which was considered the effective root zone for maize.

At the onset of the rains in the minor seasons in 2006 and 2007 (late April), the fields were harrowed, leveled and plots of 3 x 4 m were prepared. The selected organic materials, which are commonly used in smallholder farming systems, namely rice straw (C:N ratio 48.1) green leaves of the tree legume *Gliricidia sepium* (C:N ratio 18.9) and *Tithonia diversifolia* (C:N ratio 26.2) were added to randomly selected plots at a rate of 4 Mg per ha (400g m^{-2} – on a dry matter basis) at 14 days before planting and incorporated manually in the top 30 cm layer of soil or added at the same rate (400 g m^{-2}) to the soil surface soon after planting the maize seeds in other plots. In addition there were plots without added organic matter, which served as the control treatments. Thus the treatments of the experiments were the two varieties of maize (OPV – Bhadra or Hybrid - Pacific), three types of organic materials and two methods of addition. The experiment was laid out as a three factor-factorial within a randomized block design with three replicates per treatment, on adjacent sites in the two seasons to avoid carry over effects.

Uniform seeds of the two maize varieties (Bhadra for OPV and Pacific for the Hybrid; mean germination 95%) were planted in all plots at the recommended spacing of 60 x 30 cm to accommodate 55,000 plants per ha, as per local recommendations (Dept. of Agriculture 2007). The fertilizers applied to all plots were equivalent to 25 Kg N, 45 Kg P, and 30 Kg K per ha at planting, followed by a top dressing of 45 Kg N per ha at 45 days after planting, as recommended. The crop was rainfed, no supplementary irrigation was provided and weeding was carried out on 5 occasions to remove all roots of these plants, which would affect root sampling of maize at the V8 growth stage. There were no serious pests or diseases that required chemical control in both seasons.

The data collected were as follows: 1) climatic parameters for the minor season from 1997 to 2007 using a weather station located 1.2 km from the site;

2) at the V8 growth stage of maize in both seasons, soil cores were removed using an auger of dimensions 5 cm width x 10 cm length, from all plots at depths of 0 – 10 and 10 – 20 cm. The cores were taken from the center points between two rows of maize, and three samples were collected from each plot, as described by Böhm (1979). The soil cores were carefully washed using a 0.5 mm mesh and all roots collected. The total root lengths in all samples were determined using the grid technique (Tennent, 1975). Thereafter the roots were dried at 80°C for 48 hours and dry weights determined. These data were used to calculate the Root Length Density (RLD) and Root Weight Density (RWD) as follows:

RLD (cm cm^{-3}) = total length of roots in core/ volume of core (Vamareli et al, 2003);

RWD (mg cm^{-3}) = total dry weights of roots in core/ volume of core.

At crop maturity stover (shoots and roots) and seed yields were determined from pre marked sub plots of 2 x 1 m dimensions. The plants in these subplots were carefully uprooted after harvesting the maize ears, and roots washed. Thereafter the shoots and roots were dried at 80°C to a constant weight (approximately 72 hours) and weighed. The seed yields were determined (at 14% moisture content) and the ear sheaths were also dried at the same temperature for 48 hours. These data were used to determine the Harvest indices (HI). Thereafter, subsamples of the shoots, roots, ear sheaths and seeds were ground separately and total nitrogen contents were determined by the Microkjeldhal method.

This N data of the subsamples were used to calculate the fertilizer N utilization efficiency at crop maturity as described by Mengel and Kirkby (1987), Montemurro et al (2006) and Vanlauwe et al (2011):
N Harvest Index (NHI) = Ratio of N in gains to that of N in stover (Shoots, roots and sheaths);
N Agronomic Efficiency (NAE) = (Grain yields in plots with organic matter – Grain yields in plots without Organic matter) / Quantity of mineral N applied;
N Use efficiency (NUE) = Ratio between yield and total N uptake by the plant.
In these calculations, the N added via organic matter was not considered as the objective was to determine the utilization efficiency of applied mineral N.

The data of the two seasons were tested for normal distribution and when required were transformed using logarithmic values. Due to the similarity of results in the two seasons, without an interactive effect (P=0.05) of the year on measured parameters, the data was pooled prior to appropriate statistical analysis using a General Linear Model of the SAS program version 6 (SAS Institute Inc, NC, USA).The significance of treatment differences within a variety of maize and the interactions were determined by the Fishers Protected test at 0.5% probability. When possible, correlations were calculated to determine relationships between the N use efficiencies and seed yields. The data presented are means of the two seasons.

Results and Discussion

The rains received over the minor season, which correspond to the South West monsoon, are approximately 30% of the mean annual rainfall in the intermediate zone of Sri Lanka (Punyawardena et al, 2003). The climatic zone, where the experiment was located receives between 1,750 – 2,055 mm of rainfall per annum, and the experimental station receives approximately 1,800 mm. The mean rainfall received over 11 years at the location over the minor season was 385 mm (Table 1), which is 25% of the annual precipitation. Furthermore, the temperatures and pan evaporation in this season are higher with a relatively low humidity (Domros and Ranatunga, 2003), thus rainfed crops are subjected to stress conditions in this season. This was evident in this study in both seasons.

Soil moisture and inputs such as organic matter affects root development in maize (Bona et al,1995) and rooting abilities of different varieties of maize also differ (Vamerali et al, 2003). In this study, open pollinated variety (OPV) Bhadra had a more extensive root system than the hybrid Pacific, as seen by the RLD values at both depths (0 – 10, and 10 – 20 cm), dry weights and RWD values (Table 2). Even with no organic matter, the total RLD of the OPV was 25% greater than that of the hybrid, while the respective dry weights and RWD were also 11% and 6% greater. This illustrates the greater adaptability of root development of the OPV to the drier conditions of this minor season, confirming earlier studies by Sangakkara et al (2012), where OPV maize was more productive under similar conditions when intercropped with different species. Furthermore, the data also confirms reports of Vamerai et al (2003), which clearly illustrate the adaptability of root systems of maize hybrids to overcome nutrient and moisture stress.

Table 1 - Mean climatic parameters of the minor season at the experimental site (1996 – 2007).

Climatic parameter	Mean value (1996 – 2007)
Total rainfall (mm)	485.0 ± 8.9
Mean daily temperature (°C)	31.6 ± 3.4
Mean daily humidity (%)	76.4 ± 4.2
Mean pan Evapotraspiration (mm/day)	3.96 ± 0.41
Daylength (hrs)	11 – 12

There was no significant interactions between the variety of maize, organic matter and its placement for all root parameters (Table 2). Thus the response of root growth of the two maize varieties were similar to the different organic materials and placement methods, although there were variations in the significance of the two factor interactions. This suggests the presence of differences in responses of the OPV and hybrid maize to management strategies. The three selected organic materials increased root growth of both varieties of maize, thus clearly illustrating the benefits of adding these materials to enhance root growth of this popular highland cereal when grown under rainfed conditions in minor seasons. This could be attributed to the beneficial effects to the rhizosphere due to the addition of organic matter (Palm et al, 2001) and also the nutrients released by the organic matter, which could stimulate roots under dry conditions, as shown for sugar beet under field conditions (Vamerali et al, 2009).

RLD values were enhanced to the greatest extent by Tithonia leaves, irrespective of its method of placement (Table 2). This could be attributed to its greater phosphorus content (Cong and Merckx, 2005) and its quicker decomposition (Partey et al, 2012) which promotes root development (Jin et al, 2012), although mineral fertilizers were also added. The least beneficial impact on RLD was with rice straw, which had the highest C:N ratio, and thus is considered a low quality organic matter with its low nitrogen content. Such organic matter decomposes slowly (Blair et al,

Table 2 - Root growth at V8 growth stage of maize varieties as affected by organic matter incorporation (Means of 2 minor seasons).

Maize type	Organic matter	Method of placement	Root Length Density (cm cm^{-3}) 0–10 cm	Root Length Density (cm cm^{-3}) 10–20 cm	Root dry wt (mg) 0–20 cm	Root Weight Density (mg cm^{-1}) 0–20 cm
OPV (Bhadra)	Straw	Surface	18.9a#	15.6a	58.2a	1.78a
		Incorporated	25.6b	31.5b	64.1b	1.32b
	Gliricidia	Surface	22.6b	20.9c	66.2b	1.57b
		Incorporated	29.4c	34.6b	70.3c	1.16c
	Tithonia	Surface	30.9c	24.6c	69.1c	1.28c
		Incorporated	35.6d	37.3d	70.6c	0.99d
	None		12.2e	8.5e	40.2d	2.18e
Hybrid (Pacific)	Straw	Surface	15.6a	12.9a	45.2a	1.74a
		Incorporated	22.5b	29.4c	55.4b	1.09b
	Gliricidia	Surface	20.5b	17.4b	56.7b	1.40c
		Incorporated	26.8c	25.2c	59.3b	1.19b
	Tithonia	Surface	24.2c	15.6b	54.0b	1.41a
		Incorporated	27.9c	25.8c	61.4c	1.16b
	None		10.5d	6.4e	36.2d	2.05d
Interactions	Variety x Organic matter		NS	NS	*	*
	Organic matter x Placement		*	*	*	*
	Variety x Placement		NS	*	NS	*
	Variety x OM x placement		NS	NS	NS	NS

#Means of a variety followed by the same letter within a column and not significantly different – according to Fishers Protected LSD test (p=0.05)

*Indicates significance (P = 0.05) ; NS = Non significance (P = 0.05)

2005), and could also bind nutrients for its decomposition, thus not promoting root elongation as Tithonia or Gliricidia, with their lower C:N ratios, although rice straw could increase aggregate stability (Chivenge et al, 2011b). The impact of Gliricidia leaves on RLD was in-between that of Tithonia and rice straw, which also suggests its beneficial effect, due to a more rapid rate of decomposition.

Surface application stimulated the RLD values in the top soil layer to a greater extent than incorporation (Table 2). The lowest beneficial impact on surface application of organic matter was with rice straw, with an increase in RLD with Gliricidia leaves, and the highest beneficial effect was with Tithonia leaves. This is due to the retention of soil moisture with these organic mulches (Balwinder-Singh et al, 2001). Although the rice straw mulch would last longer due to slower breakdown (high C:N ratio) than the leaves of Gliricidia or Tithonia and retain moisture for longer periods of time, it did not facilitate a greater increase in RLD in to top 10 cm soil layer. The opposite was observed with Gliricidia and Tithonia, which suggests that the faster decomposition of surface applied organic matter stimulated the expansion of root lengths in the top 10 of soil, which could be attributed to the more rapid drying of the surface layer, thus promoting root expansion to extract soil moisture. The longer presence of the rice straw would retain soil moisture and thus not stimulate root expansion in the top soil layer.

Incorporation of the organic materials stimulated RLD's in both layers of soil in the two varieties of maize (Table 2), and specifically in the 10 – 20 cm layer. This clearly illustrated that incorporation of any type of organic matter increases root lengths of the rhizosphere, which is an advantageous characteristic in minor dry seasons, and could principally be due to moisture retention due to the added organic matter (Patil and Sheelawantar, 2004), especially as mineral fertilizers were used in this study to overcome nutrient deficiencies. The most beneficial effect was again with Tithonia leaves followed by Gliricidia leaves and rice straw. The benefits of Tithonia leaves could again be due to the phosphorus content, which stimulates root development of crops.

Organic matter increased root dry weights in the 0 – 20 cm horizon significantly (Table 2) and the response of the OPV was higher than that of the hybrid. This again indicated the greater adaptability of the OPV to organic matter addition in this minor dry season. Incorporation of organic matter increased root dry weights further in both varieties, and the beneficial impact was especially observed with rice straw application. This could be attributed to the development of thicker roots due to the slower breakdown of this material, which could also increase aggregate stability (Chivenge et al, 2011b), and thus water holding capacities of the rhizosphere. However detailed studies are needed for verification of this phenomenon. In contrast, the method of addition of the other two materials had only a marginal impact on root dry weights of the OPV, although in overall terms they increased root dry weights to a greater extent than in the hybrid. In contrast, in the hybrid, incorporation

Table 3 - Seeds yields and Harvest Indices of open pollinated and hybrid maize as affected by organic matter placement (Means of two minor seasons).

Maize type	Organic matter	Method of placement	Seed yield (Kg ha^{-1})	Harvest Index
OPV (Bhadra)	Straw	Surface	2,009a#	0.32a
		Incorporated	2,842b	0.36b
	Gliricidia	Surface	3,104c	0.37b
		Incorporated	3,611d	0.40c
	Tithonia	Surface	2,756b	0.35b
		Incorporated	3,511c	0.41c
	None		1,292d	0.30d
Hybrid (Pacific)	Straw	Surface	1,422a	0.30a
		Incorporated	2,242b	0.32a
	Gliricidia	Surface	2,958c	0.34b
		Incorporated	3,425d	0.37b
	Tithonia	Surface	2,785c	0.32a
		Incorporated	3,291d	0.37b
	None		1,045e	0.28d
Interactions	Variety x Organic matter		*	*
	Organic matter x Placement		*	*
	Variety x Placement		NS	NS
	Variety x OM x placement		NS	NS

#Means of a variety followed by the same letter within a column and not significantly different according to Fishers Protected LSD test (p=0.05)
*Indicates significance (P = 0.05) ; NS = Non significance (P = 0.05)

of organic matter increased root dry weights significantly when compared to the values obtained due to surface application. This phenomenon thus suggests that the root dry weights, as in the case of root lengths of the hybrid variety are more sensitive to the method of placement of organic matter than in the OPV, which in turn could be a process of adaptation of this variety to the drier conditions. However confirmatory studies are required on this aspect, as fertilizers were provided, which removed the stress for nutrients.

Root weight densities (RWD) of both varieties were lowered significantly by organic matter (Table 2). Incorporation of organic matter reduced RWD values to a greater extent than surface application, irrespective of the variety. The expansion of the root system due to organic matter was evident through this data, and the lowest RWD values were with Tithonia in both varieties. This again illustrated the beneficial effect of this organic matter in promoting root expansion in maize. As expected the least beneficial effect was with rice straw. A comparison of the two varieties indicated that RWD values of the hybrid were lowered more than in the OPV by the organic matter, especially by Gliricidia and Tithonia leaves. Thus, the two organic materials with a lower C:N ratio seem to stimulate the root expansion and develop thinner roots for exploiting the soil environment, thus lowering the RWD of hybrid maize to a greater extent. This could indeed be beneficial in extracting more moisture from soils by this variety in dry seasons.

The adaptability of the OPV to the minor season is best presented in terms of seed yields (Table 3), where the mean seed yield was 23% greater than in the hybrid, when grown without organic manures. This confirms the benefits of OPVs for drier and difficult environments (Azeez et al, 2005) as hybrids generally require good management and conducive conditions. Furthermore, incorporation of organic matter increased yields to a greater extent than when placed on the surface, which as stated by Qi et al (2012), could also be positively correlated with root growth (especially with RLD which was r^2=0.63* in this study), as reported by Vamerali et al (2003). The extensive root growth obtained with incorporating organic matter would help the plant to extract moisture and nutrients more efficiently from the soil (as seen by the RLD and RWD values – Table 2), especially under the dry conditions of these minor seasons.

The increase in seed yields due to the application of rice straw, the low quality organic matter, was greater in the OPV than in the hybrid, when compared with the yields of maize varieties grown only with mineral fertilizers (Table 3). In contrast, the two organic materials with a lower C:N ratios increased yields of the hybrid to a greater extent. The highest yields of both varieties were obtained with Gliricidia leaves, especially when incorporated and the increments in the yields of the hybrid and OPV were 233% and 179% when compared to those of the control plots. The increments in the hybrid and OPV due to incorporation of Tithonia leaves were 215% and 171% respectively, over that of control plots. These were the highest yields obtained and surface application of these two organic materials did not increase yields to similar extents. While Tithonia leaves promoted root

Table 4 - Nitrogen use efficiencies of maize varieties as affected by organic matter placement (Means of 2 minor seasons).

Maize type	Organic matter	Method of placement	N Harvest Index	N Agronomic Effciciency (Kg Kg^{-1})	N Use Efficiency (%)
OPV (Bhadra)	Straw	Surface	0.41a#	4.8a	18.5a
		Incorporated	0.45b	5.1b	19.2a
	Gliricidia	Surface	0.52c	16.8c	28.4b
		Incorporated	0.55c	21.6d	26.9b
	Tithonia	Surface	0.53c	14.4c	26.7b
		Incorporated	0.56c	20.9d	28.2b
	None		0.24d	-	12.6c
Hybrid (Pacific)	Straw	Surface	0.29a	3.6a	14.5a
		Incorporated	0.35b	4.2b	7.2b
	Gliricidia	Surface	0.38c	16.7c	22.5c
		Incorporated	0.42c	23.1d	25.0d
	Tithonia	Surface	0.37c	19.9c	23.9c
		Incorporated	0.45c	22.4d	24.7d
	None		0.18d	-	10.5e
Interactions	Variety x Organic matter		NS	NS	*
	Organic matter x Placement		NS	*	*
	Variety x Placement*		NS	*	
	Variety x OM x placement		NS	NS	NS

#Means of a variety followed by the same letter within a column and not significantly different (P=0.05) according to Fishers Protected LSD test (p=0.05)
*Indicates significance (P = 0.05) ; NS = Non significance (P = 0.05)

growth to a greater extent than Gliricidia leaves (Table 2), the benefits of the leguminous organic matter (Gliricidia leaves) could be due to its ability to release nutrients for a longer period of time than Tithonia, as shown by litter bag studies (Partey et al, 2011). The beneficial impact of these two organic materials to enhance yields of the hybrid when compared to that of the OPV could be due to the low yields of the hybrid in this minor season. However in overall terms, the yields of the OPV were higher, which is the most valuable criteria for farmers, and thus illustrated a greater adaptability to the conditions of the minor dry season.

The harvest indices were also increased by organic matter, especially in the hybrid (Table 3), when compared to values obtained with mineral fertilizers alone. As expected, incorporation of organic matter increased the harvest indices, reflecting the benefits of this practice on the yields of these two varieties of maize. Again, the higher harvest indices of the OPV illustrated its adaptability to this minor season.

Nitrogen use parameters of the OPV was significantly higher than that of the hybrid (Table 4), which again confirms its ability to utilize this important and limited nutrient to a greater extent and thus produce higher yields. This is clear evidence of its adaptability to the drier conditions of the minor season. Furthermore, the N use parameters are higher with Gliricidia and Tithonia leaves, as the breakdown of rice straw, with its high C:N ratio causes microbial immobilization of N (Kumar and Goh, 2003). This highlights the benefits of using organic materials with a low C:N ratio for increasing the most limiting nutrient in most tropical soils and enhancing crop yields.

The N harvest index (NHI) of the OPV was higher than the Harvest Indices based on seed yields (Table 3), while the increments in NHI were less obvious in the hybrid. There were no differences in NHI due to organic matter addition, except with rice straw, where incorporation increased the values in both varieties. This illustrated the benefit of incorporating rice straw for better NHI by maize varieties in this season. In contrast, the Agronomic Efficiency of N (NAE) was increased by incorporating all three types of organic matter. However the lowest NAE with rice straw could again be due to possible microbial immobilization, resulting in low N contents in seeds. The NAE in the OPV was higher than in the hybrid, when rice straw was added, which could be due to the more extensive root growth of this variety (Table 2) in this treatment. In contrast, the other two organic materials increased this parameters to similar extents, thus illustrating their ability to support the uptake of added or soil nitrogen by the maize plants, irrespective of being OPV or hybrid varieties. The N Use Efficiencies (NUE) of the two varieties also followed a similar pattern, although the values in the OPV were greater. Thus in terms of N use, the OPV was more adaptable in this season, which could lead to the higher yields (Table 3). Again, the lowest NUE was with rice straw irrespective of the method of addition. With Gliricidia and Tithonia leaves, a similar pattern in NUE was observed in the OPV, while in the hybrid, incorporation increased this parameter significantly. This showed that in the hybrid variety, which is more sensitive to the environmental conditions of the minor dry season, incorporation of organic matter, irrespective of the quality increases NUE, a practice that should be taught to farmers if they opt for maize hybrids in this season.

Correlations of the three N use parameters to yields (n = 30 per season) were 0.453*, 0.442*, and 0.610* for NHI, NAE and NUE respectively. The best positive correlation between NUE and seed yields highlighted the impact of N Use Efficiency on the seed yields, as this nutrient is very important for successful tropical maize production (Masvaya et al, 2010). Furthermore, the positive relationship between seed yields and the N Use parameters confirm the importance of Nitrogen to procure high maize yields in this minor dry seasons, as shown by Montemurro et al (2006) in Mediterranean climates.

Conclusions

This field study carried out over two minor seasons of South Asia revealed the value of organic matter and its method of addition to enhance root growth, yields and N use patterns of an OPV and hybrid maize variety. The OPV was more adapted to the dry climate of this season, thus yielding more, while the incorporation of organic matter, especially the two materials with low C:N ratios, namely Gliricidia and Tithonia leaves, enhanced root growth through the soil profile, increased yields and N use patterns and efficiencies of the hybrid, the less adaptable variety of maize, to a greater extent. The least beneficial impact was with rice straw, a popular but low quality organic matter with a high C:N ratio. The most significant impact on root growth was with Tithonia, an organic material with a high phosphorus content, while Gliricidia leaves, with its higher N content and lower C:N ratio increased seed yields. The N Use patterns as denoted by NHI, NAE and NUE were increased by both these better quality organic materials when compared to rice straw, and in the hybrid, incorporation induced greater N use efficiencies. The study clearly demonstrated the benefits of combining organic materials with mineral fertilizers to promote growth and yields of maize, the most popular highland cereal grown in smallholdings under rainfed conditions South Asia. Thus smallholder farmers need to use good quality organic materials such as Gliricidia or Tithonia leaves, rather than rice straw and incorporate the organic material in the rhizosphere to obtain better root growth, higher seed yields and greater utilization of nitrogen, the most limiting nutrient for crop production in the tropics. In terms of varieties, the response of OPVs to the drier environments of this minor season was better than the hybrid, a factor that smallholder farmers need to consider if the environment is not very conducive for these improved varieties.

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