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Organic Matter Inputs by Selected Cropping Systems on a Vertisol in the Semi-arid Tropics of India

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Abstract: Soils of the Semi-Arid Tropics (SAT) are often low in organic matter. Concern about the maintenance of organic matter levels under conditions of intensified land-use makes knowledge of organic matter returns to soil by different crops and cropping systems important. In a two year field experiment, organic matter inputs of cropping systems for the SAT were studied on a deep Vertisol. When the crops were not fertilized, Sorghum/Pigeonpea intercrop system for two years (S/PP S/PP) had higher root organic matter than the non-legume system of Sorghum, followed by Safflower for two years (S+SAF S+SAF). But, when the crops were fertilized, the non-legume system also gave fairly high root organic matter. The lowest root organic matter inputs were found in the traditional Fallow + Sorghum Fallow + Chickpea (F+S F+CKP) system. Most of the root organic matter was produced in the upper 0-30 cm layer. In addition, pigeonpea dropped around 3 t ha^{-1} a^{-1} of dry leaves. Cowpea also dropped dry leaves, but its contribution was only around 140 kg ha^{-1} a^{-1}. The improved S/PP S/PP and Cowpea/Piegonpea intercrop COW/PP S+SAF systems provided much higher organic matter inputs than the improved non-legume systems (S+SAF S+SAF), even where organic matter inputs of the latter were increased through fertilization. But, all improved systems were considerably better than the traditional system (F+S F+CKP). We concluded that longer crop cover, and greater biomass of improved cropping systems, have the potential to increase organic matter content over that of the traditional system. Particularly, the dropping of leaves by pigonpea after flowering increased organic matter addition in a situation where traditionally, all above-ground biomass is removed from the field.

Key words: Pigeonpea, *Cajanus*, Cowpea, *Vigna*, Sorghum, Safflower, *Carthamus*, Chickpea, *Cicer*, roots, leaf fall, organic matter, cropping systems, rotations, Vertisol, black cotton soil.

Low soil organic matter content is frequently the cause for structural instability (Dutarte *et al.*, 1993) and limited buffer capacity for nutrients and pH (Allison, 1973) in soils of the semi-arid tropics. In the case of Vertisols in the Indian SAT low

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nitrogen mineralization potential is by far the most important constraint caused by low organic matter content (Ali, 1992). Organic matter content is low for natural (temperature and moisture regime) (Smith and Elliott, 1990) as well as management reasons. On Vertisols, crops are traditionally grown only in the postrainy-season on stored moisture because the high clay content (40-80%) (Raychaudari *et al.*, 1963) makes tillage and sowing extremely difficult during the rainy season. An example of a traditional cropping system on a Vertisol in India is the postrainy-season sorghum and chickpea rotation (F+S F+CKP) in our experiment. Such systems provide limited crop cover and biomass production, and therefore, limited inputs of organic matter through crop residues and maximum exposure of tilled soil. This aggravates soil organic matter losses and results in low nitrogen mineralization potential.

Improved cropping systems can greatly enhance the productivity and sustainability of agricultural landuse. Prolonged crop cover on Vertisols was made possible through extension of the cropping period in the rainy season. Three steps, all part of ICRISAT's Vertisol Technology package (El-Swaify *et al.*, 1985), were essential for this achievement: (1) broadbed and furrow soil surface management, which allows fast drainage of the surface soil and prevents waterlogging; (2) dry seeding after the first pre-monsoon showers before the rainy season when soil conditions are optimum for tillage; and (3) grain mold resistant sorghum varieties, which provide grain quality when sorghum is grown under the more humid conditions in the rainy season. Employing these basic technologies, several double and intercropping rotations became possible. In our experiment, we tested three: (1) Sorghum/pigeonpea intercrop in both years (S/PP S/PP); (2) a rotation of cowpea/pigeonpea intercrop in one year and sorghum followed by safflower every other year; and (3) sorghum followed by safflower in both years (S+SAF S+SAF).

Although much work was done in quantifying the productivity increase and economic yield of double and intercropping, not much work was done to quantify the effects of intensified cropping systems on soil quality (Willey, 1996). A long-term experiment carried out at ICRISAT Asia Center for the last 14 years shows an increase in soil total N content in intensified cropping systems with pigeonpea (Rego and Seeling, 1996). However, even after 14 years, the organic matter changes were small. Because of the long duration of experiments required to measure soil organic matter (SOM) changes and the limitations to extrapolation of these data, we decided to measure organic matter inputs from different systems so that these can be used in simulation models to predict changes in SOM.

Materials and Methods

The experiment was conducted at ICRISAT Asia Center (IAC), India, on a deep Vertisol. The field was fallow for seven years and a maize crop was sown as a cover crop for one year prior to the start of the experiment. The land preparation and sowing of crops were done using bullock drawn equipments. Chemical properties of

Table 1. Chemical properties of the experimental field used prior to crop growth period

Soil depth (cm)	pH	E.C. (dS m^{-1})	NO_3 (mg kg^{-1})	Total N (mg kg^{-1})	OC (%)
0-15	8.19	0.26	2.67	639	0.62
15-30	8.33	0.17	< 1	434	0.47
30-60	8.39	0.16	< 1	370	0.44
60-90	8.23	0.23	< 1	331	0.39

the field soil prior to sowing are shown in Table 1. Measurements were made during rainy and postrainy-seasons of 1994/1995 and 1995/1996. The monthly rainfall and mean maximum and minimum temperatures for the experimental period are given in Table 2.

Four cropping systems, and where applicable, their mirror images were evaluated at three nitrogen (N) levels (Table 3) in a randomized complete block design (RCBD) with 3 replications. Nitrogen was applied only to non-legume crops. The source of N was urea. During the rainy season, crops received 20 kg N ha^{-1} at the time of sowing by placing the fertilizer along the row of the crops, and the remainder 21-24 days after sowing (DAS) as a top dressing. Postrainy season crops received the complete dose at the time of sowing. In intercrops, the N application was placed close to the rows of the non-legume crops. All crops received a basal phosphorus (P) application of 20 kg P ha^{-1} at the time of sowing.

Measurements of root growth

Plant and root samples were taken from 1 m^2 subplots in N-0 and N-80 treatments in all three replicates, except cowpea where roots were taken only from one replication. For root sampling, soil cores of 7 cm diameter were taken to a depths of 120 cm, except in case of pigeonpea, where the sampling depth was 150 cm. Two cores were taken between rows and 2 cores on the rows between plants. A fifth core was taken on top of one plant.

Samples were combined and soaked in water overnight. Subsequently roots were washed over a sieve of 1 mm mesh, and then hand picked and stored in a mixture of ethyl alcohol and water at the ratio of 2:1, at 5°C. Fresh weights of the root samples were taken after bloting them with filter paper. Subsequently roots were oven-dried at 60°C to constant weight, and dry weights were determined.

Leaf fall measurements

At weekly intervals, fallen leaves of pigeonpea and cowpea was collected from an area of 1 m x 1.5 m which was surrounded by plastic sheets. Collected leaves were then oven dried at 60°C, and their dry weights recorded.

Results and Discussion

Cumulative rainfall in both years were above the normal rainfall received in most of the years (Table 2). Rainfall distribution was normal during the rainy season in both years, but the postrainy season rainfall was high at the beginning and low or none in the later part of the season.

Table 2. Monthly rainfall (mm) and average maximum and minimum temperatures (°C) at ICRISAT Asia Center, June 1994 to March 1996

Year/Month	Rainfall (mm)	Normal rainfall (mm)	Temperature (°C)	
			Maximum	Minimum
1994				
June	144.4	104.4	33.7	23.6
July	142.9	191.2	29.4	22.4
August	196.9	127.1	28.9	22.1
September	66.0	162.6	30.4	20.9
October	247.5	83.5	29.5	20.7
November	9.6	20.9	27.1	15.6
December	0.0	5.9	27.1	10.3
1995				
January	40.0	7.6	26.2	13.2
February	0.0	9.5	31.0	16.0
March	52.2	10.6	34.4	20.2
April	8.8	28.5	37.0	22.6
May	43.8	31.2	36.9	23.7
June	136.2	104.4	36.5	25.0
July	252.0	191.2	30.1	22.8
August	245.6	127.1	30.2	22.1
September	112.9	162.6	30.2	22.1
October	361.0	83.5	29.1	20.4
November	13.0	20.9	29.3	16.2
December	0.0	5.9	28.4	13.9
1996				
January	0.0	7.6	29.6	15.4
February	0.0	9.5	31.4	16.8
March	0.0	10.6	36.0	19.3

Nitrogen application had a considerable effect on root mass of the non-legume crops (Tables 4 and 5). Highest root dry matter of rainy season sorghum was reached shortly before flowering in both years, but root mass decreased from then to maturity. In which developmental stage, maximum root mass was attained in postrainy season sorghum, was not so clear. In 1994, root dry matter declined in N-0 after anthesis, but in N-80 root dry matter still increased. In 1995, root dry matter increased till maturity in both N-0 and N-80. Kaigama *et al.* (1977) and Myers (1980) reported that maximum root growth was attained by anthesis. Studies conducted at ICRISAT (1988) and elsewhere (McClure and Harvey, 1962) suggested continued root growth after flowering.

Because of frequent replenishment of dried surface soil by the rainy-season rains, most of the rainy season sorghum root

Table 3. Treatments, crop varieties grown and plant populations

Treatments		
A. Cropping systems		
I year	*II year*	
Sorghum/Pigeonpea	Sorghum/Pigeonpea	S/PP S/PP
Sorghum + Safflower	Sorghum + Safflower	S+SAF S+SAF
Cowpea/Pigeonpea	Sorghum + Safflower	COW/PP S+SAF
Sorghum + Safflower	Cowpea/Pigeonpea	S+SAF COW/PP
Fallow + Sorghum	Fallow + Chickpea	F+S F+CKP
Fallow + Chickpea	Fallow + Sorghum	F+CKP F+S
/ = Intercropping	+= Sequential cropping	
B. Nitrogen levels		
0 kg N ha^{-1} (N-0)		
80 kg N ha^{-1} (N-80)		
C. Crops and varieties		
Rainy-season crops		*Plant population*
Sorghum - CSH-6 (*Sorghum bicolor* L.)		(12,000 plants ha^{-1})
Pigeonpea - ICPI-6 (*Cajanus cajan* (L.) Millsp.)		(60,000 plants ha^{-1})
Cowpea - GC 82-7 (*Vigna unguiculata* L.)		
Postrainy season crops		
Sorghum - SPV 421 (*Sorghum bicolor* L.)		(100,000 plants ha^{-1})
Safflower - Manjera (*Carthamus tinctorius* L.)		(80,000 plants ha^{-1})
Chickpea - Annegiri (*Cicer arietinum* L.)		(300,000 plants ha^{-1})

mass was found in the upper layers, whereas, postrainy season sorghum roots grow deeper because of the initial dry conditions, but the difference was reduced as the crops progressed towards maturity.

Newell and Wilhelm (1987) found that when corn was irrigated, it had a higher root mass in the upper 0-15 cm soil layer. Similar observations were found by Hundal and De Datta (1984) in a sorghum grown after wetland rice.

Pigeonpea is a slow growing crop in the early stages of growth, and its roots also grow slowly, particularly if it is intercropped. Pigeonpea root mass in Tables 4 and 5 is the average of pigeonpea in S/PP and COW/PP intercrops. Pigeonpea roots grew more rapidly after the harvest of the companion crop. The maximum root dry weight was found during flowering, and it declined after that. The root system of sole pigeonpea was compared with that of intercropped pigeonpea at ICRISAT (Narayanan and Sheldrake, 1976). In the intercropping system, the growth of pigeonpea roots was slow prior to the harvest of sorghum. This slow root growth of pigeonpea allows a companion crop of short duration like sorghum or cowpea to grow before the pigeonpea roots can exploit the soil volume.

Cowpea root growth was not as vigorous as sorghum or pigeonpea in all stages of growth and the highest root dry weight

Table 4. Root dry weight (kg ha^{-1}) of the different crops during flowering and at maturity

Crop	Fertilizer N (kg ha^{-1})	Flowering 1994	Flowering 1995	Maturity 1994	Maturity 1995
Rainy season sorghum	0	813	808	670	603
	80	1106	1139	876	1084
	SEm (±)	75	89	65	105
Postrainy season sorghum	0	891	744	853	848
	80	1269	970	1319	1135
	SEm (±)	91	88	110	92
Safflower	0	407	392	504	551
	80	637	573	814	769
	SEm (±)	95	86	94	108
Pigeonpea	0	1332	1376	1183	1219
	SEm (±)	114	118	97	106
Cowpea*	0	380	440	406	450
Chickpea	0	537	689	494	458
	SEm (±)	56	79	58	46

* Cowpea roots were only sampled from one plot.

was observed shortly before maturity, but the growth rate was less in later stages compared to the initial stages. Chickpea root dry weight was slightly higher than that of cowpea. The highest root dry weight was observed at flowering in both years.

Safflower root growth was higher in the fertilized crop compared to the non-fertilized crop. The highest root dry weight was observed at maturity, and the crop showed continuous root growth even though the growth is slow after flowering. This could be due to the lack of rainfall in the later part of the season, forcing crops to extend their roots in deeper layers to extract water.

Figure 1 shows root organic matter inputs to the soil profile by the different crops.

Table 5. Total organic matter inputs of different cropping systems rotations (t ha^{-1}) in two years (1994 and 1995)

System	N-0 Roots	N-0 Leaves	N-0 Total	N-80 Roots	N-80 Leaves	N-80 Total
S/PP S/PP	2.40	3.00	5.40	2.65	3.00	5.65
S+SAF S+SAF	1.65	–	1.65	2.21	–	2.21
COW/PP S+SAF[a]	1.83	3.14	4.97	2.11	3.14	5.25
F+S F+CKP[b]	0.82	–	0.82	0.94	–	0.94
SEm (±) Systems			0.08			
SEm (±) N Levels			0.05			

N Levels (kg N ha^{-1})

[a] Average of COW/PP S+SAF and its mirror image system S+SAF COW/PP.

[b] Average of F+S F+CKP and its mirror image system F+CKP F+S.

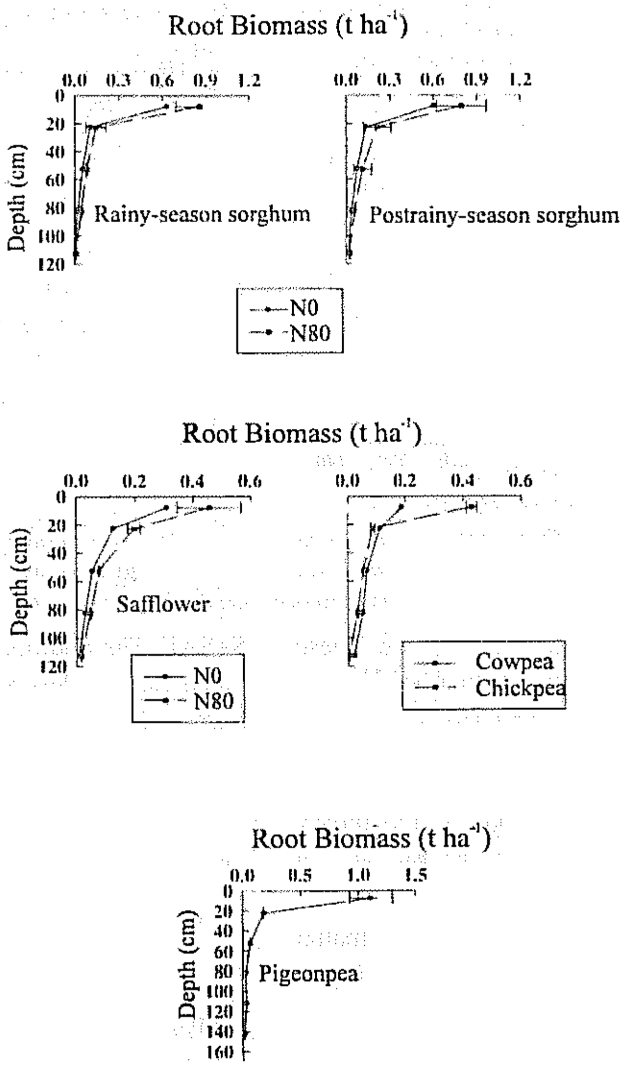

Fig. 1. Root organic matter in the soil profile of different crops during their stage of maximum root mass (average over years). Error bars represent standard errors of the mean.

Most of the root organic matter (70-80%) inputs were deposited in the upper 0-30 cm, which is the layer most crops exploit. Therefore, after decomposition of these roots, their nutrient content would become available for the crops which follow them.

In systems with pigeonpea, leaf fall is an additional source of organic matter. Leaves start falling shortly before anthesis and continue to do so until harvest. Figure 2a shows the cumulative leaf fall of pigeonpea. The pigeonpea crop can contribute

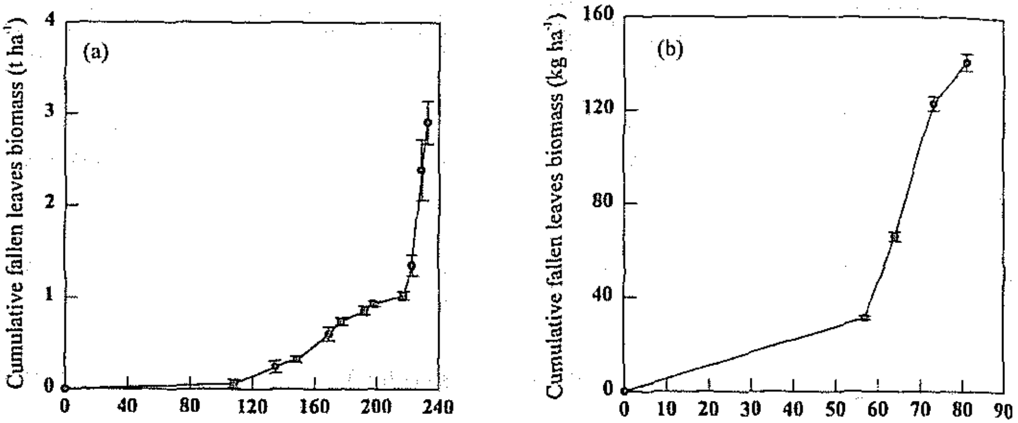

Fig. 2. Cumulative biomass of fallen leaves from (a) pigeonpea and (b) cowpea (average over years). Note different scale and unit of the Y-axis. Error bars represent standard errors of the mean.

up to 3 t ha^{-1} of fallen dry leaves. These leaves, besides being a source of N after their decomposition, also act as a mulch and reduce evaporation of water from soil. Cowpea also drops leaves but their contribution is low compared to pigeonpea. Cowpea dropped up to 140 kg ha^{-1} of leaves in a season (Fig 2b).

More important than the organic matter inputs of individual crops are the inputs of the cropping systems rotations. Table 5 shows average root dry matter inputs of the different rotations. The S/PP S/PP rotation had higher root organic matter inputs than the other rotations without N application. The largest contribution of root organic matter in this system came from pigeonpea. The systems COW/PP S+SAF also contributes a substantial amount of root organic matter without N application. The S+SAF S+SAF system contributed less root organic matter than the COW/PP S+SAF. The traditional fallow systems provided the smallest amount of root organic matter. However, systems which include pigeonpea get additional inputs of organic matter from pigeonpea leaf fall, which make them far superior to other systems in terms of organic matter inputs.

When the non-legume components of the systems were fertilized (80 kg N ha^{-1}), it was found that even though the S/PP S/PP system provided the highest root organic matter input, the non-legume system (S+SAF S+SAF) came fairly close. This is followed by the fertilized COW/PP S+SAF system. The F+S F+CKP was found to give the lowest amount of root organic matter.

The improved S/PP S/PP and COW/PP S+SAF systems provided much higher organic matter inputs than the improved non-legume systems (S+SAF S+SAF), even when organic matter inputs of the later were increased through fertilization. But all improved systems were considerably better than the traditional system (F+S F+CKP). We conclude that longer crop cover and greater biomass of improved cropping systems have the potential to increase organic matter content over that of the traditional system. Particularly the dropping of leaves by pigonpea after flowering increases organic matter addition in a situation where traditionally all above-ground biomass is removed from the field.

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