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Sustaining cotton productivity and soil fertility through *in situ* management of green manure and crop residues in semi-arid irrigated condition of Tamil Nadu

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ABSTRACT

A field experiment was undertaken between 2004 and 2007 in upland cotton (*Gossypium hirsutum* L.) on alkaline black clay loam Typic haplustalfs soil with low fertility at Coimbatore under irrigated condition to explore the suitability of burying of cotton residues *vis-à-vis* green manure (GM) sunnhemp (*Crotalaria juncea* L.) *in situ*. The treatments to cotton 'Surabhi' included *in situ* growing and burying of GM crop, recycling of cotton residues and addition of farmyard manure (FYM) alone and in all combination (@ 5 t/ha of FYM, 2.5 t/ha of crop residues or GM @ 15 kg seed/ha), along with conventional practice of crop nutrition with and without a N:P:K dose of 60:13:25 kg/ha as the controls. Results revealed that simultaneous planting of sunnhemp and cotton under ridge-furrow system, followed by burying of sunnhemp @ 2.5 t/ha *in situ* before flowering followed by earthing up was optimum for higher cotton productivity (1.70 t/ha), net return (Rs 23,240/ha), B:C ratio (1.37) and fibre productivity efficiency (FPE, 9.40 kg/ha-day). However, grain yield of rotational finger millet [*Eleusine coracana* (L.)] 'CO 13' crop grown on the residual fertility was not influenced by the treatments. The system (cotton-finger millet) productivity (2.46 t/ha) was also favoured by GM treatment. Soil fertility parameters after the trial indicated that *in situ* incorporation of GM also resulted in higher OC (0.53, 0.55 %) and N:P:K (200:23.5:599 and 194:18.3:590 kg/ha) availability in 0-15 cm and 15-30 cm soil respectively at the end of 3 years of cropping over absolute control. Climatologically favourable year (2007) played a significant role in realization of higher boll weight, seed cotton yield, net return, B:C ratio and system productivity over others. The present study suggests that *in situ* incorporation of sunnhemp GM substitute inorganic fertilizers in cotton.

Key words: Crop residues, Economics, Finger millet, *Gossypium hirsutum*, Sunnhemp, Soil fertility

Cotton, being grown in extremely diverse soil and agro-climatic condition viz., arid sub-tropical to humid tropical climates and from deep heavy vertisols to sandy loam alluviums and red lateritic soils, its productivity varies with location, soils, growing conditions (rainfed/irrigated) and management options (Rajendran and Jain, 2004). Yet, matching best management practices (BMPs) such as integrated crop nutrition along with improved genotypes has revolutionized Indian cotton scenario over a couple of years as highlighted by record production of 31.5 million bales from 9.55 m ha during 2008-09 (1 bale=170 kg). Nevertheless, cotton acreage and productivity in south zone, especially in Tamil Nadu has not increased over the years. It is mostly ascribed to either higher cost of inputs similar to other cotton growing areas or less return without any premium for a given quality of the produce or both; and that has created a sense of insecurity in the minds of cotton growers in the state. The decreasing input use efficiency aggravates the situation further. Therefore, low cost technology plays a handy for the crop's adoption and continued cultivation. To fulfill these considerations, application of appropriate and readily available (biomass) resources including *in situ* organic materials like green manure vis-à-vis fertilizer inputs remains vital for increased efficiency and lower cultivation cost (Praharaj and Rajendran, 2007).

About 23 m tonnes (t) of cotton plant stalks are generated in India annually taking into an account of an average 2.5 t of stalk generated in 1 ha of land. Thus, the year round availability of huge cotton stalks for disposal provides a suitable platform for assessing its performance in relation to known sources of standard organic/fertilizer inputs. Furthermore, in India, about 6.73 m ha of land are lying barren or produce very low and uneconomical yields of various crops due to excessive accumulation of salts. Application of organics involving manures, crop residues and green manure are also shown to reduce soil salinity over that in control and inorganic fertilizer alone since

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addition of these suppresses the adverse effects of salinity because of dilution of salts and cation exchange, and thus, lead to higher crop yield (Jeegadeeswari *et al.*, 2001).

Soil organic matter and residue decomposition during the growing season could be the important sources of nutrients to cotton. The practices that promoted the maintenance of crop residues at the soil surface also had beneficial effects on soil fertility through enhancement of soil microbial biomass and supply of mineralizable nutrients (Wright *et al.*, 2005). Therefore, keeping in view the paucity of information on *ex situ* and *in situ* management of readily available organic wastes especially under integration *vis-à-vis* NPK fertilizers in irrigated cotton for substitution of inorganic fertilizers by cost effective organics, a trial was conducted on an alkaline black clay loam soils in semi-arid tract of Southern cotton zone.

MATERIALS AND METHODS

A field trial on cotton with readily available organics was tried on a Typic haplustalfs (Periyanaickanpalayam series), medium deep, well drained soils at the Regional Station of Central Institute of Cotton Research, Coimbatore (11°N Latitude, 77°E longitude and 427.6 m above mean sea level) under Southern hills and plateau region of India for 3 years (2004-05, 2005-06 and 2006-07) at the same location and lay out under assured irrigation condition. The soil is of low fertility *viz.*, low in organic carbon (0.41%), N (166 kg/ha), medium in P (15.7 kg/ha), high for K (556 kg/ha) with pH 8.72, EC 0.35 dS/m and bulk density of 1.35 g/cc (0-15cm). The bore well irrigation water was having pH 7.4, EC 3.52 dS/m and total salt concentration of 0.23% with mostly neutral salt of sulphate and chloride of sodium.

Nine treatment combinations were tried in a randomized block design on *hirsutum* cotton (American/upland cotton) *viz.*, (*i*) surface spreading and mixing of FYM @ 10 t/ha with soil, (*ii*) cotton grown in preceding year chopped (whole plant) and incorporated @ 5 t/ha (CRI), (*iii*) sunnhemp seed sown @ 15 kg/ha as inter-row green manure (GM) crop and incorporated *in situ* at 45 days after planting, (*iv*) FYM @ 5 t/ha + CRI @ 2.5 t/ha, (*v*) FYM @ 5 t/ha. + GM, (*vi*) FYM @ 5 t/ha + Cotton residue incorporation (CRI) @ 2.5 t/ha. + GM, (*vii*) cotton residue incorporation (CRI) @ 2.5 t/ha + GM, (*viii*) N, P and K @ 60:13:25 kg/ha (NPK) and (*ix*) a control (without NPK and organics). Cotton stalks (whole plant) were cut into 4 to 5 cm long pieces and buried *in situ* in the soil 2 months before planting of cotton as per treatment. FYM was applied to cotton as per treatment at the land preparation while half of urea N along with full dose of P and K were applied at planting only in NPK followed by top

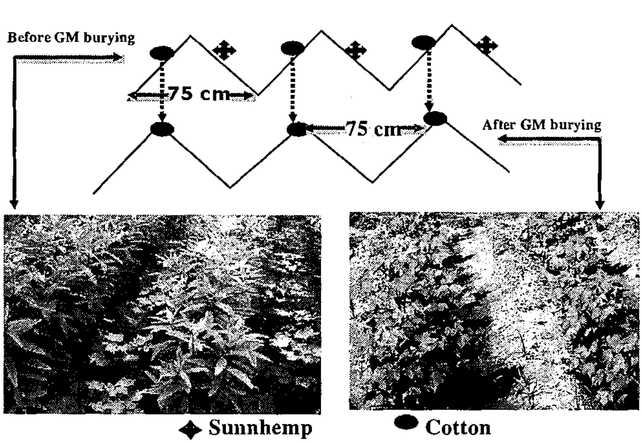

Fig. 1. *In situ* sunnhemp as green manure in ridge-furrow planted Cotton (left, before green manure burying and right, after green manure burying)

dressing of the rest of N at the earthing up (50 DAS) of the cotton. Sunnhemp as green manure was grown between rows of cotton (on the reverse side of cotton sown ridges) and buried *in situ* at 45 DAS as per treatment forming the final ridge along cotton row only. The method of sunnhemp planting (simultaneously with cotton) and its incorporation as green manure is given in Fig.1. On an average, FYM contains 0.52% N, 0.20% P and 0.51% K and the corresponding values for crop residues are 1.10, 0.10 and 0.60 and for green manure, 1.90, 0.30 and 1.70% on dry weight basis. Both FYM and cotton residues were applied to plots at specified quantity on dry weight basis while fresh sunnhemp biomass was weighed and equally applied @ 8.0 t/ha on fresh weight basis (equals to 2.5 t/ha on dry weight basis). The sunnhemp green biomass was only incorporated *in situ* in the furrows as per treatment. Both FYM and GM led to rapid mineralization within a short span following its application while in cotton residues, it was around two months for nutrients to be remobilized for crop assimilation.

Acid delinted seeds were used for the experimental planting of cotton "Surabhi". The original layout of the field trial was maintained for all 3 years. Cotton crop was sown following ridge-furrow system during first week of September at 75 cm x 30 cm spacing, and 2 plants/hills were maintained as an insurance against stem weevil incidence that is sporadic in the area. The crop management practices were uniformly adopted in all the plots. For weed control, one hoeing followed by a hand picking of weeds and earthing up was done at 45 DAS in all the plots coinciding with burying of green manure *in situ*. Thereafter, cotton picked up its growth and vigour. First picking of cotton commenced in mid-January and the second in end of February. After cotton, a finger millet crop (duration of 95-100 days) was also taken to study the residual effect, if any. Cotton was uprooted for land preparation and sowing of finger millet 'CO 13' during last week of March at 15 cm x 15 cm spacing and harvested by June end. The fingermillet crop was cut at the ground level and cotton stalks were buried immediately as per treatment (2 months before sowing of cotton during September every year).

The cotton crop received a rainfall of 552.2, 643.4 and 593.3 mm and a cumulative pan evaporation of 756.8, 674, 757.3 mm during 2004-05, 2005-06 and 2006-07, respectively. Rainfall during initial 45 days of crop growth favoured sunnhemp growth in the region. Irrigation water was given both to cotton and residual fingermillet crop as per need to overcome the moisture stress.

Fibre quality was tested with High Volume Instrument and Fibre Quality Index (FQI) was calculated as $(L^*T)/\sqrt{M}$ where, L is 2.5% span length in mm, T is bundle strength in g/tex and M is micronaire value (μg/inch) defining fibre maturity. Fibre productivity efficiency (kg/ha-day) was calculated based on unit day productivity (yield/net total phenological days). Economics of cotton cultivation were also calculated using the prevailing market prices.

Total N, P and K uptake by both cotton and finger millet was calculated depending upon per cent N, P and K content analyzed over the years and treatments. Mean N, P and K contents in plant derived on per cent dry weight basis were as under, 2.40:0.33:1.40 in seed cotton, 1.13:0.20:1.41 in cotton stalk, 1.16:0.19:0.77 in finger millet grains and 0.75:0.11:1.15 in finger millet straw. System productivity was derived by converting the finger millet yield into seed cotton yield based on market price.

Soil nutrient status for available N, P and K was analyzed in 0-15 and 15-30 cm soil depth before planting of cotton and after the harvest of last rotational crop as per standard procedures. Changes in other chemical properties of soil especially pH, EC and sodium content were also analyzed after harvest of the crop for studying the changes in salinity/alkalinity, if any. All data have been subjected to statistical analysis following normal procedures.

RESULTS AND DISCUSSION

Growth and yield parameters

Although some of the observations related to growth and yield parameters pooled over the years did not influence by the treatments yet, numerically higher values were obtained with GM alone or a combination of multiple organics involving GM, FYM and/or cotton residues (Table 1). Highest number of mean sympodial branches/plant (15.9) was recorded with GM alone and yet, was similar to that in other treatments. Similarly, opened bolls/plant and boll weight (seed cotton/boll) were not influenced by the treatments in the pooled data although relatively higher number of opened bolls with higher boll weight were picked up from the GM plots leading to increase in seed cotton yield over control as boll number is the most important attribute correlated with yield (Venugopal *et al.*, 1999).

Jackson and Gerik (1990) showed that N fertility was highly correlated with leaf area and boll number but not with boll weight or the number of (main stem) nodes. Thus, vegetative growth as evidenced by increase in length and cross sectional area of main stem internodes increases in boll number or yield. Although other plant growth parameters and yield traits at harvest were not significantly influenced by the treatments, yet higher stalk yield and boll weight recorded under GM contributed towards realization of higher crop yields (Table 1).

Influence of year of trial on the plant biometrics and yield traits was variable (Table 1). Yet, significantly higher sympodia and bolls/plant were counted during first 2 years of trial while favourable climate led to significantly higher boll weight and plant height during third year resulting highest yield amongst the years. Interaction between the years and organics on growth and yield attributes was not significant.

With regard to various fibre quality parameters, ginning out turn, seed and lint indices, 2.5% span length, fibre strength and micronaire values were not influenced by various treatments. On an average, 34.5% GOT, 8.88 g seed index, 4.68 g lint index, 29.9 mm fibre length, 21.9 g/tex strength and 3.57 μg/inch as mike were obtained over the years and treatments (pooled data). Influence of year on various quality indices revealed that similar to plant height and boll weight, significantly higher seed index (9.48), lint index (4.97), fibre length (30.6 mm), mike (3.46 μg/inch) and fibre quality index (365.6) were recorded during 2006-07 because of favourable weather condition prevailed during the year. Similar observations were made by Praharaj *et al.* (2006).

With little variations, days to achieve a specific vegetative/reproductive phase of the crop (phenology) was also little influenced by the organic treatments. Yet, an healthy and vigorously growing crop under nutritionally superior growing conditions under an optimum treatment took a little longer time to achieve a particular phenophase over that in control plot. Thus, the crop under GM treatment producing more output in terms of seed cotton yield (Table 1) required 1-3 days longer over that in control plots. Similarly, Singh and Singh (2002) reported that crop grown under optimal growing condition matured little later and most likely to give higher yield over that in nutritional limiting situation (control) where phenophases were attained early in the season.

Table 1. Seed cotton yield, yield attributes, economics and finger millet yield under various organic treatments (pooled for 3 years)

Variable	Seed cotton yield (t/ha) 04-05	05-06	06-07	Mean	Stalk yield (t/ha)	Sym-podia/ plant	Opened bolls/ plant	Boll weight (g)	FPE*	Cost of cultiva-tion (x10³ Rs/ha)	Net return (x10³ Rs/ha)	B:C ratio	Finger millet grain yield (t/ha) 2005	2006	2007	Mean	System productivity (t/ha)
Year																	
2004-05	1.72			1.72	2.19	16.3	15.8	2.82	9.52	15.3	23.50	1.54	4.09			4.09	2.51
2005-06		1.14		1.14	3.20	14.6	13.3	2.84	6.30	18.6	9.60	0.52		3.64		3.64	1.84
2006-07			2.03	2.03	3.49	14.3	11.2	3.61	11.19	22.0	36.00	1.64			4.36	4.36	2.86
SEm±				0.04	0.08	0.3	0.4	0.06	0.16		1.07	0.06				0.37	0.05
CD (P=0.05)				0.09	0.22	0.7	1.0	0.17	0.47		3.13	0.18				NS	0.14
Organics																	
FYM @ 10 t/ha	1.73	1.08	2.05	1.62	2.76	15.3	12.9	3.10	8.95	20.73	17.61	0.85	4.02	3.21	4.78	4.00	2.39
CRI @ 5 t/ha	1.68	1.20	2.12	1.66	2.99	14.7	12.7	3.01	9.20	17.35	22.06	1.27	3.66	3.40	3.80	3.62	2.36
GM (@ 15 kg/ha)	1.87	1.15	2.08	1.70	3.09	15.9	14.0	3.18	9.40	16.99	23.24	1.37	3.81	3.78	4.39	3.99	2.46
FYM 5 t/ha + CRI @ 2.5 t/ha	1.54	1.07	1.80	1.47	2.69	14.6	13.7	3.20	8.10	19.89	14.84	0.75	4.53	3.25	4.60	4.13	2.26
FYM @ 5 t/ha+ GM @ 15 kg/ha	1.74	1.24	2.11	1.70	3.01	15.4	13.3	3.23	9.38	19.81	20.39	1.03	3.97	3.83	3.89	3.90	2.44
FYM @ 5 t/ha+ CRI @ 2.5 t/ha	1.90	1.24	2.06	1.74	3.08	14.8	[illegible]	3.08	9.60	21.38	19.74	0.92	4.52	3.81	4.63	4.32	2.56
CRI @ 2.5 t/ha + GM @ 15 kg/ha	1.70	1.19	1.91	1.60	2.84	14.9	13.6	3.01	8.82	18.63	19.20	1.03	4.42	3.89	4.62	4.31	2.43
NPK	1.70	1.07	2.40	1.72	3.37	15.1	[illegible]	3.07	9.36	17.34	23.32	1.35	4.13	3.89	4.70	4.24	2.54
Control	1.66	1.06	1.73	1.48	2.78	15.0	13.0	2.93	8.18	15.62	19.44	1.24	3.73	3.68	3.86	3.76	2.20
SEm±	0.06	0.07	0.12	0.05	0.13	0.5	0.6	0.11	0.29		1.18	0.09	0.31	0.25	0.35	0.41	0.07
CD (P=0.05)	0.20	NS	0.37	0.15	0.39	NS	NS	NS	0.83		3.54	0.26	NS	NS	NS	NS	0.23

Interaction (year x treatment) was not significant.Sale price: Rs.23,500/-, Rs.100/- and Rs.4,500/tonne of seed cotton, stalk and finger millet grain respectively.
*FPE: Fibre productivity efficiency (kg/ha-day)

Seed cotton yield

Improvement in seed cotton yield is largely reflected from similar enhancement in yield traits and biometrics (Table 1) and more so because of better soil nutrient availability (following composting) in organic plots over control plots (Table 3). Seed cotton yield was significantly influenced by the treatments during 2004-05 and 2006-07. Green manure alone (1.87 t/ha) resulted in higher seed cotton yield on par with that in both NPK (1.70 t/ha) and FYM+GM+CRI (1.90 t/ha) during 2004-05. Similar results were also obtained between 2005-06 and 2006-07 where GM alone (on par with that in NPK) was invariably found better over control (Table 1).

Influence of year of trial on seed cotton yield revealed that favourable climate and significantly higher boll weight led to realization of highest yield during 2006-07 amongst the years (Table 1). Pooled analysis also showed that the seed cotton yield was maximum (2.03 t/ha) during 2006-07 and was significantly higher over other years as favourable weather conditions prevailed during the year. Interaction between the years and organics on seed cotton yield was not significant.

With regard to treatments pooled for 3 years, green manure alone (1.70 t/ha) resulted in higher seed cotton yield on par with the highest yields obtained under FYM+GM+CRI (1.74 t/ha) and NPK (1.72 t/ha). All these treatments produced significantly higher seed cotton yield over that in control (1.48 t/ha). However, a combination of crop residues along with FYM or even with GM resulted in poor seed cotton yield on par with that in control, thereby, indicating locking up of the nutrients in these combinations over the years. Thus, in the later case, the soil microbes are immobilizing available nutrients for their cell building and multiplication thereby causing temporary deficiency of mineralizable nutrients in the crop residue incorporated plots leading to yield decline (Table 1). Lachnicht *et al.* (2004) observed that C/N ratio of decomposing cotton residues fluctuated between 30 and 40 and there were no strong effect of time, tillage or type of cotton residues on C: N ratio. Similarly, Blaise and Ravindran (2003) reported that leaf + stalk or even leaf amended plot yields were equal to that in control; and stalk alone amended plots had the least seed cotton yield.

Experimental trials in western Maharastra, at Rahuri, revealed that sunnhemp grown as green manure and incorporated *in situ* improved productivity of widely spaced hybrid cotton. Sunnhemp started decomposing following *in situ* incorporation, and in the process releasing nutrients especially N for growth and performance of the crop in terms of seed cotton yield (Venugopal and Pundarikakshudu, 1999). Similarly in this field trial, when GM was applied alone, it resulted in release of nutrients following mineralization of organic sources, and probably inhibiting immobilization. Venugopal *et al.* (1999) also revealed that application of 12-18 t/ha of FYM or green manure increased yield of cotton by 16-20% at Coimbatore in Tamil Nadu.

Similar to seed cotton yield, fibre productivity efficiency (FPE) was also higher (Table 1) during 2006-07 (11.19 kg/ha-day). FPE was also improved following GM incorporation (9.40 kg/ha-day) and was comparable to NPK (9.36 kg/ha-day) and the combination of all the crop residues (FYM+GM+CRI, 9.60 kg/ha-day). The interacting influence of year of experimentation and various treatments was not significant.

NPK uptake

Mean NPK uptake in seed cotton and total NPK uptake (seed cotton + cotton stalk) by cotton were significantly influenced by the organic treatments (Table 2). Because of higher seed cotton yield, N P K uptake in seed cotton were significantly higher in GM when compared with control. Similar trend was also observed for total N P K uptake by cotton due to higher stalk yield under GM. Therefore, total N:P:K uptake (81.9:11.8:71.0 kg/ha) were significantly higher in cotton green-manured with sunnhemp over a range of treatments including control (60.2:8.8:53.5 kg/ha), and yet, was on par with those in NPK treatment (78.0:12.4:75.7 kg/ha). This implied the fact that cotton removed the same quantity of NPK from the plot under GM as that of inorganic NPK because of realization of similar outputs (seed cotton + stalk) under the existing semiarid agro-climatic condition with bimodal (both SW and NE) pattern of monsoon. Venugopal *et al.* (1999) reported that higher seed cotton and stalk yield led to higher NPK uptake under green manure and integrated nutrient management options.

Economics

Maximum net returns were calculated under NPK (Rs 23,320/ha) and GM plots (Rs 23,240/ha) followed by crop residue alone (Rs 22,060/ha), although FYM+GM+CRI resulted in highest gross return (Table 1). Significantly higher net return was realized with GM alone and NPK over that in control (Rs 19,440/ha) because of higher cost involved in FYM or in integration of various organics. Thus, addition of crop residue to FYM/GM, FYM alone or none gave significantly lower gross and net returns in comparison to GM or N P K. Besides, GM required lower initial investment (Rs 16,990/ha) when compared with N P K (Rs 17,340/ha). The study indicated that wherever feasible, GM could offer a viable option for higher productivity and higher net return to the farmers. Similar observations were also made by Blaise and Ravindran (2003).

Table 2. Effect of organic materials on mean NPK uptake in cotton and finger millet (pooled for 3 years)

Treatment	Nutrient uptake in seed cotton (kg/ha)			Total nutrient uptake by cotton (kg/ha)			Nutrient uptake in finger millet grain (kg/ha)			Total nutrient uptake by finger millet (kg/ha)		
	N	P	K	N	P	K	N	P	K	N	P	K
FYM @ 10 t/ha	40.8	5.3	23.5	71.0	10.5	62.5	46.4	7.6	30.8	117.7	18.1	140.1
CRI@ 5 t/ha	39.3	5.8	23.8	72.7	12.4	64.1	42.0	6.9	27.9	115.5	17.7	140.6
GM (@ 15 kg/ha	44.6	5.8	24.9	81.9	11.8	71.0	46.3	7.6	30.7	121.3	18.6	145.7
FYM 5 t/ha + CRI @ 2.5 t/ha	35.3	4.9	19.9	64.9	9.7	54.0	47.9	7.8	31.8	119.1	18.3	141.0
FYM @ 5 t/ha + GM @ 15 kg/ha	39.1	5.7	24.6	75.4	11.7	68.8	45.2	7.4	30.0	116.5	17.9	139.3
FYM @ 5 t/ha + GM @ 15 kg/ha + CRI @ 2.5 t/ha	41.2	5.5	23.4	77.2	12.4	69.8	50.1	8.2	33.3	126.6	19.4	150.6
CRI @ 2.5 t/ha +GM @ 15 kg/ha	40.4	5.2	22.6	72.4	11.0	62.5	50.0	8.2	33.2	123.5	19.0	145.9
NPK	40.7	5.6	24.2	78.0	12.4	75.7	49.2	8.1	32.6	124.2	19.1	147.6
Control	31.5	4.6	19.5	60.2	8.8	53.5	43.6	7.1	28.9	112.6	17.3	134.7
SEm±	1.4	0.3	1.1	3.5	0.8	3.5	1.9	0.3	1.3	2.5	0.4	2.7
CD (P=0.05)	4.3	0.8	3.3	10.4	2.2	10.5	5.8	0.9	3.9	NS	NS	NS

Table 3. Soil available nutrient status (kg/ha) and other properties at the harvest of the last crop under various organics

Treatment	0-15 cm						15-30 cm					
	N	P	K	OC (%)	pH	EC (dS/m)	N	P	K	OC (%)	pH	EC (dS/m)
FYM @ 10 t/ha	194	19.5	508	0.47	8.38	0.69	188	18.8	466	0.57	8.36	0.88
CRI@ 5 t/ha	179	16.1	477	0.43	8.54	0.78	176	15.8	432	0.46	8.60	0.79
GM (@ 15 kg/ha	200	23.5	599	0.53	8.24	0.94	194	18.3	590	0.55	8.55	0.86
FYM 5 t/ha + CRI @ 2.5 t/ha	199	17.9	601	0.47	8.61	0.69	178	16.8	525	0.50	8.55	0.91
FYM @ 5 t/ha + GM @ 15 kg/ha	187	22.4	531	0.49	8.14	0.86	175	19.1	446	0.45	8.54	0.75
FYM @ 5t/ha + GM @15kg/ha + CRI @2.5 t/ha	199	22.0	637	0.49	8.33	0.65	195	15.2	523	0.53	8.55	0.79
CRI @ 2.5 t/ha + GM @ 15 kg/ha	199	25.5	631	0.49	8.14	0.88	173	19.5	540	0.49	8.63	0.74
NPK	194	26.7	601	0.52	8.48	0.88	172	20.9	523	0.62	8.34	0.91
Control	184	17.7	539	0.47	8.38	0.93	167	15.7	420	0.40	8.59	0.80
CD (P=0.05)	NS	NS	NS	NS	0.17	NS	19.1	NS	NS	0.11	0.18	NS
Initial status	166	15.7	556	0.41	8.72	0.35	168	11.6	573	0.39	8.67	0.48

Most interestingly, with respect to unit rupee returned over rupee invested (B:C ratio), the highest one (1.37) was calculated under GM alone followed by NPK (1.35). These were significantly higher over most of the treatments indicating an economic edge of these treatments (Table 1) although the control plot (without any investment except for the seed and labour cost) gave similar but with lesser B:C ratio (1.24). Thus, the trial indicated the importance of GM in sustaining crop productivity and higher margins vis-à-vis inorganic NPK over the years. In absence of cheap and easily available organic manures, *in situ* incorporation of green and herbaceous materials like green manure plays a vital role for efficient conversion of solar energy and carbon sequestration (Praharaj *et al.*, 2006).

Finger millet

Grain yield of rotational finger millet that followed after cotton in the residual fertility was not significantly influenced by any of the organic treatments or trial year (Table 1). Similar to cotton, maximum grain yield was recorded during 2007. Although application of FYM + CRI + GM to preceding cotton led to highest finger millet grain yield of 4.32 t/ha in comparison to NPK (4.24 t/ha), GM (3.99 t/ha) and control (3.76 t/ha), yet residual soil fertility was not different enough to indicate the variation in finger millet grain yield (Table 3).

Similar to sole yield of cotton and finger millet, significantly higher system productivity (Table 1) was obtained during 2007 (2.86 t/ha). With regard to organics, GM alone (2.46), N P K (2.54) and FYM + GM + CRI (2.56) produced similar total yield but significantly superior to control (2.20). Thus, the study indicated that GM because of higher biomass (2.5 t/ha on dry weight basis) and its probable residual effects, produced better yield, margin and system productivity (of cotton in combination with short duration cereal crop like finger millet).

Mean NPK uptake in grain of finger millet was also significantly influenced by the organic treatments (Table 2). Because of relatively higher grain yield, N,P,K uptake were higher in GM and multi-organics treatments over those in control and crop residues alone. Although not significant, similar trend was also observed for total N, P and K uptake by finger millet. On an average, a finger millet crop removed a total N, P and K of 121, 19 and 146 kg/ha respectively under GM treatment in comparison to 113, 17 and 135 kg/ha under absolute control and 124, 19 and 148 kg/ha under NPK.

Soil fertility

Post-harvest soil properties after the last rotational crop (finger millet) in the depth of 0-15 cm (Table 3) revealed that available N, P, K, OC and EC were little influenced due to organic inputs because of greater soil resilience (Praharaj and Rajendran, 2007). Yet, incorporation of *in situ* GM resulted in higher OC (0.53%) and N:P:K (200:23.5:599 kg/ha) availability at the end of 3 years of cropping. Thus, invariably higher values of N, P and K were analyzed under organics over its initial status and a combination of organics, like FYM + GM + CRI still maintained relatively higher nutrient status (especially that of K) at the end of the trial. In addition, there were appreciable reductions in pH of the soil over the initial level (8.72) following application of treatments and continued cropping as the effect of treatments on soil reaction was significant. Soil pH decreased to the minimum under GM plots (8.24) and multi-organics plots involving GM only (8.14 in FYM + GM and 8.14 in CRI + GM). The control plot maintained a relatively higher pH (8.38) and the effect was because of continued cropping only.

Similar to the surface, soil available P, K and EC in the lower depth (15-30 cm) were not influenced by organic inputs. Yet, incorporation of *in situ* GM also resulted in higher OC (0.55%) and N: P: K (194:18.3:590 kg/ha) availability at the end of 3 years of cropping. Available N, OC and P_H were also improved following cropping and application of organics over the initial levels (Table 3). Significantly higher available N was analyzed under GM alone and FYM + GM + CRI over both N: P: K and absolute control. Similarly higher OC and lower pH were maintained in all the organics especially in multi-organics applied plots over those in control. The study reiterated the finding that GM or such other low cost organics played a vital role in realization of higher yield and margin besides maintaining the fertility status of the soil over long run.

Therefore, it was likely that returning residues to soil increases soil organic carbon linearly and also converts many soils from source to potential sink of atmospheric CO_2 (carbon sequestration) by enhancing productivity. Moreover, the application of residues over the soil surface reduces the soil loss and arrests thermal oxidation of surface organic matter. Besides, integrated use of fertilizers and manures seems to increase OC whereas sub-optimal levels of fertilizer application in tropics reduce the OC (Campbell *et al.*, 2000).

It was concluded that under existing upland irrigated condition, low cost technology like simultaneous planting of sunnhemp (as *in situ* green manure) and cotton under ridge-furrow planting followed by incorporation of sunnhemp at appropriate stage was helpful for realization of higher cotton productivity, net return and restoration of soil fertility in the long run. Thus, the study suggests that application of locally available cost effective organics like green manure substitute inorganic fertilizers in upland cotton.

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