Indian Journal of Agricultural Sciences **80** (4): 298–305, April 2010

Agronomic options for higher crop growth, yield and soil fertility in upland cotton (*Gossypium hirsutum*) through *in situ* management of plant wastes in south zone

C S PRAHARAJ[1], K SANKARANARAYANAN[2], N GOPALAKRISHNAN[3] and T P RAJENDRAN[4]

Regional Station, Central Institute For Cotton Research, Coimbatore, Tamil Nadu 641 003

Received: 13 July 2009; Accepted: 01 January 2010

ABSTRACT

A field experiment was undertaken during 2004–07 in 'Surabhi' upland cotton (*Gossypium hirsutum* L.) at Coimbatore (Tamil Nadu) under irrigated condition to explore the suitability of locally available and low-cost plant wastes, viz neem, grass, weed and cotton residues *vis-à-vis* farmyard manure. The treatments to ridge planted cotton included *in-situ* interrow (furrow) mulching and subsequent incorporation of whole cotton crop residues and *ex-situ* incorporation of locally available sun-dried plant wastes, such as neem (*Azadirachta indica* A. Juss) leaves, tree leaves (*Trianthema portulacastrum* L.), desert weeds (Horsepurslane or *itsit*), congress grass (*Parthenium hysterophorus* L.), field grass (mostly *Cynodon dactylon* L.), cotton stalks and farmyard manure (all @ 5 tonnes/ha in combination with a soil test-based recommended NPK dose of 60:13:25 kg/ha along with double controls (no NPK and no residues, only NPK). Results revealed that application of neem leaves @ 5 tonnes/ha was superior in respect of many performance parameters over both double controls, and was found to be equally effective to that of farmyard manure @ 5 tonnes/ha. Higher productivity in neem-amended plots was also due to increase in yield attributes, such as burst boils and seed cotton/plant, boll weight and petiole N% at 90 days after planting because of integrated nutrient option. Thus, fibre productivity efficiencies were higher in neem-amended plots over the control (41%) and NPK alone (13.7%). Highest agronomic efficiency (10.2 kg/kg) and efficiency ratio (27.7 kg/kg) were also observed under it owing to greater nutrient assimilation efficiency (higher dry weight gained/kg NPK removed over and above control). Quality of fibre measured by high volume instrument did not show the differences due to the treatments. Plant wastes-amended plots influenced organic carbon, available N and K in soil leading to higher residual fertility although a crop of *Sorghum* grown after cotton in its residual fertility was not influenced by the treatments. Maximum economic benefits were also obtained with easily decomposable bio-wastes, like neem or grass cover over that in control, NPK and farmyard manure.

Key words: Agronomic efficiency, Cotton residues, Fibre quality, *Gossypium hirsutum,* Seed cotton yield, Soil fertility

Amongst agronomic management options, integrated nutrient supply through cost-effective means for quality fibre production is visualized now than ever before. For meeting the crop demand the application of plant/crop residues even with/without composting, such as organic manures, crop/weed wastes and readily available crop (cotton) wastes shall meet the twin objectives of sustainability, i e higher yield over seasons/years (Kaul and Singh 2002). In this context, application of appropriate and readily available organic wastes in combination with inorganic fertilizer in an integration approach remains vital for low production cost and increased efficiency (Praharaj and Rajendran 2007). Moreover, such an integrated (nutrient) management option ameliorates the properties of the soil further for sustained productivity and crop profitability. In addition, plant wastes with the apparent odourless and harmless properties make it possible for a better quality of fibre (Venugopal *et al*. 1999). Availability of year-round bulk of plant/farm wastes enables to explore its use under *in situ* field condition. This envisages growing of crop embedded with plant wastes as mulch/manure in interrows and enabling crop to use solar radiation more efficiently through biophysical processes. Moreover, the cumulative benefits from application of such plant wastes warrant analysis of nutrient composition in both cotton plant and soils determining management options for a quality fibre crop. In addition, farmyard manure being a scarce input with inherit operational difficulties (cost/labour intensive for collection, handling composting, transport and distribution/application in the fields); it prompts use of alternative sources

---

[1]Senior Scientist (Agronomy), (e mail: cspraharaj@gmail.com), [2]Sr.Scientists (Agronomy) (e mail: sankaragro@gmail.com), [3]Project Coordinator (Cotton Improvement) & Head (E-mail:gopal55@rediffmail.com), [4]Assistant Director General (Plant Protection) (e mail: adgpp@icar.nic.in), Krishi Bhawan, New Delhi 110 114

for promoting integrated nutrient management. Since little information is available on these aspects, especially in management of *in situ* plant wastes in crop, a field trial was conducted for 3 years (preliminary trial for a year and confirmatory trials for 2 more years) in cotton on a loam soil at Coimbatore under south cotton zone.

MATERIALS AND METHODS

Experiment 1

A preliminary field trial on 'Surabhi' cotton (*Gossypium hirsutum* L.) with readily available plant wastes was tried on a Typic haplustalfs (Periyanaickanpalayam series), alkaline, moderately deep, well drained loamy soil at the Regional Station of CICR, Coimbatore (11°N Lat., 77°E long. and 427.6 m above mean sea level) under Southern hills and plateau region during 2004–05 under assured irrigation condition. The soil was medium fertility with 0.69% organic carbon, 296 kg available N/ha, 6 kg P_2O_5/ha, 625 kg K_2O/ha, 0.048% Na with *p*H 8.7, EC of 0.41 dS/m and bulk density of 1.49 g/cc analyzed in 0–250 mm soil. The borewell irrigation water was having *p*H 7.4, EC 3.52 dS/m and total salt concentration of 0.23% with mostly neutral salt of sulphate and chloride of sodium. A detail of physicochemical properties of the soil profile is given in Table 1.

The trial was laid out in a RBD with 9 treatment combinations (Table 2), viz soil test-based balanced NPK (60:13:25 kg/ha) alone, and in combination with various plant wastes, such as neem (*Azadirachta indica* A. Juss) leaves, congress grass (*Parthenium hysterophorus* L.), desert horsepurslane or *itsit* (*Trianthema portulacastrum* L.) weeds, field grass (mostly *Cynodon dactylon* L.), broad-leaved tree leaves in the form of leaf litter, whole cotton stalks/residues and farmyard manure @ 2.5 tonnes/ha on dry wt basis and a control for both the above. Sun-dried plant stalks with 8–10% moisture were cut into 4–5 cm long pieces for ease in application and uniform spread. These readily available wastes including farmyard manure were applied as surface mulch between the rows of cotton in furrows after emergence (10–15 days of planting). Half of urea N along with full dose of P and K were applied at planting in recommended dose of NPK as per treatment, followed by top-dressing at earthing up 45–50 days after planting. Only farmyard manure led to rapid mineralization within a short span following its application, while in other plant wastes it was around 1–2 months for nutrients to be mobilized for crop assimilation following irrigation/rainfall. The crop received a rainfall of 552.2 mm and a cumulative pan evaporation of 756.8 mm during 2004–05.

Table 1 Soil profile characteristics at the start of the experiment

Parameter	Layer 1	Layer 2	Layer 3	Layer 4
Thickness (mm)	250	280	230	180
Sand (%)	53.89	58.50	48.58	48.29
Clay (%)	25.37	29.51	23.01	32.02
Soil type	Loam	Loam	Silty Loam	Loam
B.D. (Moist in g/cc)	1.49	1.55	1.40	1.45
Water content (%) FC	25.26	27.37	28.01	30.99
Water content (%) WP	11.09	14.32	15.79	17.56
Water content (%) Sat.	34.3	36.0	37.4	39.6
Organic carbon (%)	0.69	0.57	0.53	0.30
K sat (mm/day)	130	100	80	80
Ph (1 : 2.5)	8.70	8.80	8.90	9.00
EC (dS/m (1 : 2.5 ratio)	0.41	0.30	0.37	0.40
Available N (kg/ha)	296	211	140	230
Available P_2O_5 (kg/ha)	6.0	12.6	3.8	3.3
Available K_2O (kg/ha)	625	638	946	469
Available Na (%)	0.048	0.052	0.053	0.033
$CaCO_3$ (%)	9.8	9.1	9.3	12.5

Acid delinted 'Surabhi' cotton seeds were used for planting of cotton. The crop was sown during first week of September at 75 cm × 30 cm spacing and 2 plants/hill were maintained as an insurance against stem weevil sporadic in the area. The crop management practices were uniformly adopted in all the plots. For weed control, 1 hoeing followed by a hand weeding at 45–50 days after planting was done after which 1 earthing up along the cotton row was carried out keeping the plant wastes intact in the inter-row zone. First picking of cotton commenced in mid-January and the second was in February. Normal biometric observations, seed cotton yield, yield attributes and fibre quality parameters were taken up during the preliminary trial. All data were subjected to statistical analysis following normal procedures.

Experiment II

The above trial was repeated during 2005–06 and 2006–07 on the same site and on the original layout superimposed with the modified treatments which were slightly different in the experiment II. Keeping in view the inadequate soil cover, low rate of decomposition (partial immobilization), low yield and soil nutrient status at harvest in the first experiment, experiment II was carried out with the plant wastes @ 5 tonnes/ha applied after crop emergence, but were incorporated *in situ* at the time of earthing-up (45–50 days after planting). Since the crop covered the ground fully by this time, the mulched wastes acted as organic manure after a normal irrigation/rainfall event following earthing-up. The crop was sown and grown as in experiment 1. The crop received a rainfall of 643.4 and 593.3 mm and a cumulative pan evaporation of 674 and 757.3 mm during 2005–06 and 2006–07 crop seasons, respectively. Irrigation water was given as per need. The climatic normals for the region in respect of mean annual rainfall, rainy days, $temp_{max}$, $temp_{min}$, bright sunshine hours and solar radiation for the last 25 years are 674.2 mm, 49 days, 31.5°C, 21°C, 7.3 hr and 492 cal/cm^2/day, respectively.

The details of observations taken up included plant biometrics, yield and its attributes; and fibre indices/quality parameters and soil nutrient status for available N, P and K in

Table 2 Seed cotton yield and ancillary characters under different plant wastes (Trial 1)

Treatment	Seed cotton yield (tonnes/ ha)	Stalk yield (tonnes/ ha)	Dry weight/ plant (g)	Sympodia/ plant	Burst bolls/ plant	Lint yield (g/m^2)	Boll wt.(g)	Plant height (cm)	Seed cotton/ plant	GOT (%)	SI (g)	Lint index	Earliness index
Control	1.37	3.32	151	15.1	26.9	48.7	2.48	104.6	55.4	35.6	7.63	3.70	0.94
NPK	1.51	3.35	180	14.5	30.0	52.5	2.49	106.5	74.5	35.0	8.50	3.64	0.93
NPK+neem	1.57	3.60	158	15.4	26.2	54.4	2.26	108.7	58.9	34.6	8.27	3.83	0.92
NPK+*Parthenium*	1.68	3.70	155	14.2	23.8	58.1	2.45	105.6	59.0	34.7	8.03	3.63	0.93
NPK+*Trianthema*	1.79	3.85	170	15.6	29.4	62.5	2.31	113.3	68.3	35.4	7.93	3.87	0.94
NPK+grass	1.65	3.46	150	14.0	22.9	57.5	2.55	107.4	58.0	34.9	7.97	3.87	0.94
NPK+leaf litter	1.49	3.26	141	14.5	21.6	51.7	2.54	101.7	56.3	34.7	8.23	4.00	0.94
NPK+cotton stalk	1.31	3.17	161	15.7	28.4	45.5	2.24	112.2	62.5	34.7	7.87	3.53	0.93
NPK+FYM	1.73	0.35	148	14.3	23.1	58.8	2.85	105.6	63.2	34.0	7.97	3.80	0.93
SEm±	0.11	0.43	17.6	0.8	3.8	3.7	0.19	4.0	8.9	0.9	0.09	0.21	0.06
CD (*P*=0.05)	0.32	NS	NS	NS	NS	11	NS	NS	NS	NS	NS	NS	NS

Table 3 NPK supply, seed cotton yield and economics under various organic treatments (pooled for last 2 years)

Treatment	Nutrient applied (kg/ha)				Seed cotton yield (tonnes/ha)			Stalk yield (tonnes/ ha)	FPE (kg/ha-day)	Seed cotton/ plant(g)	Total biomass (tonnes/ ha)	Cost of cultivation ($\times10^3$ Rs/ha)	Net returns ($\times10^3$ Rs/ha)	B:C ratio
	N	P			05-06	06-07	Mean							
Control	0	0	0	0	1.61	2.10	1.86	2.47	10.0	45.8	4.32	14.6	23.9	1.63
NPK	60	13	25	98	1.87	2.73	2.30	2.70	12.4	48.6	5.00	15.9	31.7	1.98
NPK+neem	143	19	79	241	2.03	3.21	2.62	2.85	14.1	65.7	5.47	17.6	36.5	2.07
NPK+*parthenium*	184	27	79	290	2.04	3.07	2.55	2.82	13.7	63.1	5.37	17.1	35.7	2.03
NPK+*trianthema*	149	21	94	264	1.96	3.12	2.54	2.73	13.7	52.6	5.27	17.3	35.3	2.03
NPK+grass	107	16	83	206	2.23	3.00	2.61	2.74	14.1	55.9	5.36	17.2	36.8	2.14
NPK+leaf litter	119	16	43	178	2.22	2.97	2.60	2.84	14	57.3	5.44	17.3	36.4	2.10
NPK+cotton stalk	147	23	91	261	2.00	3.03	2.52	3.08	13.5	52.9	5.60	18.1	33.9	1.87
NPK+FYM	86	23	51	160	2.19	2.97	2.58	3.02	13.9	55.5	5.60	18.5	34.8	1.87
SEm±					0.12	0.20	0.12	0.19	0.6	3.7	0.28		2.4	0.15
CD (*P*=0.05)					0.36	0.61	0.36	NS	1.9	10.8	NS		7.3	NS

Sale price: Rs 350 and Rs 10/100 kg seed cotton and stalk, respectively

0–15 and 15–30 cm soil depth before planting and after cotton harvest. Changes in other chemical properties of soil, especially *p*H, EC and sodium content were also analyzed after harvest of the crop for studying the changes in salinity/alkalinity. 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 SQRT(M) is square root of micronaire value (µg/inch) defining fibre maturity. Fibre productivity efficiency (FPE, kg/ha-day) was calculated based on unit day productivity (yield/net total phenological days).

Total quantities of NPK applied in various treatments were given in Table 3. Average values of NPK content (per cent dry weight basis) for farmyard manure (0.52:0.20:0.51), neem leaves (1.65:0.12:1.08), *Parthenium* (2.48:0.27:3.84), *Trianthema* (1.77:0.16:1.37), grass (0.94:0.06:1.16), leaf litter (1.18:0.06:0.35) and cotton stalks (1.73:0.19:1.31) were considered for calculation of nutrient applied/uptake to soil/by crop. Total NPK nutrients added by addition of crop residues/green manure/farmyard manure and NPK along with soil test values and crop uptake were also obtained. Agronomic efficiency and efficiency ratio based on economic yield, total biomass and NPK uptake were calculated following procedure given by Kaul and Singh 2002. Economics of cultivation were also calculated using the prevailing market prices both for inputs and outputs. After cotton, a sorghum crop was also taken to study the residual effect, if any. Data were analyzed as per standard procedures (Balaguravaiah *et al.* 2005).

RESULTS AND DISCUSSION

Trial I

Application of plant wastes invariably increased seed cotton yield to the significant level over control and cotton stalks, amended plot, and was better over NPK alone (Table 1). Amongst plant wastes, neem, *Parthenium*, *Trianthema* and common grass cover were equally effective in terms of seed cotton yield and lint yield over that in farmyard manure and NPK alone since all of them acted as surface mulches besides adding O M to soil for higher crop performance. Although non-significant, similar trend was recorded in stalk yield obtained under different treatments. Higher productivity in plots with plant wastes-amended plots was attributed to the cumulative effects of various yield attributes, not a single one *per se*. Since there exists inverse relation between opened bolls and boll weight, treatments having lesser opened bolls were having higher boll weight for compensation mechanism to work. Yet, higher biomass, sympodia, burst bolls and seed cotton/plant and plant height were obtained with integrated nutrient management options involving plant wastes and NPK over control (Praharaj and Rajendran 2007), although not to the level of significance. Soil cover of farmyard manure also behaved similarly with that of dried plant wastes in respect of the said parameters. Even quality attributes like ginning outturn, seed index, lint index and earliness index were in favour of integrated nutrient management (Table 1). Thus, an integrated nutrient management system was the most efficient way to mobilize the available plant nutrient sources to maximize crop performance in terms of fibre quantity and quality. Three years data from 267 sites in India shows a 22% yield increase with only INM over farmer's practice (Govil and Kaore 1997).

Trial II

Seed cotton yield

Application of plant wastes including farmyard manure enabled the crop to produce significantly higher seed cotton yield (Venugopal *et al.* 1999) during both years and in pooled data (Table 3). Irrespective of type of plant wastes, significantly higher seed cotton yield to the tune of 2.09, 3.05 and 2.57 tonnes/ha (average of all treatments except control) were obtained during 2005–06, 2006–07 and in pooled data; and the yields were higher by 12, 11.9 and 12% over NPK alone and 25.6, 45.4 and 38.7% over the control, respectively (Table 3). Maximum seed cotton yield (2 616 kg/ha) was recorded under neem leaves @ 5 tonnes/ha amended plots during 2006–07 (3.21 tonnes/ha) and in pooled data (2.62 tonnes/ha), indicating its superiority over both NPK and control, and was also observed to be equally effective with those of farmyard manure @ 5 tonnes/ha since both farmyard manure and neem act as surface mulch initially and add organic matter to soil following *in situ* incorporation during earthing-up for better crop performance. Addition of neem leaves (with NPK) resulted in higher seed cotton yield by 8.3, 17.5 and 13.8% over that in NPK alone during 2005–06, 06–07 and in pooled data. Thus, the role of integrated nutrient management even in case of external addition of dry waste for soil cover/incorporation *in situ* can play a key role in efficient assimilation of nutrient as per crop demand (Praharaj and Rajendran 2007).

In addition, weed wastes, grass or broad leaves-amended plots acted similar to plots with neem leaves in terms of seed cotton yield during both the years. Interestingly, when cotton stalks were combined with NPK performed better over control and was at par with NPK alone. Similar results were obtained with stalk yield also (Table 3). Thus, when an organic waste was applied in combination with optimum NPK resulted in release of nutrients following mineralization of organic sources. The role of inorganic nutrients is to inhibit immobilization in soil through supply of easily assimilable nutrients to microbes and probable net mineralization proceeds for crop uptake.

Harvest attributes and growth

Higher productivity in neem leaves-amended plots was also evident due to significant increase in harvest attributes, viz per plant seed cotton (65.7 g/plant), boll weight at picking (3.70 g) and petiole N (1.37%) at 90 days after planting over both control (45.8 g, 3.03 g and 0.96%) and NPK (48.6 g, 2.98 g and 1.02%, respectively) in the pooled data. Evidently, maximum opened boll (23.4), seed cotton and boll weight were also recorded under the above treatment. Although nonsignificant, similar higher values in respect of total biomass (5.47 tonnes/ha) and plant height (103.3 cm) were also recorded under the same treatment (Tables 3, 4). Chlorophyll content at 90 days after planting and sympodia were however not followed any pattern as similar values were obtained under all the treatments.

Improvement in seed cotton yield was largely reflected from the increases in yield traits and biometrics as above and more so because of better soil nutrient availability (following composting of plant wastes) in INM plots over control plots. Lowest values in respect of above parameters were obtained in control, followed by NPK alone on most of growth and yield parameters (Table 4). Experimental trials at western Maharastra (Rahuri) revealed that sunnhemp incorporated *in situ* improved productivity of widely-spaced hybrid cotton as it started decomposing following incorporation *in situ*, and in the process releasing nutrients, especially N for better growth and performance of the crop in terms of seed cotton yield (Venugopalan and Pundarikakshudu 1999a).

The trial also showed that a combination of cotton residues (or similar hard dried wastes) along with NPK-amended plot led to higher growth and development on par with that in control and NPK, indicating release of locked up nutrients in the combinations over the years. In the present case also, soil microbes are releasing available nutrients in NPK + plant waste combination thus, inhibiting (temporary) deficiency of mineralizable nutrients in the integrated nutrient management plots leading to yield increase (Table 3). Similarly, Blaise and Ravindran (2003) reported that leaf or leaf + stalk-amended plot yields were equal to that in control; and stalk alone-amended plots had the least seed cotton yield.

Table 4 Ancillary characters, chlorophyll content, petiole N (90 DAS) and fibre quality in various treatments (pooled for last 2 years)

Treatment	Sympodia/ plant	Burst bolls/ plant	Boll weight (g)	Plant height (cm)	Dry weight/ plant (g)	Chlorophyll content (mg/g)	Petiole N (%)	GOT (%)	Seed Index (g)	Lint index	Earliness index	2.5% SL (mm)	Strength (g/tex)	Mike (ug/ inch)	FQI
Control	18.7	18.9	3.03	99.9	127.5	1.28	0.96	33.1	9.08	4.85	0.78	31.4	24.3	3.84	390
NPK	19.7	20.5	2.98	102.9	158.6	1.30	1.02	32.9	10.13	4.97	0.79	31.4	24.6	3.86	394
NPK + neem	18.2	23.4	3.70	103.3	145.1	1.27	1.37	33.6	9.97	5.04	0.81	31.5	24.4	3.87	391
NPK + *parthenium*	19.8	22.9	3.34	102.9	134.2	1.30	1.14	33.2	10.13	5.03	0.79	31.6	24.6	3.90	396
NPK + *trianthema*	20.2	20.5	3.00	107.1	171.6	1.24	1.38	33.2	9.9	4.92	0.80	31.6	24.5	3.90	393
NPK + grass	19.9	22.3	3.08	100.8	128.7	1.27	1.14	33.0	10.02	4.94	0.82	31.1	23.8	0.83	378
NPK + leaf litter	18.4	21.1	3.09	102.5	146.6	1.29	1.10	32.6	9.9	4.80	0.81	31.4	23.5	3.90	374
NPK + cotton stalk	19.0	21.9	3.35	101.1	133.6	1.33	1.18	32.8	9.87	4.82	0.81	31.1	23.9	3.89	377
NPK + FYM	19.4	25.9	3.06	107.9	139.1	1.27	1.00	32.8	10.2	4.98	0.80	31.5	24.2	3.84	390
SEm±	0.94	2.17	0.21	4.15	14.56	0.07	0.11	0.24	0.14	0.07	0.02	0.25	0.52	0.05	9.9
CD (*P*=0.05)	NS	NS	0.63	NS	NS	NS	0.34	NS	NS	NS	NS	NS	NS	NS	NS

Therefore, in the present investigation, seed cotton per plant, boll number, boll weight and petiole N (Table 4) contributed significantly towards higher yield realization in the pooled data (Table 3). Jackson and Gerik (1990) also showed that N fertility was highly correlated with leaf area and boll number. Thus, vegetative growth as evidenced by increase in length and cross sectional area of main stem internodes increases in boll number and yield.

Fibre quality and phenology

Fibre quality parameters, viz GOT, seed and lint indices, 2.5% span length, fibre strength and micronaire values (except fibre productivity efficiency being a function of unit fibre production/day) were not influenced by various treatments. Yet, maximum values of GOT and lint index were obtained under neem leaves incorporated plots. On an average, 33.6% GOT, 9.97 g seed index, 5.04 lint index, 31.5 mm fibre length, 24.4 g/tex strength, 3.87 µg/inch as mike and 391 as FQI were obtained under the treatment in pooled data (Table 4). Fibre quality index, a composite quality index for cotton fibre (epidermal outgrowth of the seed coat of fertilized ovule) measured by high volume instrument did not show the differences following its application.

Although non-significant, yet fibre quality values were numerically higher over both control and NPK over a range of parameters. Fibre productivity efficiency calculated under the above treatment was also significantly higher over that in control (Praharaj *et al*. 2006). With little variations, days to reach a specific vegetative/reproductive phase of the crop (phenology) were also little influenced by the INM treatments (data not given). Thus, the crop under integrated nutrient options producing more output in terms of seed cotton yield required 1–3 days longer over that in control plots.

NPK and Na uptake

Differences in NPK and Na content in both seed cotton and stalk in individual years led to differential nutrient uptake in the waste-amended plots (Table 5). N, P and Na content in cotton stalk were significantly influenced by treatments during 2005–06 (data not given). Interestingly, significantly lower concentrations in respect of N (1.38%), P (0.19%) & Na (0.25%) were observed under neem leaves-amended plots over control. Yet, NPK applied plots had similar or higher values of NPK and Na contents in both seed cotton and stalk over neem leaves applied plots during both the years. Thus, lower values of NPK and Na contents observed in both seed cotton and stalk during 2005–06 and similar values during 2006–07 were indicative of efficient remobilization of nutrient towards economic parts. A higher value in cotton stalk is an example of luxury consumption and thus, was contributing towards the loss of nutrient.

Mostly N uptake in seed cotton and stalk were significantly influenced by addition of plant wastes (Table 5). Moderate level of N uptake in seed cotton yet, significantly higher over control during 2005–06 (43.4 kg/ha) and 2006–07 (66.9 kg/ha) under neem leaves-amended plots was attributed to efficient assimilation of the nutrient by cotton plants. Similarly, lower values of N uptake in cotton stalk under these plots over control during 2005–06 (40.8 kg/ha) and similar values during 2006–07 (36.7 kg/ha) were due to lower partitioning in terms of N use towards uneconomic parts like cotton stalk and higher efficiency towards economic one. Similar values in respect of P uptake in stalk (at par with both control and NPK) during 2005–06 obtained under neem-amended plots revealed efficient partitioning of nutrients to economic parts for realization of improved yield and quality. Venugopal et *al.* (1999) reported that higher seed cotton yield and stalk yield led to similar NPK uptake under integrated nutrient management options. Nutrient uptakes relating other nutrients however, were similar under all the treatments (Table 5).

Table 5 NPK uptake (kg/ha) in seed cotton and stalk as influenced by plant wastes during both the years

Treatment	2005–06								2006–07							
	Seed cotton				Stalk				Seed cotton				Stalk			
	N	P	K	Na	N	P	K	Na	N	P	K	Na	N	P	K	Na
Control	31.4	4.0	23.0	1.5	45.8	4.6	29.1	9.3	40.4	5.2	29.9	1.7	22.3	3.8	22.6	14.2
NPK	37.4	5.3	25.5	0.9	64.2	6.6	41.6	7.4	54.5	8.2	36.7	1.5	29.6	2.8	24.7	17.6
NPK+neem	43.4	4.8	25.9	1.4	40.8	5.7	36.9	7.6	66.9	7.8	40.7	2.9	36.7	3.8	31.4	21.2
NPK+*parthenium*	49.7	4.7	29.2	1.3	69.8	5.8	43.7	7.3	74.7	7.3	43.2	2.4	37.2	2.8	27.2	13.9
NPK+*trianthema*	49.8	5.3	25.4	1.4	49.8	5.1	36.8	9.6	80.1	9.1	39.9	2.1	37.3	2.7	23.4	17.2
NPK+grass	47.3	5.3	30.8	1.4	68.6	6.7	45.0	8.4	63.8	7.0	41.5	2.2	32.7	2.8	27.0	19.3
NPK+leaf litter	47.6	6.2	30.1	2.2	57.1	5.0	37.6	9.3	62.4	8.2	40.1	1.8	31.1	4.6	27.3	19.8
NPK+cotton stalk	43.2	5.5	26.2	1.1	56.8	5.8	39.7	10.7	65.4	8.3	40.0	2.0	36.8	4.6	30.6	22.5
NPK+FYM	49.2	5.6	29.3	1.3	67.8	8.1	44.7	7.6	66.1	7.7	39.3	2.0	33.9	4.8	25.7	19.7
SEm±	3.7	1.0	2.6	0.5	3.9	0.5	5.4	0.8	4.9	1.9	2.4	0.2	7.2	0.7	4.3	2.5
CD (*P*=0.05)	11.0	NS	NS	NS	11.6	1.6	NS	NS	14.7	NS	NS	0.7	NS	NS	NS	NS

Table 6 Total NPK (seed cotton+ stalk) uptake (kg/ha), agronomic efficiency (AE) and efficiency ratio (ER) under various plant wastes

Treatment	2005–06						2006–07					
	N	P	K	Na	AE	ER	N	P	K	Na	AE	ER
Control	77.2	8.7	52.1	10.8			62.7	9.1	52.4	15.9		
NPK	101.6	11.9	67.1	8.3	2.6	8.9	84.1	11	61.4	19.2	11.4	30
NPK+neem	84.3	10.5	62.8	9.1	4.2	25.5	103.6	11.6	72.1	24.1	16.3	28.4
NPK+*parthenium*	119.5	10.5	72.9	8.5	4.3	10.3	111.9	10.1	70.4	16.4	14.8	20.9
NPK+*trianthema*	99.6	10.5	62.2	11	3.6	15.0	117.5	11.7	63.2	19.3	15.4	20.2
NPK+grass	115.8	12	75.8	9.8	6.3	12.5	96.5	9.7	68.5	21.5	14.1	24.6
NPK+leaf litter	104.7	11.3	67.7	11.5	6.2	19.7	93.5	12.8	67.5	21.6	13.9	27.0
NPK+cotton stalk	100	11.3	66.0	11.8	3.9	20.5	102.2	12.9	70.5	24.6	14.5	28.4
NPK+FYM	116.9	13.7	74.1	8.9	5.8	16.4	99.9	12.5	65.0	21.7	13.9	27.3
SEm±	5.3	1.3	5.8	1.1			10	1.9	4.3	16.7		
CD (*P*=0.05)	15.9	NS	NS	NS			29.9	NS	NS	NS		

Agronomic efficiency and efficiency ratio

Because of differences in uptake pattern (mostly N) during both the years, significantly lower N uptake (84.3 kg/ha) was recorded in neem-amended plots over NPK (101.6 kg/ha). Yet, it was 9.2% higher over control (Table 6) and second to control only. Similarly, total N uptake recorded (103.6 kg/ha) during 2006–07 under neem leaves-amended plots was significantly higher over that in control, yet was at par with NPK applied plot (84.1 kg/ha). Unlike that of N, total P and K uptake was not significantly influenced by the treatments during both the years. As a result, highest agronomic efficiency (calculated from seed cotton yield and total NPK applied), followed the same trend as in N uptake and was higher under plant wastes (because of lower uptake) in comparison to NPK applied plots. Evidently, highest efficiency ratio (ER, calculated from total dry matter and total NPK uptake) were recorded under neem cover (Table 6) during 2005–06 (25.5 kg/kg) and 2006–07 (28.4 kg/kg) because of greater nutrient assimilation in the treatment. The higher values in AR and ER led to higher values of agronomic efficiency (27.7 kg/kg) and efficiency ratio (10.2 kg/kg) in the pooled data taking both seed cotton yield and stalk yield (Fig 1).

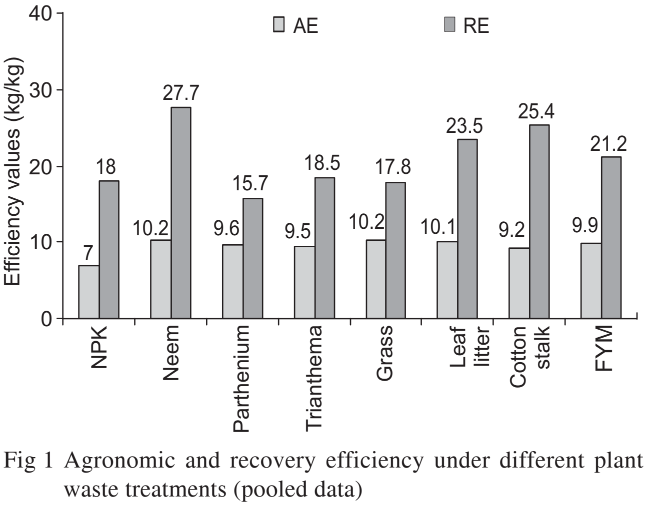

Fig 1 Agronomic and recovery efficiency under different plant waste treatments (pooled data)

Table 7 Soil fertility related properties (0-30 cm soil depth) under different organic residue treatments

Treatment	OC (%)		N(ppm)		P(ppm)		K(ppm)		Na(ppm)		Ec(dS/m)		*p*H	
	0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30
Control	0.66	0.58	131.7	101.3	7.92	8.61	305	280	504	525	0.75	0.81	8.29	8.30
NPK	0.64	0.52	129.4	91.1	9.18	9.51	296	290	502	516	0.81	0.80	8.30	8.30
NPK+neem	0.74	0.60	140.1	104.8	9.75	9.63	338	295	517	522	0.77	0.87	8.17	8.30
NPK+*parthenium*	0.73	0.61	138.8	105.9	11.21	10.68	386	341	486	507	0.65	0.76	8.26	8.33
NPK+*trianthema*	0.76	0.65	142.5	113.1	12.43	10.68	380	331	500	509	0.73	0.72	8.29	8.34
NPK+grass	0.70	0.60	136.1	104.1	10.08	8.90	350	335	520	519	0.85	0.82	8.19	8.28
NPK+leaf litter	0.67	0.62	132.4	108.5	8.74	9.22	339	293	493	515	0.84	0.85	8.21	8.32
NPK+cotton stalk	0.70	0.57	135.1	100.3	7.97	10.08	350	338	499	507	0.75	0.78	8.31	8.35
NPK+FYM	0.72	0.63	137.9	109.2	9.87	11.0	316	289	505	514	0.60	0.75	8.29	8.30
SEm±	0.02	0.06	2.5	10.4	1.21	0.74	20.1	19.9	16.6	13.5	0.09	0.07	0.06	0.04
CD (*P*=0.05)	0.07	NS	7.4	NS	NS	NS	60.2	59.8	NS	NS	NS	NS	NS	NS
Initial status	0.69	0.63	132.0	94.0	2.70	5.60	279	285	482	517	0.19	0.31	8.27	8.47

Soil fertility and nutrient balance

Post harvest soil properties in 0–15 cm and 15–30 cm revealed that many of these were little influenced due to organic waste supply because of greater soil resilience (Praharaj and Rajendran 2007). However, significantly higher level of organic carbon and available N were analyzed in 0–15 cm soil samples under neem leaves, amended plots over both control and NPK alone (Table 7). Similar trend was also observed in the lower depth although the difference was not significant. No appreciable change was also observed in soil available P, K and Na and soil *p*H and EC in the treatment over both control and NPK. Moreover, all the treatments including control could not differentiate final soil status in terms of available P and Na, soil *p*H and EC.

Thus, it is 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 (Subbian and Marimuthu 2004). Moreover, the application of residues even as surface mulch/incorporation over/into the soil surface reduces the soil loss and arrests thermal oxidation of surface organic matter. In addition, integrated use of fertilizers and manures seem to increase soil organic carbon, whereas sub-optimal levels of fertilizer application in tropics reduce the soil organic carbon. Under existing condition of higher elevation (427.6 m), as air temperature (Temp_{max}) in close proximity of soil did not rise above 35° C during the season, nutrient/moisture loss were further reduced by covering the soil with plant wastes, followed by earthing-up on and around the root zone. In addition, residues released nutrients, especially N following partial incorporation due to rain/irrigation. Thus, higher residual fertility was evident under INM approach.

Grain yield (average of 5.3 tonnes/ha) of rotational sorghum as a bulk crop followed after cotton in the residual fertility was not significantly influenced by any of the integrated nutrient management treatments. Yet, higher values were obtained with integrated nutrient management treatment over both control and NPK alone (data not given).

Economics

Cost of cultivation were similar and higher in all the plant waste-amended plots over both control and NPK as these involved an application of both organic wastes and NPK (Table 3). Yet, higher per hectare net returns were obtained under both neem (Rs 36 500) and grass cover (Rs 36 800) because of higher yield of both seed cotton and stalk (Table 3). Thus, higher benefit : cost ratios were also obtained under neem leaves (3.07), grass (3.14) and leaf litter (3.10). Lower B:C ratios were obtained under control (2.63), farmyard manure (2.87) and cotton stalk (2.87) because of lower yield in the former and higher cost of input/labour for the latter two. Similar observations were made by Blaise and Ravindran (2003).Thus, maximum economic yield advantages were obtained with easily decomposable biowastes like neem, broad leaves or grass (in that order) over that in control, NPK or even farmyard manure. As the farmers use these residues in a very limited scale/quantity (mostly for mulch), therefore these plants grown *in situ* or locally available may act an effective component in mineral nutrition of crop. Hence, in absence of ample quantities of farmyard manure as standard organic manure, dry plant wastes like neem leaves and broadleaves (undergoing relatively early decomposition) offer viable option for maintaining a stable yield through restoring soil fertility.

Thus, the trial indicated the importance of plant wastes in combination with NPK in sustaining crop productivity. Therefore, for sustainable yield and higher soil fertility; adequate blend of plant wastes and NPK are required to serve differential purposes (Praharaj *et al*. 2006) as combined application of these enabled the crop to work optimally and efficiently in harvesting solar radiation to economic parts, viz lint in cotton.

It was concluded from the foregoing that under medium fertility and irrigated condition, integrated plant nutrient system involving rational and appropriate use of fertilizers and organics (such as neem leaves or other plant wastes @ 5 tonnes/ha along with soil test based NPK @60:13:25 kg/ha) has resulted in higher productivity, nutrient-use efficiency and net returns.

Weed wastes, especially, *Trianthema* and *Parthenium* need to be studied in detail for its application, especially under field condition with regard to their toxicity and residual effects, if any in terms of allelopathy to both human and animal.

REFERENCES

Balaguravaiah D, Adinarayana G, Prathap S and Yellamanda Reddy T. 2005. Influence of long-term use of inorganic and organic manures on soil fertility and sustainable productivity of rainfed groundnut in Alfisoils. *Journal of Indian Society of Soil Sciences* **53** (4): 608–611.

Blaise D and Ravindran C D. 2003. Influence of tillage and residue management on growth and yield of cotton grown on a vertisol over 5 years in semiarid region of India. *Soil and Tillage Research* **70**: 163–73.

Govil B P and Kaore S V. 1997. On-farm experiences of IPNS development by IFFCO. (*in*) *Proceedings of the FAO-IFFCO International Seminar on IPNS for Sustainable Development,* Nov. 25–27,1997, IFFCO, New Delhi.

Kaul J N and Singh Harmeet. 2002. Role of Agronomy in food security. (*in*) *Recent Advances in Agronomy*. Singh Guriqbal, Kolar Jaspinder Singh and Sekhon Harbhajan Singh (Eds), pp 195–227, Indian Society of Agronomy, New Delhi.

Praharaj C S and Rajendran T P. 2007. Long-term quantitative and qualitative changes in cotton (*Gossypium hirsutum* L.) and soil parameters under cultivars, cropping systems and nutrient management options. *Indian Journal of Agricultural Sciences* **77** (4): 280–5.

Praharaj C S, Rajendran T P and Sankaranarayanan K. 2006. Comparative performance of irrigated *Hirsutum* cotton in conventional and organic packages in black clay loam soils of Tamil Nadu. *Journal of Indian Society for Cotton Improvement* **31**(2): 99–104.

Subbian P and Marimuthu S. 2004. Importance of carbon sequestration in soil carbon status. (*in*) *Precision Farming.* Muthukrishnan P, Chinnusamy C and Chinnamuthu C R (Eds). pp 89–91. Centre of Advanced Studies in Agronomy, TNAU, Coimbatore.

Venugopal K, Gururajan K N and Gopalakrishnan N. 1999. Crop production practices for maximizing yield of cotton in India. (*in*) *Handbook of cotton in India,* pp 104–122. Sundaram V, Basu, A K, Krishna Iyer K R, Narayanan S S and Rajendran T P (Eds). Indian Society of Cotton Improvement, Mumbai.

Venugopalan M V and Pundarikakshudu R. 1999. Long-term effect of nutrient management and cropping system on cotton yield and soil fertility in rainfed vertisols. *Nutrition Cycling in Agroecosystem* **55** (2): 159–64.