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RESEARCH

Fortified Groundnut Shells as a Soil Amendment for Improved Productivity in Oilseed Based Cropping System of Semi-arid Tropics (SAT) India

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Abstract

Soil degradation in semi-arid regions is alarming due to changed climate impacting the rainfall patterns and temperature affecting soil physico-biological properties adversely. In India, cattle shed bedding technology (CSBT) using crop residues is cheaper, easy-to-use residue recycling method for small holders in semi-arid regions. The present research work was carried out with a specific objective of soil improvement leading to resilience of land use system using indigenously available fortified crop residue for enhanced crop and cropping system yields under both rainy and post rainy conditions in semi-arid tropics of India. Thus, a study was conducted for 2 years (2013–2014 and 2014–2015) in the farmers fields with treatments having various fortifications like bedding material with groundnut shell and its manure, compost over existing practice among farmers on rainfed groundnut-fallow (L-F), castor-groundnut (NL-L) and groundnut–groundnut (L–L) oilseed based cropping systems. These systems were evaluated for soil quality parameters, productivity, fertility, soil moisture retention, compaction, crop land utilization and economics. In different cropping systems, use of fortified groundnut shell @ 16.3–22.6 t ha^{-1} $year^{-1}$ was able to recoup the soil nutrient losses (183.0 kg N, 6.1 kg P, 227.0 kg K and 0.3 kg OC ha^{-1} $year^{-1}$) closely followed by compost and distantly by inorganics application with additional benefit of enhanced crop yields by 20.2–33.1% during subsequent rainy and 20.0–25.0% during post-rainy season, improved available water content (10.7–20.3%) and increased irrigation interval by 3–5 days in NL-L and L–L system. Hence, the principle of fortifying crop residues through CSBT could be utilized globally in similar agro-ecological regions for addressing soil degradation and effective crop residue utilization for small and marginal landholders farmers.

Keywords Soil degradation · Value added manure · Sustainable crop intensification · Crop diversification · Indigenous soil fertility management · Soil moisture conservation · Crop residue

Introduction

India's 187.8 mha of land area has been degraded due to non-adoption of proper soil and water conservation measures, inappropriate land use and improper crop rotation leading to soil erosion (Bhattacharyya et al. 2015). In rainfed areas, due to frequent change in the pattern of rainfall intensities, the soil in peninsular India is more prone to degradation than other land locked areas affecting the productivity in the range of 15–67% at various degrees of soil erosion (Selvarajan et al. 2004). The degradation was observed in terms of change in soil structure and texture leading to loss of porosity, nutrients, soil organic carbon, bioactivity and productivity. The average annual soil loss of semi-arid regions of rainfed agriculture in India is less than 5 t ha^{-1} (Bhattacharyya et al. 2015) causing organic matter loss @

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11–15 g kg^{-1} of soil (1.1–1.5% by weight) (Lal 2015). Due to soil erosion and loss of organic matter, the sub-soil has lesser capacity to withhold water affecting plant growth. Agriculture is ensconced with the changing weather and extremes besides poor soil fertility and low productivity (<1 t ha^{-1}) in rainfed areas (78 m ha). In rainfed areas of India, change of weather and extremes are witnessed in the form of frequent droughts, high rainfall intensities, floods, hailstorms, etc. which triggers the soil erosion process affecting the soil quality in terms of loss of productive top soil leading to crop failures and livelihood insecurities.

In order to compensate the soil and nutrient losses, different crop residue or its product incorporation into the soil can be a viable strategy. India produces about 500 Mt of crop residues annually (MNRE 2009), out of which about 140 Mt is burnt in the fields after harvest of the preceding crop due to unavailability of labour, high cost in removing residues and lack of awareness and access to technologies about the alternate usage of crop residues with value addition (Derpsch and Friedrich 2010). Burning of crop residues result into greenhouse gas (GHG) emission, human health problems, loss of plant nutrients (Crutzen and Andreae 1990) and soil degradation (Lehtinen et al. 2014). The poor availability of quality manures under rural conditions necessitates generation of high fertile manures using locally available materials with indigenous techniques. Since, the fortified manures carry high nutrients, they can be a very good replacement of the indigenous farmyard manure. Vermi-compost and bio-fertilizers require technical knowhow, high investment and availability of quality biological inputs. An illiterate and resource poor farmer in semi-arid regions can prepare the fortified manures from crop residues like groundnut shell easily using indigenous techniques with family labour as compared to other bio-techniques of compost making. Fortified groundnut shell manures are more economical with high nutrient content having low labour requirement and less organic fertilizer investments. In this context, conversion of crop residues into manure, its fortification and the consequences of applying various organics in rainfed cropping systems need to be prioritized.

The crop residues are used in semi-arid regions depending on its lignin content, density, and palatability by livestock and nutritive value. Most cereal and pulse residues have fodder and fuel value. The groundnut shell is the abundant (15 Mt $year^{-1}$) one of the locally available biomass in India which is bulky and easy to transport (Purohit and Dhar 2015; Kumar et al. 2015). The high C/N ratio, low P and high crude fibre content of groundnut shell makes it difficult to decompose (Paul et al. 2017) which otherwise can only be exploited using indigenous techniques, like cattle shed bedding technology (CSBT) for converting them into manures using cattle dung and urine. Addition of organics is one of the measures that improve soil health and induce drought resilience (Bianca et al. 2008) apart from improving the soil micro-climate. So, fortifying locally available organic material can help small holder farmers to produce sufficient quantities of organic material for improving their soil quality. Use of fertilizer is an expensive affair and utilizing excess of crop residues for preparation of manure may be a choice for livestock rearers. The present concept also has a wider applicability for the countries having similar agro-ecological and socio-economic conditions such as Africa.

Crop residues, livestock dung and urine are some of the renewable energy sources and using them for the soil health maintenance is a sustainable option (Liu et al. 2008). Organic matter in semi-arid regions is declining due to long fallow period consisting of 3–4 cold months (October–January) and 3–4 dry summer months (February–May) with no crop cover between two consecutive rainy season crops necessitating soil amendments. Therefore, the present study was an attempt to assess the effect of various organics (including the manure generated from fortified groundnut shell) in conjunction with inorganics on soil and crops of rainy and post rainy seasons to intensify production systems. Through this study it was planned to address the issues of improving soil quality and moisture conservation through fortified crop residues and land diversification for more resilience in the rainfed cropping systems.

In order to improve productivity of oilseeds and pulses in peninsular India (contribute more than 80% production from rainfed regions), intensification is one option, which has disadvantage of excessive exploitation of natural resources. Sustainable crop intensification will be an effort to intensify cropping system with balanced utilization of land, water, energy and other inputs (agri-ecosystem) which are short in supply (Pretty et al. 2011, Murungweni et al. 2016). This approach involves logical blend of both crop and livestock for enhancing crop productivity wherein food security in future can be dealt more with suitable combinations of crop intensification as well as diversification in these areas.

Achieving food security may not entirely be possible with the common trend of lone rainfed crop grown in a year. To reduce pressure on water resources, which otherwise is caused due to exploitation of ground water for growing second crop during post-rainy season in a year, better quality rainfed lands could be brought under medium duration rainfed cropping followed by an irrigated post-rainy crop. Therefore, a strategy of growing a second successful crop on the same land by integrating it with the post-rainy season irrigation using fortified organics and on farm reservoirs (Reddy et al. 2017) can be successful in drylands. The present study is based on the hypothesis that with fortified organics application, soil quality improvement along with restoring microbial fauna and moisture conservation can be attributed for achieving higher productivity and crop land utilization. Therefore, sustainable crop intensification and diversification is possible through integration of rainy and post-rainy season crops on the same piece of land with a view to extract maximum advantage of applied organics and limited water.

Materials and Methods

Selection of Suitable Indigenous Technology

Groundnut Shell (GS) usage for manure preparation was selected as one of the best indigenous soil fertility management practices followed by the farmers through a survey using focused group meetings and personal interactions in three villages of Anantapuramu district, Andhra Pradesh (14°52′N and 77°63′E to 14°90′N and 78°01′E namely, Bukkarayasamudram, Tadipathri and Bathalapalli) and two villages of Nagarkurnool district, Telangana (16°41′N and 78°87′E to 16°44′N and 78°95′E namely, Chitlam Kunta and Padara) in Deccan Plateau of Southern India (Fig. 1). The average annual rainfall of the selected area was 560 mm with prominent monsoon season during June to September.

Fortification of Groundnut Shell

Groundnut shell layer of 50 mm thickness was spread in the cattle shed to be laden with cattle urine and dung (usually a week) and then heaped for 2–3 months for decomposition (Maruthi et al. 2008). The end product is called as Fortified Groundnut Shell (FGS), which was incorporated into the soil during preparatory cultivation of the crop. The cost of producing one quintal of FGS is around $ 7.5.

Field Experiments

Based on the lessons learnt from the experiments earlier in this area (Maruthi 2006), it was felt to experiment on cropping systems as a consequence to the improvement in the soil quality and water retention. Looking to its relevance and applicability for other similar semi-arid regions, two villages between 16°33′N and 78°13′E to 16°46′N and 78°21′E (Tadiparthy and Edammagadda) in Mahabubnagar district, Telangana, India (Fig. 1) were selected for the fortification experiments and carried out during a rainy normal year (2013–2014) and rainy deficit year (2014–2015). Rainy deficit year was decided on the basis of seasonal rainfall when received less than 25% of its long-term average value (607 mm in the study area) as per Shewale and Kumar (2005). The Mahabubnagar district has similar climatic conditions as that of Anantapuramu district of AP, India with mean sea level of 498 m, average annual rainfall of 560–600 mm during prominent monsoon season (June–September) and annual average temperature varying from 25.0 to 40.9 °C.

During the rainy deficit year (2014–2015), a total annual rainfall of 325 mm was received in 32 rainy days with peaks in June and September. There were two long dry spells of 24 days duration during pegging and pod filling stages of groundnut crop affecting the yields while the same affected the flowering and seed filling of primaries in castor (*Ricinus communis* L.) crop. During the rainy normal year (2013–2014), the total rainfall of 607.2 mm was received in 40 rainy days with no dry spell in its distribution during the crop period.

Groundnut (*Arachis hypogaea* L.) and castor are predominantly grown in the Mahabubnagar district. A systematic experiment was conducted introducing fortified groundnut shell (FGS) along with the other organic treatments over Existing Method (EM). Usually existing method followed is the use of Farm Yard Manure (FYM) @ 1t ha^{-1}along with Inorganics only (IO) @ 17.5:36.3:17.5 NPK. Other methods included Unfortified GS application (GS), fortified GS application (FGS) and compost application @ 1 t ha^{-1} in addition to EM and only inorganics (IO) @ 19:38:19 NPK.

For experimental purpose, 12 small holder farmers having livestock were selected for promoting different methods of organic usage after proper training and guidance.

Experimental Details

The experiments were laid out separately for each cropping system, i.e., rainfed groundnut-fallow (L-F); castor-groundnut as non-legume oilseed and irrigated legume oilseed combination (NL-L); groundnut–groundnut as legume oilseed combination (L–L) in a randomized block design at the farmers' field (Table 1). All five treatments including EM were imposed on these three cropping systems and replicated four times. Application of fortified organics was done once in a year and for 2 years in all the systems for the rainy season crops.

Analysis of Samples

Samples of all the treatments were analyzed for organic carbon (OC), nitrogen (N), phosphorus (P) and potassium (K) contents (Table 2). Soil samples were collected at 20 cm depth from five locations in each plot before and after crop growth period. Besides this, OC was analyzed by Walkley and Black (1934), available N by Subbaiah and Asija (1956), available P by Olsen et al. (1954) and available K by Hanway and Heidel (1952) methods.

A total of 120 plant samples comprising of 40 samples from each cropping system were taken from two adjacent $0.5 \times 0.5\ m^2$ plant samples from five locations in each plot during and after crop growth period (Kurniatun et al. 2001) in two villages of Mahabubnagar district. Samples were dried and weighed for determining total dry matter produced from each system. Micro-Kjeldhal method (Humphries 1956) was used for estimating plant N; triacid digests for P and K using spectrophotometer and flame photometer, respectively (Jackson 1973). For soil

Fig. 1 Location of study area

microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN), 40 fresh soil samples from each cropping system were taken in the plots of 12 farmers. The chloroform fumigation-incubation method (Jenkinson and Powlson 1976) was used to estimate SMBC and SMBN.

Soil and Plant Parameters

The experimental fields had alfisol of sandy loam textural class comprising 70–75% sand, 7.0–7.5% silt and 17–19% clay with bulk density of 1.35–1.43 g cm^{-3}. Soil moisture was measured gravimetrically. Soil resistance was measured in kilo Pascals (kPa) by soil penetrometer (Proving ring Penetrometer, ASAHI) to assess the soil friability. Initial and final soil samples before and after the crop growth period were analyzed for physical, chemical and biological properties to assess the soil quality and productivity. The pod and haulm yields at harvest were collected for each treatment. Castor yields were converted into Groundnut Equivalent Yields (GEY) (Ghosh et al. 2003).

Table 1 Characterization of production systems

Particulars	Groundnut-fallow (L-F)	Castor-groundnut (NL-L)	Groundnut-groundnut (L–L)
Season and Crop	Rainy season rainfed groundnut—post rainy Fallow	Rainy season rainfed Castor—post rainy irrigated groundnut	Rainy season rainfed groundnut—post rainy irrigated groundnut
Varieties	TMV-2—Fallow	Kranthi—TMV-2	TMV-2—TMV-2
Duration	105–110 days—Fallow	150–220 days—105–110 days	105–110 days—105–110 days
Sowing time—rainy	Second week of June	Second week of June	Second week of June
Sowing time—post-rainy	–	Second week of October	Second week of October

L leguminous, *F* fallow, *NL* non-leguminous

Table 2 Nutrient compositions of different materials used in the experiment ($n=72$)

Materials	N (%)	P (%)	K (%)	Organic carbon (%)
Cattle dung	0.52 ± 0.01^{a}	0.30 ± 0.01^{d}	0.21 ± 0.01^{a}	31.00 ± 1.08^{c}
Cattle urine	0.83 ± 0.01^{b}	0.0013 ± 0.0001^{a}	0.72 ± 0.03^{d}	09.90 ± 0.81^{a}
Cattle dung and urine mix	0.62 ± 0.01^{a}	0.015 ± 0.001^{b}	0.43 ± 0.02^{bc}	17.23 ± 0.56^{b}
Groundnut shell	1.04 ± 0.06^{c}	0.06 ± 0.002^{b}	0.45 ± 0.02^{bc}	34.22 ± 2.03^{c}
Fortified groundnut shell (FGS)	1.82 ± 0.19^{d}	0.16 ± 0.01^{c}	0.57 ± 0.02^{bc}	22.70 ± 1.11^{b}
Farm yard manure	0.75 ± 0.01^{b}	0.22 ± 0.01^{c}	0.39 ± 0.01^{b}	29.13 ± 1.21^{bc}
Compost	0.64 ± 0.01^{a}	0.14 ± 0.01^{c}	0.55 ± 0.01^{bc}	23.50 ± 1.53^{b}

^{abcd}Different superscripts in different rows differ significantly at $p < 0.05$

Cropping System Performance Indices

Indices, like total system productivity (TSP) was determined using Ghosh et al. (2003).

$$\text{TSP (kg per ha)} = \frac{\text{Total system yield (kg)}}{\text{Area (ha)}}$$

Pod yields of rainy groundnut/Groundnut Equivalent Yield (GEY) of castor was added to the yield of post-rainy season groundnut crops to determine total system productivity (TSP).

Harvest index is the ratio of pod yield to the total biomass yields (Ghosh et al. 2003)

$$\text{HI} = \frac{\text{Economic Yield (kg per ha)}}{\text{Economic Yield (kg per ha)} + \text{Total dry matter Yield (kg per ha)}}$$

Cultivable land utilization index (CLUI) was determined using the method suggested by Varvel et al. (2007) which indicates days of crop occupying the land in a year and was calculated as below.

$$\text{CLUI} = \sum_{i=1}^{n} \frac{\text{Land area occupied by each crop (ha)} \times \text{actual duration of that crop (days)}}{\text{Total cultivated land area (ha)} \times 365}$$

BC ratio was calculated as the ratio of gross returns (\$ ha^{-1}) and cost of cultivation (\$ ha^{-1}) for each cropping system.

In existing method at farmer's field, groundnut crop was irrigated at 7 days intervals during post-rainy season, however, during rainy season, crops were solely rainfed. After the application of fortified organics to the soil, the soil moisture measurements were made taking soil samples ($n=72$) and their field capacity (FC) and permanent wilting point (PWP) were determined by using pressure plate apparatus at 0.3 bar and 15.0 bar, respectively. Soil moisture was measured at 20 cm depth from all critical stages [in groundnut crop at flowering (20 Days After Sowing (DAS)], pegging and pod formation (40 DAS) and pod filling (70 DAS) and in castor at vegetative (30 DAS), flowering (60 DAS) and capsule filling (105 DAS) using gravimetric method. The available water (AW) was calculated on weight basis by using the above data under different cropping systems. Considering the crop evapo-transpiration (ET) and 50% allowable moisture depletion (AMD) of AW, the irrigation intervals for different treatments were calculated. Soil loss was estimated by collecting run off water sample from the experimental plot and analyzed the silt load content by using filtration and gravimetric method.

Statistical Analysis

The experiments were laid out in a randomized complete block design with five treatments and six farmers as replicates. Experimental results for each cropping system were analyzed using ANOVA for RCBD (Gomez and Gomez 1984). The independent variables in the study are soil moisture, value added products, however, the dependent variables are soil organic carbon, nutrient availability, N, P, K, SMBC, SMBN, soil resistance, etc. Statistical significance of treatments was determined using F test and treatments were compared using LSD at 5% probability. Pooled analysis of results of 2013 and 2014 were not undertaken as the 2 years were markedly different in terms of rainfall received in the study area. 2014 was a drought year received only 265.4 mm rainfall during groundnut (110 days), and castor (180 days) growing period while 2013 was normal with 543.8 mm rainfall during crop growth period of groundnut (110 days) and castor (180 days).

Results and Discussion

Farmers in arid and semi-arid regions of India keep one or another type of livestock with few acres of cropping system, whose residues are treated as waste under field conditions. The present experiment was planned keeping in view of not only utilizing the available residues into functional resources but also to improve soil health and profitability for enhanced resilience in the system. Drought resilience (Kassam et al. 2009) starts with healthy soils (1% Organic Matter is equivalent to 150 m^3 water ha^{-1}), therefore, declined soil health and water holding capacity together were addressed in this study to manage soil degradation.

Soil Moisture Characteristics

The soil moisture content was significantly ($p < 0.05$) increased at FC of the soil in different organics applied plots (Fig. 2) with minimum in L-F and maximum in L–L system. Among different treatments, FGS was able to retain maximum soil moisture in L–L followed by NL-L system. The average soil moisture content at PWP varied from 5.3 to 6.9% w/w in all the treatments with minimum soil moisture of 5.3% w/w in FGS under L–L system.

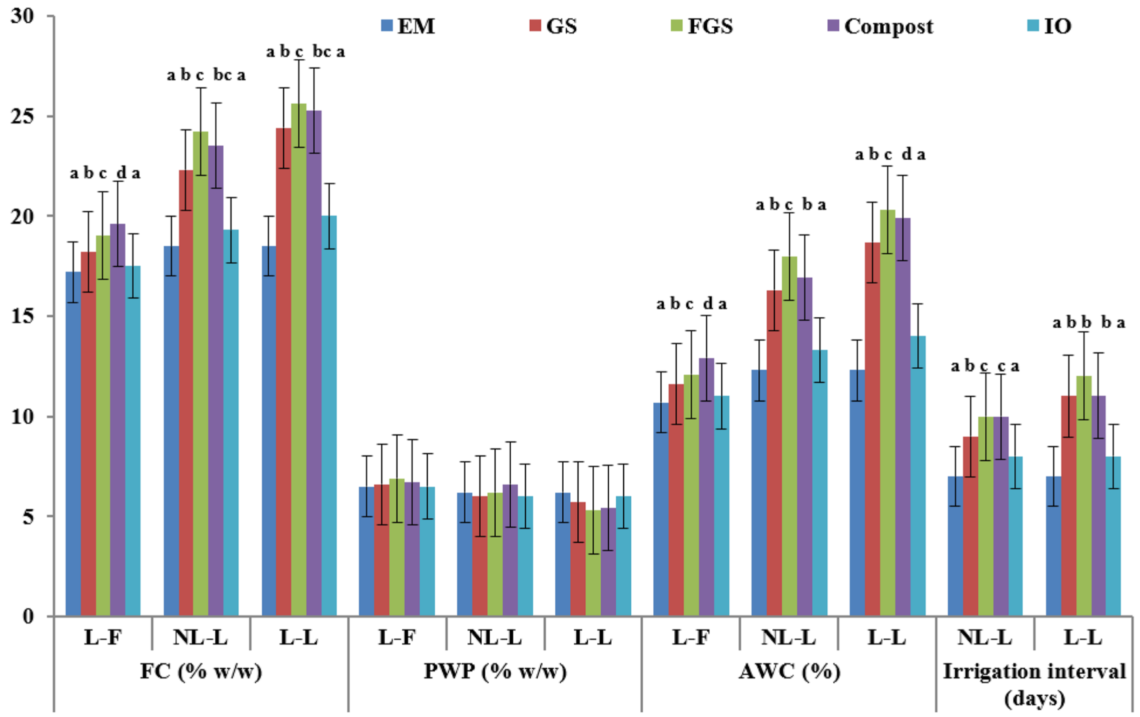

Fig. 2 Average available soil moisture in the profile in three different cropping systems in 2 years of experimentation. Irrigation interval for L-F system has not been considered as the fields were fallow during post-rainy season. *EM* existing method, *GS* groundnut shell, *FGS* fortified Groundnut shell, *IO* inorganics only, *L* leguminous, *NL* non-leguminous, *F* fallow, *FC* field capacity, *PWP* permanent wilting point; *AWC* available water content. ^{abcd}Different superscripts in each sub-head vary significantly at $p < 0.05$

The average Available Water Content (AWC) was maximum in FGS treated plots under L–L system followed by Compost and GS. As a result, irrigation interval was increased by 5 days in FGS as compared to EM followed by 4 days in both GS and Compost treated plots under L–L system. Application of GS as such in L–L sequence system had shown improved performance with the continuous soil moisture availability enhancing the soil microbial activity (Perucci et al. 1997).

Nutrient Supply by Different Organics

FGS had more potential of supplementing major nutrients N, P and K with 1.82, 0.16 and 0.57%, respectively along with an OC content of 22.7% (Table 2). The remaining organics used in the experiment, like GS, compost and inorganics had lower values of N, P and K as compared to FGS, though their OC contents are superior (23.5–33.2%) except cattle urine (9.9%).

Yield and Yield Attributes of the Oilseed Based Cropping Systems

Rainfed Groundnut-Fallow (L-F)

During the rainy deficit year (2014) with 57% of average rainfall, lowest mean yields ranged from 423 to 566 kg ha^{-1} in different treatments which was mainly due to reduction in number of filled pods per plant (42.3–56.5%) and mean 100 seed weight (17.9–32.4%) in different treatments (Table 3) over rainy normal year (23–26 filled pods per plant and 37.3–38.6 g seed weight). However, during the rainy normal year (2013), yields obtained were in the range of 1841–2213 kg ha^{-1} in different treatments which was 74.4–77.0% more than that of rainy deficit year with an increase of —% and —% in both number of filled pods per plant and mean 100 seed weight respectively. Harvest Index was not significantly affected by the varying rainfall in both the years. FGS and compost applied plots registered maximum yields during both the years with an increase of 9–19% over EM. Application of IO performed equivalent to EM in a rainy deficit year, however, a significant ($p < 0.05$) increase of 9% in yields was obtained in a rainy normal year.

In most of the arid and semi-arid regions with 110–120 days crop growing period, only one crop can be grown during the rainy season. During the rainy deficit year, although there was a 24 days dry spell at pegging stage of groundnut, FGS improved soil moisture availability enhancing the uptake of N by 10% and P by 6%, besides increasing the microbiological activity in soil by 20–25% for attaining the threshold levels of dry matter production. Increased 100 seed weight (6–8%) and number of filled pods per plant (40–50%) augmented yields in both FGS and compost applied plots over the EM. Furthermore, an indirect advantage of reduced soil resistance for easy root and peg penetration was observed. Although mild and severe moisture stresses reduce diffusion rates of plant nutrients (Ghanbari et al. 2011), the compositions, variations in concentrations of soil solutions (Junjittakarn et al. 2013) affected the nutrient uptake and enhanced soil moisture-holding capacity for extra 5 days over EM. These were attributed to the improved soil moisture and organics decomposition releasing the nutrients (Figs. 2, 3), improved soil health chemically and biologically. According to Hoang et al. (2014), mid-season deficit rainfall affects the fine root growth, water movement and ionic diffusion in soil, reducing nutrient uptake thus causing low dry matter accumulation.

Castor-Groundnut (NL-L)

Significantly ($p < 0.05$) higher castor yields over EM, GS and IO treated fields in terms of GEY were recorded from FGS and compost applied fields as 411 and 405 kg ha^{-1} during rainy deficit year, whereas 722 and 705 kg ha^{-1} were obtained during rainy normal year, respectively (Table 3). During post-rainy season of rainy normal year, significant groundnut crop yields were recorded with FGS and compost treatments over GS, IO and EM. The 100 seed weight of groundnut improved significantly ($p < 0.05$) in all the treatments over the EM irrespective of the amount of rainfall received. The maximum pod yield in rainy normal year was obtained in FGS plots followed by compost applied plots in rainy and post-rainy seasons. There was significant ($p < 0.05$) difference in the yield attributes of treatments in terms of filled pods per plant over the EM which was maximum in FGS followed by the compost treated plots. However, there was 50% reduction in the filled capsules per plant in castor during rainy season of rainy deficit year.

Indian farmers of semi-arid tropical region review the deficit rainfall situation and see the availability of ground water during the rainy season to take decision on continuing the long duration indeterminate crop into the post-rainy season to harvest extra yields. In such situations, castor crop can be grown beyond 150 days through secondaries, tertiaries and sometimes quaternaries for multiple harvests without switching to the irrigated groundnut as second crop. In this study, the non-legume oilseed crop was in primaries stage when the dry spell occurred during deficit year of experimentation, affecting castor sex ratio expression leaving only 45–50% female flowers in the raceme to be converted into capsules and into seeds. FGS and compost applied treatments performed at par, while yields from IO and/or EM were lowest. Yields improved by 25–30% through fortified organics concomitantly increasing phosphorus uptake by 20% (Shaxon and Barber 2003) in castor. This is attributed to the altered

Table 3 Impact of value added groundnut shell on pod yields, 100 seed weight and harvest index of three cropping systems

Treatments	Groundnut-fallow (L-F)				Castor[a]-groundnut (NL-L)				Groundnut-groundnut (L–L)			
	Rainy deficit year		Rainy normal year		Rainy deficit year		Rainy normal year		Rainy deficit year		Rainy normal year	
	R14	PR14–15[b]	R13	PR13–14[b]	R14	PR14–15[b]	R13	PR13–14[b]	R14	PR14–15[b]	R13	PR13–14[b]
Pod Yields (kgha^{-1})												
EM	423	Fallow	1841	Fallow	328	No second crop due to drought	655	2465	465	2066	2029	2869
GS	467		1942		353		685	2881	522	2188	2402	3458
FGS	566		2213		411		722	3317	537	2552	2772	3713
Compost	525		2014		405		705	3218	502	2436	2656	3544
IO	475		1956		336		696	2945	462	2188	2430	3226
LSD (p = 0.05)	29.5		123.4		40		47	236	42	123	363	274
Harvest Index												
EM	0.36	Fallow	0.40	Fallow	0.16	No second crop due to drought	0.18	0.33	0.36	0.40	0.40	0.33
GS	0.37		0.41		0.16		0.18	0.33	0.36	0.41	0.44	0.35
FGS	0.38		0.41		0.17		0.19	0.35	0.35	0.43	0.46	0.34
Compost	0.35		0.39		0.18		0.18	0.36	0.37	0.43	0.45	0.34
IO	0.36		0.40		0.17		0.18	0.35	0.35	0.43	0.43	0.35
LSD (p = 0.05)	–		–		–		–	–	–	–	–	–
100 seed weight (g)												
EM	25.2	Fallow	37.3	Fallow	22.2	No second crop due to drought	37.9	38.4	25.8	32.7	40.1	39.8
GS	30.4		38.1		22.5		40	39.3	30.8	33.4	40.3	40.1
FGS	31.7		38.6		23.2		40.7	40.0	33.4	37.5	41.9	40.7
Compost	29.9		38.5		23.1		40.1	39.9	32.5	36.3	41.7	40.5
IO	28.7		38.1		22.2		38.8	39.8	29.4	33.5	40.2	40.1
LSD (p = 0.05)	1.37		0.8		0.16		0.18	0.33	1.8	2.2	NS	NS
Filled pods/capsules/plant (No.)												
EM	10	Fallow	23	Fallow	10	No second crop due to drought	23	26	12	16	25	28
GS	12		24		12		24	28	14	20	27	34
FGS	15		26		15		26	32	16	24	30	38
Compost	14		25		14		25	30	15	24	29	38
IO	13		24		12		24	29	13	18	27	34
LSD (p = 0.05)	0.3		1		2.33		2	1.2	0.6	4	1.3	0.9

R13 rainy 2013, *R14* rainy 2014, *PR13–14* post-rainy 2013–2014, *PR14–15* post-rainy 2014–2015, *EM* existing method, *GS* groundnut shell, *FGS* fortified groundnut shell, *IO* inorganics only, *LSD* least significant difference

[a] Castor yields converted into groundnut equivalent yields by equating income of selling castor with the cost price of Groundnut

[b] All the post-rainy season crops were irrigated (Groundnut @ $ 35.38 per quintal (q); castor $ 27.69 per q)

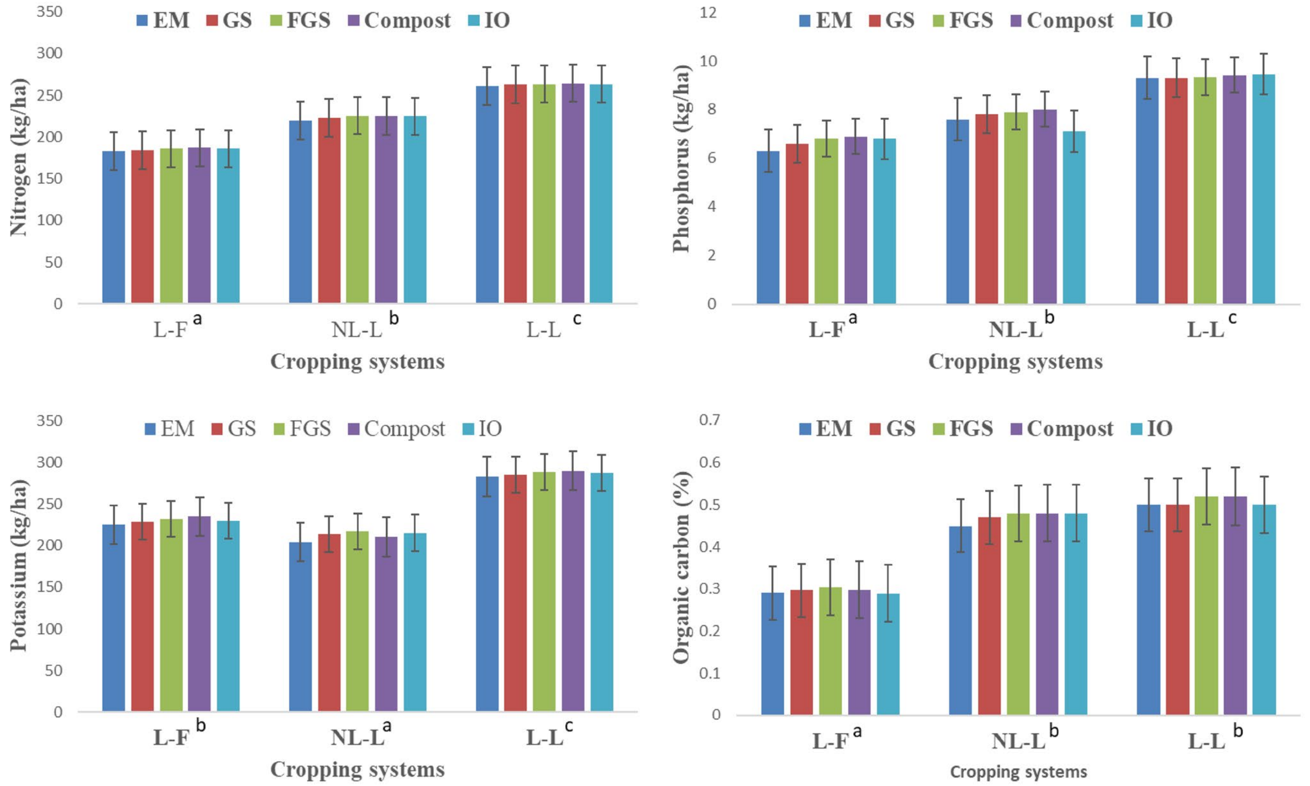

Fig. 3 Changes in the chemical properties of the soils in three oilseed based cropping systems after 2 years of experimentation (n = 72). *EM* existing method, *GS* groundnut shell, *FGS* fortified groundnut shell, *IO* inorganics only, *L* leguminous, *NL* non-leguminous, *F* fallow. ^{abc}Different superscripts in each sub-head vary significantly at $p < 0.05$

nutrient balance (Puangbut et al. 2011) by castor being a non-legume oilseed crop and drawing more P and less K compared to the post-rainy groundnut (Table 4). During both the seasons, FGS was found to be superior in terms of N uptake by the plants due to improved availability of soil moisture and nutrient conversion.

In this study, during a rainy normal year, groundnut as a second crop in the post rainy season with all the treatments registered improved yields except EM while slower decomposition of groundnut shell and reduced organics in EM affected the yields significantly ($p < 0.05$). Fortified organics application to rainy season crops increased soil moisture availability by 8.1–46.3% over EM with maximum in FGS and minimum increase in IO treated plots. As a result, the increase in AWC in the soil, helped to advance the irrigation interval by maximum of 3 days thereby reducing the frequency of irrigation and utilizing the limited available water efficiently. Application of FGS and compost could be

Table 4 Average Nutrient uptake (kg ha^{-1}) by three rainfed cropping systems as influenced by value added organics (n = 64)

Treatments	Groundnut-fallow (L-F)				Castor-groundnut (NL-L)						Groundnut-groundnut (L–L)					
	R14–15			PR14–15	R14–15			PR14–15			R14–15			PR14–15		
	N	P	K		N	P	K	N	P	K	N	P	K	N	P	K
EM	62.1	17.1	55.9	Fallow	50.7	18.9	39.8	76.2	16.8	56.2	68.1	19.1	60.2	80.1	17.1	62.3
GS	62.2	17.2	55.0		46.2	18.9	38.3	69.5	16.8	53.9	66.2	17.4	59.1	76.2	17.2	60.4
FGS	68.5	19.9	61.1		61.8	22.9	42.8	83.4	18.9	67.4	75.7	20.3	64.3	87.3	19.4	68.2
Compost	64.1	18.1	59.8		55.7	21.2	42.4	80.7	16.8	67.1	73.4	19.2	62.2	86.1	18.5	65.6
IO	64.2	18.0	56.5		54.8	16.4	32.4	78.7	16.6	65.2	71.2	18.8	60.9	84.3	18.8	65.4
LSD 5%	4.12	0.62	4.18		4.22	4.27	5.01	2.28	0.91	4.34	6.11	3.71	4.17	6.29	2.94	6.04

R14–15 rainy 2014–2015, *PR14–15* post-rainy 2014–2015, *EM* existing method, *GS* groundnut shell, *FGS* fortified groundnut shell, *IO* inorganics only, *LSD* least significant difference capitalized for increasing the irrigation interval, reducing number of irrigations and reduced soil resistance due to increased soil friability for both root and peg penetration (Benjamin et al. 2003). Similar advantage could be extracted from this type of flexible cropping system if practiced in Sub-Saharan countries besides South Asia from the prevalent long duration crops. This could be one way of crop diversification as it is the key approach in utilizing the scarce rain water in situ efficiently (FAO 2013).

Groundnut–Groundnut (L–L)

During deficit rainfall year, groundnut yields from FGS, GS and compost-applied plots were at par as compared to EM and IO treated plots (Table 3). During rainy normal year, the fortified organics was more effective in increasing the pod yield (four times during rainy season and nearly 1.5 times during post-rainy season) over the rainy deficit year.

In the sequence of castor-groundnut, castor was replaced with groundnut for further improvement in yields as was observed in both the seasons and years. This was attributed to the positive effect of continuous application of soil organics for 2 years that increased soil moisture availability by 14–65% over EM during crop growth period. As a result, the increase in AWC in the soil, helped to advance the irrigation interval by maximum of 5 days as reported in similar lines by Junjittakarn et al. (2013). Subsequently, an enhanced N and K uptake was observed by 5.0–8.8% and 5.5–10.0%, respectively in the present experiment with 3.0% reduced soil resistance for augmented peg and root penetration (Kritee et al. 2015). However, the treatment in which GS was applied, due to poor decomposition of the recalcitrant groundnut shell, N and K uptake was reduced by 5.0 and 2.6% over EM, respectively. Enhanced nutrient uptake over time reduces fertilizer requirement as well as cultivation costs. Expensive inorganic fertilizers and scarce organics compel the farmers to prudently use them for a sequence cropping. Organic manures and crop residues provide food for detrivores, stimulate plant growth and litter return contributing to stabilization of soil micro-climate (Benbi and Singh 1988).

Effect of Soil Fertility Management on Soil Quality

No significant change was observed in the experimental lands with soil textural characteristics in all the cropping systems except improvement in the soil water content at FC (Fig. 2). The average nutrient uptake of N, P and K by the plants was maximum in L–L, followed by L-F and NL-L cropping systems in rainy season and L–L followed by NL-L during post-rainy season (Table 4). Total nutrient uptake was high in post-rainy season groundnut as compared to rainy season castor and groundnut, but the uptake of P was high in castor as compared to rainfed groundnut. Although OC status improved from 0.45 to 0.47% in NL-L system, SMBC decreased significantly ($p < 0.05$) from 148.5 to 128.0 mg kg^{-1} of soil (Fig. 4). With significantly ($p < 0.01$) improved FC from 13.9 to 16.0% w/w and AWC from 8.6 to 10.7% w/w, PWP could be reached 10 days after irrigation (Fig. 2). OC increased from 0.47 to 0.50% in L–L systems which were two times over EM (Fig. 3).

Soil resistance declined after 2 years of organics application improving the soil infiltrability, where L–L system had significantly ($p < 0.05$) lower soil resistance as compared to NL-L and L-F systems (Fig. 5). Significantly ($p < 0.05$) friable soil was observed in FGS and compost applied fields. Among the treatments, lowest available N, SMBN and SMBC were observed with EM of all the systems (Fig. 4). Significant ($p < 0.05$) difference in SMBC was observed in both the

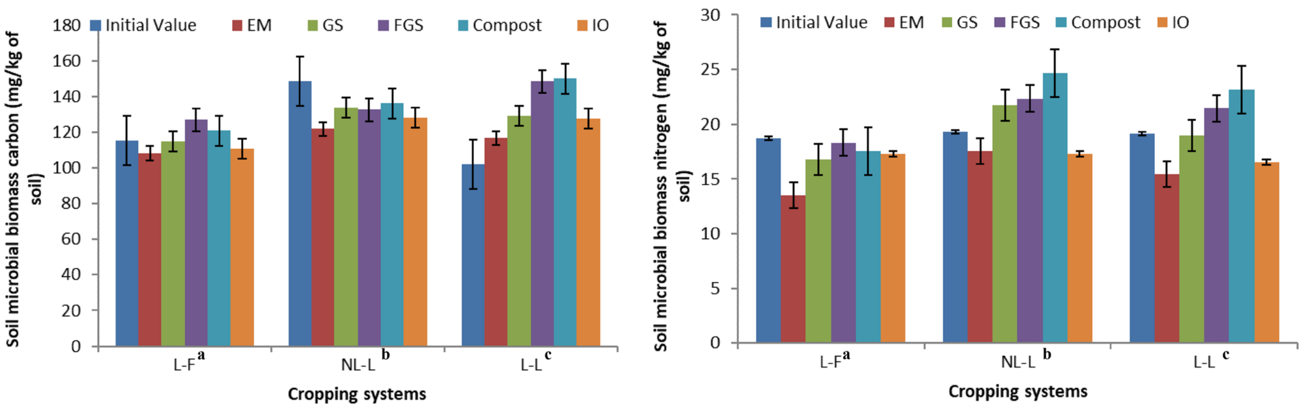

Fig. 4 Soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) in three rainfed cropping systems after 2 years of experimentation in farmers' fields as influenced by soil fertility management treatments. *EM* existing method, *GS* groundnut shell, *FGS* fortified groundnut shell, *IO* inorganics only, *L* leguminous, *NL* non-leguminous, *F* fallow. ^{abc}Different superscripts in each cropping system vary significantly at $p < 0.05$

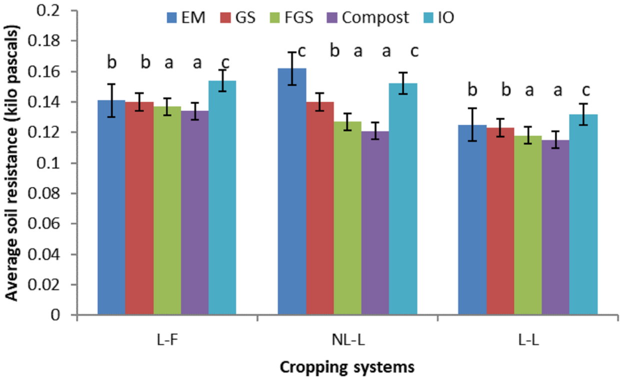

Fig. 5 Average soil resistance (kilo Pascals) recorded in the major oilseed based rainfed cropping systems at the end of 2-year experimentation. *EM* existing method, *GS* groundnut shell, *FGS* fortified groundnut shell, *IO* inorganics only, *L* leguminous, *NL* non-leguminous, *F* fallow. ^{abc}Different superscripts in each sub-head vary significantly at $p < 0.05$

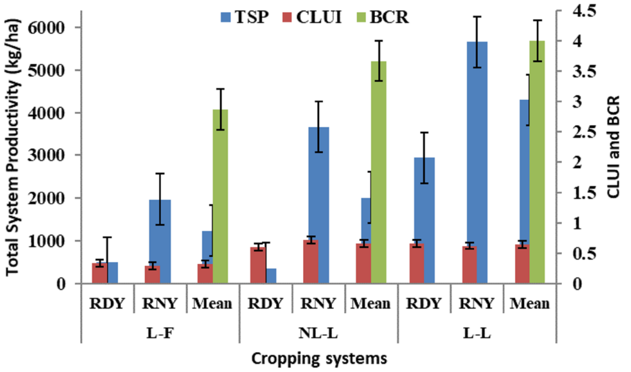

Fig. 6 System productivity, land utilization and economic indicators for oilseed based rainfed cropping systems as influenced by treatments. *TSP* total system productivity, *CLUI* cultivated land utilization Index, *BCR* benefit–cost–ratio, *RDY* rainy deficit year, *RNY* rainy normal year, *L* leguminous, *NL* non-leguminous, *F* fallow

sequence systems (NL-L and L–L), while only SMBN has shown improvement in L–L system.

After 2 years of experimentation, no conspicuous change in soil physical properties was noticed, however, available nitrogen and potassium were more in the soils of L–L system followed by L-F and NL-L systems. Soil nitrogen dynamics was conspicuous in castor as it is a non-legume crop and a high feeder of nitrogen (Chalk 1991). Also, there was a prominent change in OC due to higher leaf senescence from the castor crop during the deficit rainfall year and more biomass accumulation during the normal rainfall year (Zucca et al. 2016). Reduced SMBC and SMBN indicate reduced activity of microbes which calls for soil improvement measures to improve soil fertility levels as was observed in EM, GS and IO treated fields.

World rainfed regions with lighter soils are ensconced with the problem of long fallow periods between two rainy season crops. During this crop free period, land gets exposed to high temperatures (Bot and Benites 2005), intense solar radiation, strong winds and cyclones before the next year rainy season crop is sown. Owing to these aberrant conditions, quick degradation of soil organic matter occurs leaving the soil exposed to increased runoff and erosion affecting the resource base of the soil in the cropping system. In order to ward off this hazard, fortified organic manures have the advantage of restoring soil quality, improved soil moisture retention and nutrient availability and with increased yields.

Agronomic Indices for Productivity, Land Use and Profitability

Average TSP was 63% higher in NL-L system and 248% higher in L–L system as compared to L-F system (Fig. 6). During a deficit rainfall year, FGS and compost application enhanced TSP by 25% over EM. Land occupancy by the crops in the form of CLUI over the year was two times more in both NL-L and L–L systems (64–66%) than in L-F system (32%). Also benefit–cost–ratio of the NL-L and L–L cropping systems was 3.7 and 4.0, respectively as compared to the BC ratio of 2.9 in L-F system.

Rainfed L-F system registered low yields occupying land only 32% of total time in a year recorded lowest TSP (1.2 t ha^{-1}). However, performance of this type of cropping with long fallow periods in between could be improved only through application of low cost fortified crop residues. Though both NL-L and L–L systems occupied the land nearly 63% of time in a year, maximum benefit–cost–ratio was observed with L–L system (4.0) followed by NL-L system (3.7) and lastly the rainfed L-F (2.9) with a rider on availability of irrigation water (Lu et al. 2003).

The semi-arid regions of peninsular India are prone to soil erosion, frequent run offs, surface crust formation causing poor infiltration, moisture retention, loss of fertile surface soil and organic matter, sand casting, etc. leading to soil degradation. In the experimental area, a loss of 1.04 t soil ha^{-1} year^{-1} was observed through a runoff of 6–12% in 1–5% slope. This resulted into nutrient loss in terms of 183.0 kg N, 6.1 kg P, 227.0 kg K and 0.3 kg organic carbon (OC) per hectare per year. These losses in nutrients can be met by using either 3.7 t of FGS or 5.5 t of FYM or 4.5 t of compost in case of normal rainfall year. Through the field experiments in Mahabubnagar district, when the estimates to replenish the nutrient losses through soil degradation was made, it was found that FGS and compost were at par in meeting these requirements. In leguminous oil seed fallow system, 16.3–18.7 t of organics is able to meet the nutrient losses, however, in non-leguminous–leguminous oilseed cropping system, 21.3–22.6 t and in leguminous–leguminous oilseed cropping system, 17.3–21.2 t of organics will be required to do so.

Conclusions

FGS was found more advantageous over other conventional treatments by improving soil quality in terms of organic carbon, moisture retention, friability, productivity, soil fertility, SMBC, SMBN, system profitability and CLUI which ultimately prevents the soil degradation processes and improve yields. In different cropping systems, it was estimated that the use of FGS to the tune of 16.3–22.6 t ha^{-1} $year^{-1}$ will be able to meet the soil nutrient losses (183.0 kg N, 6.1 kg P, 227.0 kg K and 0.3 kg OC ha^{-1} $year^{-1}$) for sustaining through both crop intensification and diversification in rainfed lands of semi-arid tropics by improving land quality, productivity and its profitability. Additional benefit accrued to the other systems were 20–25% enhanced crop yields during post-rainy season, improved soil water holding capacity and increased irrigation interval by 3–5 days. The FGS should be preferred over compost due to easy methodology, ability to improve soil quality in terms of N, P, K and OC availability and indigenous nature. Application of fortified crop residues could improve the income of small and marginal farmers and organics resources by transforming rainfed lands into resilient land use systems for drought proofing during rainy as well as post rainy seasons. In case of rainy deficit years, mid-term correction as extended period of castor (NL-L) crop was found to be suitable, however, during rainy normal years, L–L system was found to be more profitable with maximum TSP and CLUI.

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