Indian Journal of Agronomy **58** (2): 168–174 (June 2013)

Research Paper

Effect of conservation agricultural and nutrient management practices on castor (*Ricinus communis*)–sorghum (*Sorghum bicolor*) cropping system in rainfed *Alfisols*

P. RAMESH[1], S.N. SUDHAKARA BABU[2], MD. A. AZIZ QURESHI[3] AND T. NAGENDRA RAO[4]

Directorate of Oilseeds Research, Rajendranagar, Hyderabad, Andhra Pradesh 500 030

Received : June 2012; Revised accepted : May 2013

ABSTRACT

A fixed-plot field experiment was conducted during 2010 and 2011 at Hyderabad, to study the effect of conservation agricultural (minimum tillage, crop residue and cover crop) and nutrient management practices (recommended dose of fertilizers, integrated nutrient management, organic nutrient management, fertilizers based on soil test crop response, and customized fertilizers) on the productivity, soil fertility, nutrient uptake and nutrient use efficiency of castor {*Ricinus communis* (L.)}–sorghum {*Sorghum bicolor* (L.) Moench} cropping system in rainfed Alfisols. There was no significant difference between the conservation and conventional agricultural practices with reference to yield attributes, seed yield and quality of either castor or sorghum. However, conservation agricultural practices resulted in higher castor equivalent yield, CEY (2.24 t/ha), economic returns (benefit cost ratio 1.72) besides improving soil organic carbon (0.41%) compared to conventional practices (2.081 t/ha of CEY, 1.60 B:C ratio and 0.37% soil organic carbon). Among nutrient management practices, customized fertilizers and fertilizers based on soil test crop response (STCR) resulted in about 18 and 15% increase in castor and sorghum seed yields, respectively compared to recommended dose of fertilizer (RDF). Application of customized fertilizers resulted in the highest system productivity (2.426 t/ha of CEY) followed by STCR (2.403 t/ha of CEY) compared to RDF (2.068 t/ha of CEY). Economic returns also followed trend similar to CEY. Organic nutrient management recorded the highest soil organic carbon (0.42%), soil available N (220 kg/ha) and K (434 kg/ha) compared to the control. Customized fertilizers recorded the highest uptake of nutrients in both castor (64.1–20.6–37.3 kg NPK/ha) and sorghum (118.3–39.3–152.5 kg NPK/ha) compared to RDF. Agronomic efficiency of N, P and K was in general, higher in either STCR or customized fertilizer treatments, whereas physiological efficiency of N, P and K was higher in INM, especially in castor.

***Key words* :** Castor, Conservation agricultural practices, Customized fertilizers, Nutrient management, Nutrient-use efficiency, Soil fertility, Sorghum

Castor is an important industrial oilseed crop and India accounts for 60 % of global castor area and 68 % of world castor production. The current castor production in the country is 13.37 lakh tonnes harvested from 8.85 lakhs ha with a productivity of 1.512 t/ha. However, wide regional disparities are encountered in its productivity with the highest being in Gujarat (1.964 t/ha) grown under irrigated conditions and lowest in Andhra Pradesh (0.509 t/ha) grown under rainfed conditions (Hegde, 2010). One of the important reasons for low productivity of castor is its cultivation in marginal and sub-marginal lands having poor soil quality i.e. shallow depth, low in organic matter content and poor fertility. These soils (mostly Alfisols) are susceptible to soil erosion and retain less moisture resulting in frequent drought-like conditions leading to poor castor productivity. Conservation agricultural practices *viz.*, minimum tillage, crop residue management and cover crops play an important role in bringing about favourable changes in soil physical, chemical and biological properties, which in turn improve the crop yields (Ramesh and Hegde, 2010). Conservation agriculture has potential for conserving resources and enhancing productivity to achieve the goals of sustainable agriculture.

Poor soil fertility coupled with inadequate and imbalanced nutrition and low/no application of organic manures is another important constraint for success crop production under rainfed conditions (Ramesh *et al.*, 2009).

[1]**Corresponding author Email**: pramesh.icar@gmail.com
[1]Principal Scientist, NAARM, Rajendranagar, Hyderabad 500 030; [2]Principal Scientist; [3]Senior Scientist, DOR, Hyderabad; [4]Head (Plant Nutrition) Nagarjuna Fertilizers & Chemical Ltd., Hyderabad 500 082, Andhra Pradesh

Site specific nutrient management (SSNM) practices *viz.*, fertilizers based on soil test crop response (STCR) equations (Subba Rao and Srivastava, 2002) and recent developments in the crop-specific customized fertilizers are drawing attention to improve the fertilizer recommendations for sustainable crop production. Customized Fertilizers (CFs) are multi-nutrient carriers designed to contain macro, secondary and/or micronutrients, manufactured through a systematic process of granulation, satisfying crop's nutritional needs, specific to its site, soil and stage, validated by a scientific crop model, capability developed by an accredited fertilizer manufacturing or marketing company. The farmers will have choice for CFs on account of crop and area specificity and the advantage of ready-to-use fertilizer material available to them. CF's can maximize nutrient use efficiency and ultimately programmed to improve soil fertility hence, they are falling under the category of environmental friendly fertilizers (Nagendra Rao and Rahman, 2011).

Castor–sorghum is the most important cropping system widely practiced on Alfisols under rainfed conditions of Andhra Pradesh. Keeping in view of the above facts, the present investigation was initiated to study the effect of conservation agricultural and nutrient management practices on the productivity, soil fertility, nutrient uptake and nutrient–use efficiency in castor–sorghum cropping system in rainfed Alfisols.

MATERIALS AND METHODS

A fixed-plot field experiment was conducted during *kharif* in 2010 and 2011 at research farm of the Directorate of Oilseeds Research, Hyderabad, Andhra Pradesh on Alfisols under rainfed conditions. The eco-region is characterized as semi-arid tropical (SAT) climate and the soil has been classified as red sandy loam with pH 6.3, EC 0.35 ds/m, low in organic carbon (0.35 %) and available nitrogen (210 kg/ha), medium in available phosphorous (22.0 kg/ha) and high in potassium (420 kg/ha) at the initiation of the experiment. Castor and sorghum were grown in 2010 and rotated with sorghum and castor crops in 2011. Castor hybrid 'DCH-519' and sorghum hybrid 'RSH-99' were sown during the first week of July and harvested during October (for sorghum) and December (for castor) in each year.

The treatments include two production systems *viz.*, conservational agricultural practices [minimum tillage, crop residue as mulch and cover crops (cluster bean in castor and horse gram after sorghum)] and conventional agricultural practices (farmer's practices *viz.*, deep plough every year, 2 mould board ploughs and 2 cultivators) in main plots. The sub-plots include six nutrient management practices *viz*., recommended dose of fertilizers (RDF), integrated nutrient management (INM), organic nutrient management (ONM), fertilizers based on soil test crop response (STCR), customized fertilizers (CF) and the control. The treatments were replicated thrice in split-plot design. The details of the nutrient management practices and their nutrient contribution were given in table 1.

In chemical fertilizer treatments, half the dose of nitrogen and full dose of phosphorus and potash was applied as basal dose at the time of sowing. The remaining nitrogen was top dressed in 2 splits ¼ at 30 days and ¼ at 60 days after seeding in both the crops. In ONM, FYM was applied a week before sowing and composted poultry manure was applied at 30 days after sowing for both the crops. The amount of manure was calculated based on nutrient composition and 100 % of recommended N. Sorghum crop was sown at 45 cm × 10 cm spacing, while castor was sown at 90 cm x 60 cm spacing. The main-plot size was 42 m × 8.0 m and sub-plot size was 7.2 m × 6.6 m.

In conservation agricultural treatment, cluster–bean as cover crop was sown between the rows of castor. The green pods of the cluster–bean as vegetable were harvested at 60 DAS. The crop residue of both cluster bean and castor (after harvest) was retained as mulch on the soil surface. Whereas in sorghum, after its harvest, horse gram was sown as cover crop with the available residual soil moisture and the crop was left for decomposition in the field.

The total rainfall received during the crop season (July - December) was 975 and 553 mm in 2010 and 2011, respectively as against the average rainfall of 730 mm. Comparison among different treatments was made by converting yield of 2 crops into castor equivalent yield on prevailing market price basis. The equivalent yield was calculated as under.

$$\text{Castor equivalent yield (t/ha)} = \frac{\text{Yield of sorghum(kg/ha)} \times \text{Price of sorghum(₹/kg)}}{\text{Price of castor (₹/kg)}}$$

After harvest, treatment wise seed and straw/stalk samples were collected for N, P and K nutrient analysis and for nutrient uptake. Nitrogen was determined by micro Kjeldahl method, P was estimated in aliquots calorimetrically using vanadomolybdate yellow color method and K was determined with flame photometer. Nutrient-use efficiency of N, P and K were calculated based on the formulae given by Duncan and Baligar (1990):

$$\text{Agronomic efficiency} = \frac{\text{Yield in fertilized treatment (Yf)} - \text{Yield in control (Yc)}}{\text{Amount of nutrient applied (Fa)}}$$

$$\text{Apparent recovery} = \frac{\text{Nutrient uptake in fertilizer treatment (Un)} - \text{Nutrient uptake in control (Uc)}}{\text{Amount of nutrient applied (Fa)}}$$

$$\text{Physiological efficiency} = \frac{Yf - Yc}{Un - Uc}$$

$$\text{Nutrient harvest index} = \frac{\text{Nutrient uptake in seed}}{\text{Total uptake by crop}} \times 100$$

At the end of the cropping cycle, the soil samples (0–15 cm) were collected and analyzed for organic carbon, available N, P and K, by adopting standard analytical methods (Singh *et al*. 2005). Statistical analysis of the data was carried out using standard analysis of variance.

RESULTS AND DISCUSSION

In general, the productivity of castor/sorghum was low in 2010 due to heavy rains (975 mm) received during the crop season (July–December), which resulted in excessive vegetative growth followed by severe incidence of *Botrytis* grey rot in castor and poor seed setting in sorghum. In contrast, the crop yields were higher due to the optimum and well distributed rainfall of 560 mm received during July–December of 2011 and without any biotic limitations.

Yield attributes and seed yield of castor

Yield attributes (spikes/plant, capsules/spike and 100-seed weight), seed yield, oil content and oil yield of castor was not affected significantly between the conservational and conventional agricultural practices (Table 2). Application of customized fertilizers (CF) recorded significantly higher number of spikes/plant (9.8), capsules/spike (38.5), 100-seed weight (26.5 g) and seed yield (0.92 and 1.528 t/ha in 2010 and 2011, respectively) compared to recommended dose of fertilizers (0.824 and 1.236 t/ha in 2010 and 2011) but were comparable with the treatment receiving fertilizers based on STCR (0.904 and 1.535 t/ha in 2010 and 2011). On an average, CF recorded 18.8% higher seed yield (1.224 t/ha) followed by STCR (18.3% higher seed yield, 1.219 t/ha) compared to RDF (1.030 t/ha). Integrated nutrient management (INM) recorded 4.3% higher seed yield (1.075 t/ha) and organic nutrient management (ONM) recorded 8.1% lower seed yield (0.946 t/ha) compared to RDF. Control plot (no manures) recorded significantly the lowest seed yield (0.770 t/ha), which was 25.2% lower than the RDF. Oil content of castor was not affected due to nutrient management practices but the total oil yield was the highest (586 kg/ha) in CF followed by STCR (579 kg/ha) and INM (512 kg/ha) and the lowest in control (364 kg/ha).

Yield attributes and seed yield of sorghum

Yield attributes (ear head weight, ear head length and 1,000-seed weight), seed yield and seed protein content of sorghum was not differed significantly between conservational and conventional agricultural practices (Table 3). Among the nutrient management practices, customized fertilizers (CF) recorded the maximum ear head weight (117.4 g), ear head length (34.6 cm), 1,000-seed weight (28.8 g) and seed yield (3.424 and 4.991 t/ha in 2010 and 2011) which was comparable with STCR (3.463 and 4.827 t/ha in 2010 and 2011) but superior to RDF (2.950 and 4.316 t/ha in 2010 and 2011). On an average, CF recorded 15.8% higher seed yield (4.207 t/ha) and STCR recorded 14.1% higher seed yield (4.145 t/ha) compared to RDF (3.633 t/ha). Control (no manures) recorded significantly the lowest seed yield (2.460 t/ha), which was 32.2% lower than the RDF. Seed protein content of sorghum was higher (10.09%) in CF, which was comparable with INM (9.96%) and STCR (9.87%). ONM and control plots recorded the lowest protein content of 9.12 and 9.18%, respectively.

Higher seed yields of castor and sorghum with customized fertilizers or STCR (Raghavaiah *et al.*, 2008) was due to favorable crop growth and higher yield attributing characters. In these treatments, nutrients are applied in proportion to the magnitude of deficiency of a particular nutrient and the correction of nutrient imbalances in soil helps in harness the synergistic effects of balanced fertilization. Choosing the right yield targets and application of appropriate nutrients helps in sustaining the soil fertility and crop yields (Subba Rao and Srivastava, 2002).

Total system productivity and economic returns

Conservation agricultural practices recorded higher castor equivalent yield, CEY (2.240 t/ha), net returns (49.6

Table 1. Nutrient management practices and their nutrient contribution

Nutrient management	Castor	Sorghum
Recommended dose of fertilizers (RDF)	60-40-30*	60-30-30
Integrated nutrient management(75 % RDF + 25 % N through FYM	60-36-37	60-28-37
Organic nutrient management(75 % N through FYM and 25 % N through poultry manure)	60-28-55	60-28-55
Fertilizers based on soil test crop response (STCR)	62-64-20	110-52-20
Customized fertilizers	65-50-37-17-5**	113-52-48-4***
Control	Nil	Nil

*Kg N, P_2O_5 and K_2O/ha; **kg N, P_2O_5, K_2O, S and Zn/ha; ***kg N, P_2O_5, K_2O and Zn/ha

× 10[3] ₹/ha) and B:C ratio (1.72) compared to conventional practices with 2.081 t/ha CEY and B:C ratio of 1.60 (Table 4). This was mainly due to the contribution of additional profit from cluster bean pods (1072 kg/ha) in conservation agriculture. Among the nutrient management practices, CF recorded significantly higher CEY (2.426 t/ha) compared to RDF (2.068 t/ha) but was on par with STCR (2.403 t/ha) and INM (2.145 t/ha). Economic returns were also higher in CF (1.81 B:C ratio) followed by STCR (1.78 B:C ratio) despite the higher fertilizer dose and cost.

Soil fertility and nutrient uptake

Soil organic carbon (0.41%) was significantly higher in conservational agricultural practices compared to conventional practices (0.37%). Soil available N, P and K were not affected between the two systems (Table 5). Among the nutrient management practices, ONM recorded significantly higher soil organic carbon (0.42%) compared to control (0.33%) and other treatments were at par. In general, CF, STCR and ONM recorded higher soil available N, P and K status compared to control plots. Application of CF recorded maximum uptake of nutrients both in cas-

Table 2. Effect of conservational agricultural and nutrient management practices on yield attributes, seed and oil yield of castor

Treatment	Yield attributes*			Seed yield (t/ha)			Oil content* (%)	Oil yield* (kg/ha)
	Spikes/ plant	Capsules/ spike	100-seed weight (g)	2010	2011	Mean		
Production systems								
Conservation agriculture	8.6	34.2	25.7	0.788	1.245	1.016	47.5	482
Conventional agriculture	8.5	33.3	25.9	0.790	1.352	1.071	47.7	510
SEm±	0.2	0.8	0.2	0.021	0.036	0.033	0.2	9.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient management								
Recommended dose of fertilizers	8.7	34.5	25.8	0.824	1.236	1.030	47.2	486
Integrated nutrient management	9.0	36.1	26.1	0.812	1.338	1.075	47.7	512
Organic nutrient management	8.0	32.6	25.5	0.708	1.184	0.946	47.7	451
Fertilizers based on soil test crop response (STCR)	9.1	38.1	26.0	0.904	1.535	1.219	47.5	579
Customized fertilizers	9.8	38.5	26.5	0.920	1.528	1.224	47.9	586
Control (No manures)	7.0	22.5	24.5	0.568	0.973	0.770	47.3	364
SEm±	0.3	1.1	0.4	0.320	0.044	0.041	0.4	26
CD (P=0.05)	0.9	3.2	1.1	0.920	0.124	0.120	NS	78

*Mean of two years data; Interaction effects were not significant for any of the characters

Table 3. Effect of conservational agricultural and nutrient management practices on yield attributes, seed yield and protein content of sorghum

Treatment	Yield attributes*			Seed yield (t/ha)			Seed Protein content* (%)
	Ear head weight (g)	Ear head length (cm)	1000-seed weight (g)	2010	2011	Mean	
Production systems							
Conservation agriculture	104.2	32.6	26.4	2.84	4.33	3.58	9.65
Conventional agriculture	103.9	32.6	26.5	2.89	4.17	3.53	9.62
SEm±	1.9	0.4	0.3	0.08	0.04	0.06	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
Nutrient management							
Recommended dose of fertilizers	100.4	32.3	25.5	2.95	4.32	3.63	9.62
Integrated nutrient management	108.7	32.7	26.8	3.04	4.45	3.75	9.96
Organic nutrient management	97.1	31.6	25.3	2.55	3.77	3.16	9.12
Fertilizers based on soil test crop response (STCR)	117.2	34.0	28.6	3.46	4.83	4.15	9.87
Customized fertilizers	117.4	34.6	28.8	3.42	4.99	4.21	10.09
Control (No manures)	83.7	29.8	23.5	1.79	3.13	2.46	9.18
SEm±	2.2	0.6	0.53	0.11	0.09	0.11	0.22
CD (P=005)	6.5	1.7	1.56	0.323	0.276	0.326	0.64

*Mean of two years data : Interaction effects were not significant for any of the characters.

tor (64.1–20.6–37.3 kg NPK/ha) and sorghum (118.3–39.3–152.5 kg NPK/ha) compared to RDF but was on par with STCR treatment.

Higher soil organic carbon in conservation agriculture was due to the addition of biomass through cluster bean (in castor) and horse gram (as cover crop after sorghum) along with the decomposition of castor crop residues applied as mulch. Intensive tillage in conventional system must have caused decline in organic matter content through accelerated oxidation, resulting in reduced capacity of the soil to regulate water and nutrient supplies to plants. When crop residues are retained on the soil surface in combination with minimum tillage, it initiates processes of conservation that lead to improved soil quality and overall resource enhancement (Bhale and Wanjari, 2009). Ramesh *et al.* (2010) also reported that application of organic manures over a period of time improve the soil organic matter content and soil fertility, there by sustaining

Table 4. Effect of conservational agricultural and nutrient management practices on total system productivity (castor-sorghum cropping system) expressed in terms of castor equivalent yield and economic returns (mean of 2 crop cycles)

Treatment	Castor equivalent yield (t/ha)	System cost of cultivation ($\times 10^3$ ₹/ha)	System net income ($\times 10^3$ ₹/ha)	System B:C ratio
Production systems				
Conservation agriculture	2.24*	28.8	49.6	1.72
Conventional agriculture	2.08	27.9	44.8	1.60
SEm±	0.05			
CD (P=0.05)	0.15			
Nutrient management				
Recommended dose of fertilizers	2.07	28.3	44.1	1.56
Integrated nutrient management	2.15	28.7	46.3	1.61
Organic nutrient management	1.85	29.7	34.8	1.17
STCR-based fertilizer application	2.40	30.2	53.8	1.78
Customized fertilizers	2.43	30.2	54.6	1.81
Control (No manures)	1.48	23.0	28.5	1.24
SEm±	0.11			
CD (P=0.05)	0.32			

*Which include the additional benefit of cluster bean pods. Market price of castor, sorghum and cluster bean pods: ₹35, 10 and 6/kg, respectively. Input price (₹/kg) of urea, SSP, MOP, FYM and PM: 5.6, 5.5, 9.0, 0.25 and 0.50, respectively.
The cost of customized fertilizers for castor is ₹ 13/kg and for sorghum, 9.25 ₹/kg

Table 5. Soil fertility and nutrient uptake of crops as influenced by conservational and nutrient management practices at the end of cropping cycle (2011)

Treatment	Soil organic carbon (%)	Soil available nutrients (kg/ha)			Uptake of nutrients by castor (kg/ha)			Uptake of nutrients by sorghum (kg/ha)		
		N	P_2O5	K_2O	N	P_2O5	K_2O	N	P_2O5	K_2O
Production systems										
Conservation agriculture	0.41	219	26.8	428	48.5	16.5	28.4	100.8	36.8	141.6
Conventional agriculture	0.37	213	26.7	424	52.5	16.9	29.9	97.0	32.3	134.0
SEm±	0.01	1.9	0.3	3.2	2.1	0.4	1.1	3.3	0.4	2.9
CD (P=0.05)	0.03	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient management										
Recommended dose of fertilizers	0.38	212	27.1	426	47.3	16.2	26.5	97.7	33.4	130.5
Integrated nutrient management	0.40	216	27.8	425	51.3	15.7	28.2	106.0	33.0	138.3
Organic nutrient management	0.42	220	26.7	434	47.1	15.6	28.7	88.5	32.2	127.6
STCR-based fertilizer application	0.40	221	29.8	424	61.2	20.3	34.1	112.9	38.6	150.8
Customized fertilizers	0.40	222	28.7	429	64.1	20.6	37.3	118.3	39.3	152.5
Control (No manures)	0.33	201	20.9	418	37.0	11.8	20.4	72.7	20.3	102.1
SEm±	0.02	2.2	1.1	4.6	4.2	1.2	2.1	6.1	1.4	4.1
CD (P=0.05)	0.05	6.5	3.2	13.4	12.5	3.4	6.2	18.2	4.2	12.2
Initial soil value	0.35	210	22.0	420						

Table 6. N, P and K-use efficiency of crops as influenced by nutrient management practices

Nutrient management	Agronomic Efficiency (kg grain/kg nutrient applied)			Apparent recovery (kg nutrient uptake/kg nutrient applied)			Physiological Efficiency (kg grain/kg nutrient uptake)			Nutrient harvest index (%)		
	N	P	K	N	P	K	N	P	K	N	P	K
Castor												
RDF	4.38	6.57	8.76	0.17	0.11	0.20	25.5	59.7	43.1	67.8	35.0	14.9
INM	6.08	10.13	9.86	0.23	0.10	0.21	25.6	93.5	46.7	67.6	40.8	15.6
ONM	3.51	7.53	3.83	0.16	0.13	0.15	20.8	55.5	25.4	70.2	38.6	13.5
STCR	9.06	8.78	28.10	0.39	0.13	0.68	23.2	66.1	41.0	67.6	42.3	13.4
CF	8.53	11.10	14.80	0.41	0.17	0.45	20.4	63.0	32.8	64.2	37.1	12.2
Control										65.6	32.1	15.2
Sorghum												
RDF	19.7	39.5	39.5	0.41	0.43	0.94	47.4	90.6	41.7	68.8	23.2	7.3
INM	22.0	47.3	35.8	0.55	0.45	0.97	39.7	104.3	36.6	66.7	21.5	7.1
ONM	10.7	23.0	11.7	0.26	0.42	0.46	40.8	54.2	25.2	61.3	17.5	6.2
STCR	15.4	32.6	84.9	0.36	0.35	2.43	42.2	92.7	34.8	65.8	20.0	7.0
CF	16.4	35.8	38.7	0.40	0.36	1.05	40.8	98.0	36.9	67.4	19.0	7.5
Control										64.0	20.0	6.4

RDF=Recommended dose of fertilizers; INM=Integrated nutrient management; ONM=Organic nutrient management; STCR=Fertilizers based on soil test crop response equations; CF=Customized fertilizers

the soil health and crop productivity.

Nutrient-use efficiency

In castor, agronomic efficiency of N and K were higher with STCR (9.06 and 28.1) and P-use efficiency was higher in CF in terms of both agronomic efficiency (11.10) and apparent recovery (0.17). However, physiological efficiency of N, P and K were found to be higher (25.6, 93.5 and 46.7, respectively) in INM compared to other nutrient management practices. Nutrient harvest index (NHI) of N was higher (70.2) in ONM, NHI of P was highest (42.3) in STCR and NHI of K was the highest (15.6) in INM practice (Table 6).

In sorghum, INM recorded the highest agronomic efficiency of N (22.0) and P (47.3) and also improved the apparent recovery of N (0.55) and P (0.45). But, both agronomic efficiency and apparent recovery of K was the highest in STCR. Physiological efficiency of N (47.4) and K (41.7) were higher in RDF, whereas physiological efficiency of P was highest (104.3) in INM. Nutrient harvest index of N, P and K were the highest in RDF (68.8, 23.2 and 7.3) and the lowest in ONM (61.3, 17.5 and 6.2) compare to other nutrient management practices. Such differences in nutrient-use efficiency of N, P and K due to crop species (Duncan and Baligar, 1990) and fertility levels (Ramesh and Sammi Reddy, 2004) were also reported in earlier studies.

Thus it may be concluded that in rainfed Alfisols, adopting conservation agricultural practices (*viz.*, minimum tillage, cover crops and residue management) improved the total productivity of castor-sorghum cropping–system besides sustaining the soil organic matter content. Application of customized fertilizers or fertilizers based on STCR resulted in 16–17% improvement in system productivity and economic returns compared to RDF.

REFERENCES

Bhale, V.M. and Wanjari, S.S. 2009. Conservation agriculture: A new paradigm to increase resource use efficiency. *Indian Journal of Agronomy* **54**(2): 167–77.

Duncan, R.R. and Baligar, V.C. 1990. Genetic, breeding and physiological mechanisms of nutrient uptake and use efficiency: An overview. In: *Crops as Enhancers of Nutrient Use*, pp.3–35. Baligar, V.C. and Duncan, R.R. (Eds.), Academic Press Inc., San Diego, California.

Hegde, D.M. 2010. Castor research and development in India: An overview. In: *Research and Development in Castor: Present Status and Future Strategies* (Ed. Hegde, D.M.), Indian Society of Oilseeds Research, Hyderabad, 1–25.

Nagendra Rao T. and Rahman, M.H. 2011. Customized Fertilizers towards balanced plant nutrition solutions for food security and soil health. In: *Abstracts of National Symposium on Innovative and Modern Technologies for Agricultural Productivity, Food Security and Environmental Management* (Eds. Biradar, D.P., Sangeetha, J. and Thangadurai D.) held on 22–23, July 2011 at Mangalore, Karnataka, Society for Applied Biotechnology (India), pp. 13–14.

Raghavaiah, C.V., Murthy, I.Y.L.N. and Riazuddin Ahmad, S. 2008. Soil test crop response calibration studies on rainfed castor in alfisols. *Indian Journal of Agricultural Sciences* **78**(9): 810–12.

Ramesh, P. and Hegde, D.M. 2010. Conservation agriculture for sustainable castor production. *Journal of Oilseeds Research* **27**(Special Issue): 191–94.

Ramesh, P., Panwar, N.R. and Singh, A.B. 2010. Crop productivity, soil fertility and economics of soybean, chickpea and blond psyllium under organic nutrient management practices. *Indian Journal of Agricultural Sciences* **80**(11): 965–69.

Ramesh, P., Panwar, N.R, Singh, A.B., Ramana, S. and Subba Rao A. 2009. Impact of organic–manure combinations on the productivity and soil quality in different cropping systems in central India. *Journal of Plant Nutrition and Soil Science* **172**(4): 577–85.

Ramesh, P. and Sammi Reddy, K. 2004. Productivity and nutrient-use efficiency of soybean and sorghum inter cropping at different levels of nitrogen in rainfed deep Vertisols. *Indian Journal of Agronomy* **49**(1): 31–33.

Singh, D, Chhonkar, P.K. and Dwivedi, B.S. 2005. *Manual on Soil, Plant and Water Analysis*, Westville Publishing House, New Delhi, p. 200.

Subba Rao, A. and Srivastava, S. 2002. Soil test based nutrient management in sustainable crop production. In: *System Approach to Plant Nutrition for Sustainable Crop Production*. Directorate of Oilseeds Research, Hyderabad, 22–32.