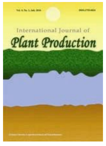

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Integrated nutrient management using deoiled *Jatropha* cake for sustained and economic food production

S.P. Wani*, G. Chander, K.L. Sahrawat, P. Narsimha Rao

Resilient Dryland Systems, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru-502324, Andhra Pradesh, India.
*Corresponding author. E-mail: s.wani@cgiar.org

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Abstract

With growing environmental and energy concerns, *Jatropha* plantations are promoted in degraded/waste lands for the biodiesel production. Nutrient rich non-edible deoiled seed cake, a by-product of *Jatropha* left out after oil extraction was evaluated at the ICRISAT centre at Patancheru, India as an environment friendly source of nutrients for rainy season maize and soybean followed by postrainy chickpea in rainfed systems. Deoiled cake as partial (50%) or full replacement of recommended basal nitrogen (N) was found superior in terms of increased crop yield over the equivalent chemical fertilizers treatments. Highest yield and net returns under full replacement of basal N for maize, while under 50% basal N replacement in case of soybean and chickpea crops were recorded by 8 to 27% in grain yield and 10 to 28% in straw yield. Deoiled *Jatropha* cake as a full replacement of N dose in maize also recorded higher N uptake and use efficiency in maize than chemical N source treatment along with increased organic C and nutrient contents in post-harvest soil samples. This study revealed the benefits of *Jatropha* deoiled seed cake as a good source of plant nutrients and soil organic C in the semi-arid tropics in addition to enhanced C sequestration under *Jatropha* plantation on degraded waste lands.

Keywords: Integrated nutrient management; *Jatropha* seed cake; Organic manure; Sustainable production; Resilience building.

Introduction

In context of depleting world's fossil fuel reserves, their escalating cost putting pressure on foreign exchequer, more energy needs for fast growing economy and the global warming problem due to fossil fuel combustion; biofuels for carbon (C) replacement in fossil fuels is considered as a strategy to plug the current issues (Achten et al., 2010b; GOI, 2009; Phalan, 2009). *Jatropha curcas* Linn. (Tropical physic nut) belonging to family Euphorbiaceae has gained attention in tropical and sub-tropical countries as a potential bio-fuel crop (Gohil and Pandya, 2008). On-farm research (Francis et al., 2005; Dubey et al., 2006; Wani et al., 2012) shows *Jatropha* a hardy plant and recommends successfully growing and rehabilitating degraded lands without compromising on the food security in heavily populated countries like India. *Jatropha* is a potential crop for the degraded/wastelands to combat multiple issues like decentralized energy, minimize/reduce C emissions and source of income for rural poor (Wani and Chander, 2013). Understanding a need for promotion, the Government of India in this context has approved a national policy on biofuels during 2009 to target a 20% blend of biofuels in gasoline and diesel by the year 2017 (Achten et al., 2010a). Therefore in addition to harnessing *Jatropha* for biodiesel, there is a need for making the best use of all by-products in the process to get the maximum benefits.

After oil extraction, a significant portion of seed yield (~70%) is left out as deoiled seed cake which is non-edible. However, the by-product deoiled cake (after oil extraction) is a rich source of organic matter and plant nutrients (Wani et al., 2012; Wani and Chander, 2013) and therefore may be very useful for recycling nutrients for crop production and cutting short the use of chemical fertilizers. This could make a very effective nutrient management strategy to meet both food and energy needs, wherein the nutrients used to produce energy crop in the wastelands are efficiently recycled through deoiled cake to produce food crops with reduced chemical fertilizer use. There are evidences that when nutrients are added through a combination of organic and inorganic sources, crop yields and nutrient use efficiency like N are improved significantly (Shah et al., 2009; Chander et al., 2013). So, looking at the large tracts already established with *Jatropha* and a potential to rehabilitate vast tracts of wastelands in India which are assessed to be >50 million ha (GOI, 2010) and that apparently could generate large quantities of deoiled cake, the studies were conducted to evaluate the use of by-product deoiled *Jatropha* cake in crop production and cutting cost of chemical fertilizers.

Materials and Methods

Experiment site and detail

An experiment was conducted during 2010-11 at the ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) farm in Patancheru, Andhra Pradesh, India with maize and soybean (rainy season/June-Sept) crops followed by chickpea (post-rainy season/Oct-Jan). Patancheru is located 545 m above mean sea level and receives around 900 mm rainfall per annum. The site falls under semi-arid tropical climate and the temperature ranges between 13 ^{o}C (minimum) to 39 ^{o}C (maximum) throughout the year. The site soil was Vertisol with high clay content. To avoid soil structure distortion with runoff rainwater which ultimately affects yields, a common problem observed in Vertisols, the crops were grown on raised beds (1.05 m) alternated with furrows (0.45 m) to safely drain excess runoff water, a landform management called as broad bed and furrow (BBF) system recommended particularly for Vertisols.

The objective of the study was to evaluate the use of deoiled *Jatropha* cake as a source of nutrients. The treatments consisted of - (i) Absolute control (without any fertilizer), (ii) Replacement of 50% of recommended basal nitrogen (N) through deoiled cake (50% basal N replacement), (iii) Replacement of 100% of recommended basal N through deoiled cake (100% basal N replacement) and (iv) No replacement of basal N through cake and application of all basal N through inorganic fertilizers (No basal N replacement). In deoiled cake added plots, the recommended phosphorus (P) and potassium (K) from chemical fertilizers were also adjusted taking into account the addition through the cake. The deoiled cake contained on an average 5.10% N, 2.24% P_2O_5 and 1.73% K_2O. The nutrient recommendations were 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} for maize and 30 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} for soybean, while 20 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1} for chickpea. The sources of N, P and K fertilizers were urea, single super phosphate (SSP), diammonium phosphate (DAP) and muriate of potash (MOP). While deoiled cake was obtained after extracting oil from pods harvested from on-station *Jatropha* plantation established in 2004 and 2006 (Wani et al., 2012). All fertilizers and deoiled cake were added as per treatments as basal application, except for N in maize which was added in 2 splits, 50% as basal and the rest as top dressing after one month of sowing. As such fifty per cent of recommended N in maize and full recommended N in chickpea was added as basal application which were adjusted as per treatments through the deoiled *Jatropha* cake. All the treatments were applied in 4.5×10 m plot size for maize and 4.5×6 m for soybean and replicated five times.

During 2010-11 rainy season, the application strategies were evaluated on maize (cv. K 235) and soybean (JS 335) crops. Both maize and soybean crops were sown in lines at 0.04-0.05 m depth using tropicultor (a low cost implement designed for seed and fertilizer placement under BBF system) on 14th July, 2010. Two rows of maize spaced at 0.75 m were sown on the raised bed with plant to plant distance of 0.15 to 0.20 m, while three rows of soybean spaced at 0.30 m were sown on raised bed with plant to plant distance of 0.10 to 0.15 m. The soybean crop was harvested on 14th October, 2010 and maize on 18th October, 2010. Similarly, during 2010-11 post-rainy season chickpea crop followed by soybean was sown on 15th October, 2010, while that followed by maize was sown on 20th October, 2010. Chickpea seeds were sown at about 0.10 m depth. Three rows of chickpea spaced at 0.30 m were sown on raised bed with plant to plant distance of 0.10 to 0.15 m. Two weedings were done at 20 days interval in maize, soybean and chickpea crops to keep the plots free of weeds. Uniform crop management practices were ensured in all the treatments. Chickpea crop followed by both soybean and maize was harvested on 15th February, 2011. At maturity, the yields were recorded in all plots representing different treatments and were converted into kg ha^{-1}.

Statistical and economic analysis

The data recorded were subjected to statistical analysis using the Genstat 13th statistical package, VSN International Ltd, UK (Ireland, 2010) to determine the least significant difference of means at 5% level (LSD 5%).

For economic analysis, the additional cost on fertilizer application was worked out on per kg market prices at Rs. 6.25 for urea, Rs. 4.00 for SSP, Rs. 22.0 for DAP and Rs. 4.80 for MOP; while additional returns were calculated based on per kg farm gate price of food grains @ Rs. 12.0- for maize, Rs. 30.0 for chickpea and Rs. 23.0 for soybean (CACP, 2014; GoI DoF, 2014).

N uptake and use efficiency indices in maize

Low N use efficiency particularly in cereals is an issue of concern worldwide. We hypothesized that regulated N supply through integrated use involving *Jatropha* cake will enhance N efficiency indices. In this context, N efficiency was worked out in terms of N uptake efficiency and N use efficiency (Delogu et al., 1998; Lopez-Bellido and Lopez-Bellido, 2001) in maize crop. N uptake efficiency (NUpE) was worked out by dividing total plant N uptake with N supply. Total plant N uptake was determined by multiplying dry weight of plant parts (grain and straw) by N concentration and summing over parts for total plant uptake. N supply is sum of soil N content at sowing, mineralized N and N fertilizer. N supply was defined (Limon-Ortega et al., 2000), as the sum of (i) N applied as fertilizer and (ii) total N uptake in control (0 N applied). Nitrogen use efficiency (NUE) was estimated by dividing grain yield with N supply.

Plant chemical analysis and N uptake in maize

As a pre-requisite to work out N efficiency indices and study the effects of nutrient replacement with deoiled cake, N uptake in maize was worked out. The plant samples were separated into grain and straw parts for the chemical analysis. Total N uptake was determined by multiplying dry weight of plant grain and straw parts with respective N concentrations and summing up both for total plant uptake. For estimation of total N content, plant materials were digested with sulfuric acid-selenium mixture and the digests were analyzed using autoanalyser (Sahrawat et al., 2002).

Post-harvest soil analysis

The post-harvest surface (0 to 0.15 m) soil samples were collected during February, 2011 after completion of maize/soybean-chickpea cropping system to study the effects on soil health. In each treatment, the samples were collected from 3 random spots and mixed together to make a composite sample. The collected samples are air-dried in the shade and sieved through a 2-mm sieve for general analysis. However, for organic C soil samples were ground to pass through a 0.25 mm sieve. Soil reaction (pH) was measured with the help of glass electrode using soil to water in 1:2 ratio. Soil C was determined by Walkley-Black method (Nelson and

Sommers, 1996). Available P was extracted using the sodium bicarbonate ($NaHCO_3$) extractant (Olsen and Sommers, 1982) and determined using colorimetric method. Exchangeable K was extracted using the ammonium acetate (Helmke and Sparks, 1996) and determined on Atomic Absorption Spectrophotometer (AAS). The available contents of S were extracted by 0.15% calcium chloride ($CaCl_2$) (Tabatabai, 1996), available Zn by diethylene triamine pentaacetic acid (DTPA) reagent (Lindsay and Norvell, 1978) and available B by hot water (Keren, 1996); while their estimations were made using the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

Results and Discussion

Crop productivity

The benefits of crop fertilization were evident in significant improvement in crop productivity over the control (Table 1). However, integrated nutrient management involving chemical fertilizers and organic deoiled *Jatropha* seed cake proved best in terms of recording highest grain yield and straw yields. During the rainy season, replacing whole of the basal N requirement through *Jatropha* cake proved best practice for maize crop; however, in case of soybean basal N replacement upto 50% proved best. Replacement of basal N through cake recorded up to 8% increase in maize grain yield and 27% increase in soybean grain yield over no replacement of basal N application i.e. over sole use of chemical fertilizers. Similarly, in post-rainy chickpea crop followed by either maize or soybean, 50% of basal N replacement recorded the highest yield; grain yield was 19 to 24% more than nutrient additions solely through chemical fertilizers. A higher productivity in *Jatropha* cake added plots is apparently due to the fact that in addition to N, P and K, *Jatropha* cake is a good source of essential secondary and micronutrients (Wani and Chander, 2013). Soil infertility due to multinutrient deficiencies in the semi-arid tropics in India including those of ignored secondary and micronutrients (Wani et al., 2003; Sahrawat et al., 2011; Chander et al., 2012) are mainly responsible for large yield gaps between current and potential achievable yields. Fertilization practices like partial nutrient additions through *Jatropha* cake or other organic manures replenish soils of other essential nutrients than only N, P and K and explains the beneficial response recorded in the present study. Moreover, in context of soil health, the role of soil organic matter is also well documented. Low soil C in tropical soils affecting ecosystem functioning is another factor contributing to poor crop productivity (Lee and Wani, 1989; Bationo and Mokwunye, 1991; Edmeades, 2003; Bationo et al., 2008; Ghosh et al., 2009; Materechera, 2010). About 44% of cake biomass is organic C (Wani et al., 2012), which apparently helped in improvement of soil biological and physical properties also and so, the benefits of replacing nutrients through *Jatropha* cake are on expected lines.

Table 1. Effects of replacing fertilizer nutrient requirements through deoiled *Jatropha* cake on crop productivity during 2010-11.

Treatment	Grain yield	Straw yield	Grain yield	Straw yield
	2010 rainy season		2010-11 post-rainy season	
	Maize (kg ha^{-1})		Chickpea (kg ha^{-1})	
Absolute control	910	3420	1860	1340
50% basal N replacement	3110	5200	2920	1900
100% basal N replacement	3660	5610	2790	1920
No basal N replacement	3380	4680	2350	1720
LSD (5%)	1493	1561	270	416
	Soybean (kg ha^{-1})		Chickpea (kg ha^{-1})	
Absolute control	650	1050	1380	1050
50% basal N replacement	1030	1660	2740	2200
100% basal N replacement	960	1580	2600	2110
No basal N replacement	810	1300	2300	2300
LSD (5%)	157	272	654	561

The results showed that application of deoiled cake can cut use and cost of 50% of N to the tune of 60 kg N ha^{-1} (basal) out of total 120 kg N ha^{-1} recommended (as basal and top dressing) in maize; 15 kg N ha^{-1} out of 30 kg N ha^{-1} recommended (as basal) in soybean; and 10 kg N ha^{-1} out of total 20 kg N ha^{-1} recommended (as basal) in chickpea. In addition, about 27 kg P_2O_5 ha^{-1} and 21 kg K_2O ha^{-1} added in maize; 7 kg P_2O_5 ha^{-1} and 5 kg K_2O ha^{-1} added in soybean and about 4 kg P_2O_5 ha^{-1} added in chickpea on account of *Jatropha* cake use is another saving in recommended nutrients through chemical fertilizers. Wani et al. (2012) have shown that a fertilized (80 kg N, 20 kg P_2O_5) *Jatropha* plantation on a degraded land produces around 1600 kg ha^{-1} seed yield, thereby around 1100 kg ha^{-1} (~70%) by-product cake and that recycles N to the tune of 60 kg ha^{-1}. Thus one ha *Jatropha* on degraded land can match the cake demand for another ha of crop plants with very efficient nutrient recycling.

Economics of crop production

The use of deoiled *Jatropha* cake resulted twin benefits of lowering chemical fertilizer costs while increasing gross returns through increased yields. Full replacement of basal N in maize showed the highest net return (Table 2), however in case of soybean and chickpea crops, replacement up to 50% of basal N showed the highest net return. As such chemical fertilizer use and costs were cut by Rs 2700/- ha^{-1} in maize, Rs 790/- ha^{-1} in soybean and Rs 670/- ha^{-1} in case of chickpea as a result of nutrient replacement through deoiled *Jatropha* cake. The highest net returns were Rs 42120/- ha^{-1} for maize with full replacement of basal N through the cake; while Rs 21200/- ha^{-1} in soybean, Rs 80470 to Rs 85870/- ha^{-1} in chickpea under 50% replacement of basal N dose.

Table 2. Effects of replacing fertilizer nutrient requirements through deoiled *Jatropha* cake on per ha net returns during 2010-11.

Treatment	Net returns (Rs ha^{-1})			
	Maize-chickpea system		Soybean-chickpea system	
	Maize	Chickpea	Soybean	Chickpea
Absolute control	10920	55800	14950	41400
50% basal N replacement	33880	85870	21200	80470
100% basal N replacement	42120	82670	20680	76970
No basal N replacement	36060	68100	15350	66600

N uptake and efficiency indices in maize

The data on N uptake in maize showed higher uptake in all fertilized plots as compared with the control (Figure 1). Even among fertilized plots, a higher N uptake was observed in plots where full or part of basal N was replaced through *Jatropha* cake addition as compared to the plot having sole addition of chemical fertilizers. Similar to yield trends, the highest N uptake was recorded in case of full replacement of basal N treatment. The conjoint application of organic and inorganic sources of nutrients apparently reduced leaching losses and thereby enhanced their availability in soil and reflected as uptake by plants.

Along with increase in N uptake, the N efficiency indices in maize also tended to improve under plots having integrated use of *Jatropha* cake and chemical fertilizers. Nitrogen uptake efficiency (NUpE) shows the efficiency of crop in obtaining N from soil (Rahimizadeh et al., 2010). Uptake of added N is the first important step and an issue of concern and hence increased NUpE has been proposed as a strategy to increase NUE (Raun and Johnson, 1999). Under absolute control without N fertilizer addition, the N uptake is taken as the index of N supply from soil and hence the NUpE (ratio of total N uptake with N supply) is unity (1) in control treatment (Figure 2). The nutrient addition through chemical fertilizers recorded NUpE of 0.42. However, under integrated nutrient management comprising chemical fertilizers and deoiled *Jatropha* cake, the NUpE values increased, while 100% of basal N replacement recorded the highest at 0.50. Similarly, the control plot recorded NUE of 24.3. A lower NUE in chemical fertilized plot (21.5) as compared with the control plot indicates the problem associated with the efficient use of N added through chemical fertilizers. The 100% basal N replacement through cake recorded a better NUE of 23.2 as compared with chemical fertilized plot. The strategy of adding basal N through *Jatropha* cake and top dressing through chemical fertilizers probably regulated N supply as per plant needs and minimized losses. Moreover, addition of other nutrients (Wani et al., 2012; Wani and Chander, 2013) through cake apparently created a synergy for efficient N resource use efficiency (Chander et al., 2014).

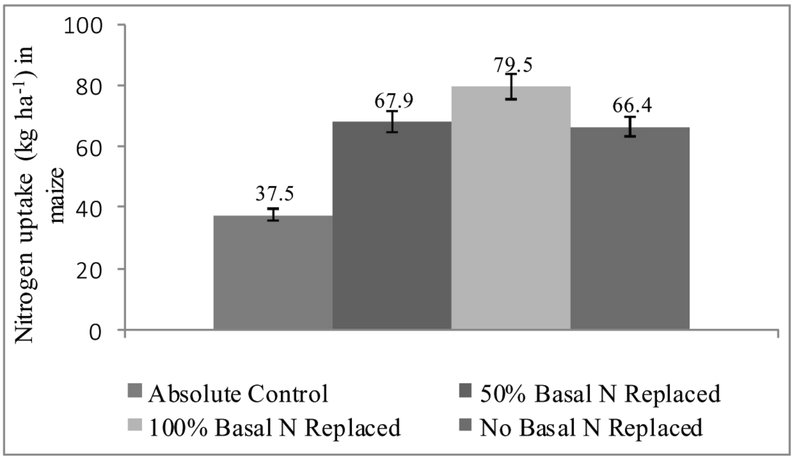

Figure 1. Effects of replacing fertilizer nutrient requirements through deoiled *Jatropha* cake on nitrogen uptake in maize, rainy 2010 season.

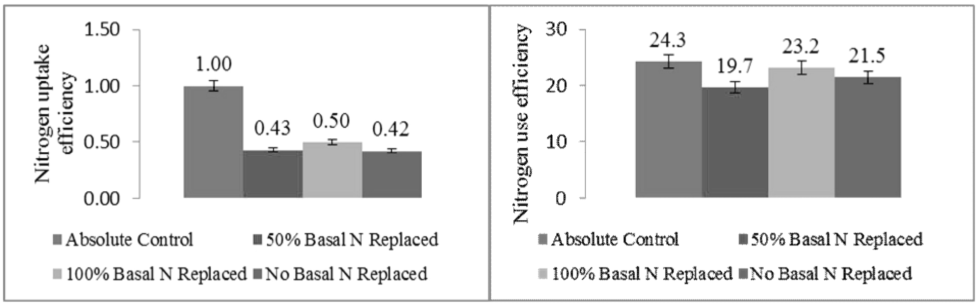

Figure 2. Effects of replacing fertilizer nutrient requirements through deoiled *Jatropha* cake on nitrogen uptake efficiency and use efficiency in maize, rainy 2010 season.

Post-harvest soil health

A post-harvest soil health evaluation both after maize-chickpea and soybean-chickpea crop cycles tended to show improvement in plots where *Jatropha* deoiled cake was added based on partially or fully replacing basal N requirement (Table 3). In general post-harvest soil health tended to improve in 100% basal N replacement in maize-chickpea cropping system and in 50% basal N replacement in soybean-chickpea systems as compared with no replacement through cake. Under these treatments, soil health tended to improve not only in terms of soil C, P and K; but also secondary and micronutrients like S, B and Zn. The improvement in soil nutrients is expected due to their release upon decomposition of the cake, in addition to dissolution of soil nutrients during decomposition process and binding strongly to check leaching losses. The integrated nutrient management practice thus in addition to recording highest yields through best nutrient use efficiency also led to production system resilience building through better soil health

Conclusion

Deoiled *Jatropha* cake left out after oil extraction from seed part may be used as a source of organic C and macro and micro nutrients for crop production. Major crop nutrient requirements could be met through *Jatropha* cake on the basis of replacing 100% basal N in maize crop and 50% basal N in legume crops like soybean and chickpea. Results showed that the integrated nutrient management leads to highest crop yields, N uptake efficiency and N use efficiency and a better post-harvest soil health. So, while *Jatropha* is used to rehabilitate waste/degraded lands to produce biodiesel, the bulk of nutrients could be effectively recycled through by-product cake to produce more food with reduced use and cost of chemical fertilizers.

Table 3. Effects of replacing fertilizer nutrient requirements through deoiled *Jatropha* cake on soil health status after 2010-11 cropping system.

Treatment	pH	OC (%)	Available nutrients (mg kg^{-1})				
			P	K	S	B	Zn
Maize-chickpea cropping system							
Absolute control	7.67	0.47	12.6	191	25.6	0.31	0.93
50% basal N replacement	7.43	0.49	24.4	171	26.2	0.35	0.93
100% basal N replacement	7.47	0.51	27.9	175	35.6	0.36	1.01
No N replacement	7.45	0.45	24.0	159	22.0	0.32	0.84
LSD (5%)	0.32	0.11	10.0	39.1	4.86	0.08	0.15
Soybean-chickpea cropping system							
Absolute control	7.54	0.41	13.3	173	22.8	0.28	0.95
50% basal N replacement	7.47	0.45	26.4	181	22.3	0.38	0.97
100% basal N replacement	7.47	0.41	23.2	173	25.7	0.35	0.95
No N replacement	7.49	0.43	24.0	185	21.2	0.31	0.92
LSD (5%)	0.29	0.13	12.7	54.3	8.22	0.09	0.18

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