Research Article

Journal of Plantation Crops, 2012, 40 (1): 40-49

A nutrient decision support system for rainfed cashew

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(Manuscript Received: 14-09-11, Revised: 25-11-11, Accepted: 08-02-12)

Abstract

In cashew, the recommended dose of fertilizers/manure per plant is effectively applicable up to 80-100 percent canopy coverage depending upon the age of the plant, plant density, soil fertility level and varieties used. After 6-8 years, a cut down of recommended doses of fertilizers or manures per plant is necessary depending on the nutrient build up in cashew garden due to the addition of nutrients from the increased cashew biomass deposit. For the judicious use of fertilizers and manures, prior soil testing is required for getting the nutrient status in the soil from time to time. A nutrient decision support system (NDSS) was developed for cashew using Visual Basic package for determining the site specific fertilizer and or manure requirement. The optimal fertilizer and manure requirement is based on the nutrient budgeting and nutrient balance approach and it depends on plant density, age of the plant, canopy biomass fallout, canopy wash nutrients, optimal yield of cashew, initial soil NPK, removal of NPK by plants and post soil NPK. The developed decision support system which was validated using field data is having the flexibility of giving the optimal quantity of inorganic fertilizers and or organic manures as selected by the user. The regression analysis of the measured optimal values against the predicted values of the inorganic fertilizers and organic manures showed a reasonable fit between two data sets (R^2 = 0.95 for inorganic fertilizers and R^2 = 0.94 for organic manures). The quantity of nutrient application to rainfed cashew can substantially be reduced using the estimated quantity obtained from NDSS.

Keywords: Nutrient decision support system, nutrient balance, rainfed cashew

Introduction

The environmental impacts such as drought, soil erosion, nutrient depletion, soil and water pollution, decreased river flows and declining groundwater levels are becoming wide spread. These changes may adversely affect land productivity, aquatic ecosystems, beneficial organisms and human health (NAAS, 2006; IFPRI, 2008; FAO, 2009). Available data shows that 40 percent of agricultural lands in the world are seriously affected by soil degradation (IFPRI, 2008). In addition to this, agriculture is influenced by climate change caused by altered global carbon, nitrogen and hydrological cycles. Therefore, attention is being focused on sustainable agriculture in order to sustain agricultural production and conserve the environment for future generations.

Growing cashew plants (*Anacardium occidentale* L.) along the barren hillocks reduce the soil erosion, improve the groundwater level, carbon build up and increase the net profit to farmers (Rejani and Yadukumar, 2010). It is estimated that about 28 Mt of primary plant nutrients are removed from the soil annually by agricultural crops in India, while only 18 Mt or even less are applied as fertilizer, leaving a net negative balance of about 10 Mt of primary plant nutrients (NPK) (NAAS, 2006). The data available from centres under the Project Directorate of Cropping Systems Research (PDCSR), Modipuram also indicated that inadequate and imbalanced fertilization as a major causative factor for low and declining crop response to fertilizers. In West Coast region of India, cashew is mainly grown as a rainfed crop along the steep slopes

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of barren hillocks where the fertile topsoil is eroded and the substratum is exposed. Hence, the nutrient content of the soil and productivity of cashew plantations are low in this region. The average productivity of cashew in India is 0.90 t/ha and in Karnataka it is 0.72 t/ha against the target of 1.0 t/ha (DCCD, 2009). Though cashew is hardy and drought tolerant, it responds well to water and nutrients (O'Farrel *et al*., 2002; Yadukumar and Rejani, 2004). The productivity of cashew for the first ten years can also be increased (2 to 3 times) by adopting high density planting system of cashew (Yadukumar *et al.*, 2001).

The present system of cashew nutrition is based on general recommendation for a whole state, without considering the variation in the inherent soil fertility and the productivity of cashew. Fertilizer dose increased the yield of high density cashew only upto first six years (Yadukumar *et al*., 2011). The fertilizer recommended is reasonable up to 80-100 percent canopy coverage which is normally achieved during the initial 6-8 years after planting. After certain stage of the crop, reduction in recommended doses of fertilizers / plant may be necessary due to the nutrient build up in soil due to the deposit of cashew biomass fall out. Approximately, the quantity of nutrients available from the cashew leaf deposit and apple is 19.5 kg N, 10.8 kg P_2O_5 and 25.2 kg K_2O / ha (Agricultural Research Station, 1994). Recyclable Cashew Biomass (RCB) available in cashew garden *viz*., cashew leaf litter, cashew apples and weed growth were converted to enriched compost by adding 20% cowdung slurry. From 5.5 tonnes of RCB per ha available in the matured cashew garden, approximately 3.5 tonnes of matured compost can be prepared in a period of 6 months with 63% recovery. This meets 46 % of N, 25% P and 13 % K requirement indicating reduction in external input of fertilizers to 1/3rd of RDF (Yadukumar and Nandan, 2005).

Productivity linked prediction models have been developed by Salam *et al*., (2008) to determine the nutrient recommendation in cashew. In this model, the fertlizer N is depending on the soil N and nut yield; fertilizers P_2O_5 and K_2O are depending on the nut yield. Nutrient removal by various crops from soils of different agro-climatic zones of Andhra Pradesh was computed on the basis of nutrient removal per specified economic yield (Singh *et al.*, 2001). The nutrient balance depending on total fertilizer nutrients used in the zone for all the crops, fertilizer use efficiency factor (N = 0.45; P = 0.25; K = 0.70), nutrient addition through organic manures and total nutrients removed by crops were determined. In Rajasthan, the nutrient balance was calculated with regard to nutrient status of soils, removal of nutrients by different crops/varieties, amount of N fixed by various legumes, and probable contribution of organic manures (Gupta, 2001). Kutra and Aksomaitiene (2003) conducted nitrogen balance studies in soil for sugar beet and grain crops at Lithuania by considering N input (N fertilizer + N in precipitation) and output (N removal by crop + N leaching). Yadukumar *et al.,* (2003) determined the optimal NPK requirement in cashew based on nutrient budgeting, nutrient balance and yield in cashew. The recommended dose of fertilizers varies with the age of plants, plant density and fertility of the soil. For the judicious use of fertilizers and manures, prior soil testing is required for getting the nutrient status of the soil from time to time and hence the optimal amount of fertilizers to be applied to the soil can be estimated. Hence, this study was undertaken with the objective of developing a decision support system model for determining the site-specific optimal nutrient requirement in cashew. The application of optimal manure to the soil will reduce the input required, cost of cultivation and finally the ecological hazards arising out of inorganic fertilizer application. From the point of view of sustainable agriculture, the adoption of optimal fertilizer/manure dose is the need of the hour. The developed DSS is having the flexibility of giving the optimal quantity of 14 organic/inorganic manures/their combinations as selected by the user.

Materials and Methods

The Study Area

The Decision Support System (DSS) was developed at Directorate of Cashew Research (DCR), Puttur, Dakshina Kannada, Karnataka during 2007-2010. The DSS developed in this study is based on the data generated from nutritional trials conducted at DCR. The nutrient budgeting and nutrient balance concept has been developed and successfully tested in key cashew growing areas of West Coast region of India and other major cashew growing states of India by DCR and AICRP – Cashew Centres (Yadukumar *et al*., 2003). The study area, DCR Farm is situated at 90 m above the mean sea level and is characterized by seasonally wet, hot humid with dry season (January to May) during the fruiting period of cashew. The average annual rainfall is 3500 mm with 120-140 rainy days and is distributed from May to November. The soil is laterite and texturally sandy clay loam in the surface soil. The soil is acidic with a pH 5.25, low to medium in N content (150- 250 kg/ha) and low in P_2O_5 (2 to 10 kg/ha) and K_2O (40 to 80 kg/ha) contents.

Development of nutrient decision support system (NDSS) for cashew

The nutrient decision support system (NDSS) for cashew was developed based on the nutrient addition and nutrient removal from the system (nutrient balance). The key principle includes the estimation of nutrient requirement and it depends on optimal yield, net profit, nutrient removal by trees, canopy biomass fallout, canopy wash N, P, K, initial and post soil N, P and K. NPK addition/deficit was estimated using the equation (Richard, 1993).

$$N = N_i + N_{CB} + N_{AM} + N_{CW} - (N_p + N_{removal}) \quad (1)$$

$$P_2O_5 = P_i + P_{CB} + P_{AM} + P_{CW} - (P_p + p_{removal}) \quad (2)$$

$$K_2O = K_i + K_{CB} + K_{AM} + K_{CW} - (K_p + K_{removal}) \quad (3)$$

where N, P_2O_5 and K_2O are the nitrogen, phosphorous and potassium (addition/deficit), N_i, P_i and K_i *are* the initial soil N, P_2O_5 and K_2O, N_{CB}, P_{CB} *and* K_{CB} are the canopy biomass N, P_2O_5 and K_2O, N_{AM} P_{AM} and K_{AM} are the applied fertilizer N, P_2O_5 and K_2O, N_{CW} P_{CW} K_{CW} are the canopy wash N, P_2O_5 and K_2O, *Np Pp* and *Kp* are the post soil N, P_2O_5 and K_2O, $N_{removal}$, $P_{removal}$ and $K_{removal}$ are the N, P_2O_5 and K_2O removal. The quantity of inorganic fertilizers and or organic manures is also dependent on the composition of nutrients in it (Thampan, 1995; Yadukumar *et al*., 2009). In the present study, leaching is considered to be negligible since fertilizer application is done at the end of the rainy season. The optimal organic manure/inorganic fertilizer requirement for rainfed cashew has been estimated with varying plant density, age of plants, initial and final soil test values of available N, P_2O_5 and K_2O.

Input data

1. Recommended dose of fertilizer and manure for cashew

The recommended dose of fertilizers (RDF) varies with the age of plants, plant density and fertility of the soil. The RDF during first year after planting (YAP) is $1/5^{th}$ of the full dose, 2YAP is $2/5^{th}$, 3YAP is $3/5^{th}$, 4YAP is $4/5^{th}$ and fifth year onwards is full dose of fertilizers. The RDF for normal density planting (200 plants/ha) is 500 g N and 125 g each of P_2O_5 and K_2O per plant/year and for high density planting (625 plants/ha) it is 250 g N and 62.5g each of P_2O_5 and K_2O /plant/year. Yadukumar *et al*., 2009 recommended the dose of organic manure/inorganic fertilizers to rainfed cashew under normal density planting. It has been reported that in high density planting system of cashew (625 plants/ha), after 6-8 years, the cut down of recommended doses of fertilizers/manures per plant is necessary depending on the nutrient build up in cashew garden (Yadukumar *et al*., 2011).

2. Nutrient balance data

The data such as nut yield, initial soil NPK, NPK addition (canopy biomass fallout, fertilizer application and canopy wash), NPK removal (by the tree) and the post soil NPK were generated from the nutrient balance studies in cashew conducted in the NATP (National Agricultural Technology Project) trial and other experiments conducted at DCR (Yadukumar *et al.*, 2003; Yadukumar *et al*., 2011). The data corresponding to five fertilizer doses ($1/3^{rd}$ RDF, $2/3^{rd}$ RDF, RDF, 2 RDF and 3 RDF) and four plant densities (200, 416, 500 and 625 plants/ha) for a period of 10 years (after cashew planting) were used in this study (Fig.1 to 2; Tables 1 to 5).

The nutrients present in a whole tree were estimated by destructive sampling method (uprooting the plant corresponding to age). Nutrient analysis were done in leaf, bark, wood and root samples collected and estimated for the total weight of individual components to determine the separate nutrient contributions. Chemical analysis of the apples and nuts were also carried out as per the standard procedure. The nutrient removal by a plant/ year (in the 6th year) was determined based on change in nutrient concentrations present in total components of identical plants in the corresponding year (6th year) and the previous year (5th year). In the NATP trial at DCR, nutrient balance studies on NPK have been conducted by considering the yield factor also (Tables 1-4). The soil samples were collected from a depth of 0-30 cm and 31-60 cm and nutrient content of the soil samples before and after manure application were determined using standard procedures (Yadukumar *et al,* 2009).

3. Field validation of the nutrient decision support system (NDSS)

The developed NDSS was validated for the optimal doses of fertilizers and manures determined (predicted values) with the measured values obtained from the field experiments (under high density and normal density planting systems). The results of validation could be evaluated by means of mean error (ME), mean absolute error (MAE) and root mean squared error (RMSE). However, RMSE is generally thought to be the best measurement of error, if the errors are normally distributed (Rejani *et al.*, 2008). In this study, ME and RMSE were used (Eqs. 4 and 5).

$$ME = \frac{1}{n}\sum_{i=1}^{n}(O-P)_i \tag{4}$$

$$RMSE = \frac{1}{n}\sum_{i=1}^{n}[O-P)_i^{\ 2}\ ]^{0.5} \tag{5}$$

where, O = observed/measured optimal dose of fertilizer/manure (kg), P = predicted optimal dose (kg) and n = total number of observed/measured data. A linear regression analysis of the measured and predicted doses of fertilizers and manures were also done.

Table 1. Nutrient balance studies on Nitrogen

Treatments	Nutrient addition (kg/ha)					Nutrient removal (kg/ha)			
	Initial soil N	Canopy biomass fallout	Fertilizer appln.	Canopy wash N	Total (A)	Post soil N	N uptake	Total (B)	N balance (kg/ha) (A-B)
T1(No fertilizer)	160	24.00	-	25.00	209	155	157	302	-93
T2 (1/3rd dose)	165	30.60	104.2	30.00	330	156	162	318	+12
T3 (2/3rd dose)	158	30.50	208.3	35.00	432	215	184	399	+33
T4 (Full dose)	163	33.50	312.5	39.00	548	241	212	453	+95

Table 2. Nutrient balance studies on Phosphorus

Treatments	Nutrient addition (kg/ha)					Nutrient removal (kg/ha)			
	Initial soil P	Canopy biomass fallout	Fertilizer appln.	Canopy wash P	Total (A)	Post soil P	P up take	Total (B)	P balance (kg/ha) (A-B)
T1(No fertilizer)	7.5	2.49	-	2.5	12.5	10.5	23	33.5	-21.0
T2 (1/3rd dose)	9.0	3.01	26.0	3.0	41.0	15.0	23	38.0	+3.0
T3 (2/3rd dose)	8.2	2.95	52.0	3.0	66.2	29.0	33	62.0	+4.2
T4 (Full dose)	7.2	3.27	78.0	3.0	91.5	29.2	34	63.2	+28.3

Table 3. Nutrient balance studies on Potassium

Treatments	Nutrient addition (kg/ha)					Nutrient removal (kg/ha)			
	Initial soil K	Canopy biomass fallout	Fertilizer appln.	Canopy wash K	Total (A)	Post soil K	K up take	Total (B)	K balance (kg/ha) (A-B)
T1(No fertilizer)	160	4.37	-	4.5	169.0	121	73	194	-30
T2 (1/3rd dose)	169	5.26	26.0	5	205.2	119	84	203	+2.2
T3 (2/3rd dose)	157	5.17	52.0	5	219.7	120	95	215	+4.7
T4 (Full dose)	155	5.73	78.0	6	244.7	119	114	233	+11.7

Table 4. Variation in nut yield with fertilizer doses

Treatment	2001-2002	2002-2003	2003-2004	Nut yield (kg/ha/year) 2004-2005	2005-2006	2006-2007	2007-2008	Mean	Nut weight (g/nut)
T1(No fertilizer)	544	1132	1640	1090	1380	954	620	1051	7.45
T2 (1/3rd dose)	912	1398	2080	1590	1879	1216	800	1411	7.70
T3 (2/3rd dose)	1017	1131	1820	1380	1875	1397	838	1351	7.95
T4 (Full dose)	1166	1429	1960	1610	1989	1308	830	1470	8.12
CD (=0.05)	302	415	214.9	266.4	295.7	227.3	87.9	137.1	NS

Table 5. Variation of cashew nut yield (kg/ha) with different fertilizer treatment and spacing (2003-10)

Treatments	2003-04	2004-05	2005-06	2006-07	2007-08	*2008-09	2009-10
S1M1	154.4	111.2	558.0	493.6	626.0	1145.0	2352.0
S1M2	241.2	122.6	464.0	502.3	730.0	1174.0	1440.0
S1M3	300.4	180.4	458.0	539.3	800.0	1250.0	2064.0
Mean S1	**232.0**	**138.0**	**493.3**	**511.7**	**718.6**	**1189.7**	**1952.0**
S2M1	299.6	216.7	628.0	1129.6	1293.0	350.0	1699.0
S2M2	485.8	244.2	745.0	985.6	1077.0	390.0	2469.0
S2M3	615.7	319.1	807.0	1163.3	1029.0	520.0	2387.0
Mean S2	**467.0**	**260.0**	**726.6**	**1092.8**	**1133.0**	**420.0**	**2185.0**
S3M1	207.2	285.5	927.0	1259.3	1353.0	540.0	2615.0
S3M2	420.0	313.4	1251.0	1173.5	1000.0	610.0	2500.0
S3M3	482.4	362.5	1240.0	801.3	1007.0	620.0	2174.0
Mean S3	**369.8**	**320.4**	**1139.3**	**1078.0**	**1120.0**	**590.0**	**2430.0**
CD- spacing (p=0.05)	48.8	56.6	200.0	295.5	164.86	180.57	178.45
Sub-effects (mean)							
M1	220.40	204.47	704.33	960.83	1090.67	678.33	2222.00
M2	382.33	226.73	820.00	887.13	935.67	724.67	2136.33
M3	466.17	287.33	835.00	834.63	945.33	796.67	2208.33
CD-fertilizer (p=0.05)	87.65	81.04	NS	NS	NS	NS	NS

Source: Yadukumar *et al.*, 2011

Note: Year of planting - 2000; S1, S2 and S3 - Plant densities viz., 200, 416 and 500 plants/ha; M1, M2 and M3 - Manure doses viz., 75 kg N, 25 kg each of P_2O_5 and K_2O (M1), 150 kg N, 50 kg each of P_2O_5 and K_2O (M2), 225 kg N, 75 kg each of P_2O_5 and K_2O/ha/year (M3)

*During 2008-09, detopping was done at 2.5 m height in high density planting system

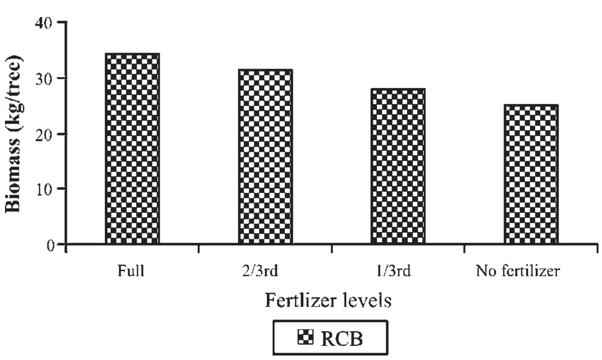

Fig. 1. Total recyclable cashew biomass from a matured cashew plant/ year with different levels of fertilizers

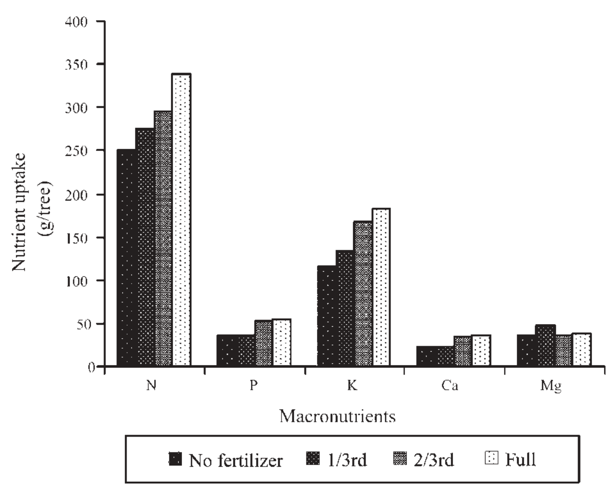

Fig. 2. Nutrients removal in a matured cashew plant in relation to fertilizer levels

Results and Discussion

Development of nutrient decision support system for cashew

A nutrient decision support system was developed for cashew using Visual Basic software (Fig.3). The developed DSS gives the fertilizer requirement for plants corresponding to different age of plant, vigour of the plant, plant densities, initial soil N, P_2O_5 and K_2O contents. The interpretations were made on the basis of suggested optimum level of N as 272-544 kg/ha, P as 12.4 to 22.4 kg/ha and K as 113-280 kg/ha (Arora, 2002).

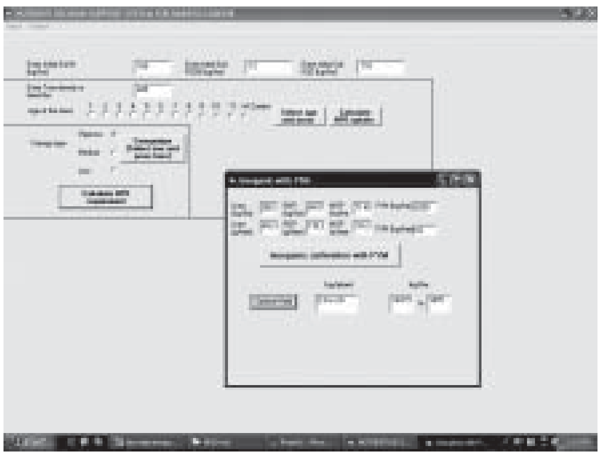

Fig. 3. The developed nutrient decision support system for cashew

Optimal organic manure/inorganic fertilizer requirement with varying density and age of plant

The optimal organic manure/inorganic fertilizer requirement with varying plant density and age was estimated. The requirement corresponding to 6^{th} year shows that the fertilizer/manure requirement per plant reduced with increased plant density (Table 6). This was mainly due to the nutrient build up in the soil due to the increased biomass fall out in the high density planting system. The recommended doses of organic/inorganic manure requirement with N, P_2O_5 and K_2O content of 160, 12 and 110 kg/ha/year (less fertile soil) in the 6^{th} year with vigorous canopy type and optimal yield were 800 g urea, 312 g rock phosphate (RP), 105 g muriate of potash (MOP) and 10 kg cow dung respectively. In case of soil test based application,

Table 6. Optimal organic/inorganic manure requirement with varying plant density

Source of fertilizer/manure		Plant density (D-plants/ha) corresponding to optimal yield (Y-kg/ha)							
		D=625 and Y=1251-1875		D=500 and Y=1150-1500		D=416 and Y=957-1248		D=200 and Y=500-600	
		Organic/inorganic manure requirement							
		kg/plant	kg/ha	kg/plant	kg/ha	kg/plant	kg/ha	kg/plant	kg/ha
Inorganic manure	Urea	0.39	245.80	0.42	209.00	0.47	195.00	0.64	127.60
	DAP	0.05	36.70	0.06	31.00	0.15	61.20	0.19	37.20
	MOP	0.11	71.50	0.11	54.00	0.10	41.50	0.05	10.50
	FYM	10.00	6250.00	10.00	5000.00	10.00	4160.00	10.00	2000.00
Inorganic manure	Urea	0.41	260.00	0.44	221.00	0.44	184.60	0.61	121.30
	RP	0.13	84.50	0.14	70.60	0.06	26.60	0.08	16.20
	MOP	0.11	71.50	0.11	53.50	0.10	41.50	0.05	10.50
	FYM	10.00	6250.00	10.00	5000.00	10.00	4160.00	10.00	2000.00
Compost	RCB+ 20% cow dung slurry	22.20	13881.20	23.20	11605.00	24.20	10075.30	30.70	6142.00
Vermi-compost	Vermi-compost alone	16.60	10410.90	17.40	8703.70	18.20	7556.50	23.00	4606.50
FYM	Farm Yard Manure alone	35.50	22210.00	37.10	18568.00	38.70	16120.50	49.10	9827.20
Poultry manure	Poultry manure alone	10.70	6663.00	11.10	5570.40	11.60	4836.20	14.70	2948.20
Neem cake	Neem cake alone	5.10	3203.00	5.30	2678.00	5.60	2325.00	7.09	1417.30
Neem cake + FYM	Neem cake	3.68	2301.90	3.90	1956.90	4.10	1725.00	5.60	1129.00
	FYM	10.00	6250.00	10.00	5000.00	10.00	4160.00	10.00	2000.00
Castor cake	Castor cake alone	4.70	2948.00	4.90	2465.00	5.10	2140.00	6.50	1304.40
Castor cake +FYM	Castor cake	3.40	2118.50	3.60	1801.00	3.80	1587.60	5.20	1039.00
	FYM	10.00	6250.00	10.00	5000.00	10.00	4160.00	10.00	2000.00
Pongamia cake	Pongamia cake alone	9.07	5668.00	8.70	4381.00	8.40	3516.00	9.30	1865.00
Pongamia cake+FYM	Pongamia cake	4.84	3030.30	5.10	2576.20	5.50	2271.00	7.40	1486.00
	FYM	10.00	6250.00	10.00	5000.00	10.00	4160.00	10.00	2000.00
Groundnut cake	Groundnut cake alone	5.90	3701.00	6.10	3094.00	6.50	2686.00	8.10	1637.00
Groundnut cake + FYM	Groundnut cake	4.20	2660.00	4.50	2261.30	4.80	1993.40	6.50	1304.50
	FYM	10.00	6250.00	10.00	5000.00	10.00	4160.00	10.00	2000.00

(Note: Estimation with N, P_2O_5 and K_2O as 160, 12 and 110 kg/ha/year respectively in the 6^{th} year with vigorous canopy type and optimal yield) for less fertile soil it was 416 g Urea, 135 g RP, 114 g MOP and 10 kg FYM and for medium fertile soil, it was 103 g urea, 131 g RP, 12 g MOP and 10 kg FYM. The recommended doses and optimal quantities of urea, RP and MOP corresponding to different ages of cashew plants under high, medium and normal density planting systems in case of low and medium fertile soils were found to vary considerably (Table 7). Hence, the soil test based nutrient application using DSS was found to be very effective in cashew garden. Increase in cashew yield due to N application was reported by Veeraraghavan *et al.* (1985) and Ghosh (1988). Positive effect of phosphorus on cashew yield was reported by Sawke *et al.* (1985). Significant positive effect of potassium on yield of cashew plant was reported by Ghosh (1988) and Ghosh (1990). Increased nut weight and nut yield due to application of higher levels of NPK was reported by Ghosh and Bose (1986), Harishu Kumar and Sreedharan (1986), Ghosh (1990) and Kumar *et al.* (1993, 1995).

The nutrient removal in 6 year old cashew plants treated with full dose of fertilizer was 339g N, 55g P and 182g K/plant/year, 2/3rd was 295g N, 53g P and 168g K/plant/year, 1/3rd was 275g N, 36g P and 134g K/plant/year and control treatment was 251g N, 36g P and 117g K/plant/year. Among three fertilizer doses *viz*., 1/3rd, 2/3rd and full dose of fertilizers, 1/3rd dose was found to be appropriate for sustainable cashew nut yield during 2001-2008 (Table 4). A nutritive balance of -93, -21 and -30 kg N, P and K respectively, per ha per year was found in control plot where no fertilizers were applied. A strong positive N balance ranged from 33 to 95, P balance ranged from 4 to 28.3 and K balance ranged from 4.7 to 11.7 kg/ha were found in plants with two third and full doses of fertilizer treatments, respectively. In treatments with one-third dose of

Table 7. Optimal organic/inorganic manure requirement (kg/plant) corresponding to optimal yield and varying plant age

Source of fertilizer/manure		Optimal organic/inorganic manure requirement corresponding to plant age (A-years) and optimal yield (Y-kg/ha)							
		A=1;Y= negligible	A=2; Y= 125-312	A=3; Y= 313- 500	A=4;Y= 501-625	A=5;Y= 626-1250	A=6;Y= 1251-1875	A=7;Y= 1876-1938	A=8; Y= 1939-2063
Inorganic manure	Urea	0.000	0.124	0.218	0.289	0.344	0.393	0.442	0.492
	DAP	0.000	0.000	0.012	0.038	0.049	0.058	0.068	0.077
	MOP	0.000	0.000	0.000	0.057	0.087	0.114	0.141	0.168
	FYM	8.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Inorganic manure	Urea	0.000	0.126	0.223	0.304	0.363	0.416	0.469	0.528
	RP	0.000	0.010	0.029	0.089	0.113	0.135	0.157	0.179
	MOP	0.000	0.000	0.000	0.057	0.087	0.114	0.141	0.168
	FYM	8.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Compost	RCB+ 20% cow dung slurry	5.000	11.000	14.800	17.900	20.100	22.200	24.200	26.200
Vermi-compost	Vermi-compost	3.750	8.300	11.100	13.400	15.100	16.700	18.200	19.700
Farm Yard Manure (FYM)	FYM alone	8.000	17.700	23.700	28.600	32.200	35.500	38.700	42.000
Poultry manure	Poultry manure alone	2.400	5.300	7.100	8.500	9.680	10.700	11.600	12.600
Neem cake	Neem cake alone	1.150	2.500	3.400	4.100	4.600	5.100	5.600	6.000
Neem cake + FYM	Neem cake	0.000	1.100	1.970	2.700	3.200	3.700	4.150	4.200
	FYM	8.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Castor cake	Castor cake alone	1.060	2.300	3.100	3.800	4.200	4.700	5.100	5.600
Castor cake +FYM	Castor cake	0.000	1.000	1.800	2.400	2.960	3.400	3.800	4.600
	FYM	8.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Pongamia cake	Pongamia cake alone	1.500	3.300	4.500	6.600	7.900	9.070	10.200	11.300
Pongamia cake+FYM	Pongamia cake	0.000	1.460	2.600	3.500	4.200	4.800	5.400	6.000
	FYM	8.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Groundnut cake	Groundnut cake alone	1.300	2.900	3.900	4.800	5.300	5.900	6.500	7.000
Groundnut cake + FYM	Groundnut cake	0.000	1.280	2.280	3.100	3.700	4.300	4.800	5.300
	FYM	8.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000

(Note: Estimation with N, P_2O_5 and K_2O as 160, 12 and 110 kg/ha/year respectively with 625 plants /ha, vigorous canopy type and optimal yield) fertilizers, a positive N, P and K balance of 12, 3 and 2.2 kg/ha/year was found. Grundon (2001) reported that an eight year old cashew plant removes 610g N, 58g P and 394g K/plant/year in Northern Australia. Mohapatra *et al.*, (1973) and Beena *et al.*, (1995) also quantified the nutrient removal by cashew.

Cashew yield response to fertilizers and manure

The application of fertilizers at 1/3rd to full dose resulted in significantly higher yield compared to control treatment where fertilizers were not applied (Table 4). Among those treatment plots receiving fertilizer doses, no significant difference in yield and net profit was found. Increased manure dose increased the yield of cashew upto six years under high density planting system and upto eight to nine years under normal density planting system (Table 5). For example, under high density with increased manure dose, the yield during 6th year increased from 927 to 1240 kg/ha whereas under normal density with increased manure dose, the yield during 9th year increased from 1145 to 1250 kg/ha.

In case of organic cultivation with a choice for less quantity manure, the user can select poultry manure or cakes like castor cake, neem cake, groundnut cake, pongamia cake etc. In case of availability of other organic manures, the user can choose vermicompost, biomass compost, FYM or FYM combination with cakes. Yadukumar *et al.*, 2009 presented recommended quantities of organic manure for a mature cashew plant along with its nutrient content. In case of inorganic cultivation the user can select urea, DAP and MOP with FYM or urea, RP and MOP with FYM. The developed decision support system was found to be feasible for determining the nutrient requirement in inorganic and /organic form for rainfed cashew garden grown along the West Coast region of India. Adoption of this model in field condition will help to maintain sustainable yield and balanced nutrient level in the soil thereby minimising the ecological hazards arising due to non-judicious application of inorganic fertilizers.

Validation of the nutrient decision support system for cashew

A scatter plot (1:1 plot) and a regression analysis of the measured optimal values against the predicted values of the organic manures and inorganic fertilizers with FYM are illustrated in Fig. 4 (a & b) which can be safely considered to be a reasonable fit between two data sets (R^2 = 0.95 for inorganic fertilizers with FYM and R^2 = 0.94 for organic manures). Further, Table 8 reveals that the mean error (ME) and root mean square error (RMSE) for optimal doses corresponding to inorganic fertilizers with FYM and organic manures during validation are reasonably low and are within acceptable limits. Hence the developed decision

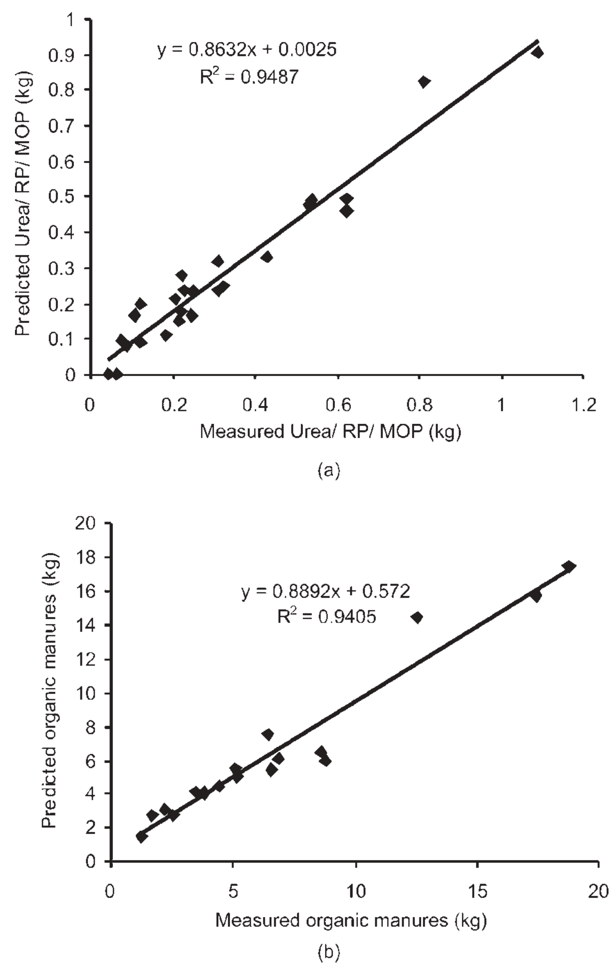

Fig. 4. (a & b). A 1:1 plot and linear regression between measured and predicted values of inorganic fertilizers and organic manures

Table 8. Results of validation of NDSS

Errors	Inorganic fertilizers with FYM	Organic manures
ME	0.04	0.14
RMSE	0.07	1.10

support system can be successfully used for finding the site specific nutrient requirement for rainfed cashew.

Conclusions

The findings of the present study indicated that for judicious use of fertilizers and or manures, prior soil testing is highly essential from time to time. The decision support system developed using Visual Basic provides the site specific optimal fertilizer/ manure requirement of cashew based on the nutrient budgeting and nutrient balance approach. The developed DSS is having the flexibility of giving the optimal quantity of inorganic fertilizers and or organic manures as selected by the user and the NDSS was validated for field data. The regression analysis of the measured optimal values against the predicted values of the inorganic fertilizers and or organic manures showed a reasonable fit between two data sets ($R^2 = 0.95$ for inorganic fertilizers with FYM and $R^2 = 0.94$ for organic manures). The application of optimal fertilizer and manure to the soil instead of recommended dose of fertilizer will help to reduce the input required, cost of cultivation and finally the ecological hazards arising in case of inorganic fertilizer application. Overall, the adoption of optimal nutrient application is strongly recommended for the sustainable management of cashew gardens.

Acknowledgement

The authors thank Dr. M. Gopalakrishna Bhat, Director, Directorate of Cashew Research, Puttur for providing facilities to develop this model. The authors also express their sincere gratitude to Dr. T.R. Rupa for her suggestions in improving the paper and the National Agricultural Technology Project (NATP) for the funding they provided for generating data for the model development.

References

Agricultural Research Station. 1994. Report of Agricultural Research Station, Ullal, D.K., Karnataka.

Arora, C.L. 2002. Analysis of soil, plant and fertilizers. In: *Fundamentals of Soil Science*. Indian Society of Soil Science, New Delhi.

Beena, B., Salam, M.A. and Wahid, P.A. 1995. Nutrient off take in cashew (*Anacardium occidentale L.*). *The Cashew* **9**(3): 9-16.

DCCD, 2009. Directorate of Cashew and Cocoa Development. *Available online*. http://dacnet.nic.in/cashewcocoa/ stat.htm#stat.

FAO. 2009. Bio-Physical, Socio-Economic and Environmental Impacts of Degradation - Egypt, Ethiopia, Ghana, Kenya, Malawi, South Africa, Tanzania, Uganda, Zambia, Zimbabwe. *Plant and Land Nutrition Management Service*. MADS- SEA Network. *Available online.*

Ghosh, S. N. and Bose, T. K., 1986. Nutritional requirement of cashew (*Anacardium occidentale L.*) in lateritic tract of West Bengal. *Indian Cashew J.* **18**(1): 11-16.

Ghosh, S. N., 1988. Effect of nitrogen, phosphorous and potassium on flowering duration, yield and shelling percentage of cashew (*Anacardium occidentale L.*). *Indian Cashew J*. **19**(1): 19-23.

Ghosh, S. N., 1990. Studies on the NPK requirement of cashew (*Anacardium occidentale L.*) in lateritic tract of West Bengal. *The Cashew* **4**: 6-9.

Grundon, N. J, 2001. A desktop study to predict the fertilizer requirements of cashew trees in Northern Australia. *CSIRO Land and Water, Atherton, Technical Report 32/ 01*, December 2001.

Gupta, A.K. 2001. Nutrient mining in different agro-climatic zones of India. *Rajasthan. Fert. News*, **46**(9): 39-46.

Harishu Kumar, P., Sreedharan, C. 1986. Nut characters as influenced by different levels of NPK in cashew (*Anacardium occidentale L.*). *Indian Cashew J*. **18**(2): 15-17.

IFPRI. 2008. International Food Policy Research Institute Report. *Available online*. http://www.commondreams. org/news 2000/0523-01.htm

Kumar, D. P., Hegde, M. and Khan, M. M. 1993. Effect of nitrogen, phosphorus and potassium on growth and yield of cashew in coastal soils of Karnataka. *Cashew Bulletin* **30**(12): 9-12.

Kumar, D. P. Khan, M. M., and Venkataramu, M. N. 1995. Effect of NPK and growth regulators on harvesting, nut yield, shelling per cent and kernel grade of cashew. *J. of Plantn. Crops* **23**(2): 96-104.

Kutra, G. and Aksomaitiene, R. (2003). Use of nutrient balances for environmental impact calculations on experimental filed scale. Europ. *J. Agron.* **20**:127-135.

Mohapatra, A.R., Kumar, K.V., and Bhat, N.T. 1973. A study on nutrient removal by the cashew tree. *Indian Cashew J.* **9**(2): 19-20.

NAAS. 2006. Low and Declining Crop Response to Fertilizers. *Policy Paper No. 35, National Academy of Agricultural Sciences*, NASC Complex, Dev Prakash Shastry Marg, Pusa Campus, New Delhi. 8 pp.

O'Farrell, P., Armour, J. and Reid, D. 2002. The effect of nitrogen on cashew in north Queensland 1995-99.

RIRDC Publication No W02/001. RIRDC Project No DAQ-257A.

Radersma, S., Otieno, K., Krah, A.N.A and Niang, A.I. 2004. System performance analysis of an alley – cropping system in Western Kenya and its explanation by nutrient balances and removal processes. *Agriculture, Ecosystems and Environment* **104**: 631-652.

Rejani R. Jha, M. K., Panda, S. N. and Mull, R. 2008. Simulation Modeling for Efficient Groundwater Management in Balasore Coastal Basin, India. *Water Resources Management* **22**(1): 23-50. DOI- 10.1007/S11269-006-9142-Z.

Rejani, R. and Yadukumar, N. 2010. Soil and water conservation techniques in cashew grown along steep hill slopes. *Scientia Horticulturae* **126**:371-378. Doi:10.1016/j.scientia.2010.07.032

Richards, N.K. 1993. Cashew Research in Northern Territory, Australia, 1987-1991. *Tech. Bull. No.202*. Govt. of Australia, pp:65.

Salam, M. A., John, P. J., Joseph, M., Poduwal, M., Kumar, P., Yadukumar, N. and Bhat, M.G. 2008. Quantitative estimation of soil fertility and fertilizer recommendations (QUEFC) for Cashew (*Anacardium occidentale* L.). *J. of Plantn. Crops* **36**(2), 86-94.

Sawke, D. P., Gunjale, R. T., Limaye, V. P. 1985. Effect of Nitrogen, phosphorous and potash fertilization on growth and production of cashewnut. *Acta Horticulturae* **108**: 95-99.

Singh, H.P., Sharma, K.L., Ramesh, V. & Mandal, U.K. 2001. Nutrient mining in different agro-climatic zones of India - Andhra Pradesh. *Fert. News* **46**(8): 29-42.

Thampan, P. K., 1995. *Organic Agriculture*. Peekay tree crops development foundation. Gandhi Nagar, Cochin -20, Kerala, India, 354 pp.

Veeraraghavan, P.G., Celine, V.A.and Balakrishnan, S. 1985. Study on the fertilizer requirements of Cashew (*Anacardium occidentale L.*). *Cashew Causerie* **7**(2): 6-8.

Yadukumar, N. and Mandal, R.C. 1994. Effect of supplementary irrigation on cashewnut yield. Water Management for Plantation Crops - Problems and Prospects. *Centre for Water Resource Development and Management*, Calicut, Kerala. pp. 79-84.

Yadukumar, N., Rao, E.V.V.B. and Mohan, E. 2001. High density planting of cashew (*Anacardium occidentale L.*). *Trop. Agric. (Trinidad)* **78**(1): 19-28.

Yadukumar, N., Raviprasad, T.N., Nagaraja, K.V., Haldankar, P.M., Godase, S.K., Susanamma, K., Gajendran, G., Mahalingam, T., Lenka, P.C., Mohapatra, R.N., and Bandyopadhyay, B. 2003. National Agricultural Technology Project. *Final Report on developing integrated production packages for enhancing productivity of cashew.* National Research Centre for Cashew, Puttur, D.K., Karnataka. 95pp.

Yadukumar, N. and Rejani, R. 2004. Evaluation of soil and water conservation techniques coupled with manuring in cashew grown under medium slope. *J. of Plantn. Crops* **32** (Suppl.): 190-195.

Yadukumar, N. and Nandan, S.L. 2005. Recycling organic waste of cashew plantations by aerobic composting. *J. of Plantn. Crops* **33** (2): 99-102.

Yadukumar, N. 2007. Organic farming in cashew. In: *Proceedings of the National seminar on Research, Development and Marketing of Cashew*, 20-21st November, Goa, pp. 36-46.

Yadukumar, N., Nayak, M.G. and Bhat, M.G. 2009. Organic production of cashew. *The Cashew* **1**(4): 11-19.

Yadukumar, N., Rejani, and B. Prabhakar. 2009. Fertigation for efficient water and nutrient management in high density cashew plantation. *J. of Plantn. Crops* **37**(2): 102-110.

Yadukumar, N. Rejani, R. Rupa, T.R. and Srividya, B.R. 2011. Optimal nutrient requirement and plant density for enhancing the cashew productivity *J. of Plantn. Crops* **30**(1): 26-29.