Bunda Journal of Agriculture, Environmental Science and Technology, Vol. 3 pp. 1-11
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ISSN 1726-3220
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SOIL FERTILITY RESPONSE TO THE APPLICATION OF SELECTED ORGANIC RESIDUES UNDER SULPHUR DUSTING IN SOUTHERN TANZANIA

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ABSTRACT

The ameliorative potential of organic residues to soil acidity caused by sulphur dusting on cashew trees was investigated in a cashew farming zone in Tanzania for two consecutive seasons starting from 2001 to 2004. This was undertaken in two agro ecological zones namely C2 and E5 dominant in the area. Residues were applied at rates of 2.8, 4.2 and 3.3 tones/ha for groundnut, maize and goat manure respectively at Makukwe and Naipanga sites. At Naliendele, cowpea (2.8 t/ha) was used instead of maize residue. Sulphur was dusted at 3 and 5 rounds equivalent to 36 and 72 kg/ha/a, respectively. Results showed a significant ($P \leq 05$) reduction in soil pH under tree dusted with sulphur but without the incorporation of residue sources. Soil pH increased by 0.57, 0.62 and 0.97 units in soils incorporated with goat manure at Naipanga, Makukwe and Naliendele respectively. Similarly, Soil Organic Carbon (SOC) slightly increased in soils incorporated with residue sources respectively with goat manure additions especially in the Rhodic ferralsol. Increased cashew yield with increased sulphur application rates was also demonstrated whereby cashew yields increased by more than 1 fold after dusting 5 rounds of sulphur. For acid poor soils, dusting of sulphur to control powdery mildew disease must ensure that potential organic residue sources are incorporated into the soil in order to buffer the soils against soil acidification.

Key words: Alkalinity, Cashewnut production, Powdery mildew, Soil fertility, Sulphur, Organic residues

INTRODUCTION

Tanzania is one of the major producers of cashewnut, one of the most expensive crops in the world. This crop in 1998 ranked first in generating foreign exchange, besides coffee, cotton, and sisal (URT, 1999). It is estimated that the area under cashew is 400,000 ha and that around 280,000 smallholders are involved (Martin *et al.*, 1997). Production of cashewnut in Tanzania reached its peak of 145,000 t in 1973 and thereafter the yield declined to about 16,000 t in 1986. The major cause of the cashewnut decline was Powdery mildew diseases (PMD) that is caused by a fungus known as *Oidium anarcadii* Noak (Intini and Sijaona, 1983; Martin *et al.*, 1997). After extensive research on control strategies, sulphur dust was recommended at the rate of five applications of 0.25 kg S per tree at two weekly intervals using a motorised blower. Dusting is normally carried out during the early morning when there is mist on the flowers and leaves in order to make sulphur stick on the leaves. Not all farmers can afford to buy a blower that costs about US $ 600. They normally hire blowers or rent the services of people who dust at a fixed price. Few large-scale farmers tend to follow all the recommended dusting regimes. The average cashew yield has been observed to increase from 1.4 to 11.6 kg per tree per season from undusted to dusted cashew trees, respectively (Martin *et al.*, 1997).

The effectiveness of dusting cashew trees with elemental sulphur is influenced by various factors including wind speed and direction, prevailing moisture condition on the surface of flowers and the time of application. Smith *et al.* (1995) explain that the efficiency of dusting is very low, with less than 20% of the sulphur dusted being deposited on trees. The remaining 80% reaches the soil where it is oxidised to form sulphuric acid, which reduces soil pH (Majule *et al.*, 1997; Majule, 1999). The use of elemental sulphur in controlling powdery mildew disease (PMD) is beneficial in increasing the yield of cashew nut but it is probably environmentally detrimental in the sense that it alters the soil properties (Majule *et al.*, 1997). Field experimentation showed that within a period of five years after a continuous dusting with sulphur, soil pH of Arenosols could be reduced from 5.6 to 5.1 in slightly buffered soils (Majule *et al.*, 1997) while in poorly buffered, it

can result in pH changes from an average of 5.4 to 4.7 which is associated with an increase of aluminium toxic levels of more than 30%.

A considerable number of studies have shown that soil pH can be increased following additions of organic residues. For example, a rise in soil pH has been reported to be correlated with the amount of basic cations present in added organic matter (Pocknee and Sumner, 1997; Sakala, 1998; Nkhalamba, 1999). These organic residues may also provide a cheap and sustainable way to improve poor and acidic tropical soils (Tian *et al.*, 1982; Lungu *et al.*, 1993; Wong *et al.*, 1998; Noble *et al.*, 1996; Sakala, 1998). However there are conflicting accounts of the effects of different organic residue addition on soil pH. Given the compositional variability of different types of organic residue, it seems unreasonable to assume that all organic residue types will have similar effects on soil pH or other soil parameters.

Long term indicated that the incubation of soils with maize residue together with sulphur tended to increase soil pH because the alkalinity generated from maize residue exceeded the amount of protons generated from the oxidation of sulphur. Additions of cashew residue in soils amended with sulphur had little effect on soil pH (Majule, 1999). Similarly, incubation experiments conducted by Sakala (1998) with groundnut (*Arachis hypogea*) residue have shown that soil pH can be raised by the residue under wet conditions from 4.3 to 5.0 within a period of 14 days. The increase in soil pH has been established to be due to the release of large amounts of soluble alkalinity from the residue for example potassium acetate, soluble calcium oxalate or tartrate contained in alkaline residue sources (Pocknee and Sumner, 1997; Sakala, 1998; Majule, 1999).

The main purpose for conducting this study was to examine ways of improving the productivity of fragile soils under the cashew farming system in the southern zone through farmers' participation. Specifically, the study investigated the effects of incorporating organic residue sources and sulphur application on soil pH, soil organic and cashewnut yield.

MATERIALS AND METHODS

Description of Study Area

This research was conducted in two villages, namely Makukwe located in Newala District in Mtwara Region and Naipanga village located in Nachingwea District in Lindi Region. Makukwe village is located on the Makonde plateau where poor and sandy soils referred to as Arenosols are found (Bennett *et al.*, 1979; Majule, 1999). This site is located in agro-ecological zone C2 (Fig. 1). Naipanga village is located in agro-ecological zone E5 and it has clayey red soils termed as Ferralsols (De Pauw, 1984).

Climatically, temperatures vary little, the average mean temperature is 24.3 ° C in the coolest month in August and 27.5 ° C in December, the hottest month. The mean maximum temperature is 30.5 ° C and the mean minimum temperature is 21.7 ° C. The rainfall pattern in the southern zone is unimodal but often has a seasonal interruption. Approximately 85% of the rainfall falls between December and April; these are defined as 'wet' months on the basis of a minimum of 50

TABLE 1. Selected properties of Luvic Arenosol and Rhodic Ferralsol soils found in two selected sites.

Soil information	pH (1:2.5)	cmol$_c$ kg^{-1}					Buffer cap.
pH^{-1}	H_2O	Al^{3+}	Ca^{++}	Mg^{++}	ECEC*	OM%**	mmol OHkg^{-1}
Makukwe	5.33	0.03	0.97	0.80	1.63	1.28	8.80
Naipanga	5.81	0.02	1.39	1.08	3.06	0.09	12.11

Source: Majule (1999).
NOTE: ECEC*is Effective Cation Exchange Capacity; OM is Organic matter.**

mm rainfall. Average annual rainfall for both regions varies between 810 mm and 1090 mm.

The soils are impoverished and the surface organic matter is the only source of soil nutrient. A number of soil groups do exist in Mtwara and Lindi. Those which meet the texture and CEC requirements of an oxic diagnostic horizon are classified as Rhodic, Xanthic or Orthic Ferralsols with an effective cation exchange capacity (ECEC) of less than 10 $Cmol^{+}kg^{-1}$ soil (Majule, 1999). Two dominant soils found in the selected sites are Luvic Arenosol and Rhodic Ferralsol. The properties of these soils are given in Baker (1995) and Majule (1999) as indicated in Table 1.

Setting of on-farm and on-station experiments

Two villages namely Makukwe and Naipanga of Newala and Nachingwea Districts, respectively and one on station located at Naliendele research station (Figure 1) were selected. Prior to the commencement of field experimental work, meetings with village leaders and key informants were undertaken. This was then followed by the establishment of farmers' research group team JUHUDI and NGUVUKAZI for Makukwe and Naipanga, respectively. The groups consisting of 21 people in each village elected their own committees and were able to allocate a cashew farm to be used for experimentation.

Experimental design and treatments

In the 2001/02 crop season, two cashew fields with young developing trees with canopy diameter of less than 4 m were identified at Makukwe and Naipanga sites. A Complete Randomized Block Design (CRBD) with three replications was adopted. In this case, 16 cashew trees constituted one replicate with three factors

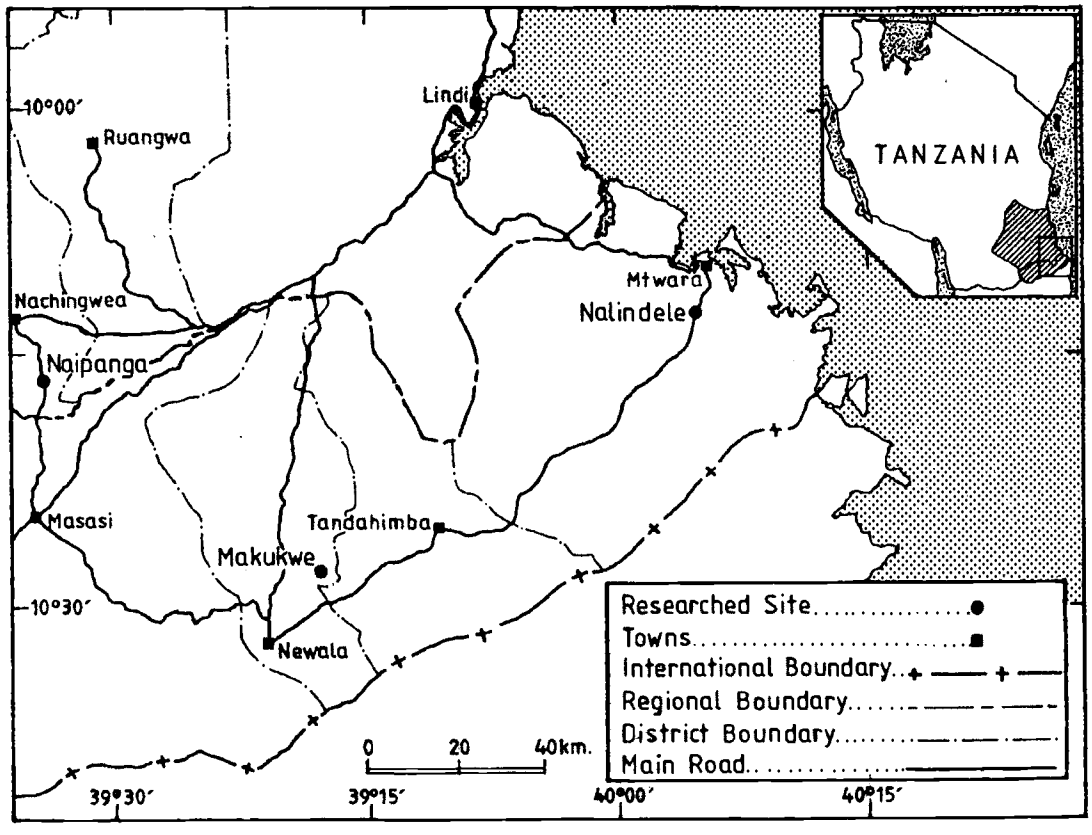


FIGURE 1. Location of study areas in the two agro ecological zones in south eastern Tanzania

TABLE 2: Experimental treatments adopted per plot

Number	Combination	Code
1	Minus residue + sulphur level 1	-RES+3S
2	Minus residue + sulphur level 2	-RES+5S
3	Plus maize residue +sulphur level 1	+MR+3S
4	Plus maize residue +sulphur level 2	+MR+5S
5	Plus groundnut residue +sulphur level 1	+GR+3S
6	Plus groundnut residue +sulphur level 2	+GR+5S
7	Plus goat manure+sulphur level 1	+GM+3S
8	Plus goat manure+sulphur level 2	+GM+5S

namely crop types, organic residues treatments and three sulphur levels as summarized below and presented in Table 2:

Crop types (2) x residues sources (4) x sulphur régimes (2) x 3 replications = 48

Major crops intercropped were maize and groundnut for on farm trials and cowpea and groundnut for the on-station experimental block. The crops intercropped were used as major source of organic residues in treatment plots. The choice of organic residue used was based on potential alkalinities contained in residues as well as residue availability and use in the area (Table 3).

Before planting, top soil samples were collected from each experimental plot at the depth of 0-20 cm for laboratory analysis. In each plot of 6 x 6 m, organic residues were applied at the rates of 10, 12 and 15 kg per plot for groundnut, goat FYM and maize residues, respectively. The equivalent amount of residue applied on hectare basis were 2.8 t/ha for groundnut and cowpea residues, 3.3 t/ha for goat manure residue and 4.2 t/ha of maize residue. The amount of residue used was calculated based on the composition values of alkalinity established earlier (Majule and Nortcliff, 2001; Omollo, 2003). Residues added were then incorporated into the soil before sulphur dusting.

The soil was analyzed for pH and organic carbon. Soil pH was measured by using a glass and reference electrode and pH meter in a ratio of 1:2.5 (soil/water) as described in Rowell (1994). Soil organic carbon was determined using Wakley-Black method (Nelson and Sommers, 1982).

Monitoring of soil fertility and cashew nut yields

The effects of organic residue incorporated in soils under different sulphur dusting regimes were assessed after two seasons of experimentation both in farmers'

Table 3. Qualities of three selected organic residues to be used in this study

Residue source	pH	Ash alkalinity	Total cations Ca	Mg	K	N%	L%	SP%	OC%
		mmmol OH/kg							
Groundnut	6.2	1320	767	458	392	1.86	8.80	0.17	41.00
Maize	7.1	397	135	148	346	0.55	7.98	1.73	44.20
Goat FYM	8.6	746	686	327	349	2.36	12.68	0.69	31.00

Sources: Majule (1999) and Sakala (1998)
Key: ca=calcium; mg=magnesium; K=potassium; N=nitrogen; L=lignin; SP=soluble polyphenol and OC=organic carbon.

fields and on-station plots. The effectiveness of two sulphur dusting regimes that is 3 and 5 rounds of sulphur applications on cashewnut yield was assessed through seasonal collection of nuts per tree undertaken by research farmers groups and casual labourers at Naliendele on station site. This task was done three days a week in order to ensure that nut theft is minimized.

Farmers evaluation of cashewnut trees performance

At the end of the season before the start of new dusting season small meetings were conducted between farmers participating in the project and a team of researchers. The major reasons for undertaking the research project described by farmers were

- To assess which cashew intercrops can perform better
- To understand the effects of sulphur dusting on soils
- To learn good agronomic practices
- To compare the effects of different organic residue sources on crop growth performance.

All the farmers who participated in the project attended a joint meeting with researchers organized separately in the two villages. Key issues for assessment were cashew yields based on different sulphur dusting regimes and farmers observation on cashewnut maturity in plots treated with different residue sources. Each of the farmers participated was given 6 bean seeds and were then asked to distribute them to the parameter they found was more correct. For example, what are you expecting to get if you don't dust sulphur on cashew trees?. Based on your experience distribute your seeds in low, average or high cashewnut yields. This was repeated for 2, 3, 4 and 5 sulphur application rounds. More seeds in a particular answer box reflected the actual situation and this was interpreted in terms of % based on the total amount of seeds provided.

RESULTS AND DISCUSSION

Results obtained from this study establish a base line for developing soil fertility management strategies based on previous studies (Majule 1999; Omollo, 2003).

Initial conditions of soil pH and soil organic carbon (SOC)

Soil pH

Table 4 presents selected soil chemical characteristics assessed prior to treatment applications. The two parameters assessed (soil pH and soil organic carbon) were not significantly differently ($P \leq 0.05$) before treatment applications. However the Naliendele and Naipanga soils recorded slightly higher soil pH values ranging from 5.02 to 5.34 for Naliendele and 4.98 to 5.18 for Naipanga. These pH values are comparable to values reported by Majule *et al.* (1997) and Omollo (2003). Soils of Makukwe are typical acid sands (pH ranging from 3.99 to 4.15) with very low buffering capacity. The major problems contributing to soil acidity is poor agronomic practices in cashew fields including the frequent removal of residues on the soil surface to keep the fields clean for cashewnut collection (Majule and Nortcliff, 2001).

Soil Organic Carbon (SOC%)

SOC% contents (Table 4) in soils under all three sites are low (≤1%) according to standards set by the National Soil Service (NSS, 1993). However at Naipanga, a typical Rhodic ferralsol has slightly higher SOC% content ranging from 0.77 to 0.82% and this was followed by Naliendele with a Cambic arenosol with SOC% ranging from 0.62 to 0,71%. SOC% at Makukwe was the lowest ranging from 0.36 to 0.44%. SOC in soils is a reflection of soil organic matter (SOM) in soils which has a significant contribution to the buffering capacity of soils. Low SOC in soils is probably due to poor cycling of organic matter attributed by frequent burning of crop residues (Majule, 1999).

Soil pH

The pattern of soil pH after three dusting seasons is presented in Figure 2. Generally, soil pH significantly ($P \leq 0.05$) decreases in sulphur-dusted soils. The magnitude of soil pH decreases were much large in all treatment plots dusted with the largest sulphur application rate (5 rounds) and without organic residue application. Decrease in soil pH was due to the oxidation of elemental sulphur explained by the following oxidation process mediated by *Thiobacillus* bacteria.

$$S + 4H_20 \longrightarrow SO_4^{2-} + 6e + 8H^+$$

TABLE 4. Soil pH and Soil organic carbon (SOC) in soils prior treatment applications

Treatment Code*	Naliendele		Makukwe		Naipanga	
	pH	SOC%	pH	S OC%	pH	SOC%
-RES+3S	5.09	0.62	4.15	0.36	5.10	0.77
-RES+5S	5.23	0.70	4.18	0.44	4.98	0.82
+MR+3S	5.19	0.66	4.05	0.37	5.13	0.83
+MR+5S	5.34	0.67	4.07	0.38	5.02	0.78
+GR+3S	5.28	0.70	3.99	0.40	5.18	0.80
+GR+5S	5.20	0.67	4.06	0.41	5.00	0.81
+GM+3S	5.20	0.71	4.03	0.38	5.12	0.75
+GM+5S	5.02	0.69	4.08	0.46	4.99	0.81
Mean	5.19	0.68	4.01	0.40	5.07	0.80

* See Table 2 for description

In this process, the net amount of protons generated from the oxidation process entered the soil displacing the basic cations, particularly Ca^{++} and Mg^{++} through the exchange process resulting into soil acidification (Rowell, 1994).

Figure 2 indicates a significant increase in soil pH following the application of organic residues. An increase in soil pH was marked with the application of goat FYM in Arenosols at Naliendele and Makukwe

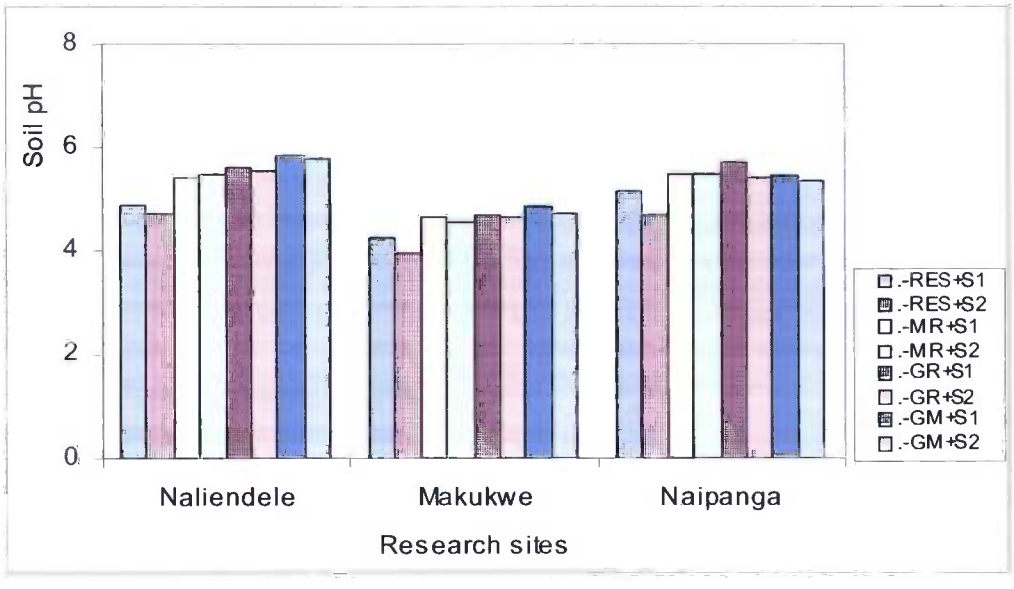


FIGURE 2: The effect of treatment combination on soil pH.

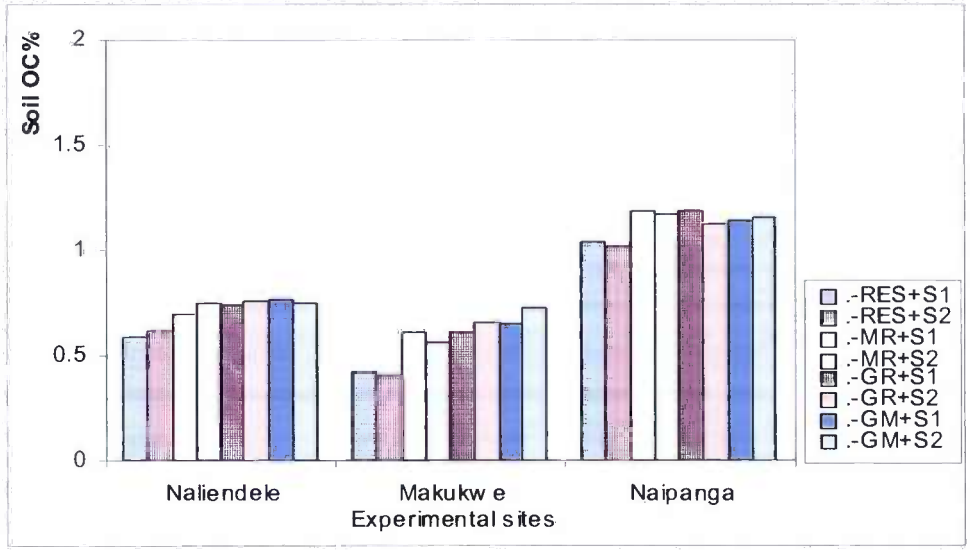


FIGURE 3: The Effect of treatment combination on SOC%

whereby soil pH increased from an average value of 5.19 to 5.85 for Naliendele and from an 4.01 to 4.87 for Makukwe. At all sites, increases in pH of the soils incorporated with different sources of residue under cashew trees dusted with 5 rounds of sulphur was slightly lower than that under tree dusted with 3 rounds of sulphur. This observation is in broad agreement with previous observations based on incubation studies (Majule, 1999; Omollo, 2003).

The principle underlying acid neutralization potential of organic residue is based on the potential alkalinities of organic residues added to the soil. The potential alkalinities of organic residues were in the order 397 (maize), 746 (goat manure) and 1320 (groundnut) mmol OH^{-1} kg^{-1}. Marked increased in soil pH following the application of goat manure corresponds to large soil pH of pure residue (pH 8.6). These observations are quite similar to those reported by Majule (1999; Majule, 2001) for similar soils.

Soil organic carbon

The effects of incorporating maize, groundnut or cowpea and goat manure on SOC is presented in Figure 3. Generally, SOC was slightly higher in Rhodic Ferralsol at Naipanga as compared with Arenosols. The application of organic residues increased SOC in most soils. However SOC contents at Naliendele and Makukwe are still on the lower side while the contents at Naipanga increased from low to moderate level (1-2%). Such small increases in SOM are not surprising for such soils. The build up of SOC takes a considerable time because a lot of carbon is lost through microbial decomposition (Rowell, 1994). Another reason for such small increases is probably due to the fact that nearly all sites have very high termite activities which have been reported to transfer a considerable amount of residue and concentrate them in termite mounds (Majule, 1999).

Previous studies have shown that long term application of sulphur can have a significant effect in reducing SOC probably due to impaired decomposition associated with acid accumulation (Majule *et al.*, 1997). In this study, the effect of elemental sulphur additions was not observed to have significant effects on SOC probably due to the fact that significant changes are observed over time (Rowell, 1994).

Response of cashew trees in terms of yield to sulphur dusting

There was quite remarkable increase of cashew yields from 3 sites used and it occurred at the first dusting season and extended to subsequent seasons. As indicated in Table 5, cashew yield varied with sites due to difference in tree ages as well as due to variations in

agroclimatic conditions. Cashew trees at Naipanga site are the youngest while those at Naliendele and Makukwe sites are older.

Cashewnut yields per tree increased by less than 1 fold following elemental sulphur dusting to control PMD due to the fact that relative young trees were used as compared to increases of 2 or 3 folds reported by Sijaona (1984) for large trees. Increase in cashew yields due to tree growth was also quite remarkable at most sites (Table 5). The effect of organic residue additions did not show a significant difference on cashew yields. However organic residue application seems to be very important in buffering the soils against soil acidity generated by elemental sulphur dusted on cashew trees. Reduced sulphur application rates from 5 to 3 rounds seem to be effective in reducing soil acidity but not quite effective in increasing cashew yield. The findings call for sustainable management of organic residue at farm level in order to maintain soil fertility and sustain the productivity of fragile soils.

Farmers' evaluation of crop performance

The normal recommended sulphur application rate is 1.25 kgS/tree for 5 rounds at an interval of 2 weeks for the first two rounds and at the interval of 3 weeks for the last 3 rounds (Smith *et al.*, 1995). Through innovative learning, most farmers at Naipanga site (Table 6) hardly reach the application rate of 5 rounds per tree. Most of them reach 4 rounds only. On the other hand, for effective control of PMD and high yields, most farmers at Makukwe tend to apply all the 5 rounds. However, in most cases, increased application rates of sulphur in individual farmers' fields increased cashew yield.

Annual intercrops can have significant effects in modifying soil physical conditions such as soil moisture content and soil workability (Rowell, 1994). Farmers are quite knowledgeable in choosing the type of crops to be intercropped with cashew trees. The performance of cashew trees in terms of nut maturity was also assessed and a summary of result is indicated below in Table 7.

Interestingly, the majority of farmers in both sites were able to recognize that cashew trees intercropped with groundnut and those within plots incorporated with goat manure were able to mature early with nuts of very high quality. Two possible explanation for such effects could be; (1) improved soil water holding capacity after residue additions or (2) soluble fractions of mineral elements including nitrates were easily utilized by young cashew trees thus stimulating nut setting and maturity. More research is needed in order to establish the mechanisms for such changes.

CONCLUSIONS

Over the past two decades, declining soil fertility asso-

TABLE 5. Cashewnut yields (kg/tree/a) for the two dusting seasons

Treatment Code	Naliendele		Makukwe		Naipanga	
	2002/03	2003/04	2002/03	2003/04	2002/03	2003/04
-RES+3S	6.67*bc*	11.20*d*	9.33*c*	14.27*c*	1.86*ab*	4.94*cd*
-RES+5S	9.90*a*	17.25*b*	12.67*ab*	20.98*a*	4.93*ab*	9.12*ab*
+MR+3S	6.54*bc*	14.47*c*	9.33*c*	15.10*c*	4.95*ab*	7.94*bc*
+MR+5S	10.65*a*	19.07*a*	13.83*a*	19.78*ab*	5.87*a*	11.87*a*
+GR+3S	5.37*c*	12.17*d*	9.83*bc*	17.22*bc*	2.57*ab*	4.83*cd*
+GR+5S	9.63*a*	18.58*ab*	10.83*abc*	19.67*ab*	2.91*ab*	8.22*bc*
+GM+3S	7.42*b*	14.23*c*	8.50*c*	14.63*c*	1.67*b*	3.70*d*
+GM+5S	11.0*b*	18.84*ab*	10.19*bc*	20.02*ab*	2.30*ab*	6.28b*cd*
$LSD_{(0.05)}$	1.48	1.64	2.93	3.24	3.61	3.21
CV%	14.38	8.52	22.68	14.95	87.11	36.88

Means with similar letters within the same column are not significantly different (P≤5%)

TABLE 6. Performance of sulphur dusting regimes (rounds) in individual farmers fields

Sulphur applications (rounds)	Naipanga Cashewnut yields recorded			Makukwe Cashewnut yields recorded		
	Low	Average	High	Low	Average	High
0	100	0	0	87	3	10
2	83	7	10	-	-	-
3	-	63	27	37	33	30
4	33	17	60	17	7	76
5	NA	NA	NA	10	13	77

Assessment by farmers has been converted into % based on seeds allocated by farmers.

ciated with elemental sulphur dusting have been seen to be a threat to the productivity of poor and delicate acid sandy soils. The debate on whether to stop sulphur dusting and use alternative organic fungicides such as Byfidan, Anvil and Topaz for controlling PMD seems to be rather difficulty since the majority of farmers are used to sulphur. However, continuing dusting sulphur to control PMD needs to undertaken with constant application of potential organic residue sources such as groundnut or goat FYM. In order to ensure the availability of residues, farmer needs to be encouraged to grow groundnut by using proper varieties and apply proper agronomic practices. This can be achieved through improved seed supply system. Also, farmers need to be encouraged to apply and spread goat FYM uniformly in their fields. The concerned authority such District councils and Rural Integrated Project Support (RIPS) programs needs to be fully involved in ensuring that farmers get all the necessary support and package needed. Extension workers needs to work hand in hand with farmers since this is lacking due to various reasons including poor working environments and lack of incentives. Finally, extension workers needs to be well informed on current issues related to soil fertility and water management so that they can integrate with farmers knowledge. This requires provision of proper training to extension staff.

ACKNOWLEDGMENTS

Authors wish to extend their sincere thanks to the Rockefeller Foundation for providing funds to undertake this study. The Directors of the Institute of Resource Assessment (IRA) of the University of Dar es Salaam and Naliendele Agricultural Research Institute

TABLE 7. Cashewnut maturity period assessment by individual farmers

Organic residue source	Naipanga Nut maturity			Makukwe Nut maturity		
	Normal	Early	Late	Normal	Early	Late
Maize	30	43	27	30	27	43
Groundnut	14	62	14	23	57	20
Goat manure	20	60	20	00	87	13

NOTE: Assessment by farmers has been converted into % based on seeds allocated by farmers

are thanked for granting permission to researchers to conduct this study. All farmers who were involved in this study are also acknowledged for their patience. Finally, we would like to thank all extension workers who worked with us tireless at different time during this project.

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