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Full Length Research Paper

Soil moisture stress mitigation for sustainable upland rice production in the Northern Guinea Savanna of Nigeria

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Northern Guinea Savanna (NGS) of Nigeria cultivable lands have sandy loam to loamy sand surface textures, low organic matter and are susceptible to erosion (wind and water). To mitigate crop moisture stress, on-farm trials involving contour-ridge-tying and contour ridging were carried out in Albasur and Dansoda villages in Dandume Local Government Area of Katsina State NGS to conserve soil against erosion and moisture for crop use in 2008 and 2009. The area NGS witness poor rainfall distribution, dry spells lasting beyond twenty one days occurring between June and July and low rainfall amounts (< 900 to 1300 mm per annum). These result in upland crops like rice (NERICA 2 var.) witnessing deficit soil moisture to undergo proper growth and production, low yields or complete crop failure. Also, soil erosion and runoff deplete water that could be available for crops and degrade farmlands for continued cultivation on the land. In this trial farmers ranked their rice grain yields while physical and agronomic data collected were statistically analysed using ANOVA and Duncan multiple range tests to separate means. Results show that cross-banded ridge resulted in significantly higher rice grain yields than the other treatments and was followed by contoured ridge. Socio-economic data collected were analyzed using descriptive statistics and budgeting technique. Costs and returns analysis results show that labour and fertilizer inputs accounted for greater proportion of total variable costs incurred in contour (15.72%), contour plus tie ridging (15.72%), planting on flat land and farmers ridging practice (16.43 and 16.55% respectively). Costs and returns analysis result shows that rice cultivation using contour and contour plus tie ridging is more profitable, implying feasible sustainable rice production through contour farming.

Key words: Rice production, soil and water conservation, moisture stress mitigation, promotion, dissemination, contour farming, costs, returns.

INTRODUCTION

The Northern Guinea Savanna (NGS) of Nigeria commonly witness poor rainfall distribution, dry spells, surface wash and runoff on farms (Kowal and Knabe, 1972), and result in soil moisture deficiency that depress crop yield or complete crop failure at the uplands (Odunze et al., 2010). Also, the upland soils have very low moisture retention capacity, poor inherent fertility status and are dominated with low activity clays; in particular kaolinitic clays (Jones and Wild, 1975; Lombin, 1987; Odunze et al., 1996; Odunze, 2006). Crops grown at the uplands in the zone include maize, sorghum,

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upland rice, cowpea, groundnut and soybeans, and these suffer moisture stress following availability of insufficient soil moisture during their growth phase. The implies that field crops would experience insufficient soil moisture to undergo proper growth and production processes, resulting in low yields or complete crop failure in the area. Strategies to ensure soil and water conservation for sustainable crop production was sought and were undertaken in two villages in the NGS of Nigeria from 2008 to 2009. Surface wash and runoff, further compounds the poor soil quality of the NGS of Nigeria as erosion degrades the land, pollutes the soil, surface and underground water and decreases productivity capacity of the lands; thus buttressing the claim that the resulting soil erosion and degradation of farmlands in Africa leads to annual decrease of 3% agricultural production (FAO, 2009).

This study therefore aimed at determining appropriate strategy (ies) that would best conserve soil and moisture on farmlands to result in optimal rice grain and stover yields and improve on farmers' livelihoods. Also the study aimed to create awareness and promote the adoption of improved land management practices for moisture stress mitigation and increase rice yield through a participatory stakeholder's action learning research.

MATERIALS AND METHODS

Study area

The study was carried out in Albasur and Dansoda villages of Dandume Local Government Areas (LGA) Katsina State in Nigeria (North 11° 24, East 7° 07.5' and Alt. 687 m). The area (NGS) witness poor rainfall distribution pattern and has annual rainfall amounts ranging between < 900 to a maximum of 1300 mm (Odunze et al., 2010).

Methodology

Following a baseline survey of Katsina State conducted by International Fertilizer Development Centre (IFDC), Dandume area was chosen as dominant upland rice producing LGA in Katsina State and upland rice (NERICA) variety was chosen for evaluation as a test crop. Moisture stress mitigation using contoured ridges, contoured ridges+ cross-banding, ridging up-down slope direction and planting on flat harrowed plots were participatorily evaluated with farmers is an action learning set up. The four treatments/strategies are presented as follows:

1. Up-Down slope Ridging practice [U-DR]
2. Contour Ridging [C]
3. Contour Ridging +tied ridges [CT] (Cross-Banded Ridges)
4. Planting on Flat and Harrowed plots [F]

Five farm families (replicates) participated in this trial in the two villages (Albasur and Dan Soda) in 2008 and 2009 and each farm family represented a replicate. Data collected was analysed statistically at 5% level of significance and means were separated using Duncan new multiple range test (DNMRT). Treatment [F] is practiced by farmers in the area ordinarily and is considered a control treatment in this study. Composite soil samples were obtained from surface soils (0 – 15 cm and 15 – 30 cm depths) in the farmers' farms, air dried, passed through 2.0 mm sieve mesh and sub samples less than 2.0 mm diameter were analysed for particle size distribution using the hydrometer method of day, (1965) and Gee and Bauder (1986). Undisturbed core (5 cm diameter by 5 cm height) soil samples from farmers' farms were obtained at 0 - 5 cm and 5 - 10 cm depths at three periods of dry spell, for the determination of bulk density (Blake and Hartge, 1986) and gravimetric moisture content (Walter, 1986). Volumetric moisture content was calculated using the formulae:

$$q = q_m p bd$$

Where q= volumetric moisture content (cm^3/cm^3), q_m= gravimetric moisture content as a ratio or percent, pb= bulk density (Mgm^{-3}), d= depth of sampling (cm).

Also, participatory action learning research on rice production that involved farmers and researchers participating to delineate iso-heights (positions of equal heights on farms), constructing contour bunds on farmers' farms and farmers following determined contour lines to establish ridges (Contour Ridging), demarcate another plots on contoured farmers' farms for ridging and cross banding (contour ridging +tied ridges), demarcate plots of land outside contoured areas and ridge along the up and down slope direction (up-down slope ridging) and another plot for harrowing to plant without ridging (planting on flat and harrowed plots) was organized with all farmers in the village who identified with the trial to create awareness and assess the treatments for best practical option(s) for adoption. Plot area was 20 by 10 m = 200 m^2 for each treatment.

Farmer exchange visits to explain better soil moisture storage; hence, improved crop performance was conducted for farmers in the study location and they were also taught ranking with stones. Farmers ranked their crop performance using 2009 rice grain yields. Socio-economic data were collected through structured questionnaire and analyzed using descriptive statistics and budgeting technique.

RESULTS AND DISCUSSION

Particle size distribution

Table 1 presents information on the particle size distribution of soils of farmers' fields in Albasur village. The data shows that the soils are dominated with sand separates with values ranging between 34 and 54% at the surface layers (0 - 15 cm) and 38 to 42% at the 15 - 30 cm depths, indicating a reduction in sand fraction with increase in depth. Silt fractions ranged between 28 and 34% at the 0 - 15 cm layers and 34 to 44% at the 15 - 30 cm depths. This suggests that silt fractions are high in the soil and increased with increase in depth. The high silt content of the soils would predispose the soils to crusting after rainfall and this could impair infiltration, gaseous exchange in soil, seed germination and encourage runoff and surface wash on the farms.

Clay fractions of the soils were moderate to high at both depths evaluated. Values range from 16 to 34% at the surface and 18 to 24% at the 15 - 30 cm depths. The high clay contents of the surface layers could detain/delay water infiltration to benefit paddy rice. However, it does appear that top soil layers in the study

Table 1. Physical properties of soils of Dandume study area.

Location/farm	Depth	Sand 2 - 0.05 mm	Silt 0.5 - 0.002 mm	Clay < 0.002 mm	Textural classification
Albasur	Cm		-------------(%)------------		USDA
Alh. MaiGari	0 - 15	54	30	16	Sandy loam
	15 - 30	40	34	26	Loam
Alh. Muktari	0 - 15	34	34	32	Clay loam
	15 - 30	38	44	18	Loam
Alh. Lawal	0 - 15	38	28	34	Clay loam
	15 - 30	42	34	24	Loam

area had been eroded leaving sub-soil rich materials as the present surface soils. Generally soils of the zone are dominated with Alfisols (Odunze, 2006; Esu and Ojenuga, 1987) and the soils characteristically exhibit argillic subsoil properties. Texture of the soils therefore ranges between sandy loam and clay loam to loam both at the surface and sub surface layers of crop rooting zone (Table 1).

Physical properties of the soils

Bulk density and moisture content

Mean bulk density of soils under the treatments (Table 2) showed significant difference, between treatments, except between contoured ridge and contour+ridge-tied treatments. The least bulk density was obtained under up-down slope (1.51 Mgm^{-3}). However, the highest bulk density obtained under the flat planting treatment (1.60 Mgm^{-3}) is attributed to silt accumulation on the surface soil layer and formation of crust which hardened to increase surface soil bulk density (Ike, 1986, 1987). The significantly lower bulk density under contour and contour+ridge-tie treatments than the flat planting treatment suggests that crusting and surface soil hardening is less prominent under the contour and contour+ridge-tied treatment (Table 2). Table 3 shows that bulk density decreased with depth in all the instances considered, with the surface layers having a significantly high bulk density value of 1.58 Mgm^{-3} while the sub-surface depths had a bulk density of 1.51 Mgm^{-3}. Perhaps crusting by silt particles at the surface layers depth could account for the higher soil moisture in the surface layers. Increasing clay at depths will impair subsoil drainage and cause temporary sub soil water stagnation (Odunze et al., 2008; Dim et al., 2008). High bulk density values under flat, contoured and contour+cross banded ridge treatments could be attributed to effect of crusting (Ike, 1987; Kowal and Knabe, 1972; Lombin, 1987) following delayed water movement/runoff, compared with up-down slope ridging (Flat planting is done on harrowed and non-ridged fields irrespective of the slope of the field) that could allow more rapid surface water movement/runoff on the farms. Also, between soil sampling dates (Table 4), bulk density did not show any statistical difference, suggesting that sampling date did not affect bulk density changes. This perhaps resulted from the fact that samples were obtained at periods of at least two weeks after the last rainfall in the village.

Soil moisture content between treatments (Table 2) did not significantly differ between treatments, though the up-down slope treatment resulted in higher than all the other treatments and is followed by contour+ridge-tie treatments. Moisture content however, increased with depth generally, perhaps moisture content increased with increasing clay content as clay would cause impaired drainage at the sub surface depths ((Odunze, 2003; Dim et al., 2008). Between dates of sampling however, moisture content did not significantly changed.

Rice yield

Table 5 shows that significantly higher rice grain yield was obtained contour+cross banded ridge (1.68tha^{-1}) and Contoured ridge (1.64 tha^{-1}) than flat planting (1.36tha^{-1}) and lastly up-down slope (1.12tha^{-1}) treatments for the 2008 and 2009 trial years. It is realizable that among the treatments, contour+cross banded ridges resulted in significantly highest grain yield than all the treatments over the two years the study was conducted. Also contoured ridge treatment resulted in significantly higher grain yield (1.64 tha^{-1}) than up-down slope ridging and flat planting.

The result would therefore suggest that contoured+cross banded ridges would result in 50% higher grain yield than up-down slope ridging. Contoured ridging gave 46% grain yield higher than up-down slope ridging. Commonly in the NGS of Nigeria, farmers plant upland rice on the flats after harrowing the fields. A few farmers however, plant on ridges made without considering slope direction, but commonly prefer up-down slope for ease of ridging operation. In the context of farmers' practice therefore, flat planting and up-down

Table 2. Soil bulk density and moisture content of rice trial sites in Dandume.

Treatments	Bulk density	Moisture content
	Mg m^{-3}	Cm^3Cm^{-3}
Contour	1.53ba	0.53a
Contour+ridge tie	1.54ba	0.59a
Up-Down slope Ridging	1.51b	0.63a
Flat	1.60a	0.55a

Means with the same letters are not significantly different.

Table 3. Soil bulk density and moisture content with depth.

Depth	Bulk density	Moisture content
Cm	**Mg m^{-3}**	**Cm^3Cm^{-3}**
0-5	1.58a	0.44b
5-10	1.51b	0.72a

Means with the same letters are not significantly different.

Table 4. Bulk density and soil moisture Content over time.

Dates of sampling	Bulk density	Moisture content
	Mgm^{-3}	**Cm^3cm^{-3}**
04-07-09	1.55a	0.57a
27-06-09	1.53a	0.61a
14-11-09	1.55a	0.55a

Means with the same letters are not significantly different.

Table 5. Rice yield in Dandume 2008 – 2009.

Treatment	Grain (tha^{-1})	Difference (%)	Stover (tha^{-1})
Contour	1.635 a	46.24	2.363 a
Contour +ridge tie	1.678 a	50.09	2.392 a
Up-down slope	1.118 b	-	2.072 a
Flat	1.355 ba	21.20	2.013 a

Means with the same letters are not significantly different.

slope planting had not supported sustainable rice grain yield but part-contributed to reduced rice yield, soil degradation and increased farmer poverty conditions. The least grain yield under up-down slope ridging is attributed to effects of runoff, moisture depletion, nutrients depletion due to surface wash and eroded/ degraded state of the soils. Adoption of contouring with cross banding of ridges on farmers' fields is potentially capable of assuring optimal upland rice grain yield, alleviating farmer poverty/livelihoods with environmental protection and sustainable soil maintenance.

Data on stover yields of rice (Table 5) under either of the treatments were not significantly different, but suggests that NERICA upland rice would yield a little over 2 tha^{-1} of stover that could be used for feeding livestock or ploughed into the soil to improve the soil carbon contents, moisture retention capacity of the soils, check nutrients loss to leaching and soil erosion.

Cost and returns analysis

The costs and returns analysis (Table 6) indicate that labour and fertilizer inputs account for greater parts of total variable costs incurred in all the treatments. Gross margin analysis of contour farming practices (Table 6) show that from one hectare of cultivated land, total cost of production for contour, contour+ridge-tie, flat planting and farmer's practice (up-down slope) in Albasur were ₦162, 888.75, ₦155,835.35, and ₦161,796.00. Also gross revenue of ₦243,250.00 was obtained for contour and contour+ridge-tie, ₦163,800.00 and ₦133,350.00/ha for planting on flat land and farmers practice respectively; thus giving a gross margin of ₦80,361.25 for contour and contour+ridge-tie, ₦7,964.65 and ₦28,446.00/ha for planting on flat and farmers practice, respectively.

The costs and returns analysis indicated that cultivation of rice through contour and contour plus tie ridging was more profitable than planting on flat. This implies that intensification and expansion of rice production through contour farming would increase rice productivity, increase income of farmers and optimize soil quality for sustainable productivity. In terms of gross margin per Naira invested, for every one Naira invested on rice production using contour and contour plus tie ridging and planting on flat land, a net gain of 49 and 5 kobo were obtained, while for farmer ridging practice a net loss of 18 kobo (-0.18) was incurred. It would however, be borne in mind however, that contours are fixed assets that would have their returns/depreciation costs on construction spread over several years.

Farmers' crop performance assessment

Table 7 shows farmers' ranking of their grain yields at a farmer participatory action learning research (PLAR) session conducted in the villages. Farmers ranked contour+ridge-tied treatment best performing treatment because it resulted in higher grain yield considering all four farmers' grain yields. Contoured ridges was assessed second best treatment for its better grain yields than their practice of either up-down slope ridging or planting on the flat harrowed fields.

Farmers found the pair-wise ranking useful because they could appreciate why over the years they had not attained yields as high as they did obtain under

Table 6. Costs and returns analysis contour farming practices in Dandume local government area of Katsina state, Nigeria.

Location : Albasur								
Treatment								
Costs/Returns Items **(1) Costs/Ha**	**Contour**	**(%)**	**Contour + ridge tie**	**(%)**	**Plant on Flat Land**	**(%)**	**Farmer Practice**	**(%)**
Seed	10,400.00	6.38	10,400.00	6.38	10,400.00	6.67	10,400.00	6.72
Fertilizer	25,600.00	15.72	25,600.00	15.72	25,600.00	16.43	25,600.00	16.55
Fungicide	1,250.00	0.77	1,250.00	0.77	1,250.00	0.80	1,250.00	0.81
Bag (Sacks)	2,100.00	1,29	2,100.00	1,29	1,440.00	0.92	1,140.00	0.74
Labour								
Land preparation	35,888.67	22.03	35,888.67	22.03	35,888.67	23.03	35,888.67	23.20
Planting	11,718.75	7.19	11,718.75	7.19	11,718.75	7.52	18,750'00	7.57
Fertilizer application	14,648.44	8.99	14,648.44	8.99	14,648.44	9.40	14,648.44	9.47
Weeding	30,517.58	18,74	30,517.58	18,74	30,517.58	19.58	30,517.58	19.72
Harvesting	12,695.31	7.79	12,695.31	7.79	12,695.31	8.47	12,695.31	8.21
Threshing	15,637.50	9.60	15,637.50	9.60	10,530.00	6.76	8,572.50	5.54
Transportation	2,432.50	1.49	2,432.50	1.49	1,146.60	0.74	1,333.50	0.86
Total variable cost (TVC)(₦)	₦162,888.75		₦162,888.75		₦155,835.35		₦161,796.00	
(2) Returns								
Average yield (kg/ha)	3475		3475		2340		1905	
Average Price (kg/ha)	70.00		70.00		70.00		70.00	
Gross Revenue (₦ /ha)	243,250.00		243,250.00		163,800.00		133,350.00	
Gross Margin (GR – TVC)(₦) /ha	80,361.25		80,316.25		7,964.65		- 28,446.00	
Return/Naira Invested	0.49		0.49		0.05		-0.18	

Table 7. Farmer pair-wise ranking of treatments performance on rice grainyield.

Farmers	Grain yield with treatments (kg/plot)				Remarks
	C	C+RT	F	UP-S	
Alh. MaiGari	22.5	22.1	20.0	24	88.6
Alh Garba	27.1	25	22.5	22	96.6
Alh. Lawal	35.7	39.5	26.8	42.8	144.8
Alh. Muktari	41.3	45.8	26.8	27.0	140.9
Total	126.6	132.4	96.1	115.8	
Ranking	2nd	1st	4th	3rd	

contoured and contoured +cross banded ridge treatments. Farmers commented that their planting of upland rice (NERICA variety) on the flat and or on the up-down slope ridges contributed to reduce their crop yields and caused erosion on their farms. In the study villages, farmers commonly plant upland rice either on the flats or on ridges made along the up-down directions.

Conclusion

In realization of the crop performance on the farmers' fields for the two years of the study, the following are inferred:

1. Contoured+cross banded ridges would support optimal upland rice grain production on a sustainable base in the NGS. Bulk density of soils under this treatment could decrease to be lower than that on flat planted fields especially because organic matter content of the soils could decrease soil hardening. Rice stover should therefore be incorporated into the soils improve the soil quality to support sustainable agricultural production.
2. Planting on the up-down slope or on the flats should be discontinued among farmers and in their place, contoured and contoured+cross-banded ridging should be adopted. These would ensure soil restoration/maintenance and sustainable productivity of the soils to aid alleviation of farmer poverty conditions with increased rice yield and improved environment.
3. Contoured +cross banded ridges and contoured ridges would also retain rain water against dry spells, check surface wash and runoff, enhance optimal rice grain yield on a sustainable basis, increase farmer income from rice production and conserve the environment against degradation.

From the above therefore, it is recommended that contoured+cross banded ridge practice be adopted as this practice would enhance rice grain yield, decrease soil crusting/hardening, mitigate soil moisture stress, control soil erosion on farmlands, ensure sustainable productivity of the soil and improve farmer livelihoods.

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