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Grain legumes for soil productivity improvement in the Northern Guinea savanna of Nigeria

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Abstract

The Nigerian savanna zone is currently witnessing increasing intensities of crop and livestock production activities that are resulting in increased soil erosion, de-vegetation of the land area, and desert encroachment especially during the dry season. These may have led to the presence of several over-grazed and bare ground areas that is highly susceptible to soil erosion. At harvest, both crop and residues are removed from the field, thus limiting potential nutrient recycling between crop and soil, and further impoverishing the nutrient status of the soils. The Nigerian savanna zone soils therefore have low total nitrogen, organic carbon, available phosphorus and cation exchange capacity. They also have very poor moisture holding capacity, and are therefore said to have poor fertility status and very low buffering capacity. The present study aimed to determine effects of grain legumes on soil potential in the arid systems was therefore imposed on the soils in the Zaria area. Results show that sole legumes and legume/maize treatments generally resulted in higher organic carbon contribution than sole maize treatment, suggesting that sole maize grown continuously on one farm for years could degrade the organic carbon content of the soil. Also, the sole legume and legume/maize treatments resulted in improvements in soil nitrogen in the range between 65.6 and 84.8 %, while nitrogen under sole maize resulted in only 5.9 % increase. In 2001, groundnut/maize intercrop resulted in significantly higher maize grain yield (1.49 t ha^{-1}) than the other treatments. Comparing between maize grain yields in 2001 and 2002, maize grain improved by 20.1% under sole maize, 95.0% under maize in sole groundnut, 92.8% under maize in soybean, and 98.4% under maize in cowpea. This would confirm that the sole legume planting for two years restored fertility status of the soils and enhanced the soil organic carbon and total nitrogen, to have resulted in greater maize grain yield than under the sole maize despite the 120 kg N fertilizer applied to the sole maize.

***Key words**:* Soil restoration, soil moisture conservation, sustainable crop and livestock production, sustainable soil management.

Introduction

The Nigerian Guinea savanna (NGS) is currently witnessing increasing intensities of crop and livestock production. Nomads and semi-nomads raise livestock by employing a free grazing feeding pattern. This practice implies that over-grazing, with its attendant enhanced soil erosion, de-vegetation of the land area and desert encroachment is increasing in scope[7, 18]. Especially during the dry season months (November to May) livestock fodder is scarce, and results in impaired livestock nutrition and health conditions [29, 30]. Crop production in the zone involves ploughing, harrowing and ridging done with no special attention to conservation measures against soil nutrient depletion (mining), soil erosion and runoff [9]. The increasing cost and erratic availability of mineral fertilizer materials inhibit farmers' access to sufficient fertilizer for crop production[7, 13]. At harvest, both crop and residues are removed from the field, thus limiting nutrient recycling between crop and soil. Crop residues are used for fencing, feeding livestock and fuel wood [1, 16, 15, 29, 30]. Obviously therefore, there is a net loss of nutrients from the cropland, a loss that can be dramatic if crop residues are not returned to the soil. Inevitably, land that is cropped year in and out without any nutrients being added will not continue to support the same yields-crop yield fall [7].

Generally, soils of the NGS zone have low total nitrogen, organic carbon, available phosphorus and cation exchange capacity. Hence, they are said to have poor fertility status and very low buffering capacity [8, 12, 19]. The soils have dominantly kaolinite clays and are sandy to sandy-loam in texture [22]. They have low available soil moisture retention capacity and encourage leaching of nutrients away from the rooting depth of most crops [18]. The soils therefore become degraded due to effects of soil erosion, over grazing, nutrient mining, and poor soil management strategies adopted by farmers. In this context, the present study aims at considering the role of grain legumes in improving/rehabilitating the soils for sustainable crop and livestock production. In the NGS of Nigeria, cowpea, groundnut and soybean are commonly grown for food and cash returns to homes. Their use for soil improvement and quality fodder production are evaluated in this paper.

Materials and Methods

Site: The project was executed in four villages, *viz;* Dunki (East 7°34', North 10°55'), Turawa (East 8°03', North 11°04'), Gobirawa (East 7°26', North 10°55'), Dan Birni (East 7°16', North 11°15') and at the Institute For Agricultural Research (IAR) farm in Zaria (East 7°30', North 11°00') from the year 2000 to 2002. In this region, upland soils belong to the alfisols order [23], and those of the study area (IAR) are described as belonging to the typic haplustalfs subgroup [26].

Climate: Long-term annual rainfall in the zone averages about 1050 mm with peaks of rain occurring between June and September. The 1999 to 2002 mean rainfall amounts ranged from 952.6 to 1397 mm, and could start in May, but often stops in the month of September or early October (Table 1). Dry season sets in by October and lasts into the month of May[10]. Soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthermic respectively [18, 23]. Mean air temperature in the Zone range between 25 and 28^{0}C during the rainy seasons (June to September) and decreases to less than 20^{0}C in the months between December and February (Table 1). The rainy season (June to September) corresponds to the rain fed cropping season in the NGS zone.

Experimental: In each village, workshops were conducted during which farmers were enlightened on the attributes of the legumes and constraints to crop production in the areas were identified. Following the workshops and participatory rural appraisal approaches in the three cropping seasons, participating farmers were able to choose from a number of leguminous crops and grew them in their own farms. In each village, the research team also established a demonstration plot with a range of species to aid technology transfer. Grain legumes tested included *Glycine max* (cv. TGX1448-2E), *Vigna unguiculata* (cv. IT93K-452-1) and *Arachis hypogea* (cv. M572-801). At both the village level (on-farm) demonstration and on-station (IAR) plots, maize (Acros97TZL Comp1-w) was included to show the effects of continuous cultivation of sole maize and maize intercropped with legumes on the soil. Maize was intercropped with legumes in two rows of maize planted at 25 cm interplant and 75 cm inter-row distance and followed by four rows of legumes at both on-station and on-farm plots for the intercrop treatments. Each plot contained ten ridges of 10 m length each. The sole maize plots were maintained on the same plot for the three-year period of the study.

In year 2001, maize was grown on two of the ten rows in each plot, planted with each of the legumes in year 2000 at the IAR on-station. The maize was grown without fertilizer application. This was to trace one-year contribution of the legumes to the soil. In 2002 at the on-station, two rows among the 10 rows in each sole legume plot not planted with maize in the previous year were planted with maize, while maintaining the sole maize and sole legume plots in place from 2000 to 2002. Also at the on-farm demonstration plots, the sole maize plot of 2000 and 2001 was retained in 2002, and the legume plots were grown to maize (Acros97TZL Comp1-w) in 2002. Maize grown in the legume plots in 2002 received 60 kg N, 60 kg P_2O_5 and 60 kg K_2O fertilizers only, while the sole maize plots under continuous maize cultivation received 120 kg N, 60 kg P_2O_5, and 60 kg K_2O recommended fertilizer rate for maize in the NGS zones. This was done to trace effects of two-year planted legume and three year continuous cropping of maize on the soil and yield of maize. In 2000, composite surface soil samples were taken from 0-15 and 15-30 cm depths at both on-station and on-farm demonstration plots prior to planting. The samples were air-dried, sieved through 2.0 mm sieve to obtain subsamples less than 2.0 mm in diameter. The subsamples were analyzed for soil pH [14], particle-size distribution and textural class [4, 5] using the hydrometer method, exchange acidity [31], organic carbon [17], available phosphorus [24], total nitrogen [3], exchangeable cations [31], cation exchange capacity by 1 N NH4OAc method [25], effective cation exchange capacity (ECEC) by sum of cations and cation exchange capacity of clay (CEC-Clay) by the formulae [27]: CEC-Clay = [CEC (soil)-3.5*%C)/ %Clay.

In 2001, composite surface soil (0-15 cm depth) samples were taken for each of the treatments at the on-station plots, air-dried, sieved through 2.0 mm sieve, subsampled and analyzed for soil pH, organic carbon, total nitrogen, available phosphorus and exchange acidity, following the methods noted above. In 2000 and 2002, undisturbed core soil samples were obtained from the on-station plots at 0-5 and 5-10 cm depths, using the 5 cm by 5 cm cores to determine bulk density and soil moisture content of the soils under the various treatments. Moisture content of the surface soils was obtained by use of the formula: $Q_v = (Q_m pd/p_w)D$, where Q_v = volumetric moisture content (cm/cm), Q_m=% soil moisture content, pd= bulk density (Mg m^{-3}), D =depth interval (cm) and p_w = particle density (2.65 Mg m^{-3}). Mean weight diameter of soil aggregates under each of the treatments was taken to determine aggregate stability rating of peds developed under the treatments. Other agronomic data obtained include ground cover rating and legume biomass assessments at 6, 8, and 10 weeks after planting (WAP), using the bided quadrant method. Canopy/crop heights at 6, 8, and 10 WAP, maize grain and stover yields, and legume residues and grain yields were also taken. Data generated were statistically analyzed using the SAS package for randomized complete block design (RCBD) and DMNRT tests. The maize and legume were taken as treatments while the on-station and on-farm trial locations were taken as replicates.

Table 1. Rainfall and air temperature (^{0}C) in the NGS of Nigeria in 1999-2002.

Month/Year	Air temp. 1999	Rainfall 1999	Air temp. 2000	Rainfall 2000	Air temp. 2001	Rainfall 2001	Air temp. 2002	Rainfall 2002
January	13.5	0	24.2	0	22.8	0	21.5	0
February	27.6	0	27.2	0	24.8	0	25.6	0
March	29.2	0	30.8	0	29.6	0	30.1	19.9
April	32.3	0	31.4	7.9	30.1	83.9	31.5	69.6
May	31.0	149.5	30.3	23.4	29.4	160.3	31.7	10.6
June	27.2	193.4	27.8	238.3	27.3	177.7	28.2	133.1
July	26.2	221.3	26.1	285.5	26.2	388.4	26.6	229.0
August	25.4	245.2	25.4	154.8	25.9	330.7	26.1	201.4
September	26.2	182.1	25.9	204.2	26.5	256.3	26.7	218.8
October	26.4	78	26.0	38.4	25.8	0	26.4	125.2
November	24.6	0	24.7	0	24.0	0	24.0	0
December	24.0	0	23.2	0	25.4	0	23.5	0
Total		1069.5		952.6		1397.3		1007.6

Results and Discussion

Initial status of the soils

Physical properties: The surface soils had sand fractions dominating the soil separates. Sand fraction ranged from 36 to 60% at the 0-15 and 15-30 cm depths, silt fraction between 20 and 40% and higher value at the 0-15 cm depths in all the locations (Table 1). The high silt values at the 0-15 cm depths may account for the common soil crusting noticed at the surface soils in the locations. Clay fraction ranged between 10 and 18% at the 0-15 cm depths but increased at the 15-30 cm depths from 20 to 38%. This would suggest that clay fraction could be increasing with increase in depth. The implication of this include that especially at the peak of rainy seasons (July, August and September), increasing subsoil clays could cause impaired drainage at such shallow depths as 30 cm [18]. This could adversely affect root growth and crop nutrient availability, as the root zone of most crops average about 50 cm. Texture of the soils were loam and sandy loam at the 0-15 cm depths, and would be conducive for crop growth and development. The subsoil clay loam, and sandy clay loam textures suggest a zone of increasing difficulty for crop root growth and ramification as well as a zone for temporary water logging.

Chemical properties: The pH(H_2O) of the soils ranged between 4.5 and 5.3 at the 0-15 cm depths, and 4.4 and 5.0 at the 15-30 cm depths (Table 2a). These values are in strongly acid range as also pH($CaCl_2$) values of the soils. The higher acidity (lower pH($CaCl_2$) values) suggests that the soils need to be amended to restore the pH values to a range between pH 5.0 and 6.5 However, exchange acidity of the soils was less than 1.0 cmol $kg^{-1}$and suggests that the soils have no acidity problems. Organic carbon content of the soils was generally very low (<10 g kg^{-1}) at both 0-15 and 15-30 cm depths, suggesting that the soils are very deficient of organic matter. Total nitrogen in the soils were very low, less than 1.5 g kg^{-1} at all the depths. Except in Gobirawa (8.0 mg kg^{-1}) and Dan Birni (7.7 mg kg^{-1}) available phosphorus in the soils was also very low. These results suggest that the soils at Samaru, Turawa, Dan Birni, Dunki and Gobirawa have inherently low fertility status. For these soils to be used for sustainable crop and livestock production, management approaches that would ensure restoration and sustained optimum fertility status of the soils should be adopted and practiced by the farmers (Table 2b).

Exchangeable calcium content of the soils was generally very low, however, in Dunki Ca values (1.25 cmol kg^{-1}) were relatively higher than in the other locations at the 0-15 cm depths and in Turawa Ca^{2+} values were moderate (2.25 cmol kg^{-1}) at 15-30 cm depths. Exchangeable Mg at 15-30 cm depth in Turawa and Gobirawa villages (0.48 cmol kg^{-1}), Dan Birni (0.42 cmol kg^{-1}) and Samaru (0.33 cmol kg^{-1}) were moderately available. At the 0-15 cm depths, all the soils had Mg values less than 0.3 cmol kg^{-1} were very low in availability. Exchangeable K values in the soils are moderate to high at the 0-15 cm depths. The highest K values were obtained at Dan Birni (0.44 cmol kg^{-1}), Turawa (0.31 cmol kg^{-1}), Gobirawa (0.29 cmol kg^{-1}) and Dunki (0.27 cmol kg^{-1}) at the 0-15 cm depths. Exchangeable K^+ values decreased at the 15-30 cm depths in all the locations studied. Exchangeable Na in the soils ranged between 0.04 and less than 0.3 cmol kg^{-1} and was very low in the soils and did not present threat for sodic soil conditions. The effective cation exchange capacity (ECEC) of the soils was generally low. The highest value of 3.05 cmol kg^{-1} was obtained in Turawa at 15-30 cm depths. Also, the CEC by 1N NH_4OAc method ranged from 3.0 to 4.6 cmol kg^{-1} at the 0-15 cm depths and from 5.8 to 8.3 cmol kg^{-1} at the 15-30 cm depths. CEC-clay values were less than 1.0 cmol kg^{-1} at all the sites and depths (Table 3). These suggest that the soils have a dominance of kaolinite clays [22] contributing very low CEC values, low fertility status and are very susceptible to leaching. This impoverished fertility status of the soils is blamed on the overgrazed condition of the land areas, use of the crop residues for fencing and for fuel

Table 2a. Particle-size distribution of soils (%) GTZ/BMZ/IITA-ILRI/IAR NGS-Nigeria demonstration fields.

Location	Depth cm	Sand 2-0.05 mm	Silt 0.05-0.002 mm	Clay <0.002 mm	Textural classification
Turawa	0-15	50	40	10	Loam
	15-30	44	36	20	Loam
DanBirni	0-15	46	38	16	Loam
	15-30	36	26	38	Clay loam
Dunki	0-15	60	26	14	Sandy loam
	15-30	50	20	30	Sandy clay loam
Gobirawa	0-15	48	36	16	Loam
	15-30	38	32	30	Clay loam
Samaru	0-15	48	34	18	Loam
	15-30	42	32	26	Loam

Table 2b. Initial chemical analysis of soils.

Location	Depth cm	Soil pH H_2o	Soil pH $CaCl_2$	Org.C g kg^{-1}	Total. Ng kg^{-1}	Avail..P mg kg^{-1}	Exchangeable cations (cmol kg^{-1}) Ca	Mg	K	Na	Exch. Al^{3+}+ H^+ cmol kg^{-1}	Base Sat. %
Turawa	0-15	5.2	4.9	3.71	0.18	5.52	0.75	0.21	0.31	0.18	0.08	0.73
	15-30	4.6	4.4	3.13	0.35	6.15	2.25	0.48	0.19	0.08	0.08	3.00
DanBirni	0-15	5.1	4.6	5.87	0.53	6.15	0.75	0.29	0.44	0.22	0.15	1.70
	15-30	5.0	4.3	4.30	0.35	7.78	0.75	0.42	0.41	0.22	0.28	1.80
Dunki	0-15	4.5	4.2	5.28	0.35	4.71	1.25	0.25	0.27	0.09	0.15	1.86
	15-30	4.1	3.8	4.89	0.53	5.24	1.25	0.25	0.19	0.18	0.43	1.87
Gobirawa	0-15	5.3	4.3	6.06	0.35	4.11	0.75	0.29	0.29	0.14	0.05	1.47
	15-30	5.0	4.4	5.28	0.35	8.09	1.25	0.48	0.24	0.18	0.13	2.15
Samaru	0-15	4.9	4.3	4.30	0.18	2.19	0.75	0.25	0.21	0.09	0.13	1.30
	15-30	4.4	4.2	3.71	0.35	2.10	0.63	0.33	0.13	0.04	0.20	1.13
Mean	0-15	5.0	4.5	5.0	0.32	4.54					0.11	1.41

Table 3. Cation exchangecapacity of the soils in 2000.

Location	Depth cm	CEC 1N NH4OAc cmol kg^{-1}	CEC-Clay cmol kg^{-1}	ECEC cmol kg^{-1}
Turawa	0-15	3.50	0.12	0.81
	15-30	6.10	0.15	3.08
DanBirni	0-15	3.00	0.17	1.85
	15-30	5.80	0.29	2.08
Dunki	0-15	3.90	0.13	2.01
	15-30	5.90	0.18	2.30
Gobirawa	0-15	4.40	0.15	1.52
	15-30	7.00	0.15	2.28
Samaru	0-15	4.60	0.16	1.43
	15-30	8.30	0.22	1.33

wood. During the dry seasons when livestock is most scarce, herdsmen prune tree leaves to feed livestock, thus exacerbating desert encroachments in the areas.

Extractable boron in the soils was generally very low (Table 4). The highest values were obtained in Turawa (0.59 and 0.5 mg kg^{-1}), DanBirni (1.5 mg kg^{-1}) and in Gobirawa (1.20 mg kg^{-1}). Very low Zn values were obtained in Dunki (0.3 mg kg^{-1} and 1.0 mg kg^{-1}) and Samaru (0.30 and 0.20 mg kg^{-1}). Available Cu values were at the medium to high range with trace amounts at the 15-30 cm depths in Turawa and Dunki and 0-15 cm depths in Dan Birni (Table 4). Manganese and iron values were generally high. Manganese values ranged between 15 and 60 mg kg^{-1} in all the soils, while Fe ranged between 150 and 180 mg kg^{-1}. The high levels of available Mn and Fe in the soils may account for the presence of Fe and Mn nodules and concretions observed on the soil surfaces, especially in Dunki and iron hard-set/outcrop surfaces noticed in Dan Birni villages. Manganese appears however not to have attained toxic levels to adversely affect plant health and production.

Table 4. Extractable micronutrients in the soils in 2000.

Location	Depth cm	B mg kg^{-1}	Zn mg kg^{-1}	Mg mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}
Turawa	0-15	0.25	0.30	36	1.00	155
	15-30	0.59	1.50	56	tr	150
DanBirni	0-15	0.51	1.50	31	Tr	180
	15-30	0.47	1.50	25	2.00	155
Dunki	0-15	0.17	0.30	30	2.00	155
	15-30	0.08	1.00	15	tr	170
Gobirawa	0-15	0.08	0.30	60	1.00	170
	15-30	0.42	1.20	56	2.00	155
Samaru	0-15	0.34	0.30	25	2.00	160
	15-30	0.17	0.20	20	1.00	160

Soil properties after research periods

Bulk density: After the research period of 2000 the least bulk density (1.26 Mg m^{-3}) was obtained under sole groundnut at the 0-10 cm depths and was followed by sole maize treatments (1.34 Mg m^{-3}) (Table 5). This could imply that sole groundnut, followed by sole maize treatments could best improve the soils' bulk density at 50% flowering stage of the legumes. Perhaps, the nature and positioning of groundnut and maize roots in the soil would account for the low bulk density of the soils at this stage. This impression was however not sustained in 2002. The highest bulk density (1.57 Mg m^{-3}) was obtained under sole cowpea and moderate bulk density (1.42 Mg m^{-3}) was obtained under sole soybean. In 2002 bare soil surface had the highest bulk density value of 1.64 Mg m^{-3}. Perhaps increasing surface crusting under bare soil treatment may have contributed to the increase in bare surface soil bulk density. The least bulk density value was obtained under sole cowpea in 2002. Data contained in Table 5 therefore shows that except for bare surface soil, bulk density at 50% flowering of the legumes averaged between 1.34 and 1.55 Mg m^{-3}, but with no clear pattern of influence due to the legume treatments.

Soil moisture: Table 5 shows soil moisture content at 50% flowering of the grain legumes. Sole groundnut with a mean moisture value of 0.12 cm^3 cm^{-3} conserved more soil moisture in the soil than the other treatments, though the differences are not significant. Also, under each of the legume treatments, soil moisture content increased beyond the 2000-year value. In particular, values doubled under sole groundnut, sole soybean and sole cowpea, suggesting that planting the legumes for more than one year enhanced better soil moisture storage in the soils.

Aggregate stability and texture of soil peds: Table 6 shows that the highest mean weight diameter of peds developed was (0.63)

Table 5. Bulk density and soil moisture under herbaceous legume treatments.

Treatment	Depth cm	Bulk density Mg m^{-3} 2000	Bulk density Mg m^{-3} 2002	Moisture content cm^{3}cm^{-3} 2000	2001	2002	X
Sole maize	0-10	1.34	1.40	0.07	0.13	0.12	0.11
Sole groundnut	0-10	1.26	1.43	0.07	0.14	0.14	0.12
Sole soybean	0-10	1.42	1.52	0.05	-	0.17	0.07
Sole cowpea	0-10	1.57	1.28	0.07	0.15	0.12	0.11
Natural fallow	0-10	-	-	-	0.23	-	0.08
Bare soil	0-10	-	1.64	-	0.12	0.20	0.11

NB: X represents mean value for 2000 to 2002

Table 6. Aggregate stability and particle-size distribution of soil aggregates in 2001 at 0-10 cm depths.

Treatment	Mean weight diameter of aggregates	Particle-size distribution (%) of aggregates: Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay <0.002 mm	Textural classification USDA 1975
Sole maize	0.48	50	40	10	Sandy clay
Sole soybean	0.63	50	38	12	Sandy clay
Sole cowpea	0.58	52	36	12	Sandy clay
Natural fallow	0.61	52	36	12	Sandy clay

Table 7. Mean chemical properties of the surface soils (0-15 cm) in 2001.

Treatment	pH H$_2$O	pH CaCl$_2$	Org. C g kg^{-1}	Org. C %Dev	Total N g kg^{-1}	Total N %Dev	Avail. P mg kg^{-1}	Avail. P %Dev	Exch. (Al^{3}+H) cmol kg^{-1}
Soy/maize	5.8	5.3	6.4	28	0.59	84.4	2.30	-49.3	0.10
Groundnut/maize	5.6	5.2	5.4	8	0.53	65.6	4.13	-9.0	0.13
Cowpea/maize	5.6	5.1	5.9	18	0.53	65.6	3.34	-26.4	0.15
Sole groundnut	5.7	5.2	5.0	0	0.53	65.6	2.55	-43.8	0.13
Sole soybean	5.7	5.1	4.6	-8	0.53	65.6	1.91	-57.9	0.13
Sole cowpea	5.9	5.4	4.1	-18	0.59	84.4	2.82	- 37.9	0.10
Sole maize	5.8	5.3	4.5	-10	0.34	5.88	2.67	-41.2	0.13
Mean 2000	5.0	4.5	5.0	-	0.32	-	4.54	-	0.11

NB. % Dev. represents percent deviation from 2000 mean values

Table 8a. Ground cover rating (%) of herbaceous legumes at 6,8, and 10 weeks after planting (WAP) in 2002.

Treatment	Dan Birni 6	Dan Birni 8	Dan Birni 10	Dunki 6	Dunki 8	Dunki 10	Gobirawa 6	Gobirawa 8	Gobirawa 10	Samaru 6	Samaru 8	Samaru 10
Soybean	2.6	7.2	28.0	3.0	12.0	31.0	-	31.0	47.0	29.6	41.0	61.0
Cowpea	10.6	16.0	74.0	2.2	4.2	28.0	-	31.4	50.0	27.8	33.0	40.0
Groundnut	2.0	4.0	10.0	27.4	25.0	58.0	15.0	44.0	74.0	29.2	22.0	70.0

Table 8b. Mean ground cover rating (%) of herbaceous legumes at 6, 8 and 10 WAPS in 2002.

Treatment	Mean rating
Soybean	24.45
Cowpea	26.43
Groundnut	31.72
MSE	347.56(NS)

obtained under soybean, followed by natural fallow (0.61) and cowpea (0.58). This implies that soybean and natural fallow followed by cowpea treatments resulted in better soil aggregation than continuous maize cropping (0.48). Also, soil ped particle sizes showed an increase of silt fraction and a rearrangement of soil separates within the aggregates when compared with values in Table 1 with dominant loam to sandy loam texture at the surface soils. Textural class of the soil peds was sandy clay, showing a deviation from sandy loam and loam of the surface soils, perhaps indicating some level of soil structural change.

Chemical properties: Table 7 presents data on chemical properties of the soils after one year (2000) cropping. The acidity of the soils under all the treatments ranged between pH(H$_2$O) 5.3 and 5.9 and pH(CaCl$_2$) 5.1 to 5.4 which were in a moderate acid range for optimal nutrient uptake in the NGS of Nigeria. Exchange acidity ($H^+ + Al^{3+}$) of the soils was very much less than 1.0 cmol kg^{-1} under the treatments, suggesting that the soils have no acidity problems. Organic carbon content of the soils was generally less than 10 g kg^{-1} and is therefore very low. However, highest value was obtained under soybean/maize (6.42 g kg^{-1}), and cowpea/maize (5.92 g kg^{-1}). This would suggest that the soybean/maize and cowpea/maize treatments best contributed organic carbon to the soils and therefore showed 28 and 18% (respectively) soil carbon credit after one year of cultivation (Table 7). Organic carbon content of the soils under sole maize treatment (4.5 g kg^{-1}) was very low but not lower than that under sole cowpea (4.1 g kg^{-1}). This would imply that sole maize and sole cowpea grown in the year 2000 might have reduced organic carbon content of the soils more than the other treatments. The sole legumes and legume/ maize treatments generally resulted in higher organic carbon contribution than sole maize treatment, suggesting that sole maize grown continuously on one farm for years could reduce the organic carbon content of the soil drastically. Also, sole legume and legume/ maize treatments would ensure carbon credit into the soils, thus improving the organic colloidal fraction and nutrient buffering potential of the soils. Total nitrogen of the soils also improved beyond values of 2000 year. However, the sole legume and legume/ maize treatments resulted in improvements in soil nitrogen in the range between 65.6 and 84.8% (Table 7), while nitrogen under sole maize increased only by 5.88%. After year 2000, available phosphorus values reduced under the treatment beyond the 2000-year value. This would suggest that these sandy loam soils would need yearly phosphorus fertilizer additions to optimal status for sustainable productivity.

Growth of crops

Legume ground cover assessment: Tables 8a and 8b present information on legume ground cover provided by the grain legumes at 6, 8, and 10 weeks after planting (WAP). The data shows that at 6WAP highest ground cover of 44% was provided by groundnut in Gobirawa village while the least (2%) was in Dan Birni still under groundnut. However, Table 7b shows that the differences between the treatment means were not statistically significant ($P<0.05$). This would suggest that ground cover provided by the food grain legumes was not different between treatments over the period 6, 8, and 10 WAP. Each of the legumes provided as much as over 60% ground cover at 10WAP in Dan Birni, Gobirawa and Samaru location (Table 7a). This could imply that at 10WAP, the legume canopy could encourage soil aggregate development [2, 11, 28] as is suggested in Table 6, perhaps resulting from good soil cover provided by the legumes.

Maize yield: Tables 9a, 9b, and 9c present data on grain yield of maize for 2000 to 2002 in Dan Birni, Gobirawa, Dunki and Samaru. Table 9b shows that grain yield of maize under cowpea/maize (1.31 t ha^{-1}) and groundnut/maize (1.23 t ha^{-1}) were higher than that under sole maize (1.06 t ha^{-1}), but not significantly ($P<0.05$). This could suggest that over the three-year period, yield of maize was not reduced due to the legume/maize intercrop arrangement. Soybean/maize intercrop resulted in a significant maize grain reduction (0.97 t ha^{-1}). In the year 2000, maize grain yield differences were not statistically significant ($P<0.05$), suggesting that the intercrop arrangement did not result in yield reduction of maize grain. In 2001, groundnut/maize intercrop resulted in significantly higher maize grain yield (1.49 t ha^{-1}) than the other treatments

Table 9a. Maize grain yield (t ha^{-1}) in 2000-2002 under GTZ/BMZ/IITA-ILRI/IAR project.

Treatment	DanBirni			Gobirawa			Dunki		Samaru		
	2000	2001	2002	2000	2001	2002	2000	2002	2000	2001	2002
Sole maize	0.04	0.96	1.47	-	2.23	1.88	0.07	0.60	0.84	1.87	2.34
Groundnut/maize	0.11	2.87	2.93	0.09	0.22	1.21	0.02	0.28	0.74	2.87	3.40
Cowpea/maize	0.17	2.20	2.69	0.07	-	2.10	0.07	1.27	0.93	3.07	4.02
Soybean/maize	0.11	.035	2.02	0.37	0.03	1.76	0.07	1.35	0.71	2.11	3.80

Table 9c. Maize grain yield with years.

Year	Mean
2000	0.33c
2001	0.99b
2002	1.41a
MSE	0.63

Table 9b. Maize grain yield means across years (2000-2002) (t ha^{-1}).

Treatment	Mean	2000	2001	2002
Sole maize	1.06a	0.96	1.27ab	1.42ab
Groundnut/maize	1.23a	0.90	1.49a	1.89ab
Cowpea/maize	1.31a	0.93	1.22ab	2.20a
Soybean/maize	0.97ab	0.94	0.62ab	1.90ab
MSE	0.63	0.06 (NS)	0.67	1.15

Means with the same letters are not significantly different (DNMRT)
NB: NS represents not significant; Location mean differences are significant (P<0.05)

(Table 9b). However, maize grain yield under sole maize (1.27 t ha^{-1}) and cowpea/maize (1.22 t ha^{-1}) intercrop were not significantly different but both higher than under soybean/maize (0.62 t ha^{-1}), though not significantly (P<0.05). In 2002, maize grain yield under cowpea/maize intercrop (2.20 t ha^{-1}) was significantly higher than each of the other treatments (Table 9b). Maize grain yield under sole maize, groundnut/maize, and soybean/maize were not statistically different in 2002, though yield under the legume/maize intercrop arrangements was higher. This could imply that legume/maize intercrop could enhance maize grain yield better than sole maize cropping. Perhaps also, the improved soil organic carbon and total nitrogen (Table 7) resulting from the legume/maize intercrop could account for the improved maize grain yield especially under the intercrop arrangements. Table 9c also show that there was a significant (P<0.05) yield improvement from 2000 to 2002, meaning that maize yield improved with the improved management practice, which included the intercrop arrangement.

Table 10 shows data for maize grain yield under sole maize cropping and maize grown on sole legume plots after one and two years of planting sole legume. In 2001, maize grain yield in the sole legume plots was significantly lower than the sole maize treatment. This may be accounted for by the fact that the legumes may not have contributed enough soil nutrients in one year (Table 7), and that no fertilizer was applied to the trials. In 2002 and after planting legume for two years, maize grain yield in these plots appreciated remarkably more than the sole maize. Maize in sole groundnut showed a 2.56% yield improvement, while maize in sole soybean showed a 23.93% yield improvement better than that under the sole maize. Maize grain yield in the sole cowpea resulted in 91.88% yield improvement and suggests that two year cropping of cowpea before planting maize would remarkably improve the soil for sustainable crop production. Also, after planting legumes for two years, only 60 kg N, 60 kg P_20_5 and 60 kg K_20 fertilizers will be required to attain the yield level expected for sole maize that received 120 kg N, 60 kg P_20_5 and 60 kg K_20. Comparing maize grain yields in 2001 and 2002 (Table 10), the data shows that maize grain improved by 20.09% under sole maize, 95.0 % under maize in sole groundnut, 92.76% under maize in soybean and 98.44% under maize in cowpea. This may confirm that the sole legume planting for two years resulted in positive carbon credit and total nitrogen in the soils [19] to have enhanced greater maize grain yield than under the sole maize despite the 120 kg N fertilizer applied to the sole maize.

Table 11a contains data on maize stover yields in 2000 to 2002. For the three years of this planting, maize stover produced under sole maize (1.62 t ha^{-1}), cowpea/maize (1.65 t ha^{-1}), and groundnut/maize (1.61 t ha^{-1}) were significantly higher than stover obtained in maize grown in legume plots (grown for two years). Stover from maize on soybean plot (1.44 t ha^{-1}), cowpea plot (1.36 t ha^{-1}) and groundnut plot (1.40 t ha^{-1}) were not significantly different, but were each significantly lower than that from soybean/maize (1.52 t ha^{-1}) (Table 11a). This would suggest that cowpea/maize and groundnut/maize treatments are capable of producing significantly high maize stover than the other legume treatments. In 2000, significantly higher stover yield was recorded under soybean/maize (0.89 t ha^{-1}) than under cowpea/maize (0.88 t ha^{-1}), groundnut/maize (0.85 t ha^{-1}) and sole maize (0.84 t ha^{-1}). However, the legume/maize intercrop treatments did not result in reduction of stover yield even in the first year. In 2001, yield of maize stover was significantly (P<0.05) higher under sole maize (1.62 t ha^{-1}) than in the other treatments, but the groundnut/maize (1.34 t ha^{-1}) treatment resulted in higher stover yield than cowpea/maize (1.24 t ha^{-1}) and soybean/maize (0.99 t ha^{-1}). In the year 2002, maize stover yield was not significantly different between treatments, but generally increased more than values obtained under each of treatments in 2000 and 2001. Also, stover yield on 'maize on cowpea' treatment (2.90 t ha^{-1}) was highest and followed by 'maize on groundnut' and 'cowpea/maize treatments' (2.82 t ha^{-1} each). Table 11b shows that yearly differences in stover yield were significant and implies that the soil conditions would have improved with years as the project continued to 2002.

Legume crop yields: Table 12 contains data on mean legume grain and fodder yield for 2001 and 2002. The data shows that significantly (P<0.05) higher grain yield was obtained under sole soybean (3.94 t ha^{-1}) treatment, followed by soybean/maize (1.74 t ha^{-1}), cowpea/maize (1.29 t ha^{-1}) and groundnut/maize (1.17 t ha^{-1}) treatments than under the other treatments. The least

Table 10. Maize grain yield (kg ha^{-1}) in 2001and 2002 after 1st year and 2nd year legume planting.

Treatment	2001	%dev.	2002	%dev. 2002	%dev..2001
Sole maize	1.87	-	2.34	-	20.09
Maize in sole groundnut	0.12	93.58	2.40	-2.56	95.00
Maize in sole soybean	0.21	88.77	2.90	-23.93	92.76
Maize in sole cowpea	0.07	96.26	4.49	-91.88	98.44

Table 11a. Maize stover yield 2000-2002 (t ha^{-1}).

Treatment	2000-2002	2000	2001	2002
Sole maize	1.62a	0.84ab	1.62a	2.40
Maize on soybean	1.44abc	0.00c	0.71c	2.90
Maize on cowpea	1.36abc	0.00c	0.71c	2.68
Maize on groundnut	1.40abc	0.00c	0.71c	2.82
Soybean/maize	1.52ab	0.89a	0.99bc	2.67
Cowpea/maize	1.65a	0.88ab	1.24abc	2.82
Groundnut/maize	1.61a	0.85ab	1.34ab	2.67
MSE	0.18	0.01	0.12	0.40 (NS)

Means with the same letters are not significantly different (DNMRT)

Table 11b. Maize stover means with years.

Year	Mean
2000	0.76c
2001	0.93b
2002	2.50a
MSE	0.18

Table 12. Mean legume grain and fodder yield (t ha^{-1}) in 2001-2002.

Treatment	Grain	Fodder
Sole soybean	3.94ba	2.34ab
Sole cowpea	0.67b	0.97ab
Sole groundnut	0.30b	1.36ab
Groundnut/maize	1.17ab	5.52ab
Soybean/maize	1.74ab	0.14b
Cowpea/maize	1.29ab	1.69ab
MSE	3.24	36.75

Means with the same letters are not significantly different (DNMRT)

Table 13. Maize and legume stover yield (t ha^{-1}) in 2000-2002.

Treatment	Summary	Maize+legume DM
Maize Stover		
Sole maize	1.62	-
Maize on soybean	1.44	3.06
Maize on cowpea	1.36	2.98
Maize on groundnut	1.40	3.02
Soybean/maize	1.52	3.14
Cowpea/maize	1.65	3.27
Groundnut/maize	1.61	3.23
Legume residues		
Sole soybean	2.34	3.96
Sole cowpea	0.97	2.59
Sole groundnut	1.36	2.98
Soybean/maize	5.52	7.14
Cowpea/maize	0.14	1.76
Groundnut/maize	1.69	3.31

grain yield was obtained under sole groundnut (0.30 t ha^{-1}) but it was not significantly ($P<0.05$) different from yield obtained under sole cowpea (0.67 t ha^{-1}). Fodder yield from the grain legumes were significantly higher under groundnut/maize (5.52 t ha^{-1}), sole soybean (2.34 t ha^{-1}), sole groundnut (1.36 t ha^{-1}) and sole cowpea (0.97 t ha^{-1}) than under soybean/maize (0.14 t ha^{-1}).

Table 13 shows that for the purpose of feeding quality fodder to livestock a combination of the maize stover with legume residues under this treatment will provide 7.14 t ha^{-1} of soybean and maize fodder. The least fodder obtained under this treatment was from cowpea+maize (1.76 t ha^{-1}). The rest other treatments produced 2.59 and 3.96 t ha^{-1} fodder, which could well cured and preserved for supplemental feeding of livestock especially in the months of January to May when feed supply is scarce and livestock scavenge for any available leaf to feed upon. For the purpose of improving the soils, annual incorporation of 2.59 to 3.96 t ha^{-1} dry matter into the soils would improve the soils organic carbon content, moisture retention capacity, nutrient buffering capacity and check leaching of nutrients from the soils. However, the practice of feeding livestock with this quality fodder and returning manure for incorporation into the soil would restore fertility status of the soils for sustainable crop and livestock production better. This is because cereal crop residues are often relatively slow to decompose in soil, and can take a long time before nutrients in the residues become available to the subsequent crop. Also, while the soil microbes are breaking down the crop residues, they tie up soil nitrogen for their own use, reducing the amount of nitrogen available to plants [6, 7]. As animals eat the palatable parts of the crop residues, the inedible fractions such as the stems are trampled underfoot (particularly if the animals are stall-fed), where they mix with the faeces and soak up urine. Trampling by the animals breaks up the stover speeding the decomposition process and increasing the capacity of the stover to absorb urine [7]. Using crop residues to soak up urine improves nutrient capture and animal-processed inedible fractions of crop residues compost faster, making the nutrient in them available sooner than when the residues are not fed to livestock but incorporated directly into the soil. Therefore, animal wastes (dung, urine and feed remains) resulting from feeding the animals with these quality feed materials should be returned to the fields and incorporated into the soils

Conclusions

From the above discussions, it is inferred as follows:

i) The impoverished fertility status of the soils is blamed largely over use of farm lands for crop production without adequate soil management, overgrazed condition of the land areas, use of the crop residues for fencing and for fuel wood which inhibits nutrient recycling into the soils and impoverishes the nutrient status of the soils. The attendant soil erosion and desertification of the overgrazed fields further degrades the land for sustainable crop and livestock production.

ii) Bulk density of the soils at 50% flowering of the legumes averaged between 1.34 and 1.55 Mg m^{-3}, but with no clear pattern of influence due to the legume treatments.

iii) Each of the legumes provided as much as over 60% ground cover at 10WAP, in Dan Birni, Gobirawa, and Samaru locations. This would imply that at 10WAP, the grain legume canopy could encourage soil aggregate development, conserve soil moisture and reduce soil bulk density conditions.

iv) Over the three-year period (2000-2002), maize grain yield was not reduced due to the legume/maize intercrop arrangement. However, the legume/maize intercrop treatments enhanced maize grain yield better than sole maize cropping. The improved soil organic carbon and total nitrogen resulting from the legume/maize intercrop could account for the improved maize grain yield under the intercrop arrangements.

v) In 2001, maize grain yield in the sole legume plots of 2000 was significantly lower than in the sole maize treatment. This is accounted for by the fact that the legumes may not have contributed enough soil nutrients in one year, and that no fertilizer was applied to the trials.

vi) In 2002, and after planting legume for two years, maize grain yield in these plots appreciated remarkably more than the sole maize. Maize in sole groundnut showed a 2.56% yield improvement while maize in sole soybean showed a 23.9% yield improvement better than that under the sole maize. Maize grain yield in the sole cowpea resulted in 91.9% improvement and suggests that two year cropping of cowpea before planting maize would remarkable improve the soil for sustainable crop production.

vii) After planting the food grain legumes for two years in the Nigerian Guinea savanna, only 60 kg N, 60 kg P_20_5 and 60 kg K_20 fertilizers will be required to attain the yield level expected for sole maize that received 120 kg N, 60 kg P_20_5 and 60 kg K_20.

viii) Fodder yield from the grain legumes was significantly high under groundnut/maize (5.52 t ha^{-1}), sole soybean (2.34 t ha^{-1}), sole groundnut (1.36 t ha^{-1}) and sole cowpea (0.97 t ha^{-1}) than under soybean/maize (0.14 t ha^{-1}).This implies that for the purpose of feeding quality fodder to livestock a combination of the maize stover with legume residues under this treatment could provide 7.14 t ha^{-1} of mixed soybean and maize fodder (dry matter).

ix) Animal wastes (dung, urine and feed remains) resulting from feeding the animals with these quality feed materials should be returned to the fields and incorporated into the soils. This practice would restore fertility status of the soil for sustainable crop and livestock production.

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