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Livestock corralling, plant density and N fertilizer effects on soil, weed, maize yield and income

Abdul Rahman Nurudeen[1]*, Larbi Asamoah[1], Kotu Bekele[1], Opoku Andrews[2], Francis Marthy Tetteh[3], Hoeschle-Zeledon Irmgard[4]

[1] International Institute of Tropical Agriculture, P. O. Box TL 06, Tamale-Ghana University of Sciences, Institute of Research, Capital City, Germany Email xy@uni-sciences.de
[2] Kwame Nkrumah University of Science and Technology, P.M.B. Kumasi-Ghana
[3] Council for Scientific and Industrial Research (CSIR)-Soil Research Institute, P.M.B. Kwadaso, Kumasi-Ghana
[4] International Institute of Tropical Agriculture, P.M.B 5320, Ibadan-Nigeria

Abstract

Small scale crop-livestock (SCL) farming system dominates in West African savanna zones. Farmers adopt different practices such as keeping cattle, sheep, and goats overnight on fallow lands to deposit manure and urine (corralling), different cropping densities and applying organic and inorganic fertilizers to increase productivity of farm lands per unit area. However, quantitative data on the interactions of these practices on crop yields, soil properties and vegetation resources is limited. A 2-year study was conducted in the Sudan savanna zone of Ghana to test the hypothesis that stocking density of sheep and goats corralling (SDSG), maize plant density (MPD) and N fertilizer rate (NFR) may increase soil properties, weed diversity, grain yield and net income. A split-split plot design with 8 household farms as replicates was used to study the effect of three SDSG (0, 70 and 140 heads ha^{-1}, main-plot), three MPD (66 667, 100 000 and 133 333 plants ha^{-1}, sub-plot) and three NFR (0-40-40, 60-40-40 and 90-40-40 NPK kg ha^{-1}, sub-sub plot). The animals were corralled from 19: 00 to 06:00 hours GMT the following day with no feed and water for 178 nights. The animals grazed communal pastures and crop residues during the day before corralling them at night. Increasing the SDSG from 0 to 140 heads ha^{-1} increased ($P<0.01$) soil chemical and biological properties. The SDSG affected weed species diversity with higher ($P<0.01$) number of broadleaves, grasses, and sedges on plots where sheep and goats were corralled. The SDSGxMPD and SDSGxNFR interactions increased grain yield and net income by more than 75%. The results suggest that maize-livestock farmers without access to mineral fertilizer could corral sheep and goats at 70 or 140 heads ha^{-1} with maize plant density at 100 000 plants ha^{-1} for improved grain yield and net income. Those with access to mineral fertilizer could corral sheep and goats either at 70 heads ha^{-1} with mineral fertilizer at 90 kg ha^{-1} N or 140 heads ha^{-1} with mineral fertilizer at 60 kg ha^{-1} N to increase grain yield and net income on Ferric Lixisol of Sudan savanna zone of Ghana and similar ecologies.

Keywords: Fertility, interaction effect, profitability, seeding rate, stocking rate

Introduction

Maize is major staple in Africa and accounts for slightly over 20% of gross domestic production in West Africa sub-region (Manyoung et al. 2000). However, maize yield on farmers' field is low due to several socio-economic and biophysical constraints, including low and declining soil fertility, low planting densities and high cost and limited access to inorganic and organic fertilizers. Grazing livestock on fallow arable land during the day or night (corralling) is among the traditional methods of soil fertility management in SCL farming system in West Africa (Powell et al. 2004). Corralling returns both urine and manure to the soil which improves soil chemical properties and consequently increase crop yield (Ikpe and Powell 2002; Sangaré et al. 2002). However, previous studies on corralling focused on soil chemical properties and millet grain yield with limited information on soil biological properties and important cereals such as maize (Ikpe and Powell 2002, Sangaré et al. 2002). Studies have shown that farmers use weed species richness as indigenous knowledge for assessing fertile arable lands in many parts of the world (Dawoe et al. 2012). Agricultural land management practices such as soil fertility amendments affects weed species diversity on arable lands (Gerowitt 2003).

Application of N fertilizer at the recommended rates could increase maize yield (Sigunga et al. 2002), but most of these trials were conducted on-station which differs from on-farm conditions. Moreover, cropping densities on farmers' field are generally below the recommended rates (Rice et al. 1998). Furthermore, conflicting results on the effect of MPD on grain yield warrant further studies. For example, Bavec and Bavec (2002) reported higher grain yield with increasing MPD, while Shapiro and Wortmann (2006) found no significant effect on grain yield with increasing MPD.

Despite the importance of corralling, plant density and N fertilizer to improving crop yields, quantitative data is limited on the interaction effects of SDSG, MPD and NFR on grain yield and financial returns in maize-livestock based cropping system. Such information is needed to sustainably intensify maize production in the SCL farming system in the West African savannas. We hypothesized that, the interaction effect of SDSG, MPD and NFR may not have significant effect on maize grain yield and net income in small-scale maize-livestock farming system.

Material and Methods

Experimental design

A split-split plot design with eight household farms as replicates was used. Main plots were three SDSG (0, 70 and 140 heads ha^{-1}) to produce 0, 2.5 and 5 t ha^{-1} respectively (Liniger et al. 2011). The sub-plots were three MPD (66 667, 100 000 and 133 333 plants ha^{-1}), and sub-sub plots were three NFR (0-40-40, 60-40-40 and 90-40-40 NPK kg ha^{-1}) based on Ragasa et al. (2013). Early maturing maize variety (Omankwa: 95 days' maturity) was planted as a test crop, due its drought tolerant, Striga (Striga hermontica) resistant and high-quality protein (Ragasa et al. 2013).

Corralling management

Djallonke sheep (27±2 kg live weight) and West African Dwarf goat (24±1.5 kg live weight) breeds were corralled for 178 nights during the follow period from 19: 00 to 06:00 hours GMT the following day with no feed and water. The animals grazed on communal native pastures and crop residues of cereals from about 08: 00 to 17:00 hours GMT daily during the corralling period.

Soil sampling

Surface soil was sampled at a depth of 0-15 cm from five different spots along the diagonals of each plot after corralling sheep and goats for 178 nights in both cropping seasons. The composite soil samples were air dried, ground, sieved and analyzed for pH, available phosphorus, total nitrogen, organic carbon, exchangeable potassium, soil microbial biomass carbon, microbial biomass nitrogen, carbon/nitrogen ratio and soil microbial quotient.

Earthworm cast

In each treatment, eight random 0.25 m^2 quadrats were taken. The number of earthworm cast in each quadrat was counted.

Weed diversity

A 1 m^2 quadrat was used for random sampling of weed species. Five random quadrats per plot along the diagonals were taken and weed species in each quadrat were identified and counted.

Grain yield and net income

Maize cobs from plants in two middle rows of each sub-sub plots were harvested, dehusked, shelled and oven dried at 65˚C to a moisture content of 13% to measure grain yield.

The net income was calculated as the difference between the total revenue and total cost of production. Maize grain prices were collected from a nearby market to estimate total revenue while the total cost of production was estimated from costs of labor, seed, fertilizer, and ploughing.

Results and Discussion

Soil properties

Soil chemical and biological properties increased ($P<0.01$) with increasing SDSG (Table 1). Raising the SDSG from 70 to 140 heads ha^{-1} increased ($P<0.01$) only soil OC and earthworm cast. The effect of SDSG on the soil chemical and biological properties might possibly due to addition of nutrients from the urine (e.g., K and N) and faeces (e.g., P and N) of the sheep and goats which served as source of organic material (food) for soil fauna. These results agreed with earlier reports on the effect of livestock corralling on soil chemical properties (Ikpe and Powell 2002; Sangaré et al. 2002) and the effect of organic manure on soil biological properties (Assmann et al. 2014).

Weed species

The weed species varied among SDSG with SDSG at 70 and 140 heads ha^{-1} supporting higher ($P<0.01$) species of broadleaf, grass, and sedge (Fig. 1). The effect of SDSG on weed species could be due to addition of more nutrients from the faeces and urine from the sheep and goat which resulted in improving soil chemical and biological properties. This result supports earlier reports on indigenous soil knowledge of farmers on the use of weed species richness as an indicator for distinguishing fertile soils from non-fertile soils (Dawoe et al. 2012).

Grain yield and income

The SDSGxMPD and SDSGxNFR interactions affected maize grain yield and net income (Table 2 and 3). Maize grain yield and net income increased with increasing SDSG and MPD. These interaction effects increased grain yield and net income by more than 75%. The significant effect of SDSGxMPD on grain yield was caused by the differences in the response of the SDSG at 70 and 140 heads ha^{-1} under the three MPD. The differences might partly be attributed to the plant nutrients from the urine and manure of the sheep and goats (Powell et al. 2004), plant stands per unit area which resulted in better interception of light and competition against weeds and higher grain yield (Bavec and Bavec 2002). The SDSGxMPD interaction effect on net income was also caused by the different response of SDSG at 70 and 140 heads ha^{-1} under the MPD on maize grain yield. The grain yield was positively correlated with the net income. These differences in the net income could be due to the high revenue accrued from the sale of more grains obtained from the high plant stands with adequate nutrient supplied from the sheep and goat corralling.

The SDSGxNFR interaction had a linear response on maize grain yield and net income. The variations in the responses of SDSG at 70 and 140 heads ha^{-1} with the three NFR caused the significant effect of SDSGxNFR on maize grain yield. The interaction effect on grain yield could be due to the adequate nutrient availability from the urine and faceas of the sheep and goats and the mineral fertilizer. The synergistic effect of the mineral fertilizer and the manure was more evident under the 90 kg ha^{-1} NFR with either 70 or 140 heads ha^{-1} SDSG. This supports earlier reports that most sustainable gains in crop productivity per unit nutrient are achieved from integrated use of manure and inorganic fertilizer (Vanlauwe et al. 2001). The grain yield was positively correlated to the net income. The interaction effect on net income might be attributed to more revenue from the sale of grains which offset the cost of production.

Conclusions and Outlook

The soil chemical and biological properties increased linearly with increasing SDSG. The SDSG affected weed species diversity with increasing SDSG supporting higher ($P<0.01$) number of broadleaves, grasses, and sedges. The interaction effect of SDSG with either MPD or NFR increased maize grain yield and net income by more than 75%. The results suggest that maize-livestock farmers with limited access to mineral fertilizer could corral sheep and goats at either 70 to 140 heads ha^{-1} with maize plant density at 100 000 plants ha^{-1} for improved maize grain yield and net income. Those with access to mineral fertilizer could use either SDSG of 70 heads ha^{-1} with 90 kg ha^{-1} NFR or SDSG of 140 heads ha^{-1} with 60 kg ha^{-1} NFR to increase grain yield and net income on *Ferric Lixisols* of Sudan savanna zone of Ghana and similar ecologies in West Africa.

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Table 1. Soil chemical and biological properties as affected by stocking density of sheep and goat corralling (SDSG) in the Sudan savanna zone of northern Ghana, averaged over 2014 and 2015 cropping seasons.

	SDSG (heads ha^{-1})					Contrast probability of F value	
Soil parameter	0	70	140	s.e	*P*-value	0 vs (70 + 140)	70 vs 140
pH (H_2O)	5.2	5.6	5.6	0.07	**	***	ns
Organic carbon (g kg^{-1})	8.3	13.8	16.6	0.59	***	***	**
Total nitrogen (g kg^{-1})	0.5	0.7	0.7	0.05	**	**	ns
Available phosphorus (mg kg^{-1})	2.2	3.3	3.1	0.19	**	**	ns
Exchangeable potassium (cmol kg^{-1}) x 10^{-2}	4.7	15.0	18.3	2.18	**	***	ns
Carbon/nitrogen ratio	16.5	21.5	23.7	1.17	**	**	ns
Microbial biomass carbon (g kg^{-1})	250.9	343.8	368.6	9.54	***	***	ns
Microbial biomass nitrogen (g kg^{-1})	20.8	24.0	24.1	0.86	**	**	ns
Soil microbial quotient (%)	2.6	3.0	3.0	0.09	**	**	ns
Earthworm cast (0.25 m^{-2})	9.0	15.7	20.5	0.79	***	***	**

*** P≤0.0001, ** P≤0.01, * P≤0.05, ^{ns} not significant.

Table 2. Maize grain yield and net income as affected by stocking density of sheep and goat corralling (SDSG) and maize plant density (MPD) in the Sudan savanna zone of northern Ghana, averaged over 2014 and 2015 cropping seasons.

SDSG (heads ha^{-1})	MPD (Plants ha^{-1})	Grain yield (kg ha^{-1})	Net income ($ ha^{-1})
0	Recommended density (RD)	874.5	-74.0
	RD*1.5 (1.5RD)	1088.3	-23.3
	RD*2 (2RD)	1428.7	60.6
70	RD	1681.5	114.1
	1.5RD	2282.1	266.0
	2RD	2205.7	240.9
140	RD	1816.7	140.4
	1.5RD	2294.1	261.9
	2RD	2717.7	365.7
SE		93.74	24.55
P-value		*	*
Contrast probability of F value			
0*RD vs (70*RD + 140*RD)		***	***
70*RD vs 140*RD		ns	ns
0*1.5RD vs (70*1.5RD + 140*1.5RD)		***	***
70*1.5RD vs 140*1.5RD		ns	ns
0*2RD vs (70*2RD + 140*2RD)		***	***
70*2RD vs 140*2RD		**	**

*** P≤0.0001, ** P≤0.01, * P≤0.05, ^{ns} not significant, 1$ = 4.4 Ghana cedis.

Table 3. Maize grain yield and net income as affected by stocking density of sheep and goat corralling (SDSG) and nitrogen fertilizer rate (NFR) in the Sudan savanna zone of northern Ghana, averaged over 2014 and 2015 cropping seasons.

SDSG (heads ha^{-1})	NFR (kg ha^{-1})	Grain yield (kg ha^{-1})	Income ($ ha^{-1})
0	0	678.2	-67.5
	60	1285.0	22.6
	90	1428.2	8.1
70	0	1241.9	57.1
	60	2252.5	252.8
	90	2675.0	311.2
140	0	1409.4	93.6
	60	2563.0	324.8
	90	2856.1	349.5
SE		104.50	27.31
P-value		**	**
Contrast probability of F value			
0*0 vs (70*0 + 140*0)		***	***
70*0 vs 140*0		ns	ns
0*60 vs (70*60 + 140*60)		***	***
70*60 vs 140*60		*	*
0*90 vs (70*90 + 140*90)		***	***
70*90 vs 140*90		ns	ns

*** P≤0.0001, ** P≤0.01, * P≤0.05, ^{ns} not significant, 1$ = 4.4 Ghana cedis.

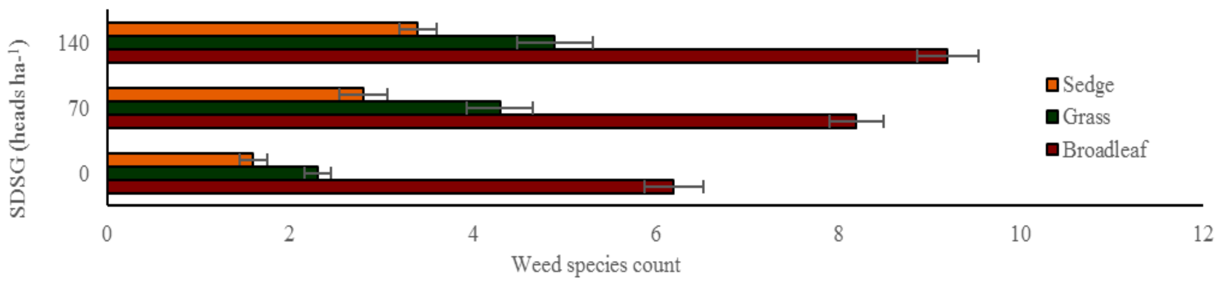

Fig. 1. Weed species count as affected by SDSG in the Sudan savanna zone of northern Ghana, overaged over 2014 and 2015 cropping seasons.