Field Crops Research 213 (2017) 38–50

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana

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ARTICLE INFO

Keywords:
Soil fertility
Spatial arrangement
Radiation interception
LER
Net benefit

ABSTRACT

Smallholder farmers in the Guinea savanna practise cereal-legume intercropping to mitigate risks of crop failure in mono-cropping. The productivity of cereal-legume intercrops could be influenced by the spatial arrangement of the intercrops and the soil fertility status. Knowledge on the effect of soil fertility status on intercrop productivity is generally lacking in the Guinea savanna despite the wide variability in soil fertility status in farmers' fields, and the productivity of within-row spatial arrangement of intercrops relative to the distinct-row systems under on-farm conditions has not been studied in the region. We studied effects of maize-legume spatial intercropping patterns and soil fertility status on resource use efficiency, crop productivity and economic profitability under on-farm conditions in the Guinea savanna. Treatments consisted of maize-legume intercropped within-row, 1 row of maize alternated with one row of legume, 2 rows of maize alternated with 2 rows of legume, a sole maize crop and a sole legume crop. These were assessed in the southern Guinea savanna (SGS) and the northern Guinea savanna (NGS) of northern Ghana for two seasons using three fields differing in soil fertility in each agro-ecological zone. Each treatment received 25 kg P and 30 kg K ha^{-1} at sowing, while maize received 25 kg (intercrop) or 50 kg (sole) N ha^{-1} at 3 and 6 weeks after sowing. The experiment was conducted in a randomised complete block design with each block of treatments replicated four times per fertility level at each site. Better soil conditions and rainfall in the SGS resulted in 48, 38 and 9% more maize, soybean and groundnut grain yield, respectively produced than in the NGS, while 11% more cowpea grain yield was produced in the NGS. Sole crops of maize and legumes produced significantly more grain yield per unit area than the respective intercrops of maize and legumes. Land equivalent ratios (LERs) of all intercrop patterns were greater than unity indicating more efficient and productive use of environmental resources by intercrops. Sole legumes intercepted more radiation than sole maize, while the interception by intercrops was in between that of sole legumes and sole maize. The intercrop however converted the intercepted radiation more efficiently into grain yield than the sole crops. Economic returns were greater for intercrops than for either sole crop. The within-row intercrop pattern was the most productive and lucrative system. Larger grain yields in the SGS and in fertile fields led to greater economic returns. However, intercropping systems in poorly fertile fields and in the NGS recorded greater LERs (1.16–1.81) compared with fertile fields (1.07–1.54) and with the SGS. This suggests that intercropping is more beneficial in less fertile fields and in more marginal environments such as the NGS. Cowpea and groundnut performed better than soybean when intercropped with maize, though the larger absolute grain yields of soybean resulted in larger net benefits.

1. Introduction

The Guinea savanna of West Africa is characterised by poor and declining soil fertility due to continuous cereal-based cropping systems without adequate soil nutrient replenishment (Dakora et al., 1987; Sanginga, 2003). The declining soil fertility coupled with an erratic unimodal rainfall regime has increased the risk of crop failure in sole cropping systems. Intercropping, the simultaneous or sequential

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http://dx.doi.org/10.1016/j.fcr.2017.07.008
Received 30 April 2017; Received in revised form 12 July 2017; Accepted 13 July 2017

growing of two or more crop species on the same piece of land (Willey, 1990), could mitigate risk of crop failure. For instance, in case the main crop (typically maize, *Zea mays* L.) fails to produce yield due to erratic distribution of rainfall within a season, the added grain legume provides food for the farm household (Rusinamhodzi et al., 2012). Consequently, farmers in the Guinea savanna commonly practise cereal-legume intercropping to safeguard household food and income. The inclusion of grain legumes is essential for soil fertility sustenance as they contribute to soil fertility enhancement through biological fixation of atmospheric nitrogen (N_2) and N mineralised from legume residues (Giller, 2001). Legumes also provide grain rich in protein and minerals for household nutrition and income (Giller, 2001).

The greater crop yields and productivity of intercrops relative to sole crops result from complementary use of resources for growth by the intercrop components (Willey, 1979; Ofori and Stern, 1987; Rao and Singh, 1990; Willey, 1990). Differences in acquisition and use of light, water and nutrients by the different intercrop components (Ofori and Stern, 1987; Willey, 1990) results in inter-species competition being smaller than intra-species competition (Vandermeer, 1989). The complementary effect can be temporal where peak demands for resources by component crops occur at different times or spatial where complementary resource use occurs due to differences in canopy and root structures (Willey, 1990). Complementarity is also likely as intercropped maize uses N from the soil for growth whilst the legume can rely more on atmospheric N_2-fixation for growth. These can be influenced by soil fertility status, spatial planting arrangements and choice of intercrop components (Midmore, 1993). Weeds and diseases may be better suppressed in intercropping than in sole cropping although this may be influenced by the intercropping pattern and the resulting canopy structure (Liebman and Dyck, 1993; Trenbath, 1993).

Spatial intercropping patterns have been studied in the Guinea savanna of northern Ghana (e.g. Agyare et al., 2006; Konlan et al., 2013) and Nigeria (e.g. Ajeigbe et al., 2010) mainly under controlled conditions. All these studies assessed the performance of different distinct alternate row intercropping patterns of maize and legumes. Rusinamhodzi et al. (2012) reported greater LER when the intercrops were planted in the same row rather than in distinct rows in Central Mozambique. Other studies (Agyare et al., 2006; Konlan et al., 2013) generally showed intercrop advantages over sole crops that declined as the width of adjacent strips of each crop was increased. For instance, Konlan et al. (2013) reported a larger LER for 1:1 alternate rows of maize and groundnut than for 2:2 alternate row intercrops. In some cases, sole crops were more productive than intercrops when two or more rows of intercropped maize were alternated with the same number of groundnut (*Arachis hypogaea* L.) rows (Konlan et al., 2013).

Knowledge on the ecological and economic performance of within-row maize-legume intercrop pattern in relation to the distinct row intercrop patterns and sole crops is limited to controlled trials in the Guinea savanna region. Studies conducted in Turrialba, Costa Rica (Chang and Shibles, 1985) and Western Australia (Ofori and Stern, 1986) reported greater maize-cowpea (*Vigna unguiculata* (L.) Walp) intercrop advantages under low soil N and P conditions. Searle et al. (1981) and Ahmed and Rao (1982) also observed larger maize-soybean (*Glycine max* (L.) Merr.) intercrop advantages when soil N fertility was poor. As smallholder farms in the Guinea savanna vary widely in soil fertility status, a better understanding of the relative performance of intercrop in relation to soil fertility is required. We studied the effects of soil fertility status and different spatial maize-legume intercropping patterns and monocultures on grain yields, intercrop efficiency and productivity and economic profitability in contrasting sites in the southern and northern Guinea savanna agro-ecological zones of northern Ghana.

Table 1a
Unit input and labour costs and grain prices used in estimating total cost (TC) and total revenue (TR) in the southern Guinea savanna (SGS) and northern Guinea savanna (NGS) of northern Ghana.

	SGS		NGS	
	2013	2014	2013	2014
Input costs (US$ ha^{-1})				
Maize seeds	9.0	6.6	7.6	7.6
Soybean seeds	40.0	27.0	39.5	28.6
Groundnut seeds	56.2	37.7	59.6	47.4
Cowpea seeds	37.5	20.1	30.4	25.2
Urea	54.3	50.4	54.3	50.4
TSP	99.5	66.0	99.5	66.0
MoP	51.1	33.9	51.1	33.9
Insecticide	6.5	4.0	6.5	4.0
Inoculant	15.0	15.0	15.0	15.0
Labour input (US$ ha^{-1})				
Ploughing	43.2	32.7	74.0	57.3
Ridging	74.0	49.1	61.7	49.1
Sowing	6.8	4.9	8.6	4.9
Fertiliser application	6.2	4.9	6.2	4.9
Spraying	6.2	4.9	8.6	4.9
Weeding	8.6	6.6	8.6	6.6
Harvesting	8.6	6.6	8.6	6.6
Threshing	4.9	4.1	4.9	4.1
Grain prices (US$ kg^{-1})				
Maize	0.51	0.38	0.37	0.36
Soybean	0.88	0.76	0.95	0.67
Groundnut (shelled)	1.86	1.43	2.52	1.79
Cowpea	1.12	0.76	1.17	0.95

Exchange rate for costs: GH¢2.00 = US$1.00 in 2013; GH¢3.02 = US$1.00 in 2014 (average rate for each year, i.e. inputs acquisition to harvest). Exchange rate for grain prices: GH¢2.08 = US$1.00 in 2013; GH¢3.20 = US$1.00 in 2014 (average rate for 3rd and 4th quarters of each year, i.e. harvest and selling period). Exchange rates were obtained from Bank of Ghana quarterly bulletin.

Table 1b
Estimated labour requirements (days ha^{-1}) of field operations of maize and legumes under sole crop systems used in estimating TC.

Activity	Cowpea	Soybean	Groundnut	Maize	Source
Sowing	12	17	11	10	Franke et al. (2010)
P & K application	2	4	2	2	Ojiem et al. (2014)
N application	–	–	–	7	Franke et al. (2006)
Spraying	2	–	–	–	Own observation
First weeding	36	36	36	25	Franke et al. (2006)
Second weeding	30	30	30	21	83% of first weeding[a]
Harvesting	14	14	34	12	Franke et al. (2010)
Threshing	17[b]	29	46[c]	23	Franke et al. (2006)

[a] Heemst et al. (1981).
[b,c] Ojiem et al. (2014).
[b]Includes the shelling of groundnut.

2. Materials and methods

2.1. Study sites and on-farm experiments

The trials were conducted on farmers' fields in the cropping seasons of 2013 and 2014. The sites were Kpataribogu (9°58′ N, 0°40′ W) in Karaga District (southern Guinea savanna, SGS; 1076 mm mean annual rainfall) and Bundunia (10°51′ N, 1°04′ W) in Kassena-Nankana East Municipal (northern Guinea savanna, NGS; 990 mm mean annual rainfall) in northern Ghana. Both sites have a single rainy season which extends from May to October in SGS and from June to October in NGS. The soils at both sites are predominantly sandy soils classified as Savanna Ochrosol and Groundwater Laterites in the Interim Ghana Soil Classification System (Adjei-Gyapong and Asiamah, 2002) and as Plinthosols in the World Reference Base for soil resources (WRB, 2015).