Received: 28 June 2020 | Accepted: 13 November 2020

DOI: 10.1002/agj2.20536

Agronomy Journal

ARTICLE

Crop Economics, Production, and Management

Maize–legume strip cropping effect on productivity, income, and income risk of farmers in northern Ghana

Nurudeen Abdul Rahman[1] | **Asamoah Larbi**[2] | **Bekele Kotu**[3] | **Mary Otiwaa Asante**[4] | **Daniel Brain Akakpo**[5] | **Shaibu Mellon-Bedi**[6] | **Irmgard Hoeschle-Zeledon**[7]

[1] International Institute of Tropical Agriculture, Tamale, Ghana

[2] Universal Developers Consultancy, Tamale, Ghana

[3] International Institute of Tropical Agriculture, Tamale, Ghana

[4] Council for Scientific and Industrial Research-Crop Research Institute, Kumasi, Ghana

[5] Wageningen Univ. and Research, Wageningen, The Netherlands

[6] Center for Development Research, Univ. of Bonn, Germany

[7] International Institute of Tropical Agriculture, Ibadan, Nigeria

Correspondence

N. Abdul Rahman, International Institute of Tropical Agriculture, Tamale-Ghana.
Email: a.nurudeen@cgiar.org

Funding information

United State Agency for International Development, Grant/Award Number: ARG#: AID-BFS-G-11-00002

Abstract

Maize (*Zea mays* L.)–legume intercropping is common cropping system among smallholder farmers in West Africa. However, little is known about the income risk reduction associated with maize–legume strip cropping in West Africa. A 3-yr study was conducted in Upper West and Northern regions of Ghana to determine the effect of maize–legume strip cropping on productivity, income, and income risk using a randomized complete block design with five replications in each region. Seven treatments were used: sole crops of maize (M) cowpea [*Vigna unguiculata* (L.) Walp.] (C) and groundnut (*Arachis hypogaea* L.) (G), a combination of two rows of M and two rows of legumes (L) (2M:2C and 2M:2G), and two rows of M and four rows of L (2M:4C and 2M:4G). Maize–legume strip cropping options (2M:2L and 2M:4L) on the average saved 90–100% of agricultural land, significantly increased income by about threefold, and reduced risk of operating at a financial loss by 75% compared with sole cropping. Smallholder farmers, especially sole legume cropping farmers in the Guinea savanna of northern Ghana and similar agro-ecologies in West Africa, could adopt maize–legume strip cropping systems (2M:4L or 2M:2L) to mitigate production risk and increase financial return.

1 | INTRODUCTION

The annual population growth rate of Africa is about 2.6%, with a projected population increase of 1.3 billion by 2050 (United Nations, 2017). This increase in Africa's population would lead to high demand for food and land use, which poses a threat to the future of agricultural production in the region. This implies that more food will have to be produced from small land areas through efficient use of natural resources with less impact on the environment. In addition, climate change threatens crop yields, especially in West Africa because of strong agricultural dependencies and limited adaptations (IPCC, 2007; Yegbemey, Yegbemey, & Yabi, 2017). According to Yegbemey et al. (2017), crop

Abbreviations: 2M, two rows of maize; 2C, two rows of cowpea; 2G, two rows of groundnut; 2L, two rows of legumes; 4C, four rows of cowpea; 4G, four rows of groundnut; 4L, four rows of legumes; C, cowpea; FSD, first-degree stochastic dominance; G, groundnut; L, legumes; M, maize; SERF, stochastic efficiency with respect to a function; SSD, second-degree stochastic dominance.

diversification and land use change strategies are among the most sustainable options for climate change adaptation. Thus, there is the need for a cropping strategy that increases productivity, income, and resource utilization per unit area of available arable lands to improve land use. One way to achieve these objectives is by intercropping (i.e., growing two or more crops on the same piece of land either in space or in time) (Ofori & Stern, 1987).

Cereal–legume intercropping, especially maize (*Zea mays* L.)–legume intercropping, is a common practice in Africa because it secures food production by reducing the risk of crop yield loss and optimizes the use of labor and land (Mucheru-Muna et al., 2010; Rusinamhodzi, Corbeels, Nyamangara, & Giller, 2012). Legumes in cereal–legume intercropping improve soil N through biological N fixation (Giller, 2001), form a soil surface cover to reduce erosion (Giller & Cadisch, 1995; Ouyang et al., 2017), and suppress weeds growth (Banik, Midya, Sarkar, & Ghose, 2006; Workayehu & Wortmann, 2011). Cereal–legume intercropping uses resources such as water, light, and soil nutrients more efficiently than their respective monocropping systems (Kermah et al., 2017; Zhang & Li, 2003). Cereal–legume intercropping arrangements exist in many ways. Intercropping two rows of maize alternated with two rows of legume increased grain yield of both maize and legume and increased economic benefit compared with the conventional system of one row of maize alternated with one row of legume in many parts of the world due to increased light penetration to the understory legume and increased fertilizer use efficiency (Du et al., 2018; Mucheru-Muna et al., 2010; Sharma & Banik, 2015; Woomer, 2007).

Crop production in northern Ghana is primarily on a subsistence basis, with an average land size of 0.6–1.3 ha (Amanor-Boadu et al., 2015). Smallholder farmers in this part of the country traditionally intercrop cereals such as millet, sorghum [*Sorghum bicolor* (L.) Moench], and maize with cowpea or groundnut. Among these cereals, maize is now the major stable crop, replacing sorghum and millet even in the dry regions of the country due to the availability of early-maturing varieties (Fosu, Kühne, & Vlek, 2004; MacCarthy, Adiku, Freduah, & Gbefo, 2017). Smallholder farming systems in northern Ghana are mainly rainfed, and the uncertainty of rainfall coupled with low soil fertility increases the risk of crop yield loss in this region. Dillon and Anderson (1990) defined risk as a dispersion around an expected output, such as yield ("yield risk") or net financial return ("economic risk"). Farmers in northern Ghana practice cereal–legume intercropping to mitigate erratic rainfall patterns and low soil fertility to safeguard household food and income. Kamanga, Waddington, Robertson, and Giller (2010) reported that intercropping maize with pigeonpea [*Cajanus cajan* (L.) Millsp.] was less risky in terms of crop yield loss and return to labor compared with maize intercrop with other legumes, such as groundnut (*Arachis hypogaea* L.), tephrosia (*Traphosia vogelii* L.), and mucuna (*Mucuna puriens* L.), in Malawi. However, there are limited quantitative data in the literature on income risk and crop yield loss associated with maize–legume intercropping systems, especially maize–legume strip cropping in northern Ghana and West Africa. In addition, apart from the study by Kermah et al. (2017) on maize–legume strip cropping in northern Ghana, on-farm evaluation of cereal–legume strip cropping, especially maize–legume strip cropping systems, has been less researched in northern Ghana. Such information may be very useful for increasing productivity and income of smallholder farming systems in the northern savanna of Ghana and similar agro-ecologies in West Africa. This study reports the productivity, income, and income risk associated with maize–legume strip cropping systems in the Guinea savanna zone of northern Ghana.

Core Ideas

- Maize–legume strip cropping reduces risk of crop yield loss.
- Strip cropping maize with legume increases net income.
- Maize–legume strip cropping reduces risk of operating at a financial loss.

2 | MATERIALS AND METHODS

2.1 | Study area

The experiment was conducted during the 2014, 2015, and 2016 cropping seasons in the Siriyiri, Passe, Goriyiri, Goli, and Zanko communities in the Upper West and Tingoli, Cheyohi No. 2, Tibogunayili, Duko, and Tibali communities in the northern regions of Ghana (Figure 1). The total amounts of rainfall received in the Upper West Region for the 2014, 2015, and 2016 cropping seasons (June–October) were 977.1, 800.3, and 943.1 mm, respectively (Figure 2a–c). In the Northern Region, the total amounts of rainfall recorded for the 2014, 2015, and 2016 cropping seasons were 977.1, 800.3, and 943.1 mm, respectively (Figure 2d–f). The average minimum temperature for both locations was 23 ˚C for the 2014, 2015, and 2016 cropping seasons; the maximum temperature was 32 ˚C for both locations and cropping seasons (aWhere.com, 2020).

The soils of the study areas in the Upper West region were derived from granite, with topsoil (0–20 cm) properties of pH, 6.1–6.7 (1:2 soil/H_2O); total N, 0.9–1.5 g kg^{-1}; organic matter, 5.5–16.9 g kg^{-1}; and texture (loam–sandy loam). Soils of the Northern region were developed from sandstones and shale, with topsoil (0–20 cm) properties of pH, 5.6–6.3 (1:2 soil/H_2O); total N, 0.5–0.9 g kg^{-1}; organic matter, 9.5–16.7 g kg^{-1}; and texture (loam–sandy loam) (Tetteh et al., 2016).

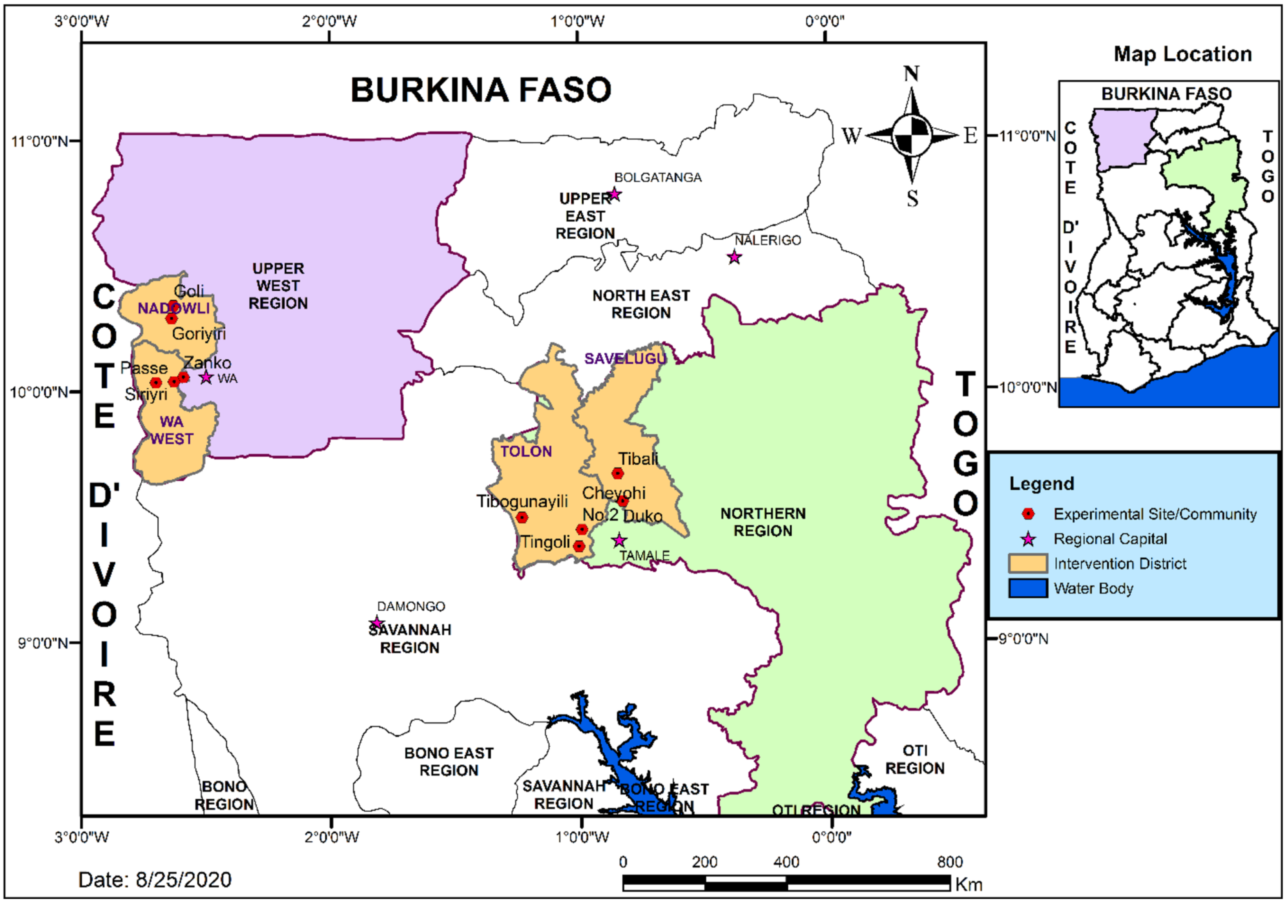

FIGURE 1 Map of Ghana showing experimental sites in the intervention communities

2.2 | Experimental design

A randomized complete block design was used. There were seven treatments: sole crops of maize (M), cowpea (C), and groundnut (G) and combinations of two rows of maize with two rows of cowpea (2M:2C), two rows of maize with two rows of groundnut (2M:2G), two rows of maize with four rows of cowpea (2M:4C), and two rows of maize with four rows of groundnut (2M:4G) (Table 1). The treatments were selected based on previous reports (Mucheru-Muna et al., 2010; Sharma & Banik, 2015; Woomer, 2007). The 2M:4C and 2M:4G treatments were selected considering the needs of female farmers for cowpea and groundnut cultivation (Britwum & Akorsu, 2016) and crop/livestock farmers who use cowpea and groundnut residues for livestock feeding (Singh & Ajeibge, 2007). The experiment was conducted in five communities in the Upper West region and five communities in the Northern regions of Ghana (Figure 1). These communities were selected because they are intervention communities in northern Ghana for the Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) project. At the regional level, each community was used as a block, where the experiment was established as a technology park for farmers to participate in, observe, and learn about the technology. Thus, the experiment was replicated five times per region. The experiment was conducted on 369 m^2 of land with a plot size of 36 m^2 and managed by researchers with farmers participating at every level of field activity to the end of the experiment.

2.3 | Agronomic practice

The experimental fields were ploughed with tractor in line with the common land ploughing practices in both regions. The maize seeds were planted at a spacing of 75 cm × 40 cm with three seeds per hill and thinned to two plants per hill after 14 d. The cowpea and groundnut seeds were planted at a spacing of 75 cm × 20 cm with two seeds per hill. The interrow spacing of the legume was maintained at the same distance as that of the maize to achieve the alternate planting arrangement of the intercropping system. Both crops were planted on the same day in each community. In the Upper West region, maize and legumes were planted in the five communities between 6 and 15 July, 8 and 22 July, and 22 June and 8 July in the 2014, 2015, and 2016 cropping seasons, respectively. In the

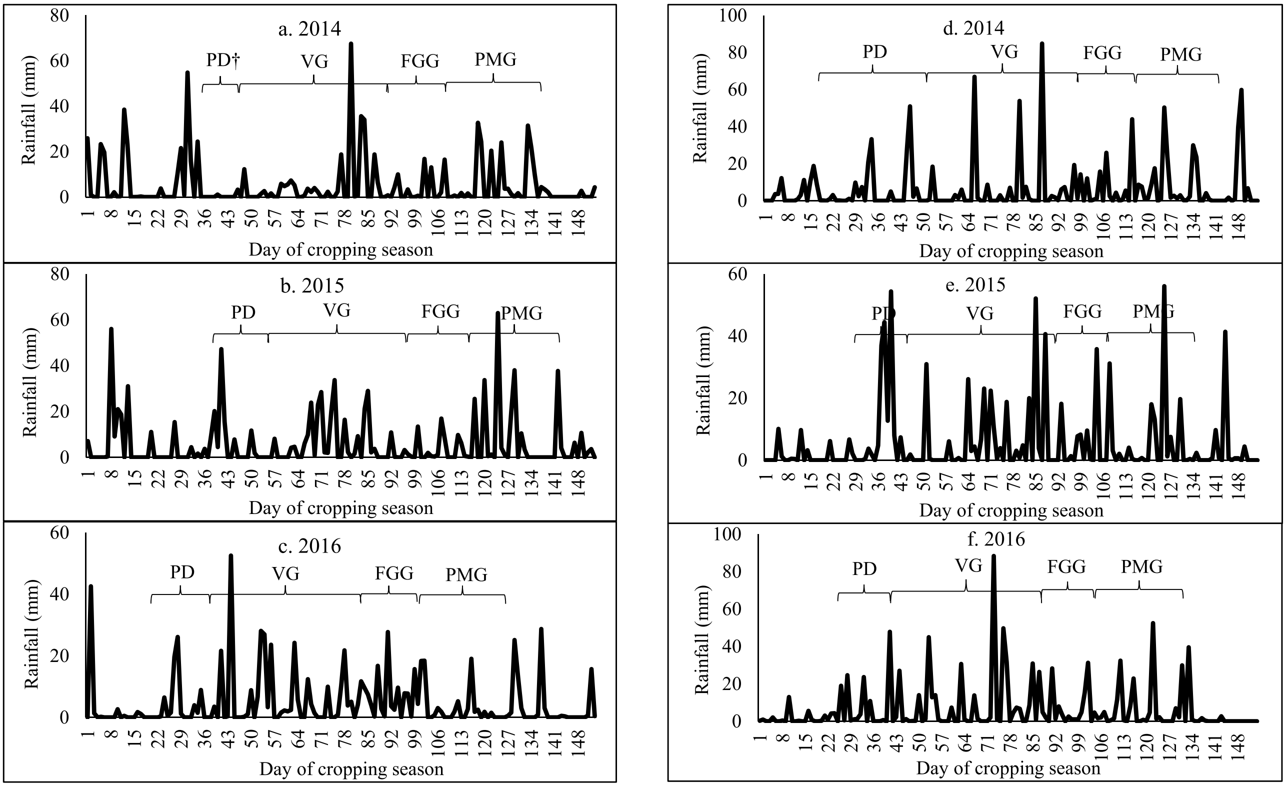

FIGURE 2 Rainfall distribution with crop growth stages in the (a–c) Upper West and (d–f) Northern regions of Ghana during the 2014, 2015, and 2016 cropping seasons (source: aWhere.com 2020). FGG, flowering and grain filling growth; PD, planting date; PMG, physiological maturity growth; VG, vegetative growth

TABLE 1 Maize–legume strip cropping system effect on grain yield and land equivalent ratio (LER) in Upper West region of Ghana during 2014, 2015, and 2016 cropping seasons

	2014				2015				2016			
	Grain yield				Grain yield				Grain yield			
Cropping system	M	C	G	LER	M	C	G	LER	M	C	G	LER
	kg ha^{-1}				kg ha^{-1}				kg ha^{-1}			
Strip cropping												
Maize (M)	3,353.3		–	–	4,117.8	–	–	–	4,218.3	–	–	–
Cowpea (C)	–	1,190.6	–	–	–	360.0	–	–	–	427.5	–	–
Groundnut (G)	–	–	928.1	–	–	–	640.0	–	–	–	973.3	–
2M:2C	3,413.3	648.8	–	1.9	3,333.3	608.9	–	2.6	3,611.7	538.2	–	2.3
2M:2G	2,541.7	–	631.3	1.7	3,320.0	–	488.9	1.6	3,933.3	–	955.8	1.9
2M:4C	2,430.0	1,734.4	–	2.6	2,522.2	431.1	–	1.8	3,856.7	527.7	–	2.3
2M:4G	3,188.3	–	693.8	2.2	3,246.7	–	508.9	1.6	3,541.7	–	928.3	1.9
SEM	474.30	379.46	145.01	0.50	443.26	101.60	76.61	0.21	361.68	32.74	60.22	0.18
Sole vs. strip cropping	0.3281	0.9985	0.1854	–	0.0723	0.2679	0.2070	–	0.3257	0.0198	0.6782	–
2M:2L vs. 2M:4L	0.7288	0.0895	0.7708	0.2692	0.3477	0.2837	0.8625	0.1065	0.8408	0.8239	0.7515	0.8358
MC vs. MG	0.9069	–	–	0.5982	0.4456	–	–	0.0306	0.9927	–	–	0.0256

Northern region, the maize and legumes were planted in the five communities between 17 June and 24 July, 29 June and 13 July, and 23 June and 12 July in the 2014, 2015, and 2016 cropping seasons, respectively.

A basal compound fertilizer (N–P–K, 15–15–15) was distributed evenly among all maize plants in the field 2 wk after planting at a rate of 40:40:40 N–P_2O_5–K_2O kg ha^{-1} in line with the common practice in these areas (Ragasa et al., 2013). Sulfate of ammonia fertilizer was applied to the maize plants 3 wk after basal application at a rate of 20 N kg ha^{-1}. Manual weeding with a hand hoe was done twice at 2 and 5 wk after planting. Cymetox super (30 g cypermethrin and 25 g dimethoate as active ingredients at 1 L ha^{-1}) was used to control thrips and aphids before flowering, and Lambda cyhalothrin (25 g cyhalothrin as active ingredient at 250 ml ha^{-1}) was used to control pod-sucking bugs after flowering.

2.4 | Grain yield and land productivity

Maize cobs and legume (cowpea and groundnut) pods from the two center rows of each plot (7.5 m^2) were harvested at maturity, shelled, winnowed, and oven dried at 65 °C to moisture content of 13 and 12% for maize and legume grain yield measurement, respectively. Land equivalent ratio (LER), which measures the productivity of intercrops against sole crops, was estimated according to Ofori and Stern (1987) as:

$$\text{LER} = \frac{\text{Yield maize intercrop}}{\text{Yield maize sole crop}} + \frac{\text{Yield legume intercrop}}{\text{Yield legume sole crop}} \quad (1)$$

2.5 | Statistical analysis

Statistical Analysis System Package (SAS Institute, 2011) was used to analyze the yield and net income data on cropping season basis.The model used was:

$$Y_{ijk} = \mu + B_i + I_j + e_{ijk} \quad (2)$$

where Y_{ijk} is an observation, μ is experimental mean, B_i is block (community) effect, I_j is treatment effect, and e_{ijk} is residual error. Treatment means of significant differences were separated using orthogonal contrast at a probability level of .05.

2.6 | Cost-benefit analysis

The data used for cost-benefit analysis include grain prices and costs of different inputs such as labor, fertilizer, seeds, insecticide, and draft power. Grain prices were collected from Esoko, a data company operating in Ghana (Esoko, 2017). The data constituted wholesale grain prices of cowpea, groundnut, and maize for the harvest months (November, December, and January) of the three cropping seasons during which the trial was conducted (2014, 2015, and 2016) and cover the major markets close to the communities where the trial was conducted (Wa in the Upper West Region and Tamale in the Northern Region). Data on labor cost were collected through interviews made with leaders of community-level farmer-based organizations. Labor cost constitutes the cost of undertaking different farm activities throughout the production season, including planting, weeding, fertilizer application, spraying, harvesting, and postharvest processing. The price data of seeds, fertilizers, and insecticides were collected from agrochemical inputs shops in Wa Municipality for the Upper West Region (about 30 km from the experimental communities) and in Tamale for the Northern Region (about 20 km from the experimental communities). The wholesale grain prices collected from Esoko were adjusted to 66% as farmgate prices for the grains (Brooks, Croppenstedt, & Aggrey-Fynn, 2007), and the latter data were used to compute gross monetary values of the grains produced. However, labor and draft power costs were not adjusted because they reflected farmgate situations. Finally, gross field benefit (net income) was computed as the difference between gross monetary value of the grains produced and the total variable cost of production. All costs and benefits were estimated in Ghana cedi.

2.7 | Risk analysis

Risk implies the probability that future outputs deviate from the expected levels of decision makers. Risk analysis involves a scientific procedure to assess risky alternatives that help economic entities or individuals to make decisions. Risk analysis methods vary in terms of their discriminatory power of risky alternatives. Methods having relatively low discriminatory power include first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD); those having relatively high discriminatory power include stochastic efficiency with respect to a function (SERF) (Anderson, Dillon, & Hardaker, 1977; Hardaker, Richardson, Lien, & Schumann, 2004; Hien, Kabon, Youl, & Lowenberg-DeBoer, 1997). In this study, we used FSD, SSD, and SERF algorithms to rank different options of maize–legume strip cropping. The reference variable for our risk analysis was the net income. The FSD was based on the assumption that humans prefer more wealth than less, whereas the SSD assumed that humans would like to avoid risky outcomes (Hien et al., 1997). We considered two distributions (1 and 2), characterized, respectively, by cumulative distributions, F_1 and F_2; F_1 had first-order stochastic dominance over F_2 if, for any value w of the target variable, $F_1(w) < F_2(w)$. Similarly, F_1 had second-order stochastic dominance over F_2 if, for any value w of the target variable,

$$\int_{-\infty}^{w} F_1\,(w)\mathrm{d}w \leq \int_{-\infty}^{m} F_2\,(w)\,\mathrm{d}w \quad (3)$$

TABLE 2 Maize–legume strip cropping system effect on grain yield and land equivalent ratio (LER) in Northern Region of Ghana during 2014, 2015, and 2016 cropping seasons

Cropping system	2014				2015				2016			
	Grain yield				Grain yield (kg ha^{-1})				Grain yield (kg ha^{-1})			
	M	C	G	LER	M	C	G	LER	M	C	G	LER
	kg ha^{-1}				kg ha^{-1}				kg ha^{-1}			
Strip cropping												
Maize (M)	2,590.4	–	–	–	3,808.8	–	–	–	4,053.3	–	–	–
Cowpea (C)	–	1,048.8	–	–	–	245.3	–	–	–	693.3	–	–
Groundnut (G)	–	–	661.3	–	–	–	387.5	–	–	–	610.4	–
2M:2C	2,702.1	1,105.3	–	2.4	3,365.3	317.6	–	2.3	3,007.7	669.3	–	1.7
2M:2G	2,917.9	–	427.7	2.0	3,114.4	–	289.1	1.7	4,728.0	–	407.5	1.9
2M:4C	1,995.7	1,045.3	–	2.0	3,242.4	303.2	–	2.4	2,298.7	656.0	–	1.5
2M:4G	2,818.7	–	414.1	1.8	3,151.2	–	369.1	1.7	4,194.7	–	458.1	1.8
SEM	284.10	97.68	106.45	0.16	424.87	63.42	47.04	0.42	518.81	93.54	68.56	0.20
Sole vs. strip cropping	0.8765	0.8300	0.1024	–	0.2639	0.4265	0.3404	–	0.2542	0.7957	0.0673	–
2M:2L vs. 2M:4L	0.1754	0.6755	0.9302	0.2201	0.9205	0.8764	0.2635	0.9209	0.2486	0.9222	0.6155	0.5357
MC vs. MG	0.0863	–	–	0.0875	0.6925	–	–	0.1989	0.0031	–	–	0.3269

The SERF applies utility functions instead of the distributions of the actual values of target variables to rank risky alternatives (Hardaker et al., 2004). Rankings were based on certainty equivalents derived from utility functions. Because the exact shape of the utility function of an individual is unknown, SERF makes the ordering for absolute/relative risk aversion function that lies anywhere between certain two values (i.e., lower and upper bounds). A detailed theoretical explanation of the SERF is reported by Hardaker et al. (2004); its description contextualized to Northern Ghana is reported by Abdul Rahman, Larbi, Kotu, Tetteh, and Hoeschle-Zeledon (2018).

3 | RESULTS

3.1 | Grain yield and land productivity

Generally, the grain yield of maize increased from 2014 to 2016 (Tables 1 and 2). The grain yields of the legumes were higher in 2014 but declined during 2015 and increased again during 2016 (Tables 1 and 2). Cropping season with good legume grain yield gave lower maize grain yield, and vice versa. The grain yield of maize and groundnut from the sole crops were not different ($P > .05$) from those of the maize–legume strip cropping during 2014, 2015, and 2016 (Tables 1 and 2). However, in the Upper West region, the grain yield of cowpea increased ($P < .05$) by 26% for 2M:2C and by 23% for 2M:4C ompared with that of the sole cowpea during 2016 (Table 1). Similarly, during 2016, the grain of maize for 2M:2G was 57% higher ($P < .01$) than that of 2M:2C, and the grain yield of maize for 2M:4G was 83% higher ($P < .01$) than that of 2M:4C in the Northern region (Table 2). The LERs of the maize–legume strip cropping systems were >1, indicating better productivity compared with the sole crops (Tables 1 and 2). However, in the Upper West region during 2015 and 2016, the LER of the maize–cowpea strip cropping was significantly higher than that of the maize–groundnut strip cropping (Table 1 . The LER for maize–cowpea at 2M:2C increased by 63% in 2015 and by 21% in 2016 compared with that of 2M:2G, whereas the LER of 2M:4C increased by 13% in 2015 and by 21% in 2016 compared with that of 2M:4G (Table 1).

3.2 | Cost-benefit and risk

Strip cropping affected ($P < .01$) net income in both regions (Table 3). Strip cropping maize with either cowpea or groundnut increased ($P < .01$) net income compared with the sole crops in all the cropping seasons in both regions. Strip cropping maize–groundnut at 2M:2G increased ($P < .01$) net income by 41% compared with that of 2M:2C, whereas 2M:4G increased ($P < .01$) net income by 138% compared with 2M:4C in the Upper West region during 2015 (Table 3). During 2016, the net income of 2M:2G was 80% higher ($P < .01$) than that of 2M:2C, whereas the net income of 2M:2G was 48% higher ($P < .01$) than that of 2M:4C in the Upper West region (Table 3). In the Northern region, the net income of 2M:2G was 59% higher ($P < .01$) than that of 2M:2C, whereas the net income of 2M:4G increased ($P < .01$) by 91% compared with that of 2M:4C during 2016 (Table 3).

Results of the FSD are displayed below the shaded cells, and those of the SSD are displayed above the shaded cells (Table 4). The 2M:4G strip cropping option was the best option in terms of the FSD criteria, implying that farmers will get the highest financial benefit if they go for this option.

TABLE 3 Effect of maize–legume strip cropping system on income (Ghana cedi ha^{-1}) in Upper West and Northern regions of Ghana during 2014, 2015, and 2016 cropping seasons

Cropping system	Upper West region 2014	2015	2016	Mean	Northern region 2014	2015	2016	Mean
Strip cropping								
Sole maize (M)	596.6	1,561.4	772.6	965.1	527.3	1,502.0	1,697.7	1,242.3
Sole cowpea (C)	607.3	−716.0	−695.9	−270.7	873.1	−412.5	304.3	255.0
Sole groundnut (G)	1,380.3	950.4	564.6	941.0	790.0	159.9	695.0	548.3
2M:2C	1,817.2	1,984.0	1,430.7	1,726.1	2,655.2	1,925.4	2,202.1	2,260.9
2M:2G	2,038.2	2,794.2	2,703.5	2,625.9	2,102.9	1,927.3	3,502.3	2,510.8
2M:4C	2,768.3	1,254.0	1,727.0	1,991.8	2,129.1	1,939.0	1,748.5	1,938.9
2M:4G	2,708.5	2,987.0	2,557.8	2,765.5	2,134.9	2,292.7	3,341.3	2,589.6
SEM	481.91	411.48	3,44.92	264.78	446.32	377.79	376.36	287.37
Sole vs. strip cropping	0.0008	0.0002	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001
2M:2L vs. 2M:4L	0.1098	0.5262	0.8283	0.4369	0.5850	0.6205	0.4222	0.6731
MC vs. MG	0.8691	0.0094	0.0040	0.0018	0.5460	0.6422	0.0008	0.1205

Note. 1 US$ = 5.72 Ghana cedi (Bank of Ghana, 2020).

TABLE 4 First-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) analysis for maize (M), Cowpea (C), Groundnut (G) and M strip cropped with either two rows of C (2C) and G (2G) or four rows of C (4C) and G (4G) in northern Savanna of Ghana

	Strip cropping	SSD M	G	C	2M:2G	2M:4G	2M:2C	2M:4C
FSD	M		x	M	x	2M:4G	x	2M:4C
	G	x[a]		G	2M:2G	2M:4G	2M:2C	2M:4C
	C	x	G		2M:2G	2M:4G	2M:2C	2M:4C
	2M:2G	x	x	2M:2G		2M:4G	x	x
	2M:4G	2M:4G	2M:4G	2M:4G	2M:4G		2M:4G	2M:4G
	2M:2C	x	x	x	x	2M:4G		2M:4C
	2M:4C	2M:4C	x	2M:4C	x	x	2M:4C	

[a]Two treatments are not different from each other.

Moreover, this option had the lowest income risk, as indicated by the results of the SSD (Table 4). The next best option was 2M:4C strip cropping in terms of both criteria. The 2M:4G and 2M:4C strip cropping options were not different in terms of financial returns as indicated by the FSD analysis, but the 2M:4G option had better income risk characteristics as shown by the SSD analysis. The 2M:2G and 2M:2C strip cropping options did not show dominance over most of the sole cropping options in terms of the FSD criteria. However, they were better than sole cropping of the two legumes in terms of the SSD criteria.

We also computed the probabilities that outcomes of each production become above/below/between target threshold levels. We used the breakeven value as a lower threshold value and 50% net income as an upper threshold value. The results showed that most of the strip cropping options generally increased the probability of having positive net income above 50% and reduced the risk of operating at financial loss as compared with the sole cropping options, particularly for the sole legume options (Figure 3). Strip-cropping maize with cowpea reduce the risk of operating at a financial loss from 77% in the case of the sole cowpea option to 17% in the case of 2M:2C and 0% in the case of 2M:4C (Figure 3). Similarly, strip-cropping maize with groundnut reduced the risk of operating at a financial loss from 30% in the case of sole groundnut to 13% in the case of 2M:2G and 0% in the case of 2M:4G (Figure 3). The risk of operating at a financial loss for sole cropping of maize declined from 13 to 0% when maize was strip cropped with either cowpea or groundnut at 2M:4C or 2M:4G (Figure 3). However, strip cropping of maize with cowpea at 2M:2C increased the risk of operating at a financial loss from 13% in the case of the sole maize option to 17% (Figure 3).

The results of SERF analysis validate the results of the FSD and the SSD analyses and show that 2M:4G strip cropping was the best option in terms of reducing financial risk, followed

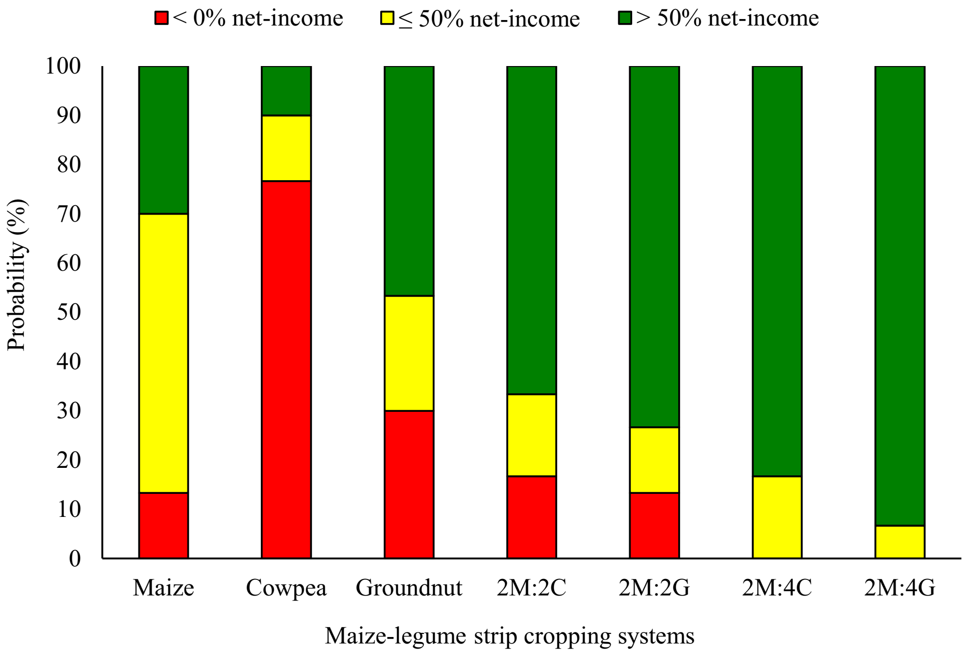

FIGURE 3 Risk of net income levels for maize (M), cowpea (C), groundnut (G), M strip cropped with either two rows of C (2C) and G (2G) or four rows of C (4C) and G (4G) in northern Savanna of Ghana

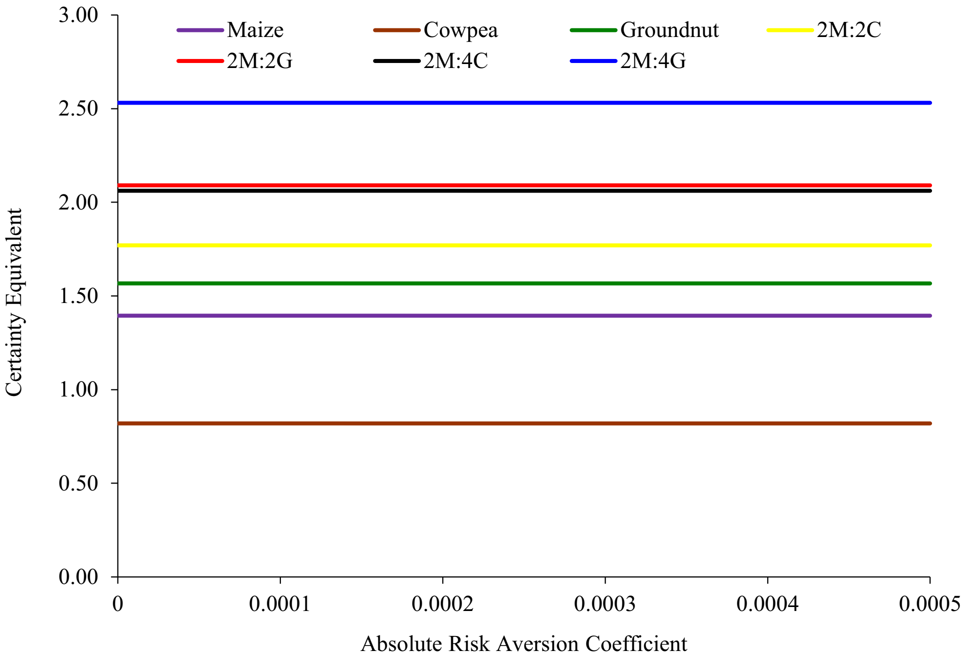

FIGURE 4 Stochastic efficiency with respect to SERF for maize (M), cowpea (C), groundnut (G), M strip cropped with either two rows of C (2C) and G (2G) or four rows of C (4C) and G (4G) in northern Savanna of Ghana

by 2M:4C, 2M:2G, and others (Figure 4). The ranks of the treatments were similar under the assumptions of risk neutrality and strong risk aversion, whereas the pattern does not change if any intermediate risk aversion coefficients are considered. The distance between the lines representing the treatment can be interpreted as the amount of risk premium a farmer has to pay as he/she moves between the treatments. For instance, the lines representing 2M:2G and 2M:4C strip cropping options were almost overlapping, which shows that the risk premium for the changes that occur between these two treatments was small, implying that farmers at all risk aversion levels would not have a strict preference between the two options.

4 | DISCUSSION

4.1 | Grain yield and land productivity

The higher maize grain yield obtained in the 2016 in both regions could be due to the high and stable distribution of rainfall received during the vegetative, flowering, and grain filling stages of the maize plant because these are the growth stages when much water is required for good seedling establishment, growth, and grain filling. The low amount of rainfall received during the physiological maturity stage (drying stage) of the maize in 2016 in both regions might have also contributed to the increase in grain yield because this growth stage requires less water to ensure fast drying of the maize cobs and reduce yield loss from pest and disease attack (Figure 2). Similar to the maize grain yield, 2016 had the highest groundnut grain yield, and this could be attributed to the amount and distribution pattern of the rainfall received during the growth stages of the groundnut (Figure 2. However, the higher cowpea grain yield recorded in 2014 could be due to the lower amount of rainfall received during seed emergence to vegetative state for good seedling establishment and the high amount of rainfall received during the flowering, pod, and grain filling stages (Figure 2). In a similar maize–legume intercropping study conducted in Zimbabwe for 12 yr, the authors reported rainfall fluctuation as the main cause of maize and legume grain yields variations between seasons (Waddington, Mekuria, Siziba, & Karigwindi, 2007). The effect of the rainfall distribution on the yield pattern of the crops shows how robust the strip cropping system is in terms of spreading risk associated with crop yield loss. For example, a cropping season with lower maize grain yield was compensated with higher legume grain yield, and vice versa. This result supports the findings that intercropping of cereals with legumes is an effective crop yield loss risk-spreading strategy from erratic rainfall pattern for smallholder farmers (Waddington et al., 2007; Mucheru-Muna et al., 2010; Rusinamhodzi et al., 2012).

The higher cowpea grain yield observed from maize–cowpea strip cropping than the sole cowpea during the 2016 in the Upper West region (Table 1 could be due to the presence of the maize in the maize–cowpea strip cropping options that reduce the impact of the high amount of rainfall received during seedling establishment and vegetative stages of the cowpea because the cowpea plants do not require much water at these growth stages. The variation in the maize grain yield between the maize–groundnut and maize–cowpea strip cropping in the Northern Region during 2016 (Table 2 could be attributed to the competitive ability and the plant architecture of the groundnut and cowpea plants in the strip cropping systems. Kermah et al. (2017) reported higher competitive ratios for cowpea than groundnut in maize–legume intercropping experiments conducted in the northern and southern Guinea savanna agro-ecological zones of Ghana. The LERs for all the maize–legume strip cropping options were >1 in the three cropping seasons in both regions (Tables 1 and 2), indicating better productivity of the intercrop compared with the sole crop (Ofori & Stern, 1987). Average LERs of 2.0 obtained by the maize–legume strip cropping across the three cropping seasons in the Upper West region and 1.9 observed for the strip cropping in the Northern region indicate that, on average, 100 and 90% of lands were saved in both respective regions for other agricultural and related activities. The higher yield productivity of the maize and legumes in the strip cropping could be due to the complementary and efficient use of resources such as water, nutrients, and light among the components of the maize–legume strip cropping relative to the sole cropping. Similar results have been reported on the effect of a cereal–legume intercropping system on the efficient use of resources (Kamara et al., 2019; Kermah et al., 2017; Sharma & Banik, 2015). The difference in the LER for the maize–cowpea and maize–groundnut strip cropping systems could be attributed to the effect of the strip cropping system on the grain yield of both maize and legumes. For instance, the grain yield of sole cowpea was lower than that of 2M:2C and 2M:4C, whereas the grain yield of sole groundnut was higher than that of 2M:2G and 2M:4G during 2015 and 2016 in the Upper West region (Table 1). In line with our results, Rusinamhodzi et al. (2012) reported higher LER for intercropping maize with cowpea than maize with pigeonpea in distinct row.

4.2 | Cost-benefit and risk

The net incomes from the maize–legume strip cropping options were higher compared with those of the sole crops over the 3-yr period in both regions. This could be due to the higher productivity of the strip cropping options as indicated in the LER of the strip cropping options (Tables 1 and 2). In line with our result, several authors have reported an increase in financial benefit of cereal–legume intercropping relative to a monocropping system (Kamara et al., 2019; Ouyang et al., 2017; Sharma & Banik, 2015; Singh & Ajeibge, 2007; Workayehu & Wortmann, 2011). The net income from the maize–groundnut strip cropping was higher than that of the maize–cowpea strip cropping in the Upper West region irrespective of the plant arrangement. This could be explained by the differences in the grain yields and the prices of the two legumes. Mucheru-Muna et al. (2010) reported a similar financial benefit from maize–groundnut intercrop compared with maize–cowpea intercrop at Machang'a in the central highlands of Kenya.

Strip cropping maize with either cowpea or groundnut reduced the risk of operating at a financial loss compared with the sole cropping options. Particularly, the risk impact of strip cropping with respect the sole cowpea is substantial. This could be due to factros related to crop and cropping system. Cowpea is reported to suffer most from insect pest infestation, with grain yield loss of as high as 100% if no control measures are taken (Jackai & Daoust, 1986; Singh & Van Emden, 1979; Tanzubil, Zakariah, & Alem, 2008). Hailu, Niassy, Zeyaur, Ochatum, and Subramanian (2018) reported significant reductions in fall army worm and stem borer with maize–legume intercropping compared with sole maize cropping, especially at the early growth phases up to tasseling. While cropping maize with either groundnut or cowpea in any of the combinations constitute risk-reducing characteristics, combining maize and groundnut gave better results than strip cropping maize with cowpea in terms of reducing the risk of operating at a financial loss. Particularly, the 2M:4G strip cropping option was the best option regarding income risk reduction. The variation could be attributed to the high price of groundnut grains compared with that of the cowpea grains. A study in Malawi reported that intercropping maize with pigeonpea was less risky in terms of crop yield loss and return to labor compared with intercropping maize with other legumes such as groundnut, tephrosia (Tephrosia vogelii Hoo.f.), and mucuna [*Mucuna puriens* (L.) DC.] (Kamanga et al., 2010). The reduction in risk of operating at a financial loss by the maize–legume strip cropping, especially the 2M:4L, is an important feature of the technology given that most smallholder farmers in developing countries are risk averse (Hurley, 2010; Wik, Kebede, Bergland, & Holden, 2004). The higher risk of operating at a financial loss associated with the 2M:2C option compared with the sole maize cropping option could be due to the high probability of yield loss from the cowpea, which translates into lower net income compared with the sole maize cropping.

5 | CONCLUSIONS

Maize–legume strip cropping resulted in better grain yield productivity, income, and income risk reduction than that of the sole cropping. The LERs for the maize–legume strip cropping options were >1, indicating better productivity than the sole cropping systems and, on average, saved 90–100% of agricultural land for other agricultural related activities. The net income from maize–legume strip cropping increased significantly by about threefold compared with that of the sole cropping. Strip cropping maize–groundnut resulted in higher net income than that of the maize–cowpea strip cropping, although this result does not hold in all geographical locations. All the strip cropping options were better in terms of reducing income risk, with an average of 75% reduction in risk of operating at a financial loss compared with that of the sole cropping options. Maize–legume strip cropping was effective in reducing the risk of operating at a financial loss for the sole legume cropping system compared with the sole maize cropping system. Strip cropping maize–legume at 2M:4L gave better results in terms of income risk reduction. Therefore, the adoption of maize–legume strip cropping (2M:4L or 2M:2L) options by smallholder farmers, especially the sole legume cropping farmers in Guinea savanna zone of northern Ghana and similar agro-ecologies of West Africa, will increase productivity and income while reducing the risk of operating at a financial loss.

ACKNOWLEDGMENTS

This work was supported by the United State Agency for International Development (USAID)-funded Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) West Africa project. We thank Fuseini Dokurugu and Ismail Mahama of International Institute of Agriculture, Tamale-Ghana for assistance during field establishment and data collection from the two regions.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ORCID

Nurudeen Abdul Rahman https://orcid.org/0000-0003-4073-5610
Bekele Kotu https://orcid.org/0000-0002-5488-8426
Irmgard Hoeschle-Zeledon https://orcid.org/0000-0002-2530-6554

REFERENCES

Abdul Rahman, N., Larbi, A., Kotu, B., Tetteh, F. M., & Hoeschle-Zeledon, I. (2018). Does nitrogen matter for legumes? Starter nitrogen effects on biological and economic benefits of cowpea (*Vigna unguiculata* L.) in Guinea and Sudan Savanna of West Africa. *Agonomy*, *8*, 120.

Amanor-Boadu, V., Zereyesus, Y., Ross, K., Ofori-Bah, A., Adams, S., Asiedu-Dartey, J., … Salin, M. (2015). *Agricultural production survey for the northern regions of Ghana: 2013-2014 results. Final report*. Accra, Ghana: METSS/USAID.

Anderson, J. R., Dillon, J. L., & Hardaker, J. B. (1977). *Agricultural decision analysis*. Ames: Iowa State University Press.

aWhere. (2020). Retrieved from http://www.developer.awhere.com/api/

Banik, P., Midya, A., Sarkar, B. K., & Ghose, S. S. (2006). Wheat and chickpea intercropping systems in an additive series of experiment: Advantages and weed smothering. *European Journal of Agronomy*, *24*, 325–332. https://doi.org/10.1016/j.eja.2005.10.010

Bank of Ghana. (2020). Daily interbank FX rates. Retrieved from http://www.bog.gov.gh/treasury-and-the-markrts/daily-interbank-fx-rates/

Britwum, A. O., & Akorsu, A. D. (2016). *Qualitative gender evaluation of agricultural intensification practices in northern Ghana*. Ibadan, Nigeria: International Institute of Tropical Agriculture.

Brooks, J., Croppenstedt, A., & Aggrey-Fynn, E. (2007). *Distortions to agricultural incentives in Ghana*. Washington, DC: World Bank's Development Research Group.

Dillon, J. L., & Anderson, J. R. (1990). *The analysis of response in crop and livestock production*. New York: Pergamon Press.

Du, J. B., Han, T. F., Gai, J. Y., Yong, T. W., Sun, X., Wang, X. C., … Yang, W. Y. (2018). Maize-soybean strip intercropping: Achieved a balance between high productivity and sustainability. *Journal of Integrative Agriculture*, *17*, 747–754. https://doi.org/10.1016/S2095-3119(17)61789-1

Esoko. (2017). Retrieved from https://esoko.com/foodpricesghana

Fosu, M., Kühne, R. F., & Vlek, P. L. (2004). Improving maize yield in the Guinea savannah zone of Ghana with leguminous cover crops and PK fertilization. *Journal of Agronomy*, *3*, 115–121.

Giller, K. E. (2001). *Nitrogen fixation in tropical cropping systems* (2nd ed.). Wallingford, U.K.: CAB International.

Giller, K. E., & Cadisch, G. (1995). Future benefits from biological nitrogen fixation: An ecological approach to agriculture. *Plant and Soil*, *174*, 255–277. https://doi.org/10.1007/BF00032251

Hailu, G., Niassy, S., Zeyaur, K. R., Ochatum, N., & Subramanian, S. (2018). Maize–legume intercropping and push–pull for management of fall Armyworm, Stemborers, and Striga in Uganda. *Agronomy Journal*, *110*, 2513–2522. https://doi.org/10.2134/agronj2018.02.0110

Hardaker, J., Richardson, J. W., Lien, G., & Schumann, K. D. (2004). Stochastic efficiency analysis with risk aversion bounds: A simplified approach. *Australian Journal of Agricultural and Resources Economics*, *48*, 253–270. https://doi.org/10.1111/j.1467-8489.2004.00239.x

Hien, V., Kabon, D., Youl, S., & Lowenberg-DeBoer, J. (1997). Stochastic dominance analysis of on-farm-trial data: The riskiness of alternative phosphate sources in Burkina Faso. *Agricultural Economics*, *15*, 213–221.

Hurley, T. A. (2010). *Review of agricultural production risk in the developing world*. Washington, DC: HarvestChoice.

IPCC. (2007). Summary for policymakers. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Lindenand, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 7–22). Cambridge, U.K.: Cambridge University Press.

Jackai, L. E., & Daoust, R. A. (1986). Insect pests of cowpeas. *Annual Review of Entomology*, *31*, 95–119. https://doi.org/10.1146/annurev.en.31.010186.000523

Kamanga, B. C. G., Waddington, S. R., Robertson, M. J., & Giller, K. E. (2010). Risk analysis of maize-legume crop combinations with smallholder farmers varying in resource endowment in central Malawi. *Experimental Agriculture*, *46*, 1–21. https://doi.org/10.1017/S0014479709990469

Kamara, A., Tofa, A., Ademulegun, T., Solomon, R., Shehu, H., Kamai, N., & Omuigui, L. (2019). Maize–soybean intercropping for sustainable intensification of cereal-legume cropping systems in northern Nigeria. *Experimental Agriculture*, *55*, 73–87. https://doi.org/10.1017/S0014479717000564

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D., Abaidoo, R. C., & Giller, K. E. (2017). Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. *Field Crops Research*, *213*, 38–50. https://doi.org/10.1016/j.fcr.2017.07.008

MacCarthy, D. S., Adiku, S. G., Freduah, B. S., & Gbefo, F. (2017). Using CERES-Maize and ENSO as decision support tools to evaluate climate-sensitive farm management practices for maize production in the northern regions of Ghana. *Frontiers in Plant Science*, *8*, 31. https://doi.org/10.3389/fpls.2017.00031

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckex, R., & Vanlauwe, B. (2010). A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field Crops Research*, *115*, 132–139. https://doi.org/10.1016/j.fcr.2009.10.013

Ofori, F., & Stern, W. R. (1987). Cereal-legume intercropping systems. *Advances in Agronomy*, *41*, 41–90. https://doi.org/10.1016/S0065-2113(08)60802-0

Ouyang, C., Wu, K., An, T., He, J., Zi, S., Yang, Y., & Wu, B. (2017). Productivity, economic, and environmental benefits in intercropping of maize with chili and grass. *Agronomy Journal*, *109*, 2407–2414. https://doi.org/10.2134/agronj2016.10.0579

Ragasa, C., Dankyi, A., Acheampong, P., Wiredu, A. N., Chapoto, A., Asamoah, M., & Tripp, R. (2013). *Patterns of adoption of improved maize technologies in Ghana* (Working Paper 36). Washington, DC: International Food Policy Research Institute.

Rusinamhodzi, L., Corbeels, M., Nyamangara, J., & Giller, K. E. (2012). Maize-grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research*, *136*, 12–22. https://doi.org/10.1016/j.fcr.2012.07.014

SAS Institute. (2011). *Base SAS® 9.3 procedures guide*. Cary, NC: SAS Institute.

Sharma, R. C., & Banik, P. (2015). Baby corn-legumes intercropping systems: I. Yields, resource utilization efficiency, and soil health. *Agroecology and Sustainable Food Systems*, *39*, 41–61. https://doi.org/10.1080/21683565.2014.942764

Singh, B. B., & Ajeigbe, H. (2007). Improved cowpea-cereals-based cropping systems for household food security and poverty reduction in West Africa. *Journal of Crop Improvement*, *19*, 157–172. https://doi.org/10.1300/J411v19n01_08

Singh, S. R., & Van Emden, H. F. (1979). Insect pests of grain legumes. *Annual Review of Entomology*, *24*, 255–278. https://doi.org/10.1146/annurev.en.24.010179.001351

Tanzubil, P. B., Zakariah, M., & Alem, A. (2008). Integrating host plant resistance and chemical control in the management of Cowpea pests. *Australian Journal of Crop Science*, *2*, 115–120.

Tetteh, F. M., Larbi, A., Nketia, K. A., Senayah, J. K., Hoeschle-Zeledon, I., & Abdul Rahman, N. (2016). *Suitability of soils for cereal cropping in Northern Ghana: Evaluation and recommendations*. Ibadan, Nigeria: International Institute of Tropical Agriculture.

United Nations, Department of Economic and Social Affairs, Population Division. (2017). *World population prospects: The 2017 revision, key findings and advance tables*. Working Paper No. ESA/P/WP/248. New York: United Nations.

Waddington, S. R., Mekuria, M., Siziba, S., & Karigwindi, J. (2007). Long-term yield sustainability and financial returns from grain legume-maize intercrops on a sandy soil in subhumid north central Zimbabwe. *Experimental Agriculture*, *43*, 489–503.

Wik, M., Kebede, T. A., Bergland, O., & Holden, S. T. (2004). On the measurement of risk aversion from experimental data. *Applied Economics*, *36*, 2443–2451. https://doi.org/10.1080/0003684042000280580

Woomer, P. L. (2007). Costs and returns of soil fertility management options in Western Kenya. In A. Bationo, B. Waswa, J. Kihara, & J. Kimetu (Eds.), *Advances in integrated soil fertility management in Sub-Saharan Africa: Challenges and opportunities* (pp. 881–890). Dordrecht: Springer.

Workayehu, T., & Wortmann, C. S. (2011). Maize–bean intercrop weed suppression and profitability in southern Ethiopia. *Agronomy Journal*, *103*, 1058–1063. https://doi.org/10.2134/agronj2010.0493

Yegbemey, R. N., Yegbemey, E. O., & Yabi, J. A. (2017). Sustainability analysis of observed climate change adaptation strategies in maize farming in Benin, West Africa. *Outlook on Agriculture*, *46*, 20–27. https://doi.org/10.1177/0030727016689638

Zhang, F. S., & Li, L. (2003). Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil*, *248*, 305–312. https://doi.org/10.1023/A:1022352229863

How to cite this article: Abdul Rahman N, Larbi A, Kotu B, et al. Maize–legume strip cropping effect on productivity, income and income risk of farmers in Northern Ghana. *Agronomy Journal*. 2021;1–12. https://doi.org/10.1002/agj2.20536