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Interactive effect of organic manures, mineral fertilizers and seasons on agronomic parameters of intercropped maize (*Zea mays*. L), common beans (*Phaseolus vulgaris.* L) on oxisol in the Noun Valley (Cameroon Western Highlands)

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Intercropping is a common practice among small-scale farmers of common beans and maize in developing countries, but the agronomic performance of these crops is generally poor due to inappropriate farming practices. This study evaluates the interactive effect of season and mineral-organic fertilizers on soil fertility and the agronomic performance of the intercropped common bean-maize system. The field experiment was arranged in a split-split plot design, with the following combinations: season in the first (S1) and second (S2) seasons of 2022, mineral manures, NPK 14-23-14 and 20-10-10 applied at rates of 300 kg/ha (NPK14_300 and NPK20_300) and 600 kg/ha (NPK14_600 and NPK20_600), and organic fertilizers; coffee parchment biochar applied at 2.5 t/ha (Bio_2.5), poultry manure applied at 2.5 (FPP_2.5) and 5.0 (FPP_5.0) t/ha, and a control. The results showed that bean diameter, thousand-seed weight of maize, water pH, and available phosphorus differed significantly ($P < 0.05$) when season (S), EM (mineral fertilizer), and EO (organic fertilizer) interacted. The NPK14_300 and NPK20_300 treatments were profitable and recommendable to smallholder farmers. In conclusion, integrated soil fertility management and cropping season are recommended in the study area and other similar agro-ecological zones for increased, stable, and sustainable production of the intercropped maize-common bean system.

Key words: Oxisol, organic manure, mineral fertilizer, season, *Zea mays*, *Phaseolus vulgaris*, Cameroon Western Highlands.

INTRODUCTION

Food security is a complex challenge for many developing countries. Cameroon is a country with a typically agrarian economy, where agriculture employs over 70% of Cameroonians (Molua, 2010; Ngoucheme et al., 2020). Apart from industrial plantations and a few large private farms, Cameroonian agriculture is dominated by small-scale family farmers (MINADER, 2012). These subsistence farms are the main targets of sustainable actions to lift the majority of the population out of poverty. Maize and beans, mainly considered cash crops, correspond to significant market demand and are likely to increase farmers' incomes. Food insecurity in developing countries is influenced by a variety of socio-economic and political factors, with poor soil condition being a major one (Partey et al., 2011). As many farmers in developing countries use low-input farming methods that rely on soil organic matter, it is essential to adopt appropriate land use and soil management practices to improve and maintain soil quality. Maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) play a crucial role in both food and trade, being grown to meet basic needs on small farms located in different regions of the globe, particularly in sub-Saharan Africa (Baijukya et al., 2016). Kidney beans are of great nutritional and economic importance for humans and livestock feed (Maingi et al., 2001), and they contribute to improving soil fertility by forming a symbiosis with rhizobia to fix atmospheric N_2 (Bedoussac et al., 2015; Latati et al., 2016). It is believed that intercropping common beans could be an alternative to monocropping maize and common beans, with the aim of making sustainable farming systems more intensive on small farms (Lunze et al., 2012; Kermah et al., 2018). Intercropping is widely used by small-scale farmers due to land scarcity, as the plots they individually own are rarely larger than 1.5 ha (Lunze et al., 2012). By practicing intercropping, the dangers of total crop failure can be avoided. The yield of association crops is compared with that of individual crops, which is generally higher, as this practice can lead to a reduction in yield. Santalla et al. (2001), Lithourgidis et al. (2011), Bedoussac et al. (2015), and Kermah et al. (2018) reported that farmers are frequently concerned about the high labor requirements and overall lower yield of cereal and legume crops when grown in a mixture compared to a single crop. The combination of common beans and maize offers benefits in terms of protection against disease and undesirable insects (Chen et al., 2004). Intercropping promotes an increase in total production on a given plot of land by making efficient use of available plant resources (Pretty and Bharucha, 2014; Brooker et al., 2015).

The overall productivity of intercrops is attributed to differences in the acquisition and utilization of growth resources such as nutrients, moisture, and light interception (Giller, 2001; Yu et al., 2016). Maize is grown in all five agro-ecological zones of Cameroon, despite the challenges associated with soil acidity (Tekeu et al., 2021). Additionally, population growth has led to an intensification of agriculture and an expansion of cultivated land, resulting in a reduction in the soil's resting period. Although the Cameroonian government has introduced large-scale production measures in recent years, the available quantity of the third most important foodstuff produced in Cameroon remains insufficient. In Cameroon, dry beans are the third most consumed dry vegetable after groundnuts and cowpeas (Kamtchoum et al., 2018). Despite this, most of the production comes from the main common bean-growing area in the mountainous western regions, comprising the North-West and West regions (Djeugap et al., 2014), which account for over 90% of national production. Intensive agriculture has shown that the exclusive use of inorganic fertilizers is not advantageous, as it leads to soil deterioration (Zhao et al., 2019). Organic fertilizers play an essential role in increasing organic matter and maintaining the soil's physical, chemical, and biological characteristics (Sharma and Mittra, 1991). The aim is to reduce the cost of fertilizing crops and to adopt renewable energy sources, in addition to promoting the use of biomass. Amendments that can increase agricultural productivity and improve soil quality and sustainability include biochar (Igalavithana et al., 2016) and poultry manure (Agbede et al., 2017). However, the mechanism explaining their impact on severely degraded soils in sub-Saharan Africa is still insufficiently studied. Mixing different organic matter with inorganic nutrients has been shown to be an effective way of regulating nutrient availability in the soil and reducing leaching while improving soil condition (Shilpha et al., 2017). The use of chicken droppings and biochar in soils combined with chemical fertilizers has resulted in a significant improvement in the growth and yield characteristics of maize and common beans (Tolessa and Friesen, 2001; Qadiri et al., 2023). In Cameroon, research has been conducted to assess the effects of applying mineral fertilizers in combination with organic fertilizers on the yield of common beans and maize in pure cultivation (Kaho et al., 2011; Dou et al., 2012; Shilpha et al., 2017; Kamtchoum et al., 2018). However, there are very few studies on the consequences of using mineral fertilizers in combination with organic fertilizers on intercrop yield.

The basic idea of this study was that the combined

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effect of the cropping season (comprising two seasons), mineral fertilization with NPK fertilizers, and organic fertilization with coffee parchment biochar and poultry manure would significantly improve the growth and yield of intercropped maize and beans, as well as the chemical properties of the soil, compared with the separate application of mineral and organic fertilizers. The aim of this study was to evaluate the interactive effect of season, mineral fertilizer, and organic manure on the agronomic performance of common beans and maize, the dynamics of chemical properties, and the economic profitability of maize-bean composite varieties in an intercropping system in an oxisol of the West Cameroon Highlands.

MATERIALS AND METHODS

Study site

Field experiments were conducted in Fosset village (Figure 1), located 7 km west of Foumbot in the Noun Valley, during the 2022 cropping season, with season 1 running from April to July and season 2 running from July to October. The site is situated on ferralitic soil over granite, at latitude 05°29′32.6″ North, longitude 10°42′28.5″ East, and 1052 m above sea level. The site's climate is high-altitude equatorial with mountain facies, marked by two seasons: a rainy season from mid-March to mid-November and a dry season from mid-November to mid-March, with an average temperature of 21°C and annual rainfall of 1950 mm. During the experiments, total rainfall was 790 and 779 mm for maize, and 358 and 770 mm for beans in seasons 1 and 2, respectively. The council of Foumbot, unlike the other councils in the Department of Noun, is situated on a vast plain. Its average altitude ranges from 1,100 to 1,300 m above sea level. The relief is gentle over much of the area, with isolated knolls and residual hills of very low elevation. Foumbot's soils are primarily black tropical ferruginous soils with low leaching rates and high agronomic value. Black soils resulting from volcanic eruptions are found in the central and northern parts of the council; initially very rich and well-structured; they are becoming progressively poorer due to overexploitation. Hydromorphic soils are found in the lowlands; too waterlogged during the rainy season, they are suitable for dry-season crops, particularly market gardening. The remainder of the council consists of burnished or lateritic soils, which are shallow and acidified. The main boundary on the western side of the commune is marked by the River Noun, Foumbot's main water resource. Human activity in Foumbot is primarily focused on farming and livestock breeding, with production mainly for local consumption and the surplus sold on the market. The commune's territory is dominated by agricultural zones covered by annual, semi-perennial, and perennial crops.

Plant material

The study used the maize variety KASSAI (CHC201) and the bean variety GLP190. Both varieties are composites developed by the Institut de Recherche Agricole pour le Développement (IRAD) in Foumbot and released by the Ministry of Agriculture and Rural Development (MINADER) in Cameroon. The CHC201 variety is a white-grain genotype with a high ripening period of 90-110 days after sowing (DAS). It was selected for its adaptation to high-altitude soils and its high yield potential, ranging from 4 to 7 t/ha.

The GLP190 bean composite is a dwarf variety with large red seeds speckled with white. It has an average ripening period of 70-90 DAS. It is preferred for its high yield potential of 2 to 4 t/ha and its compatibility with maize. Soil samples were collected at a depth of 0-20 cm prior to seedbed preparation at two different sites (Fossets 1 and 2) used during both growing seasons.

METHODOLOGY

Experimental set-up and combinations

Field experiments were carried out over two seasons and at two sites in the village of Fosset. Soils were ploughed to a depth of 20 cm using a hand hoe. Coffee parchment biochar and laying poultry manure were weighed and spread evenly over the plots at the required rates. This study used a biochar application rate recommended by the manufacturer Net Zéro, located in Nkongsamba, Cameroon. The rate of laying poultry manure was within the levels (2.5 - 20 t/ha) recommended and adopted by Boukong (2017). The doses of NPK mineral fertilizers, which were not commonly used by producers, were applied within the limits of 300 and 600 kg/ha, and urea was applied at 100 kg/ha, based on surveys of producers in Foumbot. The cultivation system used was intra-row intercropping (Figure 2).

A factorial experiment was conducted using a subdivided plot design with six replications. The factors were season as the main factor, with 2 modalities (season 1 and season 2); NPK mineral fertilizer as a secondary factor, with 5 modalities (0, 300, 600 kg/ha) of 20-10-10, (300 and 600 kg/ha) of 14-23-14, and organic fertilizer as a tertiary factor, with 4 modalities (0, 2.5 t/ha of biochar, 2.5 and 5.0 t/ha of laying poultry manure). When 300 kg/ha of NPK were applied, 200 kg were allocated to maize and 100 kg to common beans. When 600 kg/ha of NPK were applied, 500 kg were allocated to maize and 100 kg to common beans.

The experimental units consisted of 3.6 × 2 m plots with a 2 m path between blocks and a 1 m path between experimental units. Maize or common bean seeds were sown in each seedbed. The CHC201 maize variety was sown at a spacing of 90 cm between rows and 20 cm within a row. Consequently, there were four maize rows and eight bean rows in an experimental unit, with 40 maize plants and 80 bean plants per plot, equivalent to 55,555 maize plants and 222,222 common bean plants per hectare. Complete inorganic fertilizers (20-10-10 + 6 SO_3 and 14-23-14 + 5 S + 1 B_2O_3) were applied at 14 DAS. Egg-laying poultry manure and coffee parchment biochar were applied to the entire experimental unit according to the modalities mentioned above and raked in 7 days before sowing. A quantity of urea equivalent to 100 kg/ha was applied at panicle initiation to maize for all treatment combinations. Other cultural practices were followed as recommended for both crops. Pest and disease control was achieved by spraying plants with insecticides: 'K-OPTIMAL' (Lambda-Cyhalothrin 15 g/l + Acetamiprid 20 g/l) to protect plants from biting and flying insects, and 'Legionnaire Plus' (Emamectin Benzoate 100 g/kg) to control armyworm. A fungicide, NORDOX 75WG (copper oxide), was used to protect the beans from rust.

Data collection

Plant growth characteristics, including crown diameter, plant height, and leaf area index for maize, and crown diameter and plant height for common beans, were measured every two weeks until 56 days, when they no longer increased. Yield characteristics such as ear diameter and length, 1000-seed weight, and dry grain yield at 15% moisture content were determined for maize. For beans, the average number of pods per plant, thousand-seed weight, and dry grain yield at 10% moisture content were measured. In each experimental unit, plants in the inner rows were identified and

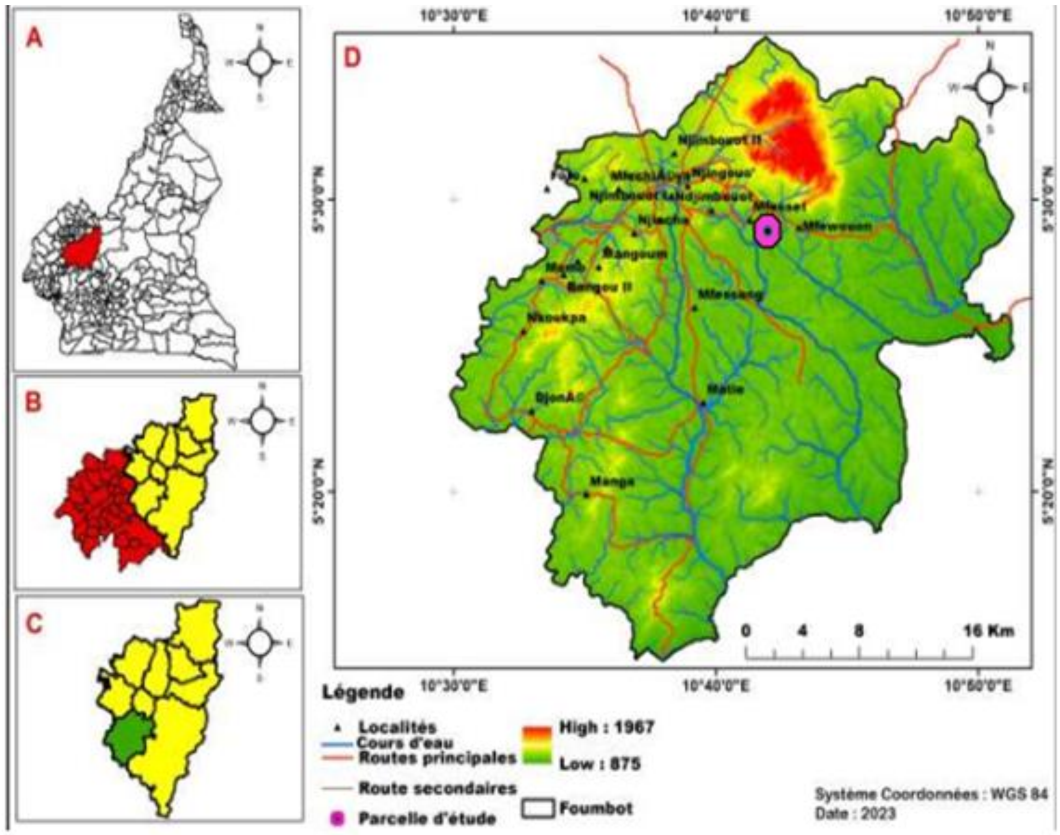

Figure 1. Location map of the study area. (A) Location of the West Region in Cameroon; (B) Location of the Noun Division (Yellow colour) in the West Region; (C) Location of Foumbot Sub-division (green colour) in the Noun division; (D) Geographical position of the studied site in Foumbot Sub-division.

Figure 2. Experimental plot showing intercropped maize-beams.

marked with stakes for consistent measurements. For common beans, plants in the innermost 2 rows, corresponding to 6 bunches (12 plants), were randomly selected for measurement. For maize, 7 plants from the inner 2 rows were marked and used for the study.

Soil sampling and laboratory analysis

Composite samples of disturbed soils collected per block were mixed, air-dried, and sieved using a 2 mm sieve, then analyzed using standard methods to determine particle size fraction, organic matter (OM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), cation exchange capacity (CEC), and pH. The coffee parchment biochar used in the experiment was obtained from the Nkongsamba-based company 'Net Zero,' and the laying poultry manure was sourced from the Dschang market. Both materials were air-dried and sieved using a 2 mm sieve. Analyses were conducted to measure organic carbon (OC), N, nitric nitrogen, ammoniacal nitrogen, available and total P, K, Ca, Mg, Na, CEC, pH, moisture content, and ash content, in accordance with the official international methods of the International Association of Analytical Chemistry (AOAC, 2003).

Statistical data analysis

GenStat Release version 9.2 (Genstat, 2008) was used for the analysis of variance (ANOVA), while graphs were generated using R software (R Development Core Team, 2023). Since only one variety of maize and one variety of beans were used as intercrops, the factors included cropping seasons, mineral fertilizers, and organic manures. A 5% threshold Duncan's HSD test was employed to compare the means of the combinations.

Economic analyses

Individual treatment profitability was calculated on the basis of the Benefit-to-cost ratio (FAO, 2005). Any BCR > 1 indicates that the fertilizer was profitable. According to the same reference, a BCR = 2 indicates a 100% return on investment but over a short period, and any BCR > 2 secures the farmer's profitability over a long period (Yannick et al., 2013; FAO, 2005). BCR = value of yield increase / cost of fertilizer. Net profitability is obtained as follows: net profitability = value of yield increase - cost of fertilizer. A positive net return (NR) implies that fertilizer use has been profitable.

RESULTS

Soil characteristics

The soil at Fosset 1 is clayey, while at Fosset 2 it is silty-clayey. Soils on both sites are yellowish-red on the surface (5 YR 4/6) when wet, with a gentle 4% slope. Water pH values are 4.7 for Fosset 1 and 5.0 for Fosset 2. Total nitrogen is average at the study sites, with values of 0.18% for Fosset 1 and 0.15% for Fosset 2. Available phosphorus content is low at both sites, with values of 8.92 mg/kg for Fosset 1 and 10.73 mg/kg for Fosset 2. Exchangeable potassium is also low, with values of 0.25 cmol/kg for Fosset 1 and 0.14 cmol/kg for Fosset 2. Organic carbon content is average, at 2.34% for Fosset 1 and 2.37% for Fosset 2. Cation exchange capacity (CEC) is moderate for both sites, with values of 21.33 cmol/kg for Fosset 1 and 14.00 cmol/kg for Fosset 2. The clayey and silty-clayey soils, combined with average levels of organic matter, should support good surface water retention.

Biochar and manure were alkaline and moderately alkaline, with water pH values of 10.0 and 7.7, respectively. Biochar had higher concentrations of OC, K, Na, P, carbon-to-nitrogen ratio (C/N), and CEC, with values of 42.48%, 5.08 cmol/kg, 0.38 cmol/kg, 0.09%, and 764 cmol/kg, respectively, compared to hen droppings, which had values of 34.88%, 1.41 cmol/kg, 0.20 cmol/kg, 0.08%, and 737 cmol/kg, respectively. However, laying poultry manure had higher concentrations of N, nitric and ammoniacal nitrogen, P, Ca, and Mg, with values of 4.02, 0.93, 0.81, 0.72, and 0.38%, respectively, compared to biochar, which had respective values of 2.07, 0.85, 0.64, 0.26, 0.52, and 0.24%.

Effect of season, organic and mineral fertilizers on maize and bean growth

The effect of season (S), mineral fertilizer (EM), and organic fertilizer (EO), all combined at type and rate, on maize and bean crown diameter, height, and maize leaf area index (LAI) at 42 and 56 DAS is presented in Table 1. The interaction of S x EM x EO significantly influenced the growth of both crops at 42 and 56 DAS. At 56 DAS, season 2 (S2), with a mean rainfall of 770 mm, combined with NPK 14-23-14+5S+1B2O3 at 600 kg/ha (NPK14_600) and laying poultry manure at 5 t/ha (FPP_5.0), significantly (P = 0.000) increased bean neck diameter, resulting in a higher diameter of 10.59 mm compared to the control (5.44 mm). This was also significantly greater than the interactions of S2 x NPK14_600 (7.16 mm), S2 x FPP_5.0 (7.34 mm), NPK14_600 x FPP_5.0 (8.67 mm), and the individual factors S2 (6.32 mm), NPK14_600 (6.71 mm), and FPP_5.0 (6.92 mm) (Table 1).

Conversely, the S x EM x EO interaction was not significant for maize crown diameter, height, leaf area index, or crown height and diameter at 42 DAS. However, when considering the interactions of EO and EM (EO x EM), S and EO (S x EO), and S and EM (S x EM), significant effects (P = 0.05) were observed for growth variables compared to the individual factors of EM, EO, and S (Table 1). Specifically, the combination of FPP_5.0 (EO) and NPK 20-10-10 + 6 SO3 at 300 kg/ha (NPK20_300) significantly increased (P = 0.044) maize collar diameter at 42 DAS, with the highest value of 23.81 mm obtained from NPK20_300 x FPP_5.0 compared to the control (18.60 mm) and individual factors NPK20_300 (21.59 mm) and FPP_5.0 (22.18 mm).

The interaction of NPK14_600 x FPP_5.0 significantly (P < 0.001) increased bean height at 56 DAS, with the highest value of 66.50 cm compared to the control (52.60 cm) and the single effects of NPK14_600 (61.60 cm) and

Table 1. Effect of seasons, mineral fertilizers and organic fertilizers on height, collar diameter of maize and bean plants and Leaf Area Index of maize at 42 and 56 days after sowing (DAS).

Season (S)	Mineral fertilizer (kg/ha)	Organic fertilizer (t/ha)	Corn						Beans			
			Neck diameter (mm)		Height (cm)		Leaf area index		Neck diameter (mm)		Height (cm)	
			42DAS	56DAS	42DAS	56DAS	42DAS	56DAS	42DAS	56DAS	42DAS	56DAS
					108.9		4.7		6.2			
	NPK_0	EO_0	18.6	20.5	99.4	165.5	3.2	4.5	6.88	6.01	56.5	52.6
	NPK_0	Bio_2.5	25.4	24.1	97.8	177.3	4.9	5.7	5.78	5.94	59.8	54.9
	NPK_0	FPP_2.5	22.9	23.2	102.9	184.9	4.2	5.6	5.73	6.46	59.4	58.2
	NPK_0	FPP_5.0	22.2	22.5	120.1	201.1	3.7	5.1	5.70	6.23	60.5	63.4
	NPK20_300	EO_0	21.6	24.1	97.2	186.8	4.1	5.1	5.80	6.06	54.1	55.3
	NPK20_300	Bio_2.5	22.6	24.6	96.7	180.2	4.3	5.1	5.68	6.31	55.4	54.2
	NPK20_300	FPP_2.5	25.2	24.2	110.7	202.2	4.8	5.8	5.79	6.40	61.9	63.7
	NPK20_300	FPP_5.0	23.8	27.7	120.6	218.2	5.2	5.9	6.24	6.44	62.8	62.8
	NPK20_600	EO_0	24.3	25.7	104.9	199.6	4.2	5.8	6.92	6.23	60.7	59.4
S1	NPK20_600	Bio_2.5	24.7	24.2	102.9	185.4	4.7	5.8	6.11	7.24	60.3	58.4
	NPK20_600	FPP_2.5	27.6	26.6	115.8	213.0	5.2	6.0	6.35	6.14	62.5	61.1
	NPK20_600	FPP_5.0	26.5	27.3	123.2	224.6	5.1	6.3	5.94	6.48	64.3	63.6
	NPK14_300	EO_0	26.1	23.5	110.5	198.2	5.2	8.3	6.40	5.93	60.4	57.1
	NPK14_300	Bio_2.5	25.0	23.9	103.6	188.2	4.6	5.4	5.50	6.06	57.9	59.1
	NPK14_300	FPP_2.5	25.0	27.9	117.9	203.3	4.8	5.7	6.16	6.68	58.8	60.9
	NPK14_300	FPP_5.0	27.0	26.1	110.9	200.8	4.7	5.5	6.18	6.66	62.1	59.8
	NPK14_600	EO_0	26.4	24.4	115.6	201.4	5.0	5.7	6.98	6.36	55.7	61.6
	NPK14_600	Bio_2.5	26.8	25.5	108.8	203.9	5.0	6.1	5.64	5.99	58.6	59.2
	NPK14_600	FPP_2.5	25.2	25.1	122.6	219.2	5.1	6.0	6.88	6.00	59.9	63.8
	NPK14_600	FPP_5.0	26.5	26.5	91.2	214.0	4.8	5.7	6.75	6.75	57.9	66.5
							2.4		5.7	6.32		
	NPK_0	EO_0	18.6	20.5	54.1	165.5	3.3	4.5	5.01	5.44	56.5	52.6
	NPK_0	Bio_2.5	17.8	17.7	66.8	140.5	2.4	3.7	5.71	5.84	54.3	55.3
	NPK_0	FPP_2.5	18.6	17.5	78.3	165.5	2.5	4.3	5.90	5.77	59.4	58.9
	NPK_0	FPP_5.0	22.2	22.5	66.8	201.1	3.7	3.9	5.93	7.34	55.3	63.4
	NPK20_300	EO_0	21.6	21.9	71.6	178.1	1.9	5.2	5.10	5.69	50.0	53.0
S2	NPK20_300	Bio_2.5	18.3	20.1	84.7	170.2	2.4	4.2	5.63	6.17	54.6	55.6
	NPK20_300	FPP_2.5	19.9	21.1	67.9	190.9	2.8	5.1	5.89	6.49	64.0	66.4
	NPK20_300	FPP_5.0	23.8	22.5	82.8	192.4	2.9	5.4	6.36	6.80	60.0	65.1
	NPK20_600	EO_0	17.5	22.4	62.5	183.1	2.1	5.2	5.70	5.82	54.5	60.0
	NPK20_600	Bio_2.5	15.1	20.9	61.2	179.1	2.4	4.8	4.89	6.26	53.6	60.6
	NPK20_600	FPP_2.5	17.7	20.9	85.3	194.5	2.7	5.3	5.49	6.00	53.6	62.8

Table 1. Contd.

NPK20_600	FPP_5.0	19.6	22.6	68.4	207.5	3.2	5.6	6.56	6.51	57.9	64.3
NPK14_300	EO_0	18.6	21.1	63.4	173.3	2.4	4.7	6.13	5.79	56.3	56.2
NPK14_300	Bio_2.5	19.8	20.7	82.2	178.2	2.9	4.8	6.14	5.89	57.8	61.7
NPK14_300	FPP_2.5	18.0	21.4	72.1	192.1	2.4	5.1	5.64	6.61	57.6	62.7
NPK14_300	FPP_5.0	17.1	22.5	71.6	183.6	2.4	5.0	5.31	6.61	58.4	63.2
NPK14_600	EO_0	17.5	24.4	59.3	201.4	2.2	5.7	5.21	7.16	53.9	61.6
NPK14_600	Bio_2.5	19.0	22.2	63.5	194.6	2.4	5.2	5.66	5.64	52.9	60.8
NPK14_600	FPP_2.5	17.3	20.4	65.1	200.4	2.3	5.4	5.89	5.92	60.1	63.3
NPK14_600	FPP_5.0	16.3	23.9	79.8	204.6	2.1	5.7	5.16	10.59	51.8	66.5
S	Duncan 0.05	0.000	0.130	0.004	0.196	0.007	0.161	0.009	0.965	0.279	0.219
EM		0.240	0.000	0.024	0.000	0.246	0.003	0.72	0.006	0.512	0.000
S x EM		0.204	0.085	0.021	0.505	0.417	0.442	0.13	0.006	0.39	0.988
EO		0.066	0.000	0.000	0.000	0.038	0.236	0.364	0.000	0.011	0.000
S x EO		0.434	0.252	0.038	0.775	0.973	0.615	0.107	0.000	0.692	0.734
EM x EO		0.044	0.081	0.143	0.052	0.262	0.078	0.846	0.000	0.284	0.001
S x EM x EO		0.565	0.790	0.266	0.847	0.838	0.222	0.471	0.000	0.971	0.826

NPK20_300= complete fertilizer NPK 20-10-10 applied at 300 kg/ha, NPK20_600= complete fertilizer NPK 20-10-10 applied at 600 kg/ha, NPK14_300= complete fertilizer NPK 14-23-14 applied at 300 kg/ha, NPK14_600= complete fertilizer NPK 14-23-14 applied at 600 kg/ha, Bio_2,5= Biochar applied at 2.5 t/ha, FPP_2,5= laying hen droppings applied at 2.5 t/ha, FPP_5,0= laying hen droppings applied at 5 t/ha.

FPP_5.0 (63.40 cm). Maize height at 42 DAS was significantly increased (P = 0.021 and P = 0.038) by the interactions of S x EM and S x EO, with the highest values of 115.60 and 120.10 cm obtained from S1 x NPK14_600 and S1 x FPP_5.0, respectively, compared to the control (99.40 and 98.90 cm), and the single effects of S1 (108.90 cm), NPK14_600 (91.20 cm), and FPP_5.0 (97.00 cm) (Table 1).

The double interactions of EM x EO, S x EO, and S x EM were not significant for crown diameter at 56 DAS, maize height and LAI at 42 and 56 DAS, crown diameter, and bean height at 42 and 56 DAS. Season, studied as an individual factor, significantly increased (P = 0.01) maize height and bean collar diameter at 42 DAS, with the highest values of 108.70 cm and 6.17 mm obtained in season 1 compared to season 2 (70.4 cm and 5.67 mm). EO, when studied as an individual factor, significantly (P = 0.01) increased bean height at 42 DAS, with the highest value of 59.4 cm obtained with FPP_2.5 compared to the control (56.5 cm). EM and EO, studied as individual factors, significantly increased (P = 0.00) maize neck diameter at 56 DAS, with the highest values of 24.4 and 24.2 mm obtained with NPK14_600 and FPP_5.0, compared to the controls (20.5 and 22.5 mm). Similarly, EM and EO as individual factors significantly (P = 0.00) increased maize height at 56 DAS, with the highest values of 201.4 and 201.1 cm obtained with NPK14_600 and FPP_5.0, compared to the controls (165.5 and 178.4 cm). S and EO, as individual factors, significantly increased (P = 0.01 and 0.03) maize LAI at 42 DAS, with the highest values of 4.69 and 3.72 obtained in season 1 and with FPP_5.0, respectively, compared to season 2 (2.42) and the control (3.25). EM, studied as an individual factor, significantly (P = 0.00) increased maize LAI at 56 DAS, with the highest value of 5.7 obtained with NPK14_600 compared to the control (4.5) (Table 1).

Effect of season, organic and mineral fertilizers on maize and bean yield parameters

Dry grain yield (Rdtm), thousand-seed weight

Table 2. Effect of seasons, mineral fertilizers and organic fertilizers on cumulative maize and bean yield, 15% dry grain yield, 1000-seed weight, cob length and cob diameter for maize, and 10% dry grain yield, 1000-seed weight and average number of pods per plant for common bean.

Season (S)	EM (kg/ha)	EO (t/ha)	Corn					Beans		
			Rdttot (kg/ha)	Rdtm (kg/ha)	Pmgm (g)	De (mm)	Le (cm)	Rdth (kg/ha)	Pmgh (g)	Ngp
S1					663.7					
	NPK_0	EO_0	2840	2338	431.8	46.8	13.2	964	387.5	8
	NPK_0	Bio_2.5	4617	3548	670.8	49.6	15.2	1096	367.1	6
	NPK_0	FPP_2.5	5583	4466	494.5	51.9	15.7	1117	401.2	8
	NPK_0	FPP_5.0	9264	7853	448.3	52.2	16.2	1247	401.1	7
	NPK20_300	EO_0	8593	7347	661.1	51.9	16.7	1246	374.9	7
	NPK20_300	Bio_2.5	9074	7816	751.3	48.9	16.6	1258	388.6	7
	NPK20_300	FPP_2.5	9350	8093	721.7	52.7	16.6	1256	419.7	8
	NPK20_300	FPP_5.0	1064	9254	732.9	52.3	17.6	1387	389.9	6
	NPK20_600	EO_0	8478	7271	676.8	52.8	15.9	1207	421.7	7
	NPK20_600	Bio_2.5	9500	8072	694.4	50.2	17.8	1429	406.2	8
	NPK20_600	FPP_2.5	10218	8762	714.7	53.5	17.8	1456	375.6	7
	NPK20_600	FPP_5.0	11020	9350	708.4	53.3	18.4	1670	397.7	7
	NPK14_300	EO_0	8833	7574	728.7	49.9	16.6	1259	368.8	7
	NPK14_300	Bio_2.5	9157	7839	713.6	50.9	16.2	1317	388.9	7
	NPK14_300	FPP_2.5	9558	8137	723.4	50.9	18.1	1421	398.3	7
	NPK14_300	FPP_5.0	10054	8588	734.6	51.2	17.2	1465	367.4	7
	NPK14_600	EO_0	9801	8445	726.1	51.2	18.7	1423	380.7	6
	NPK14_600	Bio_2.5	9685	8119	761.9	49.8	16.4	1565	404.6	8
	NPK14_600	FPP_2.5	9801	8369	713.8	51.3	17.2	1627	370.3	7
	NPK14_600	FPP_5.0	10868	9251	711.4	54.4	18.2	1678	407.3	7
S2										
	NPK_0	EO_0	2642	2080	494.1	46.8	13.2	964	389.2	6
	NPK_0	Bio_2.5	4073	3170	511.9	41.9	12.4	904	511.9	6
	NPK_0	FPP_2.5	4770	3772	512.2	44.6	15.7	997	512.2	5
	NPK_0	FPP_5.0	9264	4338	549.9	46.6	15.5	1216	549.9	9
	NPK20_300	EO_0	7413	6442	547.7	46.5	15.2	971	547.7	7
	NPK20_300	Bio_2.5	7927	6944	534.0	46.2	16.0	984	534.0	6
	NPK20_300	FPP_2.5	8068	7007	536.7	46.4	15.2	1061	536.7	8
	NPK20_300	FPP_5.0	8716	7593	567.8	49.2	16.5	1123	567.8	7
	NPK20_600	EO_0	7477	6457	548.1	50.2	15.9	1020	548.1	7
	NPK20_600	Bio_2.5	8791	7610	543.2	47.1	16.6	1181	543.2	6
	NPK20_600	FPP_2.5	9520	8300	532.9	49.6	17.8	1221	532.9	9
	NPK20_600	FPP_5.0	9969	8595	515.2	48.8	16.7	1373	515.2	8

Table 2. Contd.

NPK14_300	EO_0	7861	6685	580.5	45.1	15.0	1176	580.5	8
NPK14_300	Bio_2.5	7963	6738	569.5	46.2	14.5	1225	569.5	7
NPK14_300	FPP_2.5	8407	7073	538.6	46.5	15.3	1333	538.6	6
NPK14_300	FPP_5.0	8819	7420	536.1	47.2	15.8	1399	536.1	8
NPK14_600	EO_0	9801	7980	584.0	48.2	15.8	14283	561.9	7
NPK14_600	Bio_2.5	9108	7985	536.2	47.4	16.3	1123	536.2	8
NPK14_600	FPP_2.5	9555	8331	556.8	48.8	16.7	1223	556.8	8
NPK14_600	FPP_5.0	10868	9251	570.8	48	16.8	1556	570.8	7
Saison (S)	Duncan 0.05	0.006	0.006	0.000	0.000	0.010	0.158	0.000	0.970
EM		0.000	0.000	0.000	0.000	0.000	0.008	0.132	0.650
S x EM		0.097	0.008	0.000	0.050	0.430	0.810	0.041	0.840
EO		0.000	0.000	0.464	0.000	0.000	0.000	0.839	0.320
S x EO		0.533	0.453	0.008	0.750	0.140	0.877	0.540	0.250
EM x EO		0.001	0.026	0.058	0.140	0.030	0.641	0.208	0.170
S x EM x EO		0.995	0.993	0.015	0.390	0.570	1.000	0.295	0.320

NPK20_300= complete fertilizer NPK 20-10-10 applied at 300 kg/ha, NPK20_600= complete fertilizer NPK 20-10-10 applied at 600 kg/ha, NPK14_300= complete fertilizer NPK 14-23-14 applied at 300 kg/ha, NPK14_600= complete fertilizer NPK 14-23-14 applied at 600 kg/ha, Bio_2,5= Biochar applied at 2.5 t/ha, FPP_2,5= laying hen droppings applied at 2.5 t/ha, FPP_5,0= laying hen droppings applied at 5 t/ha.

(Pmgm), ear diameter (De), ear length (Le) of maize, dry grain yield (Rdth), thousand-seed weight (Pmgh), and number of pods per plant (Ngp) of beans, total maize and bean yield (Rdttot), under the different combinations of season (S), mineral (EM), and organic (EO) manures are shown in Table 2. The interactive effect of S x EM x EO significantly influenced only one maize yield parameter. S1 with a mean rainfall of 790 mm, EM, NPK 14-23-14+5S+1B_2O_3 fertilizer with an application rate of 600 kg/ha (NPK14_600), and EO, that is biochar with an application rate of 2.5 t/ha (Bio_2.5) significantly (P = 0.015) increased Pmgm compared to double effects, individual factors and the control. The interaction S1 x NPK14_600 x Bio_2.5 gave the highest value (762 g) followed by the highest double effect (726 g); S1 x NPK14_600 (664 g) had the highest single effect when S was studied as a single factor. The lowest Pmgm value (432 g) was obtained for the control (Table 2). However, the interactive effect of S x EM x EO was not significant for other maize and bean yield parameters. Indeed, the interaction NPK14_600 x FPP_5.0 was significant (P = 0.026) and gave the highest value of Rdtm (9250 kg/ha) compared to the interaction S1 x NPK14_600 (8450 kg/ha), the individual factors NPK14_600 (8380 kg/ha), FPP_5.0 (7850 kg/ha), S1 (7370 kg/ha), and the control with the lowest value (2340 kg/ha) (Table 2). Bean thousand-seed weight was significantly (P = 0.015) increased by the S2 x NPK14_600 interaction with a value of 562 g higher than the main factors S2 (517 g), NPK14_600 (476 g), and the control (389 g) with the lowest value (Table 2).

The NPK14_600 x FPP_5.0 interaction was significant (P=0.001) and gave the highest value of Rdttot (10870 kg/ha) compared with the individual factors NPK14_600 (9170 kg/ha), FPP_5,0 (5840 kg/ha), S1 (7370 kg/ha), and the control with the lowest value (2840 kg/ha) (Figure 3a, b and c and Table 2). Corn cob length was significantly (P = 0.03) increased by the NPK20_300 x FPP_2.5 interaction with the value of 17.80 cm higher than the main factors NPK20_300 (15.90 cm), FPP_2.5 (15.70 cm), and the control (13.20 cm) had the lowest value. When S, EM and EO were studied as individual factors, maize ear diameter and bean dry grain yield were significantly increased compared with the control (Table 2). Corn ear diameter and bean dry grain yield at 10% moisture were significantly influenced by season, EM and EO. Ear diameter differed significantly (P=0.000) with the highest value in season 1 (51 mm) compared to season 2 (47 mm). Ear diameter also differed significantly when EM was applied as an individual factor, with the highest value (50.2 mm) obtained for the NPK20_600 treatment compared with the control (46.8 mm). The single effects of NPK14_600, NPK14_300 and NPK20_300 did not significantly influence ear diameter. The application of EO as a single factor significantly increased corn ear diameter, with the highest value (50.31 mm) obtained for the FPP_5.0 treatment compared with the control (47.86 mm) and Bio_2.5 (47.90 mm). Treatments FPP_5.0 and FPP_2.5 did not show statistically different values. Dry grain yield at 10% moisture content differed significantly (P = 0.008) with the higher value (1423 kg/ha) for the NPK14_600 treatment compared with the control (964 kg/ha). Treatments NPK20_600, NPK 14_300 and NPK 20_300 were not significantly different from NPK14_600. Dry grain yield at 10% moisture, when EO is taken as a single factor, differed significantly (P = 0.000) with a higher value (1411 kg/ha) for treatment FPP_5,0 compared to control (1063 kg/ha), FPP_2,5 (1271 kg/ha), Bio_2,5 (1208 kg/ha). No significant difference was observed with the number of pods per plant with all the factors studied (Table 2).

Effect of season, organic and mineral fertilizers on soil chemical properties

The effect of season, mineral fertilizer and organic fertilizer on soil chemical properties is shown in Table 3. The interactive effect of S x EM x EO significantly influenced soil chemical properties at 45 and 90 days before harvest. When the three factors (S, EM, EO) were considered together, interactions were significant for pH-water (pH-water 45) at 45 DAS, and available phosphorus content (Pass) at 90 DAS. Indeed, already at 45 DAS (Figure 3), the S1 x NPK20_600 x Bio_2.5 interaction significantly (P = 0.000) increased pH-water 45 with the highest value (5.4), compared to S1 (5.0), NPK20_600 (4.7) and Bio_2.5 (5.2) studied as individual factors (Figure 3d, e and f and Table 3); in double interaction S1 x NPK20_600 (5.1), S1 x Bio_2.5 (5.2), and NPK20_600 x Bio_2.5 (5.0); and to the control with the lowest value of 4.8 (Table 3). The interaction S1 x NPK14_600 x FPP_5.0 was significant (P=0.000) and gave the highest value of Pass (49.27 mg/kg) compared with S1 (25.14 mg/kg), NPK14_600 (17.26 mg/kg) and FPP_5.0 (21.37 mg/kg) studied as individual factors and in double interaction S1 x NPK14_600 (37.10 mg/kg), S1 x FPP_5,0 (32.19 mg/kg), and NPK14_600 x FPP_5,0 (41.95 mg/kg), and to the control which had the lowest value of FPP_5,0 (7.93 mg/kg) (Table 3). On the other hand, the interactive effect of S × EO, S x EM, and EM x EO was significant for pH-water 90 and MO. The S1 x FPP_2.5 interaction was significant (P = 0.000) and gave the highest value of pH-water 90 (5.6), which was identical to that of the S1 x FPP_5.0 double interaction when compared to the individual factors S1 (5.4), FPP_2.5 (5.5), and the control which had the lowest value (4.9). The S2 x NPK14_600 interaction significantly (P = 0.000) increased MO giving the highest value (5.13%), compared to the individual factors S2 (4.38%), NPK14_600 (5.09%), and the control with the lowest value (4.10%). Also, the NPK14_600 x FPP_2.5 interaction significantly (P = 0.000) increased MO with the highest value (5.66%), compared to the individual factors NPK14_600 (4.38%), FPP_2.5 (4.09%), and the control with the lowest value (3.30%).

Economic analysis of the different treatments

Table 4 presents an economic analysis of mineral and organic manure inputs to maize and bean crops, for the first and second cropping seasons in the year 2022; evaluated by Benefit-to-cost ration and NR. Apart from treatment combinations that received only urea, biochar applied at 2.5 t/ha (Bio_2.5), which showed BCR values < 1 in season 2, all other treatment combinations generally gave BCR values > 1. In both seasons (S1 and S2), treatment combinations consisting of the complete fertilizers NPK 20-10-10 + 6 SO_3 applied at dose 300 kg/ha (NPK20_300) and NPK 14-23-14 + 5S + $1B_2O_3$ applied at doses 300 (NPK14_300) , NPK 14-23-14 + 5S + $1B_2O_3$ applied at dose 300 +2.5 kg/ha (FPP_2,5); in season one (S1), treatment combinations consisting of the complete fertilizers NPK 20-10-10 + 6 SO_3 applied at dose 600 kg/ha (NPK20_600) and NPK 20-10-10 + 6 SO_3 applied at dose 300 kg/ha (NPK20_300) +2,5 t/ha (FPP_2,5) showed BCR values > 2. The highest BCR values of 3.26 and 3.18 were recorded in season 1, compared with 2.61 and 2.81 in season 2 for the treatment combinations NPK 20-10-10 + 6 SO_3 applied at a rate of 300 kg/ha (NPK20_300) and NPK 14-23-14 + 5S + $1B_2O_3$ applied at a rate of 300 kg/ha (NPK14_300). On the other hand, negative RN values were recorded for treatment combinations with BCR < 1, while the highest RN values were recorded for treatment combinations NPK14_300 and NPK20_300 with respective values of 1641 and 1605 US Dollar (USD) for season 1. Generally speaking, BCR and RN values were relatively higher in season 1 compared to season 2 and followed the same trend.

DISCUSSION

Soil characteristics as affected by the different treatments

The results showed that the soils at both sites (Fossets 1 and 2) had low concentrations of P, K, Ca, Mg and Na,

Table 3. Effect of seasons, mineral fertilizers and organic fertilizers on some soil chemical properties at 45 and 90 days after sowing (DAS).

Season (S)	Mineral fertilizer (kg/ha)	Organic fertilizer (t/ha)	Corn and beans			
			pH-H_2O 45 DAS	pH-H_2O 90 DAS	Available P 90 DAS	Organic matter 90 DAS
S1			5.0	5.4	25.14	
	NPK_0	EO_0	4.8	4.7	7.93	3.30
	NPK_0	Bio_2.5	5.2	5.5	19.63	4.46
	NPK_0	FPP_2.5	5.0	5.6	20.85	3.64
	NPK_0	FPP_5.0	5.1	5.6	32.19	4.45
	NPK20_300	EO_0	4.9	4.9	10.69	3.49
	NPK20_300	Bio_2.5	5.1	5.5	18.58	4.01
	NPK20_300	FPP_2.5	5.0	5.5	21.69	3.94
	NPK20_300	FPP_5.0	5.1	5.6	24.42	4.05
	NPK20_600	EO_0	4.9	4.8	14.43	3.68
	NPK20_600	Bio_2.5	5.4	5.5	24.65	4.22
	NPK20_600	FPP_2.5	5.1	5.5	28.62	4.37
	NPK20_600	FPP_5.0	5.1	5.6	31.59	4.63
	NPK14_300	EO_0	4.9	4.9	14.27	3.38
	NPK14_300	Bio_2.5	5.1	5.6	29.27	4.48
	NPK14_300	FPP_2.5	5.1	5.6	32.07	4.12
	NPK14_300	FPP_5.0	5.1	5.7	34.32	4.49
	NPK14_600	EO_0	5.0	4.9	37.10	5.09
	NPK14_600	Bio_2.5	5.1	5.5	36.02	5.59
	NPK14_600	FPP_2.5	5.1	5.6	45.86	5.66
	NPK14_600	FPP_5.0	5.0	5.7	49.27	5.36
S2						4.38
	NPK_0	EO_0	4.7	4.8	7.76	3.33
	NPK_0	Bio_2.5	4.9	5.4	20.98	4.34
	NPK_0	FPP_2.5	5.0	5.5	21.99	4.54
	NPK_0	FPP_5.0	5.0	5.4	23.66	4.77
	NPK20_300	EO_0	4.9	4.9	11.33	3.80
	NPK20_300	Bio_2.5	5.0	5.3	20.19	4.43
	NPK20_300	FPP_2.5	4.9	5.5	21.65	4.07
	NPK20_300	FPP_5.0	5.0	5.6	26.06	4.57
	NPK20_600	EO_0	4.6	4.9	9.36	3.83
	NPK20_600	Bio_2.5	4.6	5.3	21.36	3.53
	NPK20_600	FPP_2.5	5.0	5.3	25.79	3.84
	NPK20_600	FPP_5.0	5.0	5.2	27.84	4.47

Table 3. Contd.

NPK14_300	EO_0	4.9	5.1	13.98	3.56
NPK14_300	Bio_2.5	5.1	5.4	23.93	4.90
NPK14_300	FPP_2.5	4.9	5.5	25.70	4.68
NPK14_300	FPP_5.0	5.0	5.5	28.99	4.43
NPK14_600	EO_0	4.8	5.3	15.63	5.09
NPK14_600	Bio_2.5	4.9	5.2	32.48	5.64
NPK14_600	FPP_2.5	5.0	5.4	33.01	5.66
NPK14_600	FPP_5.0	5.1	5.4	34.62	5.78
Saison (S)	Duncan 0.05	0.024	0.497	0.075	0.154
EM		0.164	0.003	0.000	0.000
S x EM		0.14	0.24	0.000	0.014
EO		0.000	0.000	0.000	0.000
S x EO		0.003	0.000	0.005	0.666
EM x EO		0.051	0.134	0.000	0.000
S x EM x EO		0.000	0.533	0.000	0.100

NPK20_300= complete fertilizer NPK 20-10-10 applied at 300 kg/ha, NPK20_600= complete fertilizer NPK 20-10-10 applied at 600 kg/ha, NPK14_300= complete fertilizer NPK 14-23-14 applied at 300 kg/ha, NPK14_600= complete fertilizer NPK 14-23-14 applied at 600 kg/ha, Bio_2,5= Biochar applied at 2.5 t/ha, FPP_2,5= laying hen droppings applied at 2.5 t/ha, FPP_5,0= laying hen droppings applied at 5 t/ha.

and were acidic with average organic matter and total N contents. These conditions are typical of Oxisols in western Cameroon (Kenfack et al., 2023). The lack of available phosphorus in the soils of the study area may be due to the low pH of the soil, which causes P to be fixed by Fe and Al oxides and hydroxides. These resultsconfirm those of Yerima and Van Ranst, (2005). Total nitrogen and organic carbon levels are average in the soils of the study sites.

Influence of treatment on the agronomic pameters of maize and beans

The results of this study also showed that combinations of the factors growing season and mineral fertilizers had a significant influence on the growth and yield of maize and beans. This difference in growth and yield between seasons is probably due to weather conditions, particularly the amount of rainfall, its distribution over time, and its intensity. Rainfall was lowest in season 1 for beans (358 mm), spread over the months of May, June, and July, with amounts of 114, 189, and 55 mm respectively, compared with 770 mm in season 2, spread over the months of July, August, and September, with amounts of 217, 405, and 148 mm respectively. For maize, rainfall was highest in season 1 (790 mm), spread over the months of May, June, July, and August, with amounts of 114, 189, 338, and 149 mm respectively, compared with 779 mm in season 2, spread over the months of July, August, September, and October, with amounts of 217, 405, 157, and 0 mm respectively. Rainfall was unevenly distributed, with a value of 405 mm (instead of 175-235 mm) in the second month, which would have delayed maize growth and reduced yields. These results are consistent with those of Beernaert and Bitondo (1993) and Kenzong et al. (2022), who reported a significant reduction in yield with an increase in rainfall. For beans, the total amount of rainfall during the cycle (770 mm) had an impact on the beans at flowering, with rainfall of 405 mm in the month of flowering in season 2, resulting in a significant reduction in thousand-seed weight and a 15% reduction in yield between the two seasons. These results are consistent with the studies of Beernaert and Bitondo (1993), who reported the

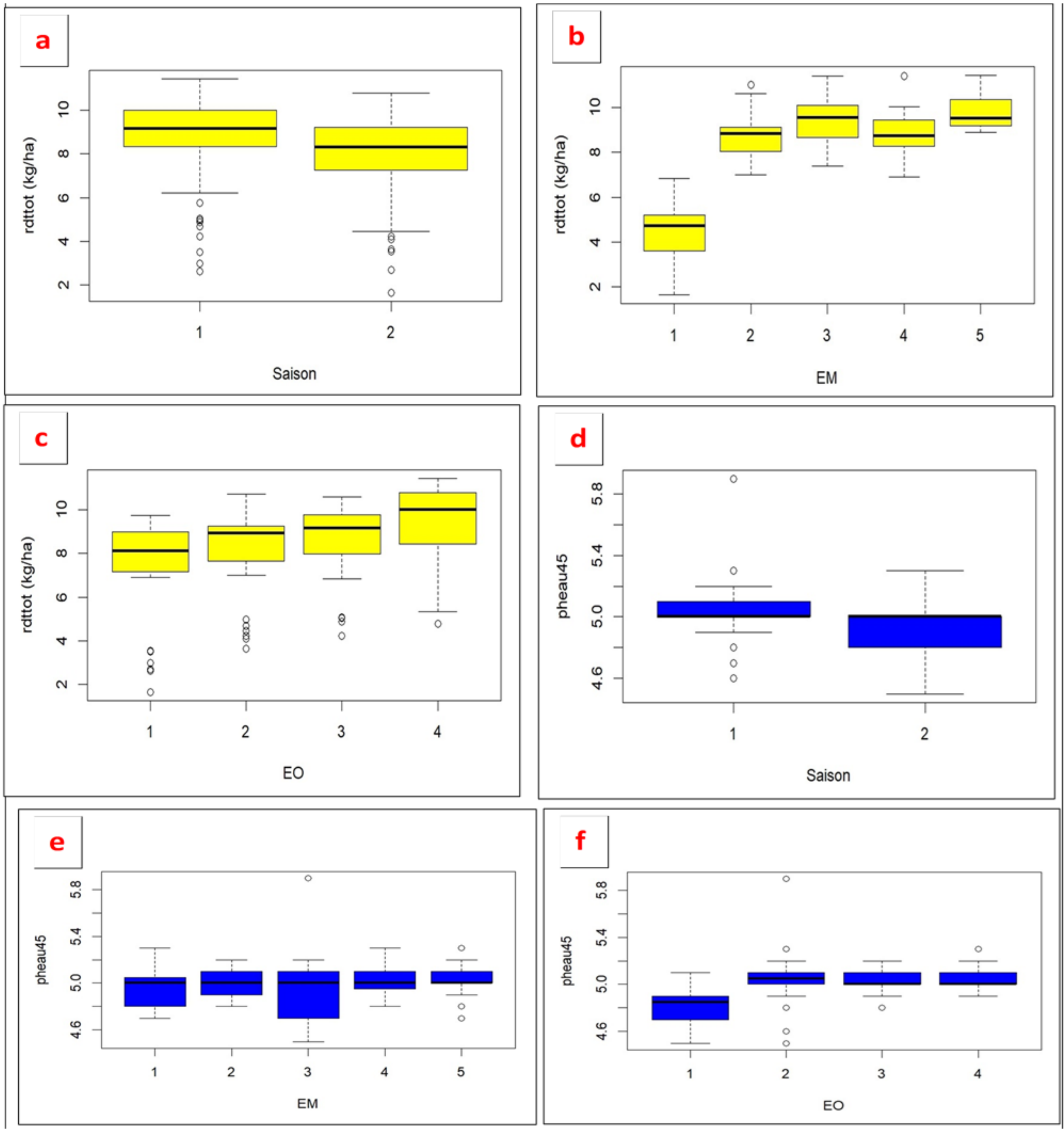

Figure 3. Cumulative box plots of total maize and bean yields, pH water at 45 DAS as a function of season, mineral fertilizer and organic fertilizer, Rdttot = Total yield.

effect of rainfall on bean production and a reduction in bean yield when large quantities of water were applied at the initial and maturity stages.

Chemical fertilizers are used in modern agriculture to correct known plant nutrient deficiencies and improve crop quality. NPK fertilizers play an essential role in the growth and development of most cereal crops, particularly corn. During the maize growth period, growth parameters such as plant height and stalk diameter are strongly influenced by the presence of NPK fertilizers. With regard to the doses of mineral fertilizer applied, plant height and stem diameter increased with the doses applied, while remaining low on the unfertilized plot. Maize vegetative growth was therefore significantly affected by increasing the level of NPK fertilizer applied. These results corroborate those highlighted by other researchers (Asghar et al., 2010; Nyembo et al., 2012; Kugbe et al., 2019). Asghar et al. (2010) reported that

Table 4. Economic implications of the different tratments.

Mineral fertilizer (kg/ha)	Organic fertilizer (kg/ha)	Urea (kg/ha)	Yield Maize S1 (kg/ha)	Yield Beans S1 (kg/ha)	Yield maize S2 (kg/ha)	Yield beans S2 (kg/ha)	BCR S1	BCR S2	NP S1 (USD)	NP S2 (USD)
T0	T0	0	2104	426	1862	462	0.00	0.00	0.00	0.00
NPK_0	EO_0	100	2464	574	2080	562	1.29	0.83	56.21	-32.57
NPK_0	Bio_2.5	100	3520	1096	3170	904	1.03	0.87	28.20	-120.92
NPK_0	FPP_2.5	100	4466	1117	3772	997	1.97	1.58	670.56	395.13
NPK_0	FPP_5.0	100	4890	1247	4338	1216	1.46	1.33	509.04	358.04
NPK20_300	EO_0	100	7347	1246	6442	971	3.26	2.61	1604.54	1120.68
NPK20_300	Bio_2.5	100	7816	1258	6944	984	1.77	1.43	1067.94	594.01
NPK20_300	FPP_2.5	100	8093	1256	7007	1061	2.23	1.84	1401.06	943.66
NPK20_300	FPP_5.0	100	9254	1387	7593	1123	1.93	1.50	1446.17	762.41
NPK20_600	EO_0	100	7271	1207	6457	1020	2.08	1.75	1172.12	798.64
NPK20_600	Bio_2.5	100	8072	1429	7610	1181	1.52	1.34	929.83	595.38
NPK20_600	FPP_2.5	100	8762	1456	8300	1221	1.92	1.72	1406.05	1084.15
NPK20_600	FPP_5.0	100	9350	1670	8595	1373	1.71	1.47	1370.97	908.48
NPK14_300	EO_0	100	7574	1259	6685	1176	3.18	2.81	1640.51	1345.37
NPK14_300	Bio_2.5	100	7839	1317	6738	1225	1.76	1.51	1091.16	728.27
NPK14_300	FPP_2.5	100	8137	1421	7073	1333	2.30	2.01	1531.94	1183.88
NPK14_300	FPP_5.0	100	8588	1465	7420	1399	1.81	1.59	1295.37	938.90
NPK14_600	EO_0	100	7739	1424	7980	1188	2.22	2.12	1431.38	1304.91
NPK14_600	Bio_2.5	100	8119	1565	7985	1123	1.54	1.31	993.83	564.59
NPK14_600	FPP_2.5	100	8369	1627	8331	1223	1.86	1.64	1380.88	1015.67
NPK14_600	FPP_5.0	100	9553	1678	8949	1556	1.67	1.55	1355.58	1102.88

BCR= benefit-to-cost ratio; NP= net profit, S1=season 1, S2=season 2; USD= United States Dollar.

maize plant height increased linearly with increasing NPK application; with plants treated with fertilizer recording the maximum height (198.55 cm) and those not treated having the minimum height (143.60 cm). The common bean is a legume that can fix atmospheric nitrogen (N_2) in the soil in symbiosis with soil rhizobia. However, in addition to nitrogen, P and K are also required. In nutrient-poor soils, bean growth has been greatly enhanced by the application of moderate doses of chemical fertilizers (Arf et al., 2011; Nascente et al., 2012). In general, the application of NPK fertilizer increased common bean growth compared with the control. The difference between NPK14_100 and NPK20_100 was not significant. This result is in agreement with those obtained for the same crop (Hussein et al., 2016). Hussein et al. (2016) reported that bean plant height was significantly affected by all treatments compared with the control. NPK recorded the highest value, at 23.7 cm, while the control value was 19.6 cm. On the other hand, NPK fertilizers help increase grain yield when applied at the right time and rate, with favorable soil pH. However, excessive or inadequate levels can reduce yield under current conditions. The use of chemical fertilizers increases crop yields when the acidity of the environment is favorable (pH 5.5 - 6.5), as the elements they contain are readily available to crops, unlike organic fertilizers. According to Asghar et al. (2010), mineral fertilizers play an important role in increasing maize yields, contributing 40-45%. Indeed, Kolawole and Joyce (2009) reported that maize plants treated with an NPK fertilizer of 400kg/ha produced significantly higher kernel and 100-seed weight than unfertilized plants.

The application of NPK fertilizer increased common bean yield and yield components because chemical fertilizers are readily available to provide immediate nutrients to the plants when required. These results are consistent with those of Hussein et al. (2016), who reported that common bean productivity was affected by the application of NPK fertilizer (2030 kg/ha), whereas the control value was 1550 kg/ha. Poultry manure significantly improved soil chemical properties, likely due to its favorable C/N ratio (9), which promotes rapid mineralization and nutrient release compared to other amendments. The quality of an organic amendment is defined by its relative nutrient content (particularly nitrogen), lignin content, and C/N ratio (Kamtchoung et al., 2018). Khalil et al. (2005) noted that poultry manure contains no lignin, unlike crop residues, leading to relatively rapid decomposition and a high concentration of organic acids that enhance soil nitrogen uptake and availability, thereby improving cereal yields. These findings confirm the study by Law-Ogbomo and Remison (2009), who reported that the highest maize grain yield (5770 kg/ha) and 1000-grain weight were achieved with the application of 5 t/ha of poultry manure, indicating this as the optimal level for maize growth and yield in a rainforest Ultisol. In contrast, results from Fosset indicated that 5 t/ha yields (7853 kg/ha) were higher but less economically profitable than those from 2.5 t/ha (7231 kg/ha). For beans, our results do not align with those of Hussein et al. (2016), who found that pod production increased with poultry manure and was significantly different from the control. Our findings are consistent with those of He et al. (2021) and Pathy et al. (2020), who reported significant increases in maize grain yields with the use of biochar. The positive effect of biochar on maize yield can be attributed to its improvement of soil structure and microbial activity, its provision of minerals and organic carbon to the soil, and its enhancement of nutrient storage, transformation, and uptake (Phares et al., 2022).

Interactions between the season, mineral fertilization, and organic fertilization were found to be significant for soil chemical properties (Table 3). These influences stem from the fact that organic fertilizers not only provide nutrients directly to the soil and crops but also enhance soil biological activity through microorganisms and promote nutrient recycling (Safdar and Kor, 2014). The increase in pH (5.4) in biochar-amended soils is primarily due to the initial pH of the biochar, which was 10.0. This increase contributed to a reduction in aluminum saturation, aligning with the findings of Schulz and Glaser (2012), who demonstrated that biochar reduces bioavailable aluminum levels and the acidity of tropical soils. The significant change in soil pH under biochar positively impacted P availability; in tropical soils, P becomes blocked at pH levels below 6.0 and becomes available at pH levels between 6.0 and 8.0 (Zhang, 2010). Soil nutrient concentrations increased with poultry manure application due to the release of nutrients as the manure decomposed. Chicken droppings have been shown to increase OC, N, P, K, Ca, and Mg (Adekiya et al., 2019). This study's integrated data analysis revealed that, among different fertilization measures, the combination of organic fertilizer with chemical fertilizer and season had the most pronounced effect on improving soil nutrients. Although organic fertilizers do not immediately supply as many nutrients as chemical fertilizers, they need to be transformed and decomposed before plants can absorb them, which may influence changes in soil microbial communities.

Economic implications of the different treatments

To assess the financial incentives for a farmer to use fertilizer, it is necessary to calculate the BCR and/or NR before proposing the adoption of a fertilizer treatment. BCR values greater than 1, obtained with the majority of treatments, imply the profitability of the fertilizer applied, indicating that the investment is economically viable. Although a fertilizer use is considered 100% profitable with a BCR of 2 (FAO, 2005), the NPK20_300 and NPK14_300 treatment combinations presented BCR values greater than 2—specifically, 3.26 and 3.18 respectively for season 1, and 2.61 and 2.81 respectively for season 2. The results obtained for these treatment combinations guarantee a profitable return on investment for the farmer and would be attractive to small-scale farmers. These findings align with those of Nyembo et al. (2012), who reported a BCR of 3.0 with the application of NPK 10-20-10 at a rate of 300 kg/ha, combined with 200 kg/ha of urea at flowering. High fertilizer application rates were associated with lower BCRs due to the large quantities used (t/ha) and the underestimation of their effectiveness throughout the crop cycle. This aligns with the results of Roy et al. (2006) and Nyembo et al. (2012), who noted that high doses of chemical fertilizers significantly reduce profitability. The BCR values less than 1 obtained with combinations using only urea at 45 DAS and Bio_2.5 in season 2 indicate a negative return on fertilizer investment; consequently, these fertilizer treatments are unlikely to be adopted by farmers.

To identify a promising fertilizer treatment for smallholders, the NR, which is more comprehensible to farmers, was considered. The use of BCR alone can be misleading, as it is a poor tool for identifying the most profitable fertilizer rate and for determining the likelihood of adoption when BCR is greater than 2 (Kelly, 2006).

CONCLUSIONS

The aim of this study was to evaluate the interactive effects of season, mineral fertilizers, and organic manures on the agronomic performance of common beans and maize in an intercropping system. The principal results showed that the application of NPK fertilizers increased common bean growth compared to the control, with no significant difference between NPK14_100 and NPK20_100. Additionally, poultry manure and biochar significantly influenced maize and bean growth and yields in the intercropping system. Both mineral fertilizers and poultry manure, applied at both double and single rates, had a significantly positive interaction in season 2, improving crop agronomic features compared to the control. The combinations of growing seasons, mineral fertilizers, and organic fertilizers significantly influenced the growth and yield of maize and beans. The differences in growth and yield between seasons are attributed to weather conditions, particularly the amount, distribution, and intensity of rainfall. The interactions between seasons, mineral fertilizers, and organic fertilizers were significant for soils, likely due to their combined effects in enhancing soil biological activity and promoting nutrient recycling. The net returns associated with NPK14_300 and NPK20_300 treatments in both seasons (1641 and 1605 USD respectively in season 1, and 1345 and 1120 USD respectively in season 2) are relatively substantial and would be recommendable to smallholder farmers, given the low rate of fertilizer applications involved in these combinations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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