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RESEARCH NOTE

Effects of Different Tillage and Cropping Systems on the Productivity of Maize (*Zea mays* L.) and Soybean (*Glycine max* L.) in Nueva Ecija, Philippines

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Intercropping can improve agronomic nitrogen use efficiency (aNUE), land equivalent ratio (LER), and productivity compared to monocropping. A study conducted in Nueva Ecija examined five cropping systems: monocrop maize (M), monocrop soybean (S), maize-soybean intercropping (M+S), soybean with Rhizobium inoculant (SwR), and maize-soybean intercropping with Rhizobium inoculant (M+SwR). These systems were further evaluated under two tillage systems: conventional tillage (CT) and reduced tillage (RT). The study examined the response of different cropping and tillage systems on agronomic traits, yield performance, and economic profitability. The intercrop of maize (0.53) and soybean (1.18) resulted to higher aNUE of 1.71 compared to monocrop of the two commodities. In addition, net income of M+S in reduced tillage system was increased to PhP 177,787.00, with an average LER of 1.70. However, tillage systems did not significantly affect the agronomic or yield components of maize and soybean which can be attributed to less sensitivity to the type of tillage used. Meanwhile, plant height (213.70 cm) and grain yield (5.99 Mg ha^{-1}) of maize were higher in monocropping than in intercropping. Similarly, the harvest index of soybean was highest in monocropping at 0.33 among cropping systems. Although monocropping provided higher yields compared to maize-soybean intercropping, this yield advantage did not necessarily translate to economic benefits. The study highlights the economic, aNUE, and LER benefits of intercropping. However, realizing these benefits in agricultural practice will require advancements in technology and farmer training. Further research is recommended to explore these systems' effects on production in marginal or less fertile soils, focusing on the role of inoculation and cropping systems.

Keywords: conventional tillage, inoculation, intercropping, reduced tillage, monocropping

INTRODUCTION

Maize (*Zea mays* L.) is the second essential crop in the Philippines and plays a vital role in ensuring food security (Gerpacio 2003). It is cultivated by approximately 1.8 M Filipino farmers, many of whom depend on maize as their primary source of income. From October to December 2024, maize production in the Philippines reached approximately 1.93 MMT, reflecting a 0.6% decline from the 1.95 million metric tons recorded during the same period in 2023. The total harvested area for maize in this quarter is estimated at 597.94 thousand hectares, marking a 2.8% reduction from the 615.30 thousand hectares harvested in the previous year. Despite these declines, yield per hectare has improved by 2.2%, rising from 3.16 metric tons in 2023 to 3.23 metric tons in 2024 (PSA 2025).

Among maize varieties, white lagkitan, also known as waxy or glutinous maize, is a commonly grown type of white maize in the Philippines. This open-pollinated variety mature at 70 to 75 days after seeding (DAS) and has an average plant height of 224 cm. It is characterized by soft kernels that range in size from small to large, excellent eating quality, and moderate resistance to downy mildew. Its yield varies from 6.5 to 8.5 Mg ha^{-1} (Aday et al. 2000). However, maize farmers face challenges such as fluctuating market prices, climate variability, and research to enhance productivity and sustainability (CIMMYT 2018).

Soybean (*Glycine max* L.) is another essential crop, serving as a rich source of plant-based protein for a balanced diet. One notable soybean variety developed by Central Luzon State University is CLSoy-1. This non-photoperiod-sensitive variety mature at 93 DAS. Also, CLSoy-1 exhibits uniform maturity, non-lodging characteristics, and moderate resistance to shattering, bacterial pustule, and rust. It has a yield potential of up to 2.18 Mg ha^{-1} (NSIC 2015).

Intercropping, the practice of cultivating two or more crops on the same land, is demonstrated superior outcomes compared to monocropping. Studies show intercropping cereals like maize with legumes such as soybean can provide a yield advantage ranging from 25 to 96%, depending on fertilization and crop combinations (Bechem et al. 2018). This practice enhances resource efficiency by improving the utilization of sunlight, water, and nutrients (Xu et al. 2020). Additionally, intercropping increases land-use efficiency (Zhang and Li 2003), generates higher gross and net incomes (Pradhan et al. 2016), supports soil health by increasing soil fertility, texture, and organic matter (Pariyar et al. 2019), and sustainable environmental footprint (Fan et al. 2020). The maize-soybean strip intercropping system contributes to household food security by providing diverse and nutritious food sources (Iqbal et al. 2018).

Despites its benefits, cropping systems also presents challenges, particularly in the face of climate change. The production of maize in the Philippines is very limited due to low yield, limited irrigation, high costs of inputs such as seeds, fertilizer, and labor (Salazar et al. 2021), soil erosion and degradation (Syngenta News 2022). Monocropping system often require higher chemical inputs and fuel consumption, contributing to environmental degradation (Jensen et al. 2020). Meanwhile, intercropping demands more complex management techniques compared to monocropping, as it requires the coordination of multiple crops with differing growth habits, planting arrangements, spacing, nutrient requirements, and harvest schedules (Bedoussac et al. 2015; Himanen et al. 2016; Huss et al. 2022). To address these issues, identifying crops that are complementary and with familiar cultural management can help identify suitable intercropping system in the locality that can contribute to higher productivity of farmers. In this regard, this study was conducted to evaluate the effects of different cropping and tillage systems on the productivity of maize and soybean under the agroecological conditions of Nueva Ecija. Specifically, it aims to determine the most effective system in terms of crop yield, land equivalent ratio (LER), agronomic nitrogen use efficiency (aNUE), and net income. The study also tests the hypothesis that intercropping enhances productivity, improves aNUE, and increases net income compared to monocropping.

MATERIALS AND METHODS

Experimental site

The research study was conducted in Licab, Nueva Ecija, Philippines, from February to June 2023. The municipal center of Licab is located approximately between 15°32' North latitude and 120°45' East longitude. The area has an average annual temperature of 28.88°C (83.98°F), which is 1.66% above the national average in the Philippines. It receives an average annual rainfall of 129.63 mm (https://weatherandclimate.com). According to the Modified Coronas Classification, Licab falls under a Type I climate, characterized by a distinct dry season from November to April and a wet season from May to October.

Soil sampling and analysis

Soil samples were collected from a depth of 30 cm before the study began. The collected samples were air-dried, securely packed, and analyzed by the Soil Science Division of the University of the Philippines Los Baños (UPLB), Laguna. Analyses included soil pH, organic matter (OM), total nitrogen (N), available phosphorus (P), potassium (K), cation exchange capacity (CEC), and soil textural classification. Final soil sampling was done after all the data were gathered, and the experiment was harvested. The Bureau of Soils and Water Management (BSWM) determined the soil pH, OM and nitrogen content from the soil samples submitted.

Land preparation

The experimental area was prepared using both conventional and reduced tillage systems. Under conventional tillage, plots were plowed and harrowed three times, whereas in reduced tillage, they were plowed and harrowed once.

Experimental design and layout

The field was laid out following a split-plot arrangement within a Randomized Complete Block Design (RCBD) with three replications. The main plot factor was the tillage system, consisting of two levels: reduce tillage (RT) and conventional tillage (CT) (Table 1). The sub-plot factor was the cropping system, classified into monocropping and intercropping. Conventional tillage for monocrop maize and monocrop soybean served as the control. Each of the three blocks was subdivided into 10 plots, each measuring 5.25 m x 5 m, with a planting distance of 75 cm x 25 cm between rows for both monocrop maize and monocrop soybean. Figure 1 illustrates the methods used for monocropped maize, monocropped soybean, and maize-soybean intercropping.

Field operations and crop management

Soybean seeds were planted first, followed by maize two weeks later, using the straight-line method with a spacing of 75 cm x 25 cm. A total of 140 hills were planted in monocrop plots and 280 seeds in intercrop plots per 26.25 m^2 area. In the intercropping system, soybean was planted in between maize rows in a 1:1 ratio.

The recommendation fertilizer application rates were 120-60-40 kg of NPK ha^{-1} for maize and 20-40-20 kg of NPK ha^{-1} for soybean. In the intercropping system, 120-60-40 kg of NPK ha^{-1} was applied between the maize and soybean rows.

Hand weeding was conducted during the 3rd and 5th weeks after planting to minimize weed competition. Manual irrigation was provided using water sprinklers during the vegetative stage of the crops. Irrigation was done twice a week, i.e. every Tuesday and Friday. Similarly, irrigation was applied before sowing the second crop (maize), and supplemental irrigation was given to both crops as needed.

For harvesting, mature soybean pods were manually collected when approximately 80% of the pods had dried and leaf senescence had occurred. Maize was manual harvested at physiological maturity, around 70 - 75 DAS. After harvest, the fresh weight of the crops was measured using an analytical balance.

Plant sample preparation and analysis

Leaf, stem, root, and grain samples for nitrogen analysis were collected at the maturity stage for both

Table 1. Treatments used in Nueva Ecija.

Factor	System	Description	Code
Main plot	Tillage	Reduced tillage	RT
		Conventional tillage	CT
Sub-plot	Monocropping	Maize	M
		Soybean	S
		Soybean with Rhizobium	SwR
	Intercropping	Maize and soybean intercropped	M+S
		Maize and soybean with Rhizobium intercropped	M+SwR

maize and soybean. The samples were oven-dried for 3-5 days at 70°C. Subsequently, 200 g of the dried samples were sent to BSWM for analysis of total nitrogen content using the Kjeldahl method (Bremner 1965).

Data Gathered

Maize

The growth parameters measured for maize included plant height and number of days to maturity. Plant height was recorded by measuring from the base of the plant to the neck node (just below the tassel) at the maturity stage. The number of days to maturity was determined by counting the days from seeding to physiological maturity, typically at 70-75 DAS.

The yield components collected were 1000-grain weight and grain yield. These were determined using a digital weighing balance for each treatment. Grain yield was then calculated as suggested by Adhikari et al. (2015):

$$\text{Grain yield (Mg ha}^{-1}) = \frac{10{,}000\ \text{m}^2}{\text{ASP}} \times \frac{\text{GW}}{1000} \times \frac{100\text{-MC}}{100\text{-}14}$$

where: ASP = area of sample plot
GW = grain weight from sampling area
MC = moisture content (14 %)

Soybean

Growth parameters of soybean such as plant height and days to maturity were recorded. Plant height was measured from the ground level to the tip of the main stem at the maturity stage. Data were collected from 10 sample plants per plot. Days to maturity was recorded by counting the number of DAS until 80% of the plants had reached maturity.

For yield components, the total number of pods per plant, total number of seeds per plant, 1000-seed weight, and grain yield were assessed. Seeds harvested from the pods per treatment were weighed using a digital weighing balance. The grain yield of soybean was calculated using the formula of Wei et al. (2020):

$$\text{Grain yield (Mg ha}^{-1}) = \frac{10{,}000\ \text{m}^2}{\text{ASP}} \times \frac{\text{GW}}{1000} \times \frac{100\text{-MC}}{100\text{-}12}$$

where: ASP = area of sample plot
GW = grain weight from sampling area
MC = moisture content (12 %)

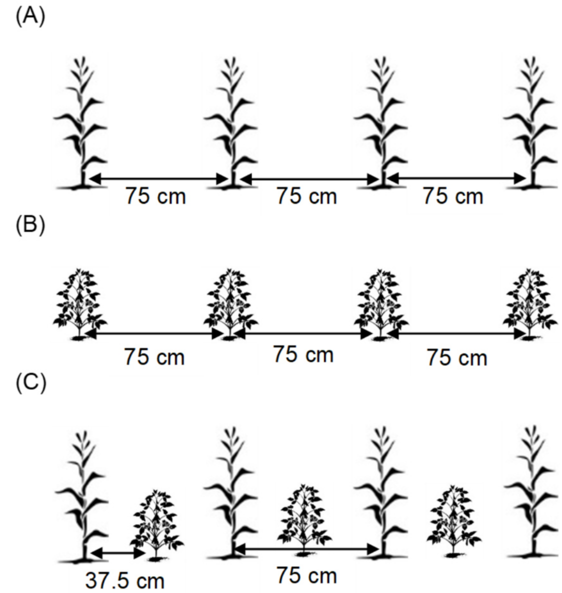

Figure 1. Maize monocropping (A), soybean monocropping (B), and maize-soybean intercropping (C).

Table 2. List of properties of soil in Nueva Ecija before and after the conduct of the experiment.

Soil properties	Value	
	Before	After
pH	5.8	7.05
CEC (cmol kg^{-1})	34.12	-
Organic matter (%)	4.04	3.40
Nitrogen (%)	0.16	0.13
Phosphorus (mg kg^{-1})	2.93	-
Potassium (cmol kg^{-1})	0.27	-
Sand (%)	16	-
Silt (%)	43	-
Clay (%)	41	-
Textural Class	silty clay	-

Table 3. Analysis of variance for total N, soil pH and organic matter of soil in response to tillage systems and cropping systems.

Sources of variation	Total Nitrogen	Soil pH	Organic matter
Tillage system (A)	0.0853^{ns}	0.0733^{ns}	0.0587^{ns}
Cropping System (B)	0.7174^{ns}	0.4862^{ns}	0.6061^{ns}
AxB	0.8824^{ns}	0.6992^{ns}	0.8764^{ns}
CV (A) %	11.23	1.62	11.94
CV (B) %	13.43	1.89	11.85

Other parameters

Land Equivalent Ratio (LER). The Land Equivalent Ratio (LER) was used to determine the total land productivity in an intercropping system. It is calculated by adding the fractions of each crop's yield in the intercropping system relative to its yield in monocropping. The LER was computed using the formula from Willey and Osiru (1972):

Economic Analysis. Profit was evaluated following the economic manual by CIMMYT (1988), using a step-by-step approach to partial budgeting. This process involved calculating total variable costs, gross income, and net income for each treatment. Total variable costs included all expenses related to agricultural operations, such as land preparation, sowing, intercultural operations, harvesting, and post-harvest activities for each treatment. Gross income was obtained by multiplying the price of maize by its actual yield. Net income was calculated by subtracting the total variable costs from the gross income.

Harvest index (HI). HI was calculated based on the method of Kemanian et al. (2007), where the economic yield (grain yield) is divided by the biological yield (dry matter plus grain yield):

Agronomic Nitrogen Use Efficiency (aNUE). This was calculated according to the formula of the EU Nitrogen Expert Panel (2015), as the proportion of crop nitrogen yield to the total nitrogen fertilizer applied. Nitrogen output was computed by multiplying the grain weight at maturity by the percent concentration of N, while nitrogen input was based on the recommended fertilizer rate for maize.

Statistical Analysis

The collected data were analysed using the Shapiro-Wilk test for normality and Barlett's test for homogeneity before determining significant differences through Analysis of Variance (ANOVA) in a split-plot RCBD. Mean differences in agronomic parameters were assessed using the Least Significant Difference (LSD) test at a 5% significance level. All statistical analyses were performed using the Statistical Tool for Agricultural Research (STAR), version 2.0.1.

RESULTS AND DISCUSSION

Complete soil properties were characterized as baseline information before the planting of the experiments, and major soil properties such as pH, organic matter (OM), and nitrogen content were gathered after harvest to elucidate the effects of tillage and cropping systems used under Nueva Ecija condition which was classified to have silty clay soil texture. The soil pH value of 5.8 falls within the optimum range for the cultivation of maize and soybean. The cation exchange capacity (CEC) value of 34.12 cmol kg^{-1} is regarded as favorable for crops; as a CEC above 10 cmol kg^{-1} is preferred for optimal plant growth (dpi.nsw.gov.au). The organic matter (OM) content of 4.04%, aligning with the range found in most productive agricultural soils (3%-6%). In addition, the soil contained 0.16% total nitrogen (N), 2.93 mg kg $^{-1}$ phosphorus (P), and 0.27 cmol kg $^{-1}$ potassium (K) (Table 2).

After the experiment, a slight decrease in total N (23.08%) and OM (18.82%) was observed compared to the baseline values (Table 2). The decrease in total nitrogen and OM in the soil may be due to the nutrient absorption by maize and soybean, which also utilize organic matter components during their growth. As these crops mature, they take up nutrients from the soil, leading to a natural reduction in available N and OM, especially if crop residues were not fully returned to the soil (Chen et al. 2014). However, the pH level of the soil after the experiment shifted to slightly toward neutrality from its initially acidic condition. This change may be attributed to the biological nitrogen fixation by soybean. The legumes form symbiotic relationships with nitrogen-fixing bacteria (*Rhizobium*), which can reduce soil acidity by consuming hydrogen ions during nitrogen fixation (Alves et al. 2021).

In terms of the effect of tillage and cropping system, total N, pH and OM content in soil exhibited no significantly differences under cropping system, tillage system, and its interaction (Table 3).

Agronomic and Yield Performance of Maize

Cropping systems significantly influenced plant height at maturity (P<0.05), while tillage systems and their interactions showed no significant effects (Table 4). Maize plant height ranged from 193.50 cm - 213.70 cm, which monocropped maize being taller than intercropped maize. However, the National Seed Industry Council (2015) reports that Los Baños Lagkitan has an average plant height of 224 cm. These findings indicate a height reduction of 4.5% for M, 12.9% for M+S and 13.4% for M+SwR, compared to the expected height.

During maize growth, nitrogen is essential as it is a building block of amino acids and plant protein. However, in intercropping, soybean competes for the nitrogen during the early vegetative stage of maize. Furthermore, shading caused by soybean, which was planted 16-18 days earlier than maize, may have reduced light availability, resulting in shorter maize plants compared to its potential height of 224 cm. This agrees with Osang et al. (2015), who reported that shading by taller plants can reduce the photosynthetic rate of shorter companion crops. Similarly, Li et al. (2020) found that the reduced performance of maize in intercropping systems was due to nutrient competition.

For days to maturity, both the cropping system and its interaction with tillage systems had significant effects (P<0.05) (Table 4). According to the National Seed Industry Council (2015), Los Baños Lagkitan is expected to mature between 70 - 75 DAS. As shown in Table 4, the average days to maturity across different treatments ranged from 66 - 70 DAS. Notably, M+SwR had a significantly longer maturity period, extending 4 days longer than monocrop maize. This delay may be attributed to biological and ecological interactions in intercropping, particularly with *Rhizobium* inoculation. Intercropping introduces interspecific competition for light, water, and nutrients, potentially delaying development when nutrient uptake is not synchronized between crops (Agegnehu et al. 2006). Additionally, *Rhizobium* inoculants enhance nitrogen fixation in legumes, which can influence the companion maize crop. While increased nitrogen availability can enhance growth, it may also prolong the vegetative stage, thereby delaying physiological maturity (Sinclair and Valdez 2002).

The highest grain yield of maize was observed in the monocropping system (5.99 Mg ha^{-1}), followed by M+S (4.97 Mg ha^{-1}) and M+SwR (4.38 Mg ha^{-1}) (Table

Table 4. Mean performance of agronomic and yield components of maize in response to tillage systems and cropping systems[1].

Treatments	Plant height at maturity (cm)	Days to maturity (80%)	1000-Grain weight (g)	Grain yield (Mg ha^{-1})	Harvest index
Tillage Systems (A)					
Conventional	202.14	69	279.29	5.23	0.61
Reduced	199.46	68	276.26	5	0.61
Mean	200.8	68	277.77	5.12	0.61
P-value (A)	ns	ns	ns	ns	ns
Cropping Systems (B)					
M	213.70 a	66 b	266.02	5.99 a	0.55
M+S	195.20 b	69 a	287.25	4.97 b	0.68
M+SwR	193.50 b	70 a	280.05	4.38 b	0.59
Mean	200.8	68	277.77	5.12	0.61
P-value (B)	0.0138	0.0004	ns	0.0032	ns
P-value (AxB)	ns	0.0232	ns	ns	ns
CV (A)	1.52	2.74	8.42	4.03	15.82
CV (B)	4.93	1.2	11.76	11.24	19.44

[1]Means followed by the same letter are not significantly different at the 0.05 probability level (LSD).
monocrop maize (M), maize-soybean intercropped (M+S), maize-soybean with Rhizobium inoculant intercropped (M+SwR); CV: Coefficient of Variation

Table 5. Mean performance of agronomic and yield components of soybean in response to tillage systems and cropping systems[1].

Treatments	Plant height at maturity (cm)	Days to maturity (80 %)	Number of pods per plant	Number of seeds per plant	1000-Grain weight (g)	Grain yield (Mg ha^{-1})	Harvest index
Tillage Systems (A)							
Conventional	90.95	104	190.38	317.83	88.38	1.11	0.28
Reduced	90.78	104	176.96	310.92	87.53	1.1	0.28
Mean	90.87	104	183.67	314.38	87.95	1.11	0.28
P-value (A)	ns	ns	ns	ns	ns	ns	ns
Cropping Systems (B)							
S	88.85	104.33	195.17	332.67	83.2	1.28	0.33 a
SwR	88	104	188.75	323.83	91.83	1.11	0.24 b
M+S	93.52	103.67	177.37	292.67	85.85	1.08	0.30 ab
M+SwR	93.1	104	173.38	308.33	83.2	0.95	0.23 b
Mean	90.87	104	183.67	314.38	87.95	1.11	0.28
P-value (B)	ns	ns	ns	ns	ns	ns	0.0381
P-value (AxB)	ns	ns	ns	ns	ns	ns	ns
CV (A) %	2.42	2.45	6.22	5.51	15.05	21.43	14.76
CV (B) %	7.08	2.37	18.18	17.77	10.05	13.39	21.46

[1]Means followed by the same letter are not significantly different at the 0.05 probability level (LSD).
monocrop soybean (S), monocrop soybean with Rhizobium inoculant (SwR), maize-soybean intercropped (M+S), maize-soybean with Rhizobium inoculant intercropped (M+SwR); CV: Coefficient of Variation

4). This yield reduction in intercropping treatments can be attributed to competition for nutrients and solar radiation within the mixed cropping environment. These findings are consistent with Gard and Mckibben (1973), who reported that intercropping systems tend to reduce yield compared to monocropping. Moreover, cropping systems, tillage, and their interactions had no significant effect on 1000-grain weight and harvest index (Table 4).

Agronomic and Yield Performance of Soybean

ANOVA results indicated no significant differences in plant height, maturity, number of pods and seeds per plant, 1000-grain weight, and grain yield. However, the harvest index showed a significant effect due to cropping systems. Table 5 presents the mean performance of soybean across treatments.

According to the National Seed Industry Council (2015), the CLSoy-1 variety typically mature at 93 DAS. However, in this study, soybean matured later than expected, likely due to high rainfall during the maturity phase. As the crop approaches maturity, water management through gradual reduction, especially during the late reproductive phases, supports full pod development and minimizes yield loss. Controlled deficit irrigation applied after flowering but before harvest helps avoid abrupt stress-induced pod abortion while improving water use efficiency (Yonts et al. 2018). With respect to harvest index (HI), monocrop soybean achieved an HI of 37.50%, which was higher than that of SwR and M+SwR (Table 5). *Rhizobium* bacteria, which form symbiotic associations with soybean, can utilize approximately 4-16% of the carbon fixed by the plant (Kaschuk et al. 2009). This may explain why *Rhizobium* inoculated soybean plants showed a lower HI, carbon may have been diverted for bacterial use, improving biomass production but limiting the translocation of nutrients and photosynthates to the grains. Sun et al. (2024) claimed that yield is

Table 6. Mean performance of maize and soybean in Agronomic Nitrogen Use Efficiency (aNUE) and Land Equivalent Ratio (LER) in response to tillage systems and cropping systems[1].

Treatments	aNUE- Maize	aNUE-Soybean	Combined (Maize +Soybean)	LER
Tillage Systems (A)				
Conventional	0.53	1.36	1.41	1.73
Reduced	0.59	1.13	1.26	1.66
Mean	0.56	1.25	1.33	1.7
P-value (A)	ns	ns	ns	ns
Cropping Systems (B)				
M	0.67	-	0.67 b	-
S	-	1.53	1.53 a	-
SwR	-	1.21	1.21 ab	-
M+S	0.53	1.18	1.71 a	1.74
M+SwR	0.48	1.07	1.55 a	1.65
Mean	0.56	1.25	1.33	1.7
P-value (B)	ns	ns	0.0384	ns
P-value (AxB)	ns	ns	ns	ns
CV (A)	28.19	40.23	18.6	32.14
CV (B)	23.76	46.4	42.12	9.23

[1]Means followed by the same letter are not significantly different at the 0.05 probability level (LSD); monocrop maize (M), monocrop soybean (S), monocrop soybean with Rhizobium inoculant (SwR), maize-soybean intercropped (M+S), and maize-soybean with Rhizobium inoculant intercropped (M+SwR); CV, Coefficient of Variation

Table 7. Actual yield, gross income, total variable cost, and net income for maize and soybean in comparison of cropping system at each level of tillage system.

Tillage systems	Cropping systems	Actual yield	Gross income[a]		Total variable cost[b]		Net income[c]	
		($Mg\ ha^{-1}$)	($PhP\ ha^{-1}$)	($USD\ ha^{-1}$)	($PhP\ ha^{-1}$)	($USD\ ha^{-1}$)	($PhP\ ha^{-1}$)	($USD\ ha^{-1}$)
Conventional Tillage	M	6,680	219,919	3,927	58,610	1,047	161,309	2,881
	M+S	6,244	234,594	4,189	65,270	1,166	169,324	3,024
	M+SwR	5,763	216,753	3,871	65,330	1,167	151,423	2,704
	S	1,281	76,887	1,373	46,013	822	30,875	551
	SwR	1,093	65,565	1,171	46,073	823	19,493	348
Reduced Tillage	M	6,042	198,898	3,552	61,842	1,104	137,056	2,447
	M+S	6,395	240,229	4,290	62,442	1,115	177,787	3,175
	M+SwR	5,378	201,801	3,604	62,502	1,116	139,299	2,487
	S	1,289	77,353	1,381	43,185	771	34,168	610
	SwR	1,127	67,604	1,207	43,245	772	24,359	435

1 US$= PhP 56 as of January 2024;
[a]Gross income is calculated by multiplying the field price of maize by the actual yield.
[b]Total variable costs represent the sum of all costs that vary for a particular treatment.
[c]Net income is computed by subtracting gross field benefits from total variable cost.

influenced by nutrient deficiency or surplus. In this study, the yield of soybean either as monocrop or intercrop did not meet the potential yield of 2.18 Mg ha^{-1}. This may be attributed to high rainfall in Nueva Ecija during critical pod-filling to grain-filling stages. Ploschuk et al. (2022) reported that waterlogging from excessive rainfall could cause more than 50% yield reduction in soybean. Additionally, the pod-filling stage of soybean coincided with the active vegetative and reproductive stages of maize, resulting in competition for available nutrients between the two crops.

Agronomic Nitrogen Use Efficiency (aNUE), Land Equivalent Ratio (LER), and Economic Analysis

In terms of cropping systems, S, M+S, and M+SwR achieved significantly higher agronomic nitrogen use efficiency (aNUE) values of 1.53, 1.71, and 1.55, respectively, compared to monocrop maize (M), which recorded a value of 0.67 (Table 6). These findings indicate enhanced aNUE in maize-soybean intercropping systems. This aligns with the findings of Sousa et al. (2022), who reported that intercropping cereals with legumes enhances nitrogen fixation per plant compared to monocropping, due to increased nitrogen competition from the cereal component. Moreover, maize-soybean intercropping has been shown to significantly reduce fertilizer requirements compared to monocropping systems (Xu et al. 2020). According to Kebede (2021), legumes can transfer a portion of the fixed nitrogen to associated cereal crops, enhancing overall nitrogen utilization in intercropping systems.

In terms of land equivalent ratio (LER), no significant differences were observed among cropping systems, tillage systems, or their interactions. However, the average LER of 1.70 (Table 6) suggests that monocropping would require 70% more land to achieve the same productivity of intercropping. This result highlights that LER values greater than one indicate increased land-use efficiency. This observed LER of 1.70 is notably higher than the global average for maize-soybean intercropping, which stands at 1.32 ± 0.02 (Xu et al. 2020).

From an economic perspective, the farmgate prices of corn and soybean in Central Luzon in 2022 were PhP 32.92 per kg and PhP 60.00 per kg, respectively (PSA 2022). The total variable costs included all expenses related to agricultural operations, such as land preparation, sowing, intercultural operations, harvesting and post-harvest activities for each treatment. Results showed that conventional tillage with intercropped maize-soybean with *Rhizobium* inoculation incurred the highest total variable costs at PhP 65,330 (Table 7). The lowest variable costs were recorded under reduced tillage with monocrop soybean (PhP 43,185) and monocrop soybean with *Rhizobium* (PhP 43,245) (Table 7). Reduced tillage decreased the variable cost by 2.8% compared to conventional tillage.

In terms of gross and net income, reduced tillage with maize and soybean yielded the highest returns, with a gross income of PhP 240,229 and a net income of PhP 177,787 (Table 7). Conversely, the lowest gross and net incomes were observed under conventional tillage with monocrop soybean and *Rhizobium*. These results indicate that intercropped maize and soybean systems provide higher gross and net incomes compared to monocropping. This finding aligns with Fan et al. (2020), who noted that the economic returns from maize-soybean intercropping exceed those from monocropping, as two crops are harvested from the same plot. Farmers benefit from intercropping as it enhances food production to meet population demands and provides nutritional security through dual crops in single field.

CONCLUSION

In Nueva Ecija conditions, maize-soybean intercropping achieved the highest agronomic nitrogen use efficiency (aNUE) at 1.17 among the cropping systems. Additionally, the net income of the intercropping system (PhP 177,787.00) was higher than of monocropping, and the land equivalent ratio (LER) was greater than one. The LER value of 1.70 indicates that maize-soybean intercropping enhances productivity and improved land use efficiency.

Moreover, intercropped delayed maize silking by 3-4 days, although this did not affect soybean development. Monocropped maize exhibited taller plant height (213.70 cm) compared to intercropped maize and soybean with *Rhizobium* inoculant (193.5 cm), and without (195.2 cm). Similarly, grain yield was higher in monocropped maize (5.99 Mg ha^{-1}) among the maize intercrop. The findings showed that monocropping leads to higher yields compared to intercropping systems. However, this yield advantage does not necessarily translate into greater economic benefits. In terms of tillage systems, no significant variation was observed in the agronomic or yield components of maize and soybean, suggesting that plant performance was not sensitive to the type of tillage used.

Intercropping demonstrated an advantage in terms of aNUE, LER, and net income. However, realizing these benefits in Philippine agriculture will require technological advancements and farmer's capability. Further research on cropping systems is needed to identify optimal crop combinations that enhance mutual benefits between species for increasing the yield of the primary crop while providing additional income opportunities for farmers.

This study was done in sites with fairly fertile soils; therefore, the advantage of *Rhizobium* inoculation may not have been fully evident. Conducting similar research in marginal or unfertile soils would provide better insights into the effects of inoculation and intercropping. Lastly, there is a need for validation of the study with the same cropping systems across multiple locations.

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