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Research Article

Relay-cropping soybean-maize in saturated soil culture increases efficiency of land use and nitrogen fertilizer

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ABSTRACT

Relay-cropping in saturated soil cultivation could increase land efficiency, but its effect on land use and nitrogen fertilizer efficiency is unclear. The research objective was to evaluate the land productivity of the relay-cropping system by calculating the land equivalent ratio (LER) and the effectiveness of nitrogen fertilizer, and by determining the effect of previous soybean biomass. The experiment was arranged in a three-factor randomized complete block design. The first factor was the cropping patterns of soybean and maize, i.e., relay-cropping soybean-maize and maize monoculture. The second factor was the maize varieties, i.e., Pioneer 27 and Sukmaraga. The third factor was the application of N fertilizer with 4 doses: 0, 50, 100, and 150 kg ha^{-1}. The results showed that the application of soybean biomass increased maize yield by 7.24%. Pioneer 27 produced a higher yield than Sukmaraga, and the dose of N fertilizer of 150 kg ha^{-1} resulted in the highest yield of 7.50 tons ha^{-1}. The highest LER of 2.18% was achieved in the relay-cropping without applying follow-up N fertilizer (control). The experiment concludes relay-cropping after soybean save land by about 118% and save N fertilizer by 33.3%. The reduction of N fertilizer application by 33.3% (100 kg N ha^{-1}) reduced corn cob productivity by 13.3%, and is not significantly different from 150 kg N ha^{-1}.

Keywords: chlorophyll, LER, plant residue

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INTRODUCTION

The area of paddy fields in Indonesia in 2019 was recorded at 7.46 million ha, which was a decrease of 630,000 ha as compared to the area of paddy fields in 2015. The productivity of most paddy fields in Indonesia has experienced a leveling-off, where the addition of input units is not followed by an increase in economic production (Al-Jabri, 2013). One of the problems of low land productivity can be overcome by an intercropping system, i.e., planting more than one commodity on the same land and time. The advantages of intercropping in increasing the efficiency of resource utilization have been proven (Martin-Guay et al., 2018). Intercropping is widely used in order to increase food security, diversification of cropping systems, labor efficiency, and sustainable agricultural development (Tilman, 2020), increase soil organic and N cycle (Cong et al., 2015), and reduce pests (Zheng et al., 2020), weeds (Weerarathne et al., 2017) and diseases infections (Boudreau, 2013).

One of the intercropping types is relay-cropping. According to Lamichhane et al. (2023), relay-cropping system utilizes two crops where the second crop is inserted into the first crop field before harvest. Success in the relay-cropping two is determined by two factors: time of planting and proper commodity. The timing of planting will determine the level of competition. The difference in planting time between two crop species on a piece of land can reduce competition in the utilization of nutrients, space to grow, water, and light intensity. The delay in planting time of one of the commodities intercropped also has the aim that the maximum growth of each commodity does not occur at the same time. Moreover, commodities also determine the possible competition. For example, maize and soybean plants can be incorporated into the system because they have complementary positive effects. Maize requires high nitrogen, while soybean can fixate free nitrogen from the air with the help of *Rhizobium japonicum* bacteria.

Cropping maize after soybean facilitates maize to utilize soybean biomass residues which contain a lot of nitrogen and consequently will reduce the use of inorganic N fertilizer for maize. Research by Yong et al. (2018) showed that relay-cropping maize and soybean save the use of inorganic N fertilizer, and the harvested yield is even higher than the use of conventional doses of inorganic N fertilizer. Moreover, Xu et al. (2020) carried out a meta-analysis and found that intercropping of maize and soybean plants generally has an average LER (land equivalent ratio) of 1.32±0.02, and FNER (fertilizer N equivalent ratio) of 1.44±0.03 so monoculture requires 44% more N fertilizer than does intercropping to achieve the same results in the same unit area of intercropping.

Ghulamahdi et al. (2016) noted that the best way to produce soybean in Indonesia is by using saturated soil culture (SSC). SSC is a planting system that provides continuous water irrigation and keeps the water level constant so that the layer below the soil surface becomes saturated condition. The constant water level will eliminate the negative effect of excess water on plant growth because the soybeans will acclimatize and then the plants will improve their growth (Ghulamahdi et al., 2016). The relay-cropping of maize and soybeans on wetlands with saturated soil culture technology has never been studied, which is why this research was conducted. This study aimed to evaluate the productivity of the relay-cropping system by calculating the land equivalent ratio (LER) value, the efficiency of applying N fertilizer to maize, and determining the effect of previous soybean biomass on maize.

MATERIALS AND METHODS

Research design

The research was conducted at Sawah Baru Experimental Station, IPB Darmaga, from January to June 2022. The materials used were edamame soybean seeds of the Biomax 1 variety, while the maize seeds used hybrid maize of the Pioneer P27 variety and composite maize of the Sukmaraga variety. The inorganic fertilizers used were urea, SP-36, and KCl. Other materials used were *Rhizobium*, manure, agricultural lime, and herbicides with the active ingredient glyphosate.

This experiment used a three-factor randomized complete block design. The first factor was the cropping pattern consisting of a relay-cropping system of soybean-maize and maize monoculture systems. In the relay-cropping system, maize was planted when soybeans were at 45 days after planting (DAP). The young harvested soybean (edamame) biomass was then applied as organic fertilizer to maize commodities. The second factor was the maize variety, Pioneer P27 and Sukmaraga variety. The third factor was the dose of N fertilizer in the second application to maize at 4 weeks after planting (WAP) (follow-up N fertilizer), which consisted of 4 levels: 0, 50, 100, and 150 kg ha^{-1}. Thus, there were 16 treatment combinations, and each treatment combination was repeated 3 times so that there were 48 experimental plots. To calculate the value of the land equivalent ratio, 1 soybean monoculture plot, which was repeated 3 times, was added so that there were a total of 51 experimental plots.

Experimental procedure

The land was cleared of weeds by applying an herbicide with the active ingredient glyphosate at an application dose of 2.5 L ha^{-1}. The size of each experimental plot was 3 m x 4 m. Two soybean seeds were planted in holes with a spacing of 30 cm x 15 cm so that in one plot of the soybean monoculture experiment, there were 520 soybean plants. While, 1 maize seed was planted in holes with a spacing of 75 cm x 20 cm so that in one plot of the maize monoculture experiment, there were 80 maize plants.

The population of soybean in one plot of the soybean relay-cropping experiment was 50% lower than in the monoculture treatment, i.e., 260 plants, while the population of maize in relay-cropping experiment was similar to those in the monoculture treatment, i.e., 80 plants. At the time soybean were harvested, except for the pods, all parts of the fresh soybeans biomass from roots to leaves incorporated into the soil in rows of maize plants as green manure in the plots relay-cropping system. The soybean harvest was carried out at 74 DAP and the maize harvest at 103 DAP.

Saturated soil culture (SSC) was prepared by making drainage channels around the plots with a depth of 30 cm and a width of 25 cm. The drainage channels were continuously filled with water from the planting date to harvest with a water level of 20 cm from the soil surface. Thus, the soil layer under the roots was considered saturated.

Fertilizer application

Manure as much as 2 tons ha^{-1} and agricultural lime as much as 2 tons ha^{-1} were applied to the land before planting. The soybean was inoculated with *Rhizobium sp*. with a dose of 12.5 g kg^{-1} seed before planting. The fertilizers 200 kg SP36 ha^{-1}, and 100 kg KCl ha^{-1} were applied at planting time. The urea fertilizer was given as foliar application when the plants were at 3, 4, 5, and 6 weeks after planting with the total dose of 400 L ha^{-1} urea solution with a concentration of 10 g urea L^{-1} of water.

Fertilizers applied for maize were 200 kg SP36 ha^{-1}, 100 kg KCl ha^{-1}, and 150 kg urea ha^{-1}, which were applied at planting time. The second fertilization with urea was carried out at 4 dose levels, i.e., 0, 50, 100, and 150 kg ha^{-1} at 28 DAP.

Observation

The observed growth variables for maize were plant height, number of leaves, and biomass fresh and dry weight at 8 WAP, while the observed production variables for maize were cob length, cob diameter, grain weight per cob, and plant productivity. Physiological observations were carried out in the chlorophyll content of maize plants at 7 WAP, where leaf nutrient uptake was obtained by multiplying leaf nutrient content by leaf dry weight.

The evaluation variables observed in the intercropping experiment are as follows:

1. LER (land equivalent ratio), is a measure of land use efficiency. The LER value was calculated using the formula (Mead and Willey, 1980):
   $\mathrm{LER} = \sum_{i=1}^{n} \left(\frac{yi^I}{yi^S}\right)$ where yi^I and yi^S are the production results of each "I" in intercropping and "S" in a monoculture system; and n is the number of commodity types in the intercropping system.
2. ATER (area time equivalent ratio), a measure of land use efficiency based on time, is a more realistic comparison because it considers the timing of the two commodities planted in both intercropping and monoculture systems. The ATER value was calculated using the formula (Hiebsch & McCollum, 1987):
   $\mathrm{ATER} = \sum_{i=1}^{n} \frac{ti^S}{t_I}\left(\frac{yi^I}{yi^S}\right)$ where ti^S is the growing time of plants in the monoculture system; t_I is the total growing time of the two commodities in the intercropping system.
3. CR (competitive ratio), is a measure that shows how many times a commodity is more competitive than other commodities in an intercropping system. The CR value was calculated using the formula (Willey & Rao, 1980):

CR= $\left(\frac{I_a/S_a}{I_b/S_b}\right)$ $\left(q_b/q_a\right)$ where I_a and I_b are the production results of commodities a and b in the intercropping system; S_a and S_b are the production results of commodities a and b in the monoculture planting system; q_a and q_b are the proportions of land for commodities a and b in the intercropping system.

4. A (aggressivity), is a value to measure the ability to compete between types of plants and between commodities in obtaining resources in an intercropping system. The A value was calculated using the formula (McGilchrist & Trenbath, 1971):
   Aab = $\left(\frac{Yab}{Yaa\ x\ Zab}\right)$-$\left(\frac{Yba}{Ybb\ x\ Zba}\right)$ where Yab, Yba, Yaa, and Ybb respectively are the yield of commodity 'a' in the intercropping system, the yield of commodity 'b' in the intercropping system, the yield of commodity 'a' in the monoculture system and the yield of commodity 'b' in the monoculture system.

Data analysis

The data were analyzed with ANOVA (analysis of variance). If the result showed a significant effect, further tests were then carried out using the DMRT (Duncan's Multiple Range Test) at α=5% significance level. Observational data were processed using the R Studio Program.

RESULTS AND DISCUSSION

Plant growth characteristics

The relay-cropping system with the application of green fertilizer from soybean biomass residues did not affect plant height and the number of leaves at 8 WAP (Table 1). The higher growth in relay-cropping system was speculated due to maize plant aged less than 4 WAP were shaded by soybean canopy. It is known that shading stimulate larger auxin biosynthesis triggers cell elongation resulting in faster vegetative growth (Kantikowati et al., 2022). In the early response to shade signals, auxin biosynthesis, transport, and sensitivity are all rapidly activated, thus promoting cell elongation of the hypocotyl and other organs (Ma & Li, 2019).

Table 1. Plant height and number of leaves of maize at 8 WAP.

Treatment	Plant height (cm)	Leaf number
Cropping pattern		
Relay-cropping	201.52	11.2
Monoculture	207.39	10.9
Variety		
Pioneer 27	202.11	12.0a
Sukmaraga	206.79	10.2b
Urea dosage (kg ha^{-1})		
0	185.70b	10.5b
50	207.45a	10.7ab
100	207.99a	11.5a
150	216.67a	11.6a

Note: * Numbers followed by the same letter in the same column and the same treatment factor are not significantly different in the α=5% of DMRT test.

There was no significantly different in plant height of the two varieties of maize, but the difference in the number of leaves of the two at 8 WAP was proven (Table 1). The number of leaves of the Pioneer 27 variety was more than that of the Sukmaraga variety. The dose of N fertilizer in the second application of fertilizer to maize plants 4 WAP (follow-up N fertilizer) had a significant effect on plant height and the number of leaves;

the higher the dose of follow-up N fertilizer, the higher the value of plant vegetative growth parameters. This is because urea is a source of nitrogen where higher N uptake increases rubisco activity and photosynthesis (Heckathorn et al., 1996). High N absorption accelerates mesophyll cell division and epidermal cell elongation, which are the components that play an important role in plant growth (Ramzan et al., 2023).

The relay-cropping system with the use of crop residues from intercrops (soybean biomass residues) had no significant effect on the fresh and dry biomass of maize plants at 8 WAP (Table 2). However, it significantly reduced fresh and dry biomass observed at harvest time compared to that of maize plants without the application of soybean biomass. This is presumably due to the influence of differences in light interception in the monoculture and relay-cropping systems. The monoculture system has a lower plant density, and that causes higher light interception than the relay-cropping system as it has a higher plant density. The canopy of existing soybean at the time maize was planted reduced the light interception by the maize. High planting density increases light competition between individuals and between crop species (Pithaloka et al., 2015). The fact that the dry biomass weight of maize in the intercropping system was lower than the dry biomass weight of maize in the monoculture system is also reported by (Liu et al., 2022). Alsabah et al. (2014) and Rui et al. (2022) also reported in a study that the dry weight of biomass in the relay-cropping system is lower than in the monoculture system. This is presumably because the decomposition process of the green manure from soybean residues incorporated in the relay-cropping system at 4 WAP of maize is not fully completed. According to Jahan et al. (2016), incorporating crop residues into the soil in a rotation system between potato-mungbean-rice cause soil N temporarily unavailable due to N were used by microorganisms in their life cycle. However, whether or not the cause of the lower dry weight of biomass in relay-cropping is the depletion of soil N, needs further evaluation.

Table 2. Biomass weight per plant at 8 WAP and harvest.

Treatment	Biomass weight at 8 WAP (g)		Biomass weight at harvest (g)	
	Fresh	Dry	Fresh	Dry
Cropping pattern				
Relay-cropping	340.46	70.89	143.72b	61.93b
Monoculture	340.46	73.31	190.45a	75.62a
Variety				
Pioneer 27	336.44	66.48	167.12	72.42
Sukmaraga	344.48	77.72	167.06	65.14
Urea dosage (kg ha^{-1})				
0	300.95	62.76	149.07	59.89b
50	349.91	79.52	178.79	72.18a
100	330.11	68.39	161.24	67.75ab
150	380.87	77.74	179.25	75.30a

Note: * Numbers followed by the same letter in the same column and the same treatment factor are not significantly different in the α=5% of DMRT test.

The weight of fresh biomass did not differ between varieties and between levels of follow-up N fertilizer (Table 2). Dry biomass weight increased by 20% with the application of 50 kg of urea ha^{-1} compared to the dry biomass weight without fertilizer.

Components of plant production

The cropping system treatment had no significant effect on cob weight, cob length, cob diameter, the weight of 100 grains of maize, and cob production per hectare, but had a significant effect on the number of grain rows per cob (Table 3). The number of columns per cob in the relay-cropping system was greater than in the monoculture system. The increase in the number of columns per cob in the relay-cropping system appeared to be associated with a larger cob diameter although statistically, the cob diameter was not significantly different from that of maize in the monoculture system.

Table 3. Weight, length, diameter, and number of rows of maize at harvest.

Treatment	Maize cob			Number of rows	Weight 100 grains	Cob productivity (tons ha^{-1})
	Weight (g)	Length (cm)	Diameter (mm)			
Cropping Pattern						
Relay-cropping	136.72	16.30	44.6	14.9a	26.02	6.20
Monoculture	123.95	16.54	43.7	14.3b	26.12	5.79
Variety						
Pioneer 27	154.85a	16.60	46.5a	15.6a	25.96	7.20a
Sukmaraga	105.83b	16.22	40.9b	13.1b	26.18	4.79b
Urea dosage (kg ha^{-1})						
0	99.15c	14.68b	42.6c	14.4	24.88b	4.50c
50	122.14bc	16.90a	43.4bc	14.3	25.51ab	5.48bc
100	140.24ab	16.92a	44.5ab	14.9	26.60ab	6.50ab
150	159.83a	17.24a	46.1a	14.6	27.30a	7.50a

Note: * Numbers followed by the same letter in the same column and the same treatment factor are not significantly different in the α=5% of DMRT test.

The weight of dry biomass at harvest in the monoculture system was 22% higher ($p < 0.05$) than that in the relay-cropping system (Table 2). The lower weight of dry biomass in the relay-cropping system compared to that in the monoculture system was suspected as a result of the application of green manure of soybean biomass residues that had not been completely decomposed, where there was immobilization of nutrients in the soil so that N nutrients were not yet available for maize plants.

The cob productivity per hectare was not significantly different between the two planting systems (Table 3). Productivity in the relay-cropping system was 7% higher ($p > 0.05$) than that in the monoculture system. The results of the previous study, which was carried out for 3 years, showed that the application of green manure to legume had increased the yield of wheat grain to the maximum in the 3rd year due to an increase in soil quality i.e., an increase available-P, exchangeable increase in K, Ca, and Mg, as well as an increase in soil pH (Amede et al., 2021). Ansari et al. (2022) also mentioned that the use of harvest residues as green manure increases soil organic C, C pool, C lability index, and C-microbial biomass. Pioneer 27 variety showed higher values on cob weight, cob diameter, number of grain rows, and cob productivity per hectare (Table 3). The productivity of the Pioneer 27 variety was 50% higher than that of the Sukmaraga variety.

The application of follow-up N fertilizer increased the cob productivity compared to the application of follow-up N fertilizer (control). Nitrogen application at doses of 100 and 150 kg urea ha^{-1} increased productivity by 44% and 66% ($p < 0.05$) respectively (Table 3).

Chlorophyll and nutrient status

The relay-cropping of soybean-maize caused the levels of chlorophyll a and b per mass of maize leaves at 7 WAP to be significantly higher than that of maize leaves in the monoculture system (Table 4). Chlorophyll has a role in the process of photosynthesis, while chlorophyll b a role in expanding the absorption spectrum of light, and that is an adaptation mechanism for shaded plants. The fact that the maize plants in the relay-cropping system had higher chlorophyll content than in the monoculture system could be due to the plant's response to the shading from the soybean plants. However, the higher levels of chlorophyll in maize leaves in the relay-cropping system also seemed to be caused more by higher N levels in the leaves (Table 5) due to the contribution of N elements from green manure of soybean biomass residues. Chlorophyll acts as a photosynthetic organ composed of elements N so the application of green manure affects the chlorophyll content (Marsuni et al., 2013). The leaf tissue of maize plants in the relay-cropping system had a 19% higher N nutrient content than in the monoculture system, and the P content was also higher and significantly different from that of maize plants in the monoculture system. However, the K content in the leaf tissue of maize plants in the relay-cropping system was lower than in the monoculture planting system (Table 5). Green manure containing high N affects the formation of chlorophyll. The results of the analysis of nutrients in soybean plant tissue were 2.98% N, 0.28% P, and 0.56% K.

Table 4. Leaf pigment content per mass and per area of maize leaves.

Treatment	Chlorophyll content (mg g^{-1})			Chlorophyll content (mg cm^{-2})		
	a	b	Total	a	b	Total
Cropping Pattern						
Relay-cropping	1.689a	0.494a	2.184	0.0364a	0.0106	0.0470
Monoculture	1.506b	0.452b	1.958	0.0320b	0.0096	0.0416
Variety						
Pioneer 27	1.693a	0.504a	2.198a	0.0346	0.0103	0.0448
Sukmaraga	1.503b	0.441b	1.944b	0.0338	0.0099	0.0437
Urea dosage (kg ha^{-1})						
0	1.192b	0.351b	1.543b	0.0234c	0.0069b	0.0303c
50	1.576a	0.467a	2.044a	0.0338b	0.1003a	0.0438b
100	1.814a	0.541a	2.355a	0.0394ab	0.0117a	0.0511ab
150	1.810a	0.531a	2.342a	0.0402a	0.0118a	0.0519a

Note: * Numbers followed by the same letter in the same column and the same treatment factor are not significantly different in the α=5% of DMRT test

Table 5. NPK nutrient contents in maize leaves at 8 WAP.

Treatment	N (%)	P (%)	K (%)
Cropping pattern			
Relay-cropping	2.12a	0.42a	1.29b
Monoculture	1.78b	0.34b	1.49a
Variety			
Pioneer 27	2.11a	0.39	1.39
Sukmaraga	1.79b	0.38	1.39
Urea dosage (kg ha^{-1})			
0	1.72b	0.42	1.57a
50	1.68b	0.35	1.41ab
100	2.11a	0.36	1.28b
150	2.29a	0.39	1.30b

Note: * Numbers followed by the same letter in the same column and the same treatment factor are not significantly different in the α=5% of DMRT test.

Evaluation of relay-cropping system

The land equivalent ratio (LER) in the relay-cropping system shows a value of > 1 (Table 6), which means that the relay-cropping system can improve land use efficiency compared to the monoculture system. The research conducted showed that the variables of planting or yield of soybean productions determine the LER value because the total population of maize plants planted in the monoculture and relay-cropping system is the same.

The area time equivalent ratio (ATER) value is smaller than the LER value because the calculation includes the time required by plants from planting to harvesting. Competitive ratio (CR) is the ability of plants to obtain resources both vertically (water and nutrients) and horizontally (light intensity and space to grow). The results showed that the value of the competition ratio for maize was higher than that for soybeans (Table

6). The CR value strengthens the Aggressivity value, where the higher the CR value of a commodity in the intercropping system, the stronger the aggressiveness of the commodity in competing for resources (Ceunfin et al., 2017).

Table 6. Land equivalent ratio, area time equivalent ratio, competitive ratio, and aggressivity.

Treatment	Land equivalent ratio (LER)	Area time equivalent ratio (ATER)	Competitive ratio		Aggressivity	
			Soybean	Maize	Soybean	Maize
Variety						
Pioneer 27	1.75	1.10	0.21	6.60	-3.94	3.94
Sukmaraga	1.82	1.15	0.18	6.77	-4.39	4.39
Urea dosage (kg ha^{-1})						
0	2.18a	1.38a	0.18a	6.96a	-5.29b	5.29a
50	1.56b	0.99b	0.19a	7.54a	-3.79ab	3.79ab
100	1.54b	0.95b	0.27a	4.95a	-2.98a	2.98b
150	1.85ab	1.18ab	0.14a	7.26a	-4.59ab	4.59ab

Note: Numbers followed by the same letter in the same column and the same treatment factor are not significantly different in the α=5% of DMRT test

CONCLUSIONS

The relay-cropping soybean-maize had higher LER value than monoculture planting system. The highest LER value of 2.18 in the control (without application of follow-up N fertilizer). The LER value after the application of follow-up N fertilizer at doses of 50, 100, and 150 kg ha^{-1} were 1.56, 1.54, and 1.85, respectively, while the highest ATER value occurred at the application of follow-up N fertilizer at a dose of 0 kg ha^{-1}, reaching 1.38. The ATER value decreased because there was an effect of longer periode of land use in the relay-cropping system. The application of follow-up N fertilizer up to 150 kg ha^{-1} linearly increased cob weight, cob length, cob diameter, the weight of 100 grains, and productivity.

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