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Agronomic and Yield Performance of Maize-Mungbean Intercropping with Different Mungbean Seed Rates under Loamy Sand Soils of Cambodia

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Abstract: Increasing crop productivity through crop diversification under the same unit area has been considered as a way for sustainable intensification of cropping systems. This research was conducted on loamy sand soil at the Crop Research Station of Royal University of Agriculture (RUA) in Cambodia. The objective was to evaluate the growth and yield of maize (*Zea mays* L.) and mungbean (*Vigna radiata* L.) crops and land-equivalent ratio (LER) of maize-mungbean intercropping system using different seed rates of mungbean at 0% (0 kg ha^{-1}), 25% (10 kg ha^{-1}), 50% (20 kg ha^{-1}), 75% (30 kg ha^{-1}), 100% (40 kg ha^{-1}) of recommended rates. The experiment was laid out using Randomized Complete Block Design (RCBD) with three replications. The agronomic traits and yield of both crops were measured at harvest. The weeds were removed three times to measure biomass. The results showed that there was no significant difference in agronomic traits and yield of maize under either maize-mungbean intercropping or maize monocropping irrespective of different mungbean seed rates. The highest mungbean seed rates as recommended did not decrease the growth and yield of intercropped maize. In contrast, the presence of mungbean in the intercropping suppressed weed growth significantly and the trend of weed biomass decreased with increasing mungbean seed rates. The intercropped mungbean grain yield decreased in comparison with monocropping mungbean. Overall, the land equivalent ratio (LER) was higher than 1 under the intercropping, showing its agronomic benefits, compared to monocropping. Therefore, maize-mungbean intercropping is a potential practice for improving productivity and managing weeds. Further research needs to be investigated under different ecological and social-economical niches to determine overall potential benefits and opportunities for scaling.

Keywords: agronomic performance; LER; intercropping; seed rates

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1. Introduction

Intercropping is the cultivation of two or more crops in the same field [1,2]. Under low-input cropping systems, intercropping plays a vital role in optimizing utilization of resources (e.g., nutrient, light and water) and in enhancing soil fertility, especially with the inclusion of legumes [3]. In addition to increased crop productivity, it also enhances efficient land utilization. However, growing more than two crops together as intercropping may require proper management to minimize the competition for resources among different crops [4]. Cereal-legume intercropping has been reported as a good companion planting and commonly practiced [1] due to its complementarities between legume and cereal [5]. Legume crops use less nitrogen from the soil [4] because it is able to fix atmospheric N, and some portion may be beneficial for its companion cereal grain crops [4,6].

Maize (*Zea mays* L.), among the top three cereal crops in Asia [7], contributes to ensure global food and nutritional security [8]. In Cambodia, it is the third important crop after rice (*Oryza sativa* L.) and cassava (*Manihot esculenta* Crantz) with the cultivation area and total production of 140,162 ha and 792,503 tons respectively in 2021 [9]. Mostly, maize is cultivated in the northwest, northeast provinces and also along the banks of Mekong river and Tonle Sap Lake [10]. Montgomery et al. [11] reported that most of maize growers cultivate the same crops continuously as a monocropping system. Mungbean (*Vigna radiata* (L.) R. Wilczek) is traditionally grown in many Asian countries [12] and is used in many purposes including human food and livestock feed [13]. Seeds can be consumed as human food when green or after maturity, and biomass is fed to livestock. Seeds are rich source of protein, carbohydrates and vitamins [14]. In Cambodia, Mungbean is considered as the fourth important non-rice crop which is cultivated in both the upland and lowland areas [15]. In 2021, the crop covers the cultivation area of 24,569 ha with the total production of 30,047 tons [9]. The crop can be planted in different cropping systems, either as a monocrop or crop rotation or as an intercrop with cereals. Mungbean has been reported as beneficial to subsequent rice growth and yield under sandy soils of Cambodia [16].

Weed infestation and soil degradation become a challenging constraint to maize production, particularly in North West Cambodia [17]. Weeds are considered as one of the major limiting factors causing significant decline in maize yields. It has been reported that 93% of the farmers used herbicides to control weeds in maize production systems [18]. Valentin et al. [19] stated that a continual maize monocropping in Southeast Asian environments caused soil erosion and runoff, resulting in depletion of natural resources. Intercropping systems have the opportunity to minimize weed infestation and competitiveness, while providing additional yield benefits [4].

Research has shown that maize had better land use efficiency and more ecological benefits when intercropped with legumes [20]. Grain legumes play a vital role as protein source which accounts for 33% of global protein requirement [21]. Different types of legume crops have been reported having many benefits when intercropped with maize, for instance with soybean (*Glycine max* L. Merr.) resulting in high yield and nutrient acquisition [22] and with mungbean (*Vigna radiata* L.) leading to better economic and biological productivity [23]. Apart from that, maize-legume intercropping can suppress weeds due to rapid and greater canopy cover which reduces light for weeds, compared to monocropping of maize [24,25].

Polthanee and Trelo-ges [26] showed that soil moisture content at 0–15 cm depth was maintained in an available range during most of the growing period between mungbean monocropping and maize-mungbean intercropping, thus it was more efficient in the intercropping. In general, the maize-legume intercropping systems increased land use efficiency by about 48% to 66% depending on the legume species. Utobo et al. [27] concluded that maize-mungbean additive intercropping systems had more efficient land resource use, considerable yield advantage relative to their monocrops. Moreover, mungbean residue can improve the soil fertility through the supply of C and N to successor crops [16].

Considering the importance of both maize and mungbean in the cropping systems, and problems of monocropping maize, the research focusing on maize-mungbean is crucial. Not much research has been conducted to evaluate the agronomic benefits of maize-mungbean intercropping in Cambodia. A better understanding of competition between maize and mungbean under different cropping systems is needed to evaluate its impacts on yields and its ability to improve overall productivity of the system. Therefore, it is hypothesized that intercropping maize with optimum rates of mungbean seed rates does not decrease maize yield, but provides additional grain yield of mungbean and added benefits weed management. Therefore, the objectives of this study were to (1) evaluate the growth and yield of both maize and mungbean crops under monocropping and intercropping systems; and (2) assess the land-equivalent ratio (LER) of maize-mungbean intercropping under different seed rates of mungbean.

2. Materials and Methods

The experiment was conducted at Crop Research Station (11°30′47″ N, 104°54′3″ E) of Royal University of Agriculture (RUA), Phnom Penh, Cambodia. The experiment was planted on 13 March 2020 and harvested on 18 June 2020. The characteristics of experimental soil analyzed at the Soil Laboratory of Faculty of Agronomy, RUA are described in Table 1.

Table 1. Soil characteristics of the experimental site before the start of the experiment.

Soil Properties	Values
Soil pH (H_2O, 1:2.5)	6.23
Soil organic matter (Walkley & Black wet composition, %)	3.71
Total nitrogen (N) (Kjeldahl digestion, %)	0.02
Available phosphorus (P) (Olsen method, ppm)	14.28
Exchangeable K (meq/100 g)	0.23
Cation Exchange Capacity (Ammonium acetate pH 7.0, cmolc/kg)	12.99
Sand (%)	81
Silt (%)	15
Clay (%)	4
Texture (Hydrometer method)	Loamy sand

2.1. Treatment Application and Experimental Layout

The treatments consisted of five different seed rates of mungbean intercropped with maize: Maize-Mungbean 0% (Maize Monocropping), Maize-Mungbean 25% (10 kg ha^{-1} = 13 plants m^{-2}), Maize-Mungbean 50% (20 kg ha^{-1} = 26 plants m^{-2}), Maize-Mungbean 75% (30 kg ha^{-1} = 49 plants m^{-2}) and Maize-Mungbean 100% (40 kg ha^{-1} = 52 plants m^{-2}). Recommendation seed rate (100%) for mungbean is broadcasted at the rate of 40 kg ha^{-1} [28]. In order to calculate Land Equivalent Ratio (LER), mungbean was cultivated with the five different seed rates as monocropping. The experiment was laid out in randomized complete block design (RCBD) with three replications.

2.2. Climate Conditions

Both rainfall and temperatures were recorded during the experiment using data loggers (HOBO UX100-003; Onset Computer Corporation, Bourne, MA, USA) at 15 min interval for the temperature and Davis® 0.2 mm Rain Gauge Smart Sensor (HOBO S-RGF-M002) for rainfall. The rainfall and temperatures were shown in Figure 1.

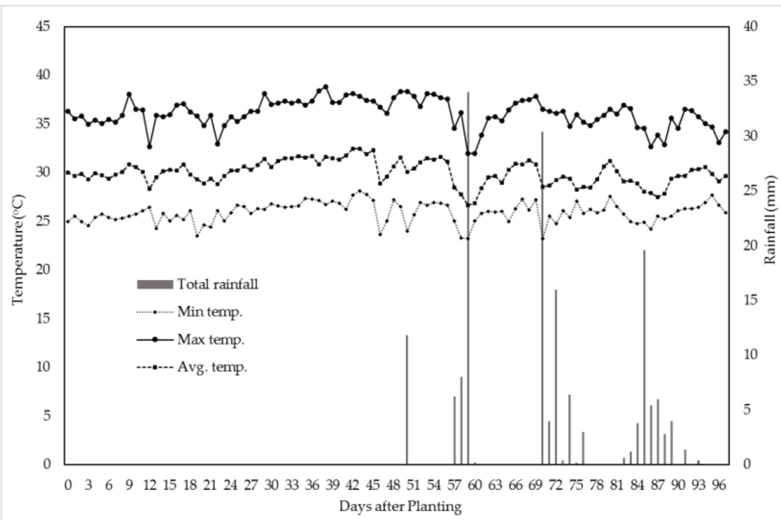

Figure 1. Temperature and rainfall during the experiment.

Maize is generally planted in February to March, particularly in the upland area of Cambodia, but the planting can also be delayed till June. Maize is sensitive to prolonged high temperature exceeding 38 °C which may cause heat stress during flowering stage. However, during our experiment the temperature did not reach 38 °C during flowering stage and the rain started from early May. The rain did not affect maize as the loamy sand soil in this experiment did not cause any waterlogging. In addition, this hybrid is tolerant to waterlogging. Thus, the growing season in this experiment is considered as favorable for maize production.

2.3. Plant Materials

Maize Sugar King F1, tropical hybrid sweet maize, was used for this research. This hybrid has strong plant vigor and good root system and tolerant to lodging. It is one of the most common sweet maize hybrids grown by farmers in Cambodia.

CARDI Chey mungbean was released by the Cambodian Agricultural Research and Development Institute of Cambodia in 2001. Its designation line is VC 1973A which originated from the World Vegetable Center, Taiwan [28].

2.4. Agronomic Practices

After land preparation, a well-composted cattle manure was applied at a rate of 10 t ha^{-1} as basal dose two weeks before planting. Fertilizers were applied based on the recommended dose of CARDI for maize at a rate 75:45:25 (N:P_2O_5:K_2O kg ha^{-1}). Urea, Single Super Phosphate (SSP) and Potassium Chloride (KCl) were used as sources of N, P_2O_5 and K_2O respectively. 100% of P_2O_5 and 50% of N and K_2O were applied as basal dose while the remaining 50% of N and K_2O were applied as top dressing at four weeks after planting. For direct comparison on monoculture and intercropping and to estimate land equivalent ration (LER), the same fertilizer doses were applied to both systems. The previous crop was tomato. The mungbean seeds were not inoculated.

In each treatment, maize was cultivated in four rows and eight hills per row. The spacing between the maize rows was 0.75 m and between maize plants was 0.25 m, with a total plant density of 53,333 plants per hectare. Thus, the plot size was 2 m width by 3 m length. Three seeds of maize were planted (direct seeded) at a depth of three centimeters, while mungbean was placed between the maize rows based as per treatments to maintain the target different seed rates (plants per square meter).

2.5. Data Collection

2.5.1. Maize and Weeds

Days to male and female flowering in maize were recorded when all the plants in each plot flowered. Five plants were randomly selected and measured for ear height, plant height and plant biomass at harvest. Briefly, ear height and plant height were measured at the distance from the soil surface to the first ear and topmost leaf tip, respectively. At harvest, the same five random plants were selected for maize ear weight per plant. Maize yield was expressed as total fresh ear weight per hectare. Five cobs from each plot were selected for measuring their lengths, husked maize ear weights, and diameter. Cob diameters were measured using a digital caliper. Weeds were collected from the whole plot at 10, 20 and 30 days after planting (DAP). Biomass of weeds and maize were oven-dried at 70 °C for two days and weighed. Chlorophyll reading index (CRI) was measured using portable SPAD-502 m (Minolta, Spectrum Technologies, Aurora, IL, USA). CRI was measured on two upper leaves of five sample plants per plot.

2.5.2. Mungbean

Days to flowering in mungbean was determined when 50% and 100% of all the plants flowered. Five sampled mungbean plants were randomly selected for counting the number of grains per pod, and number of branches per plant. Mungbean was hand harvested about two weeks before maize. The grain yield was harvested from all the plants in each plot. The grain weights were converted to weight at 12% moisture content and expressed as per hectare basis. The biomass as oven dried at 70 °C for two days and weighted. To estimate harvest index (HI), the grain yield was divided by the total above ground biomass yield [29]. One-hundred grain weight was measured.

Land Equivalent Ratio (LER) was used to evaluate the yield performance between intercropping and monocropping systems using formulae of Willey [30] as follows where yield was expressed as kg ha^{-1}.

$$\text{LER} = \frac{Yield\ (Intercropping_{Maize})}{Yield\ (Monocropping_{Maize})} + \frac{Yield\ (Intercropping_{Mung\ Bean})}{Yield\ (Monocropping_{Mung\ Bean})} \quad (1)$$

2.6. Statistical Analysis

All the data was tested for normality of distribution before being subjected to Analyzes of Variance (ANOVA) for significance in both treatment effect and interaction; and mean values were assessed by Tukey's HSD test at 5% level of significance in order to compare agronomic performance of maize, and of mungbean, weed dry biomass and chlorophyll reading index under different mungbean seed rates. The analyses were performed using Statistix 8 program (Version 8.0, Analytical Software, 1985–2003)

3. Results

There was no significant effect of mungbean seed rates on growth traits (ear height, plant height, biomass), phenology (days to male and female flowering) or yield traits (ear length, weight of ear with husk, ear weight and ear diameter) of maize (Tables 2 and 3). Similarly, there was no significant interaction between mungbean seed rates and cropping systems (mungbean intercropped with maize vs. mungbean monocropping), except for number of branches per plant and dry biomass of munbean (Tables 4 and 5).

Table 2. Effect of mungbean seed rates on ear height, plant height, and flowering of maize under maize-mung bean cropping system.

Mungbean Seed Rates (kg ha^{-1})	Ear Height (cm)	Plant Height (cm)	Day to Flower		Plant Biomass (g)
			Male	Female	
0	78.67 ± 5.03	234.20 ± 9.42	45.67 ± 1.15	48.67 ± 1.15	625.50 ± 8.40
10	86.67 ± 7.63	234.60 ± 15.24	46.67 ± 0.58	49.00 ± 0.00	623.17 ± 0.35
20	86.33 ± 4.04	235.27 ± 11.37	46.00 ± 1.00	49.00 ± 1.00	610.33 ± 0.85
30	79.00 ± 11.53	229.60 ± 4.20	46.33 ± 1.15	49.67 ± 0.58	600.57 ± 3.75
40	78.00 ± 7.55	232.20 ± 0.40	46.33 ± 1.15	49.00 ± 1.00	619.73 ± 5.28
p Value	0.27 ns	0.92 ns	0.78 ns	0.69 ns	0.41 ns

Value is the mean ± standard deviation (SD); "ns" denots non-signfinificant difference between treatments at $p \geq 0.05$.

Table 3. Effect of mungbean seed rates on length, ear weight with husk, ear weight per plant and diameter of maize ears under maize-mungbean cropping system.

Mungbean Seed Rates (kg ha^{-1})	Length (cm)	Ear Weight with Husk (g)	Ear Weight Per Plant (g)	Ear Diameter (cm)
0	22.37 ± 0.15	364.23 ± 45.03	468.40 ± 28.00	3.86 ± 0.39
10	22.23 ± 0.15	265.08 ± 91.36	527.87 ± 67.59	3.59 ± 0.20
20	22.63 ± 0.46	341.40 ± 39.38	586.19 ± 3.15	3.77 ± 0.47
30	21.83 ± 0.55	297.12 ± 24.58	430.13 ± 41.11	3.49 ± 0.17
40	22.93 ± 0.41	337.33 ± 38.74	481.08 ± 54.02	3.80 ± 0.48
p Value	0.09 ns	0.19 ns	0.17 ns	0.74 ns

Value is the mean ± standard deviation (SD); "ns" denots non-signfinificant difference between treatments at $p \geq 0.05$.

Table 4. Significance, analysis of variance effects of main and interaction effects of mungbean seed rates and cropping systems on different agronomic traits for mungbean.

Source	df	$DTF_{50\%}$	$DTF_{100\%}$	NGPP	NBPP	OHGW	DB	GY	HI
Mungbean seed rates (MSR)	3	ns	ns	**	**	*	ns	**	ns
Cropping system (CS)	1	ns	ns	ns	**	ns	**	**	ns
MSR × CS	3	ns	ns	ns	*	ns	**	ns	ns
Error	14								
Total	23								

DTF: Day to flowering, NGPP: Number of grains per pod, NBPP: Number of branches per plant, OHGW: One hundred grain weight, DB: Dry biomass, GY: Grain yield, HI: Harvest index. * and **, significant at $p < 0.05$ and $p < 0.01$ levels, respectively. "ns" denotes non-significant difference between treatments at $p \geq 0.05$.

Table 5. Monocropped mungbean and maize yields, compared to intercropping and yield deviation from monocropping and land equivalent ratio (LER).

Mungbean Seed Rates (kg ha^{-1})	Mungbean Grain Yield (t ha^{-1})		Yield Deviation from Monocropping		Maize Yield as Total Fresh Ear Weight (t ha^{-1})		LER Mungbean	LER Maize	LER
	Monocropping	Intercropping	Intercropping	% Decrease	Monocropping	Intercropping			
10	0.70 b ± 0.07	0.38 d ± 0.02	−0.32	−45.71	24.98	24.55 ± 3.60	0.84 ± 0.32	0.98 ± 0.14	1.82 ± 0.27
20	0.88 ab ± 0.10	0.60 c ± 0.01	−0.28	−31.82		27.53 ± 6.47	0.67 ± 0.25	1.10 ± 0.26	1.77 ± 0.08
30	0.99 a ± 0.08	0.69 b ± 0.03	−0.30	−30.30		22.94 ± 2.19	0.60 ± 0.19	0.91 ± 0.09	1.52 ± 0.19
40	1.06 a ± 0.21	0.82 a ± 0.02	−0.24	−22.64		25.66 ± 2.88	0.68 ± 0.17	1.03 ± 0.12	1.70 ± 0.21
p-Value	0.02 *	0.00 **	-	-		0.30 ns	0.14 ns	0.63 ns	0.98 ns

Value is the mean ± standard deviation (SD); * and **, significant at $p < 0.05$ and $p < 0.01$ levels, respectively; ns, nonsignificant at $p \geq 0.05$, "ns" denotes non-significant difference between treatments at $p \geq 0.05$; different letters in a column denote significant difference by Turkey HSD's (Honesty Significant Difference) test.

Significant differences were detected for number of grains per pod, number of branches per plant, one-thousand grain weight and grain yield as affected by mungbean seed rates while the cropping systems significantly influenced number of branches per plant and dry biomass (Table 4).

Under either monocropping or intercropping system, it was observed that mungbean yield increased significantly when seed rate increased (Table 5). However, mungbean under intercropping with maize had lower grain yield compared to monocropping. Generally, mungbean yield under intercropping decreased between 0.24 and 0.32 t ha^{-1}, equivalent to 22.64 and 45.71%, respectively.

The yield of maize was not significantly different between monocropping and intercropping systems. Moreover, there was no significant difference in maize yield under different mungbean seed rates. In general, maize had higher LER than that of mungbean (Table 5). In all mungbean seed rates, the intercropping increased overall LER, compared to monocropping. LER of intercropping ranged between 1.52 and 1.82.

Under monocropping of maize, the weed population was high. On the contrary, the trend of weed biomass decreased with increasing seeding rates. Taken together, the utilization of the recommended seeding rates of mungbean as proposed by CARDI effectively suppressed weeds (Figure 2).

Chlorophyll reading index (CRI) was not different under either different mungbean seeding rates. However, CRI of mungbean under intercropping system was relatively lower, compared to monocropping system (Figure 3).

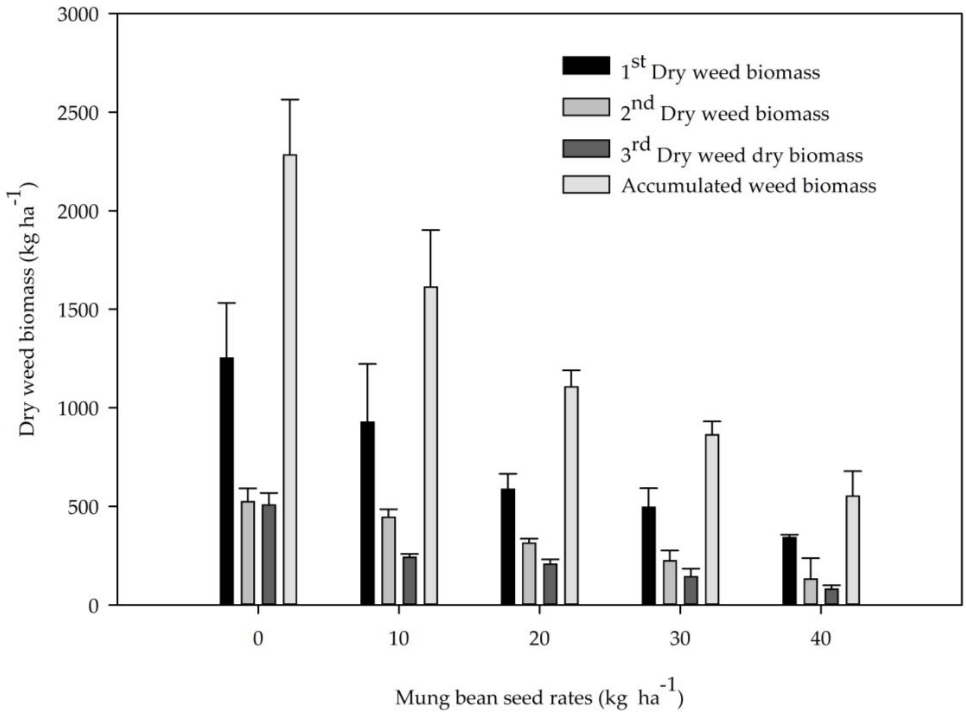

Figure 2. Weed dried biomasses during the crop growth. The error bar is the standard deviation. different letters in a column denote significant difference in accumulated weed biomass by Turkey HSD's (Honesty Significant Difference) test.

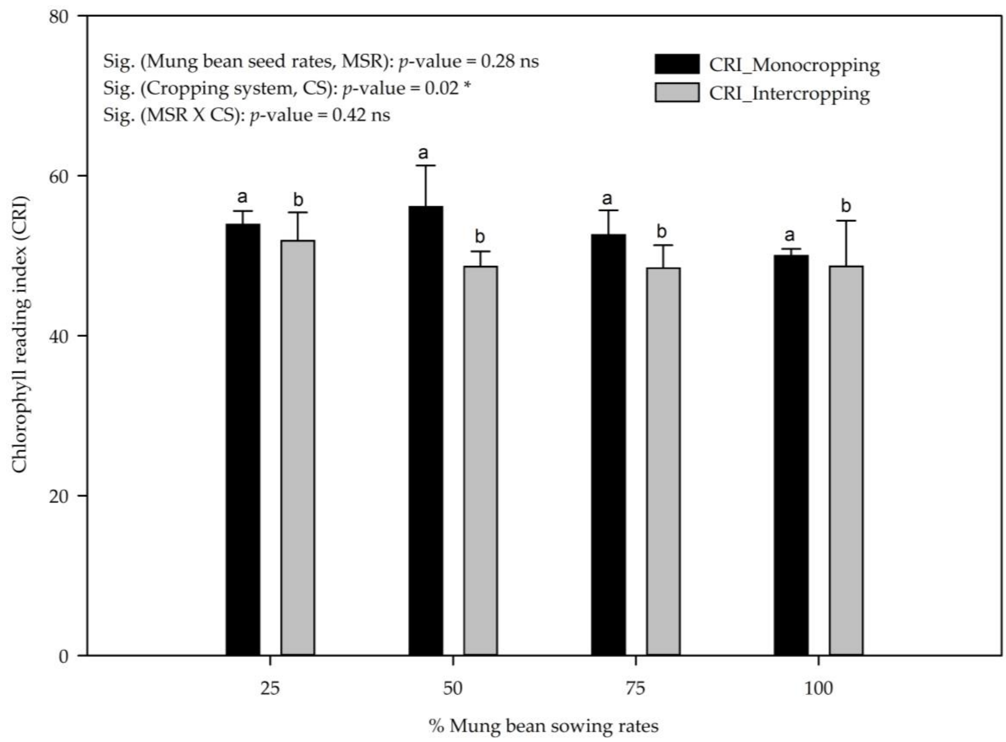

Figure 3. Chlorophyll reading index (CRI) of mungbean as affected by different rates of mungbean seed. The error bar is the standard deviation. "ns" denotes non-significant difference between treatments. * denotes significant difference between treatments at $p < 0.05$. Different letters in a column denote significant difference in accumulated weed biomass by Turkey HSD's (Honesty Significant Difference) test.

4. Discussion

In our research, maize growth and yield was not affected by cropping systems (monocropping or intercropping) under different seed rates of mungbean. Similar results were reported by Worku [31] where mungbean did not impact on maize yield. Mugi-Ngenga et al. [32] reported that yield of maize was not reduced under intercropping with legume. A legume species like mungbean fix nitrogen from atmosphere [3] which may account for 78% of N content [33]. Thus, the competition for soil N for maize crops was minimized in the intercropping system. Moreover, 7–11% of N for maize crop can derive from mungbean [33]. Therefore, the competition under high seed rates of mungbean in the intercropping may have compensated with the contribution of N from mungbean to the neighboring maize plants, particularly in the later part of the growing season during grain filling stages. Although Chamkhi et al. [3] showed that inclusion of legume increased the maize production up to 35% under intercropping systems.

In our research weeding was done three times to measure weed biomass, thus, the competition between weeds and maize crop was absent, which may have resulted in such a response. The monocropping maize may decline without weed control, which needed to be investigated in future study. Further study needs to be investigated under the absence of weed control, which may affect the monocropping maize's growth and yield.

The decline of mungbean yield in intercropping compared to monocropping has been reported previously [31]. This was due to the competition between maize and mungbean [34,35]. In addition, mungbean is short-day crop and generally is sensitive to photoperiod [12]. Moreover, the intercropped maize had a better radiation use efficiency (RUE) compared to monocropped maize [36]. Thus, legumes may have received lower radiation under intercropping with maize as shown by lower CRI. Moreover, the nitrogen used by maize may have reduced the soil N during the early vegetative stages which may have impacted nodulation and N fixation, resulting lower grain yield and biomass of mungbean [37]. The nitrogen status of plant can be analyzed indirectly using SPAD readings [38] which are positively correlated with leaf chlorophyll content [39]. Islam et al. [40] also reported the positive correlation between CRI and crop yields. The use of recommended broadcasting rates of mungbean (100% plant density) maintained the higher grain yield compared to reduced rates under either monocropping or intercropping. Few others found contradicting results, where there was reduction of mungbean yield under monocropping, compared to intercropping [41]. Highest rates of mungbean either under intercropping or monocropping was 40 kg ha^{-1}, which is a recommended rate for monocropping mungbean [28]. Perhaps, this recommendation needs to be further evaluated under different conditions and under different cropping systems.

In general, LER is used to measure land productivity [1]. LER was better under maize-mungbean cropping [34] as indicated by being higher than 1 [36]. For instance, the LER of maize-mungbean intercropping was between 1.77 and 1.80 [42] and between 1.70 and 1.89 [36]. In our research the LER value was between 1.52 and 1.82 (Table 5), indicating the benefits of a maize-mungbean intercropping to utilize the land efficiently compared to monocropping, as shown by others [1,4,36]. In addition, complementary and mutual interaction between maize and mungbean may have occurred [43]. We acknowledge that in intercropping systems several other indicators (e.g., area time equivalent ratio, aggressivity, competitive ratio, relative crowding coefficient) in addition to LER can be used to quantify benefits of complementarity, competition and facilitation, which are worthy of evaluation in future research. In addition, in this research we did not conduct the cost-benefit analysis which is important for adoption and scaling and must be considered in future research.

The results clearly show that there were no negative impacts of intercropping on maize yields in comparison with monocropping. One of the limitations of this research was that it was conducted for one year and one location. Repetition of the experiment at the same location, and similar or more favorable climate condition for both maize and mungbean would still show benefits of intercropping, compared to monocropping. However, future research must consider different genotypes, (both maize and mungbean), soil types, soil moisture conditions and multi-locations to capture interactions between various biophysical and environmental conditions.

5. Conclusions

The current study shows that the growth and yield of maize did not decrease when intercropped with mungbean regardless of seed rates (0 to 100%, 0 to 40 kg ha^{-1}), compared to monocropping maize. In addition, the land Equivalent Ratio (LER) in intercropping is more than 1, which shows mungbean-maize intercropping is a potential practice to utilize the resources efficiently and is more productive compared to monocropping. Thus, the current recommended mungbean seed rates can be used in maize intercropping without negatively impacting the maize yield, but in turn it can significantly suppress the weed population. As a result, under intercropping weed controls are not generally needed. However, the growth and yield of mungbean was reduced under intercropping in comparison with monocropping mungbean. Weeds were removed in both cropping systems, which may be partly responsible for observed responses. Even though this experiment was carried out in one year, the results would be important as directions for future research that could significantly benefit cropping system in Cambodia. Therefore, future research is needed to quantify LER under different weed and nutrient management strategies and under different soil types and environmental conditions. Such research would be helpful to identify the regions for scaling intercropping systems to increase overall productivity and resilience of cropping systems in Cambodia and to assess the cost-benefit of intercropping against monocropping.

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