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Studies on Yield, Land Equivalent Ratio and Crop Performance Rate in Maize–Mungbean Intercropping

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A field experiment was conducted on maize–mungbean intercropping to assess the yield advantage from the viewpoint of growth process. Three maize densities (75×50, 75×30, 75×15 cm²) were intercropped with mungbean one row between maize rows. Intercropping did not affect the maize yield, but the yields of mungbean were greatly affected. The maximum and minimum yields of mungbean were obtained in a mungbean monoculture plot and mungbean intercropped with a high–density maize plot, respectively. The leaf photosynthetic rate of maize in different plots was insignificant. That of mungbean, however, was significantly affected, and it decreased under the higher density plot. The total dry matter production in per unit area increased due to intercropping. The crop growth rate (CGR) and net assimilation rate (NAR) of maize were highest in the low–density plot and total the CGR and NAR were also highest in the low–density plot at later stages of growth. Land equivalent ratios (LER) were higher than 1.0 in all intercrop plots and crop performance ratio (CPR) was higher than 1.0 only in low–density plot. The highest LER (1.79) and CPR (1.23) were observed in the low–density plot.

INTRODUCTION

Suitable land areas for food production remain fixed or are diminishing; yet farmers and agronomist are faced with the task of increasing production. Raising productivity, through a more effective use of natural (e.g. light) and added (e.g. fertilizer) resources, is possible through intercropping (Midmore, 1993). Intercropping reduces damage caused by diseases, insects and weeds. The choice of crops, population density and crop geometry such as row orientation, in intercropping systems, permits the effective use of natural resources through suitable competition among the component crops to obtain higher yields. Successful crop mixtures extend the sharing of available resources over time and space, exploiting variations between component crops, in with such characteristics as rates of canopy development, final canopy width and height, photosynthetic adaptation of canopies to irradiance conditions and rooting depth. Intercropping of legumes with cereals offers a wide scope for developing energy–efficient and sustainable agriculture. Advantages in radiation usage have been suggested for combinations of a tall cereal C4 species grown as intercrops with shorter C3 legumes (Trenbath, 1986). In an intercrop

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canopy, the tall C4 species provide greater light penetration so that better light distribution is available over the leaves located in the lower stratum. The understory C3 species is shaded, but this is partially offset by its higher photosynthetic rates per unit radiant energy at a low light intensity (Warren Wilson, 1969). Maize (*Zea mays*) is a tall stature C4 plant without photosynthetic saturation by light energy, and mungbean (*Vigna radiata*) is a short stature C3 plant with photosynthetic saturation. Although some authors (Mandal *et al*, 1990, Chowdhury and Rosario, 1992 and Chowdhury, 1993) studied maize–mungbean intercropping, most of the studies emphasized only the analysis of yields and yield components.

The aim of this experiment is to analyze the yield improvement in maize–mungbean intercropping, in which different density plots of maize have been intercropped with mungbean, from the viewpoint of growth process.

MATERIALS AND METHODS

Site

The experiment was conducted at the farm of Kyushu University, Japan from June 1999 to October 1999.

Treatments and management

The following experimental plots were designed as the main plots and sub plots.

Main plots:

T1=Maize ($75\times50\,cm^2$)+1 row mungbean between maize rows

T2=Maize ($75\times30\,cm^2$)+1 row mungbean between maize rows

T3=Maize ($75\times15\,cm^2$)+1 row mungbean between maize rows

Ma2=Maize monoculture ($75\times30\,cm^2$)

Mu=Mungbean monoculture (37.5 cm row sowing)

Sub plots:

Ma1*=Maize monoculture ($75\times50\,cm^2$)

Ma3*=Maize monoculture ($75\times15\,cm^2$)

Concerning the main plots, three replications, one plot size was $7\times6\,m^2$ and the other two plot sizes were $6\times5\,m^2$, were prepared. The sub plot's size was $6\times5\,m^2$ with no replication. $CaCO_3$ of 3500 kg ha^{-1} was applied to the total area at the time of final land preparation. A chemical fertilizer (8–8–8%=N, P_20_5, K_20) of 1000 kg ha^{-1} was used for the maize monoculture and the intercrop plots and 250 kg ha^{-1} for the mungbean monoculture. All fertilizers were applied as basal. Maize variety Tx–120 (TAKII EUROPE B. V.) and mungbean variety Kanti were used in this experiment. The plots were covered with mulch cloth (20507 BKD, UNITIKA) to prevent weed infestation. Before setting the mulch sheets in the field, holes with a 5 cm diameter were made according to maize plant spacing for density treatments. After setting the mulch sheets in the field, 10 cm width slits were made in the sheets, with a position between the maize rows, for mungbean sowing in intercropping treatment plots. For the mungbean monoculture, 10 cm width slits were also made in the mulch sheet with a 37.5 cm interval. Three seeds of maize were sown in each spot and the mungbean were sown in rows in the slits. After emergence, the maize seedlings were thinned out and one seedling was maintained in each spot. The mungbean were thinned out maintaining an approximate 10 cm distance between plants.

Growth analysis

Plants of $0.75\,m^2$ ($1\,m \times 0.75\,m$) in each plot (T1, T2, T3, Ma2 and Mu) with three replications were sampled for growth analysis at 30, 52, 73 and 96 days after sowing (DAS). Plant materials were separated into leaves, stems and fruits (depending on the growth stage). The leaf area was measured with an automatic area meter (AAM-8, Hayashi Co. Ltd., Japan). The plant materials were chopped and dried at 85 °C for 72 hours. Maize, including the Ma1 and Ma3 plots, were harvested at 111 DAS and the mungbean at 125 DAS.

Photosynthesis

The leaf photosynthesis of maize and mungbean were measured by a portable photosynthesis apparatus (LI-6400) at 53 DAS from 10.30am to 3.30 pm using artificial red blue light ($1000\,\mu mol\ m^{-2}\ s^{-1}$) to overcome the cloudy condition of the sky. Fully expanded central leaflets of the trifoliate leaf of the mungbean and the 10 th leaves (from the bottom) of the maize were used for this purpose with three replications. In both cases the middle parts of leaves were used for measurement.

Land equivalent ratio (LER) and crop performance ratio (CPR)

LER and CPR were calculated by the following equations, which were rearranged by using the original formula (LER, Mead and Willey (1980): CPR, Harris *et al.* (1987), Azam-Ali *et al.* (1990))

$$\text{Partial LER} = Q_{int,cropa} / Q_{mono,cropa} \quad (1)$$

$$\text{Total LER} = \Sigma\,(\text{partial LER}) \quad (2)$$

$$\text{Partial CPR} = Q_{int,cropa} / (P_{int,cropa} \times Q_{mono,cropa}) \quad (3)$$

$$\text{Total CPR} = (Q_{int,cropa} + Q_{int,cropb}) / [(P_{int,cropa} \times Q_{mono,cropa}) + (P_{int,cropb} \times Q_{mono,cropb})] \quad (4)$$

where, $Q_{int,cropa}$ and $Q_{mono,cropa}$ are the yield per unit area in the intercrop and mono crop of species a, respectively, and $Q_{int,cropb}$ and $Q_{mono,cropb}$ are also those of species b, and $P_{int,cropa}$ is the proportion of the intercrop area sown with species a and $P_{int,cropb}$ is also that with species b.

RESULTS

Dry matter

Maize

The dry matter weight per unit area of maize in the high-density plot T3 showed significantly high at 30 DAS (Fig. 1). At 52 DAS, though the same plot also showed the highest, the difference among the treatments was insignificant. At 73 DAS, the maize monoculture produced the highest dry matter, which was statistically insignificant with that of the T3 plot. At a later growth stage (96 DAS), the maize monoculture was followed by T3, T1 and T2 treatments in terms of dry matter production. However, the differences were insignificant.

Mungbean

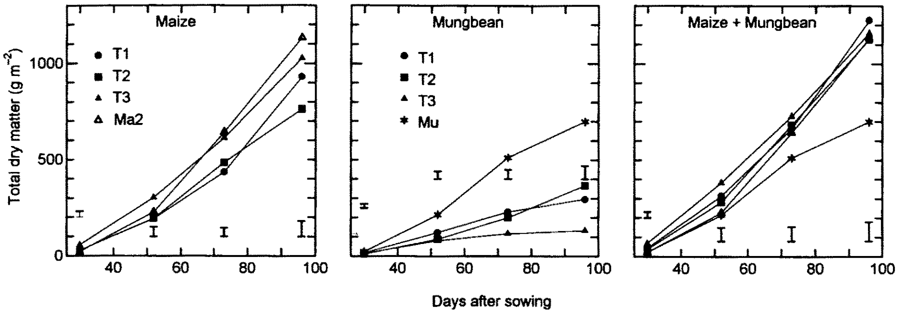

Fig. 1. Changes of total dry matter of the component crops in maize-mungbean intercropping and monocrops. T1, T2 and T3 show maize densities 75×50, 75×30 and 75×15 cm², respectively, and Ma2 and Mu show maize (75×30 cm²) and mungbean (37.5 cm row sowing) monocultures, respectively. Vertical bars show S. E of the means.

The dry matter accumulation pattern in mungbean is also shown in Fig. 1. Among the treatments, the mungbean monoculture produced significantly higher dry matter (g m^{-2}) over the growing period. At 52 DAS, the dry matters of mungbean in the intercrop treatments did not differ significantly but at 73 DAS they differed significantly. At a later growth stage, the mungbean monoculture was highest and followed by the T2, T1 and T3 plots in terms of dry matter production. The minimum dry matter was observed in the T3 plot over the whole growing period.

Total Dry matter

Among all treatments, significantly higher dry matter was observed in maize high-density T3 at 30, 52 and 73 DAS. At 96 DAS, higher dry matter was observed in the T1 treatment, which was followed by the T3, T2, and Ma2 treatments but the differences were insignificant (Fig. 1). Among the treatments, the minimum dry matter was found in mungbean monoculture Mu.

Leaf area index (LAI)

Maize

The highest LAI was observed in the high-density plot T3 over the whole growing period except at the last sampling, where the maize monoculture overtook T3 (Fig. 2). The minimum LAI was observed in the low-density plot T1 over the whole growing period. The LAI of the maize monoculture and low-density plot T1 increased up to 96 DAS, while the LAI of the T3 and T2 plots increased up to 52 and 73 DAS, respectively.

Mungbean

The LAI of mungbean on all plots increased up to 73DAS, and then it decreased (Fig. 2). The LAI of plot T1, which was the maize low-density plot, was higher than that of the T2 plot, except at the last sampling, where the T2 plot overtook T1. The maximum LAI was observed in the mungbean monoculture over the growing season, which was followed by those of the T1, T2 and T3 plots.

Total LAI

Total LAI was increased up to 73 DAS in all the plots, except the maize monoculture

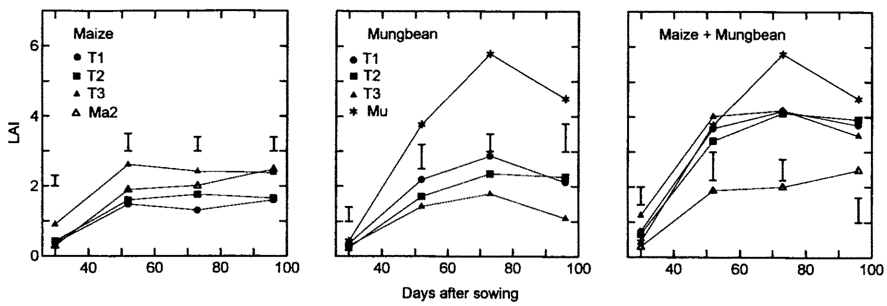

Fig. 2. Changes of LAI of the component crops in maize–mungbean intercropping and monocrops. T1, T2, T3, Ma2 and Mu are the same as in Fig. 1. Vertical bars show S. E of the means.

(Fig. 2). Total LAI of the T3 plot was the highest from 30 to 52 DAS, after that the mungbean monoculture LAI became the highest. Finally, the highest LAI was observed in the mungbean monoculture, which was followed by those of T2, T1, T3, and the maize monoculture. The minimum LAI was observed in the maize monoculture throughout the entire growing period.

Crop Growth Rate (CGR)

Maize

Crop growth rate (CGR) of maize, at different growth stages, is shown in Fig. 3. CGR of all the plots increased with the progress of the plant age except the T2 plot, of which the CGR decreased after 73 DAS. Among the plots, the maize monoculture showed the highest CGR over the growing period. From the early to middle growth stage, the CGR of the T3 plot was higher than those of the T2 and T1 plots. A sharp increase in the CGR of the T1 plot was observed from 73 to 96 DAS. Finally, the CGR of the T1 plot and the maize monoculture were almost the same, which were then followed by those of T3 and T2 plots.

Mungbean

The CGR of the mungbean monoculture and the T1 plot increased up to 73 DAS and thereafter it decreased. The CGR of the T2 plot increased up to 96 DAS. But the CGR of the T3 plot decreased with the progress of the growth stage. The highest CGR was observed in the mungbean monoculture plot in all stages, which was then followed by those of the T2, T1 and T3 plots.

Total CGR

The total CGR increased up to the latter stages of growth, except the mungbean monoculture (Fig. 3). The CGR of mungbean decreased after 73 DAS. At an early stage, the CGR of maize high–density T3 was higher than those of others, but finally the CGR of maize low–density T1 overtook that of T3.

Net assimilation rate (NAR)

Maize

NAR decreased with the progress of the plant age, up to 73 DAS, in all the plots.

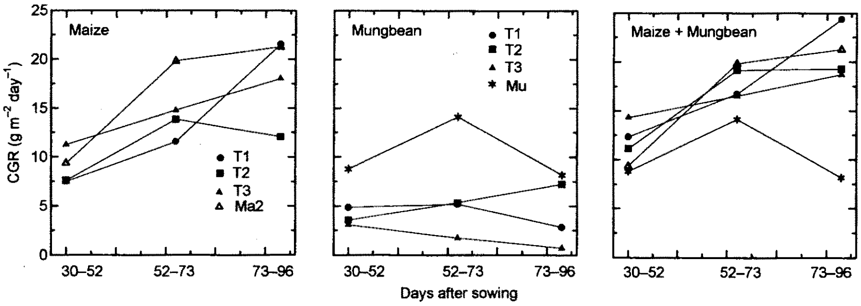

Fig. 3. Changes of crop growth rate of the component crops in maize–mungbean intercropping and monocrops. T1, T2, T3, Ma2 and Mu are the same as in Fig. 1.

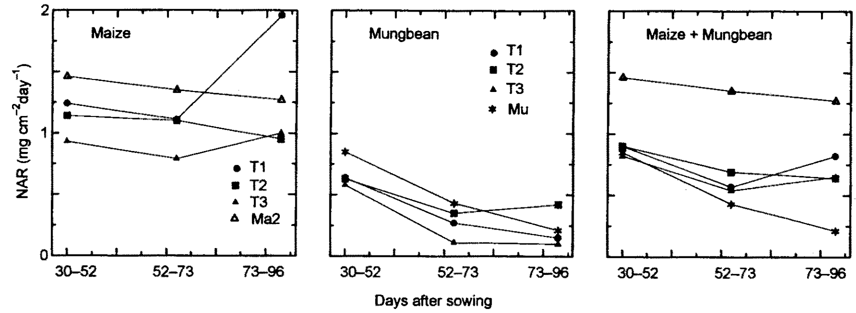

Fig. 4. Changes of net assimilation rate of the component crops in maize–mungbean intercropping and monocrops. T1, T2, T3, Ma2 and Mu are the same as in Fig. 1.

After 73 DAS, NAR increased only in the maize high– and low–density plots (Fig. 4). In early stages, from 30 to 73 DAS, higher NAR was observed in maize monoculture, but in later stages, NAR of maize low–density T1 was higher. Although the lowest NAR was observed in maize low–density T3 from 30 to 73 DAS, it was higher than that of T2 from 73 to 96 DAS.

Mungbean

NAR of mungbean decreased with the progress of the plant age except for the T2 plot (Fig. 4). The NAR of the T2 plot decreased up to 73 DAS, after 73 DAS it increased. The NAR of the mungbean monoculture was higher than those of the other plots from 30 to 73 DAS but after 73 DAS it was lower than that of the T2 plot.

Total NAR

NAR decreased with the progress of the plant age up to 73 DAS in all plots (Fig. 4). After 73 DAS, NAR increased only in the maize high– and low–density plots. The NAR of the maize monoculture was higher than those of the other plots in all growth stages.

Leaf Photosynthesis

Maize

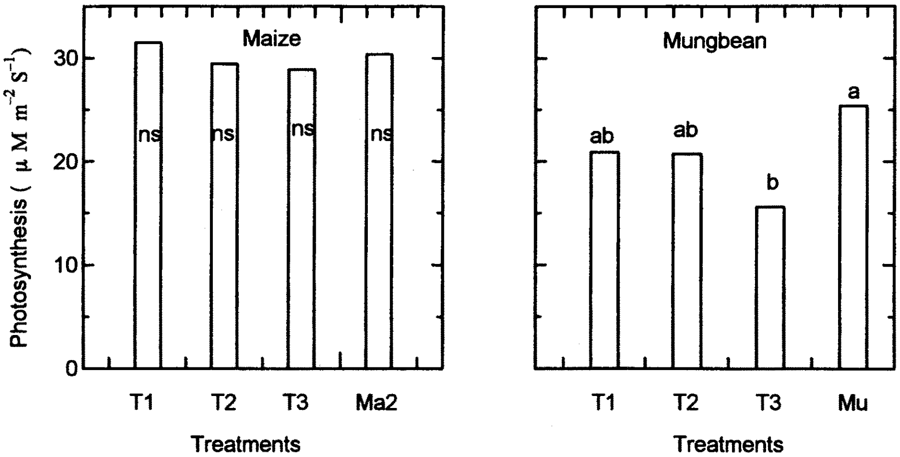

Fig. 5 Photosynthesis of the leaves of maize and mungbean at different treatments in maize–mungbean intercropping at 65 DAS. A common letter in the figure shows insignificant difference at the 5% level by Duncan's Multiple Range Test. ns=not significant. T1, T2, T3, Ma2 and Mu are the same as in Fig. 1.

Comparatively higher leaf photosynthesis was observed in T1 and the maize monoculture, however the differences were insignificant (Fig. 5).

Mungbean

Leaf photosynthesis varied significantly among the plots. The maximum leaf photosynthesis was observed in the mungbean monoculture, which was statistically similar to that of the T1 and T2 plots. The minimum leaf photosynthesis was found in the T3 plot.

Yield and yield components

Maize

Yield components of maize varied significantly depending on the density treatments

Table 1. Yield and yield components in maize–mungbean intercropping

Treatment	Maize				Maize				
	No. of Cobs m^{-2}	No. of Seeds cob^{-1}	100-seed weight g	Yield g m^{-2}	No. of Pods m^{-2}	Effective pod ratio	No. of seeds pod^{-1}	100-seed weight g	Yield g m^{-2}
T1	2.96c**	479.94a**	31.78a*	451.51ns	122.96b**	0.67ns	9.08ns	2.87ns	19.84b**
T2	4.44b	405.87a	27.15bc	480.17„	123.70b	0.66	9.03„	2.75„	19.92b
T3	8.00a	283.10b	25.19c	558.67„	62.96c	0.67	9.45„	2.72„	12.54c
Ma2	4.59b	419.67a	29.19ab	523.28„	–	–	–	–	–
Mu	–	–	–	–	205.04a	0.67	9.31„	2.71„	36.14a

T1, T2, T3 Ma2 and Mu are same as in Fig. 1

* , ** and ns show that the means followed by the same letters in the column are not significantly different at 5% and 1% level of probability, and not significant, respectively, by Duncan's Multiple Range Test.

but the yield did not vary (Table 1). The number of cobs per square meter increased with the increase of maize plant density. The number of seeds per cob was the maximum in the low–density T1, which was statistically similar to those of the maize monoculture and the T2 plot. It was minimum in the high–density T3 plot. The hundred seed weight was the maximum in the T1 plot, which was similar to that of the maize monoculture. The hundred seed weight of T2 and the maize monoculture, with the same density as T2, were identical. Although the seed yield was insignificant, a comparatively higher seed yield was observed in the T3 plot, which was followed by that of the maize monoculture.

Mungbean

Among the yield components, only the number of pods per square meter was significantly different (Table 1). The maximum number of pods per square meter was obtained in the mungbean monoculture. A statistically similar number of pods per square meter was observed in the T1 and T2 plots and the minimum was observed in the T3 plot. The effective pod ratio, the number of seeds per pod and the 100–seed weight were not influenced by the density treatments. The seed yield was statistically different. The maximum seed yield was observed in the mungbean monoculture, which was significantly higher than those in the other treatments. A statistically similar seed yield was found in the T1 and T2 plots and the minimum was found in the T3 plot.

Land Equivalent Ratio (LER)

The LER of the intercrop treatments were higher than 1.0 (Table 2). If we calculate

Table 2. Land equivalent ratio (LER) and Crop performance ratio (CPR)

A (calculated by using the yield of a maize monoculture, which the density is the same as each intercrop)

Treatment	Yield ($g\ m^{-2}$)		Partial LER		Total LER	Partial CPR		Total CPR
	Maize	Mungbean	Maize	Mungbean		Maize	Mungbean	
T1 (75 cm×50 cm)	451.51	19.84	1.24	0.54	1.78	1.24	1.10	1.23
T2 (75 cm×30 cm)	480.17	19.91	0.91	0.55	1.46	0.91	1.10	0.92
T3 (75 cm ×15 cm)	558.67	12.54	1.01	0.34	1.35	1.01	0.69	1.00
Ma 1 (75 cm×50 cm)*	363.95	–	1.00	–	1.00	–	–	–
Ma 2 (75 cm ×30 cm)	523.28	–	1.00	–	1.00	–	–	–
Ma 3 (75 cm ×15 cm)*	553.10	–	1.00	–	1.00	–	–	–
Mu	–	36.14	–	1.00	1.00	–	–	–

* Sub plots mentioned in Materials and Methods

B (calculated by using the highest yield of a maize monoculture, in which the density is high)

Treatment	Yield ($g\ m^{-2}$)		Partial LER		Total LER	Partial CPR		Total CPR
	Maize	Mungbean	Maize	Mungbean		Maize	Mungbean	
T1 (75 cm×50 cm)	451.51	19.84	0.81	0.54	1.36	0.81	1.10	0.83
T2 (75 cm×30 cm)	480.17	19.91	0.86	0.55	1.41	0.86	1.10	0.88
T3 (75 cm ×15 cm)	558.67	12.54	1.01	0.34	1.35	1.01	0.69	1.00
Ma 3 (75 cm ×15 cm)*	553.10	–	1.00	–	1.00	–	–	–
Mu	–	36.14	–	1.00	1.00	–	–	–

* Sub plots mentioned in Materials and Methods

the LER by using the same population density of maize in the sole and intercropping plots, the highest LER was observed in the T1 plot (Table 2A). But, when we calculate it by using the highest yield of maize in a sole plot, the LER of T2 was the highest (Table 2B).

Crop Performance Ratio (CPR)

The CPR of maize in the intercrop plots was higher than 1.0 in the T1 and T3 plots (Table 3), in which the highest CPR was obtained in the low-density plot T1. For mungbean, the CPR of T1 and T2 was higher than 1.0, but in T3 it was less than 1.0. In the case of intercrop CPR, only that of the T1 plot was higher than 1.0.

DISCUSSION

In the present experiment, maize monocultures of three densities and intercropping of three densities, in which each maize monoculture was intercropped with mungbean, were conducted. Therefore, two types of LER and CPR were calculated, which were obtained by **(A)** comparing the intercrop yield with the monoculture yield, in which the density is the same as each intercrop density, and by **(B)** comparing the intercrop yield with the highest yield of the monoculture among all the density plots of the monocultures.

The total LER of all density treatments calculated by both **(A)** and **(B)** are higher than 1.0 (Table 2), indicating an advantage for maize-mungbean intercropping. The total LER of the low-density plot, calculated by **(A)**, is especially higher than that calculated by **(B)**. However in this experiment, even in the high-density plot, the LER is 1.35. Probably this result comes from the lower LAI (=1.5~2.5) of maize attained by this experiment (Fig. 2) (Chaudhury and Posario, 1992, Hirota *et al.*, 1995).

The total CPR in the low-density plot T1, calculated by **(A)**, was higher than 1.23 while all other total CPR including the total CPR by **(B)** are close to 1.0 or less than 1.0. The CPR of maize in the low-density plot, calculated by **(A)**, was higher than 1.0, and the CPR of mungbean in the high-density plot was 0.69, suggesting that there was a depression of mungbean growth by intercropping. The total CPR of intercropping calculated by **(B)** were 1.0 or less than 1.0.

Regarding higher rates of both LER and CPR on low-density plots, from the viewpoint of growth characteristics, further discussion will be done hereafter. There was no significant difference in maize yields among the density treatments including both intercropping and monoculture plots, though the maize yield increased with density increment in intercropping (Table 1). On the other hand, the yield components differed among the treatments depending on the density; the low-density plot had a lower cob number m^{-2} but it had a higher seed number cob^{-1} and 100 grain weight. This result is supported by the higher CGR in low-density plot at later stages, which was also supported by a higher NAR, even though a lower LAI was observed (Fig. 2, 3, 4). The leaf photosynthesis of maize in low-density plot is little bit higher than that of the other densities, although the differences were statistically insignificant (Fig. 5). In the case of mungbean, only the pod number m^{-2} was significantly different among the yield components. In this experiment the mungbean yield was determined by the pod number m^{-2}, which were fixed at a relatively early stage, compared to the other yield components

(Table 1). The yield of mungbean in low–density plot was intermediate between those of the monoculture and high–density plot.

Though the concept of LER is different from CPR (Harris *et al.*, 1987), the results of these both indicators show that the low–density of intercropping reveals a higher yield advantage. However, while the total LER calculated by **(B)** are still higher than 1.0, the total CPR calculated by **(B)** becomes less than 1.0. The concept of LER has so close relation to the agricultural aspect that LER obtained by the **(B)** method, which compares intercrop yield to the highest yield of the monocultures, has a reasonable base. However, the CPR relates more to the biological base, because the relationship between LER and CPR is as $CPR_a=LER_a$/(proportion of *a* crop area in intercrop), in which CPR should include a more biological base because the available natural resources become clear due to the declaration of the occupied land area by crop *a*. Therefore, CPR calculated by **(A)** would be a more meaningful indicator than that obtained by **(B)** for the evaluation of an intercropping system from a biological stand point.

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