Cropping system diversification for food production in Mindanao rubber plantations: A rice cultivar mixture and rice intercropped with mungbean

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Including food production in non-food systems, such as rubber plantations and biofuel or bioenergy crops, may contribute to household food security. We evaluated the potential for use of rice, mungbean, rice cultivar mixtures, and rice intercropped with mungbean in experiments planted in young rubber plantations in the Arakan Valley of Mindanao. Rice mixtures consisted of two- or three-row strips of cultivar Dinorado, a cultivar with higher value but lower yield, and high-yielding cultivar UPL Ri-5. Rice and mungbean intercropping treatments consisted of different combinations of two- or three-row strips of rice and mungbean. We used generalized linear mixed models to evaluate the yield of each crop alone and in the mixture or intercropping treatments, as well as a land equivalent ratio for yield, and weed biomass, the severity of panicle blast, brown spot, and brown leaf spot, and rice bug abundance. We also analyzed the yield ranking of each cropping system across site-year combinations to determine mean relative performance and yield stability. When weighted by their relative economic value, UPL Ri-5 had the highest mean performance, but with decreasing performance in low-yielding environments. A rice and mungbean intercropping system had the second highest performance, tied with high-value Dinorado but without decreasing performance in low-yielding environments. Rice and mungbean intercropped with rubber have been adapted by farmers in the Arakan Valley.

Cropping system diversification for food production in Mindanao rubber plantations: A rice cultivar mixture and rice intercropped with mungbean

Short title: Plantation diversification for food

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ABSTRACT

Including food production in non-food systems, such as rubber plantations and biofuel or bioenergy crops, may contribute to household food security. We evaluated the potential for use of rice, mungbean, rice cultivar mixtures, and rice intercropped with mungbean in experiments planted in young rubber plantations in the Arakan Valley of Mindanao. Rice mixtures consisted of two- or three-row strips of cultivar Dinorado, a cultivar with higher value but lower yield, and high-yielding cultivar UPL Ri-5. Rice and mungbean intercropping treatments consisted of different combinations of two- or three-row strips of rice and mungbean. We used generalized linear mixed models to evaluate the yield of each crop alone and in the mixture or intercropping treatments, as well as a land equivalent ratio for yield, and weed biomass, the severity of panicle blast, brown spot, and brown leaf spot, and rice bug abundance. We also analyzed the yield ranking of each cropping system across site-year combinations to determine mean relative performance and yield stability. When weighted by their relative economic value, UPL Ri-5 had the highest mean performance, but with decreasing performance in low-yielding environments. A rice and mungbean intercropping system had the second highest performance, tied with high-value Dinorado but without decreasing performance in low-yielding environments. Rice and mungbean intercropped with rubber have been adapted by farmers in the Arakan Valley.

Keywords agricultural diversification; agroforestry; *Ageratum conyzoides*; *Cochliobolus miyabeanus*; cultivar mixtures; *Hevea brasiliensis*; intercropping; *Leptocorisa acuta*; *Magnaporthe oryzae*; rubber plantations

Introduction

The spread of agricultural non-food systems, such as rubber plantations, is a major factor for smallholder farmers and farm laborers, who often must navigate potential shifts from traditional swidden systems (Fox & Castella 2013; Josol & Montefrio 2013; Li et al. 2014; Manivong & Cramb 2008; Mertz et al. 2013; Montefrio & Sonnenfeld 2013; van Vliet et al. 2012; Vongvisouk et al. 2014). Increasing rubber production has the potential to reduce household food security, if less land is used for local food production (Weinberger 2013). In addition, the cleared land between young trees is wasted from an economic standpoint, and may be subject to erosion, if it is not planted with other crops. The use of intercropping of food crops in tree plantations has the potential to address both of these problems. Rubber trees may be intercropped with a range of other plant species, including food crops and tea, cocoa, coffee, rattan, fruit trees, and cinnamon (Jessy et al. 2016; Pathiratna & Perera 2006; Penot & Ollivier 2009; Wu et al. 2016). Guo et al. (2006) concluded that rubber-tea intercropping provided a higher land expectation value than separate rubber and tea monocultures in Hainan, China. Rubber intercropping with a crop like banana, before latex is produced, may even ultimately improve rubber production (Rodrigo et al. 2005). Systems of rubber intercropping in Nigeria often gave improved productivity, including systems of intercropping with soybean and melon, or with melon and maize (Esekhade et al. 2003). In Kerala, India, adoption of intercropping of rubber with pineapple, banana, and cassava was reported as most common (Rajasekharan & Veeraputhran 2002).

Planned diversification of plantations can be implemented at multiple scales. Smallholder farms have included both small-scale rubber production and rice (Dove 1993). An annual cropping system intercropped in rubber plantations might include intercropping of a staple cereal with a legume for additional nutritional benefits to local consumers. Including a legume in the system can also increase N availability in soils (Schroth et al. 2001; van Noordwijk et al. 2004).

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Within the cereal species, the use of cultivar mixtures may provide additional benefits (Finckh et al. 2000; Garrett & Mundt 1999; Meung et al. 2003). A striking example is the great success of rice mixtures composed of a higher-value rice cultivar susceptible to rice blast, with a lower-value rice cultivar resistant to rice blast (Zhu et al. 2000). The effects of increased system diversity can be difficult to predict, however, and functional diversity designed to achieve particular cropping system goals may be more useful than haphazardly constructed diversification. The effects of system diversification need to be studied empirically because what seem like intuitive outcomes may not be observed in practice.

In the Arakan Valley of Mindanao, the southernmost island group of the Philippines, demand for rubber drove replanting because the majority of rubber trees in the region were more than 30 years old and had reduced latex production (R. Hondrade, personal observation). When replanting, farmers would need to wait approximately five to seven years before they could begin tapping the new rubber trees. This interval is an opportunity for the production of annual crops such as upland rice, corn, vegetables, and grain legumes between the immature rubber trees. Such intercropping can produce household food and may also generate income while waiting for the rubber trees to reach a productive age.

The objectives of this study were to evaluate the effects of three types of diversification in rubber agroforestry that included mungbean (*Vigna radiata*) intercropped with rice mixtures. The response variables we considered were crop yield and system constraints – disease severity, insect abundance, and weed biomass. We evaluated (1) the effect of rubber tree age on rice and mungbean planted between rubber rows, (2) the effects of rice cultivar choice and mixing cultivars, and (3) the effect of rice and mungbean intercropping. We also illustrate the use of a split plot design in generalized linear mixed models for intercropping that could be useful for analysis of other intercropping experiments.

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MATERIALS AND METHODS

Experimental sites

The experimental sites were in the Arakan Valley Complex in the province of Cotabato in Central Mindanao, Philippines. Arakan has 28 villages, 10 of which are major rice producing villages. Its total land area is 69,432.79 ha with about 16,798 ha utilized for crop production. The landscape of Arakan is dominated by rolling hills, valleys, and mountain ranges.

Planting design

We evaluated the set of eight cropping treatments (Table 1), described in more detail below, in farmers' fields for three seasons (2006-2008), with planting date details in Table S1. Two fields, one with 1-year-old rubber trees and one with 3-year-old rubber trees, were selected in each of three municipalities - Antipas, Arakan, and Pres. Roxas – to represent local systems and so that there would be minimal differences among locations other than rubber tree age. The experimental design in 2006 was a split-plot design with rubber tree age as the whole plot treatment. Each farm contained three complete blocks of subplots that were assigned to the eight crop treatments (specified below). Thus, block was the whole-plot subsample. The eight intercropping treatments (Table 1) were applied to each block in each farm (Fig. 1).

Due to water-logging in some municipalities, the experiments in 2007-2008 were moved. During these years, two-year experiments were conducted in three fields with 1- to 2-year-old rubber trees in the municipality of Arakan, in the villages of Doroluman, Naje, and Sabang. The experiment was established in 2007 on 17 July (Doroluman, with 1-year-old rubber), 12 June (Sabang with 1.5-year-old rubber), and 16 May (Naje with 2-year-old rubber) (Table S1). The experimental design in 2007-2008 was a split-plot design with the two years as repeated measures (Fig. S2). The whole plot treatment was the farm, which was considered a random effect. The eight intercropping treatments were applied to the subplot in each block.

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Eight rice and mungbean treatment combinations (Table 1) were planted between the rubber tree rows. Two rice cultivars were included in the design: Dinorado, a higher-value but lower-yielding cultivar, and UPL Ri-5, a higher-yielding but lower-value cultivar, along with a high-yielding mungbean variety, Pag-asa 7. Ten rows (each 10-m long) of rice and/or mungbean were planted between the rows of rubber trees, with 0.4 m between rows and 0.2 m between hills for both rice and mungbean. The distance from the base of the rubber trees was 1-1.5 m and there were border plants outside the experimental plots to minimize interplot interference.

Statistical analysis

The details of the AOVs are given in Tables S2 and S3, following the design structures in Figures S1 and S2. The response variables were crop yield, land equivalent ratio, weed biomass, crop height, and the disease and pest ratings for each crop. The responses represent a range of different probability distributions for statistical analyses. Because subplot yield (dry (air- or sun-dried) weight/row for each crop (Dinorado, UPL Ri-5, or mungbean)) was approximately normally distributed, these data were analyzed in a linear mixed model using the MIXED procedure in SAS (Version 9.2).

The same model structure was used for generalized linear mixed models for response variables that were not normally distributed, such as some disease ratings and mungbean yield in 2006. The assumption of normality was tested using a Shapiro-Wilk test, and a Q-Q plot was evaluated where a heavy tail suggested use of a gamma distribution. Because of an upward skew in some data, the gamma distribution with log link function was used to analyze those responses using the SAS GLIMMIX procedure. The responses for which the gamma distribution was used were Dinorado yield, panicle blast, brown leaf spot and rice bug data in 2006; UPL Ri-5 brown spot, brown leaf spot, panicle blast, leaf blast, and rice bug data; and also mungbean yield in 2006 and pod rot data in 2007-2008. The ilink option was used for calculating the least square means on the data scale. A Tukey-Kramer adjustment (at significance level 0.05) was used in multiple comparisons of performance within a crop across the different treatments in which that crop occurred. The F test was utilized to test the treatment effects in the AOV. Weed dry weight was evaluated for each treatment (not evaluated separately for different crops). Weed weight was approximately normally distributed after square root transformation. We evaluated the effects of rubber tree age and cropping treatments (including the no-crop treatment) on weed weight in a linear mixed model. Ratings of disease severity were evaluated as approximately continuous.

Yield and economic value of intercrops: rice and mungbean

Both UPL Ri-5 and Dinorado are preferred rice varieties of Arakan farmers for various reasons: Both mature in approximately 128 days. Their cooked grain quality is acceptable to consumers, while Dinorado has greater volume increase and better palatability. UPL Ri-5 is higher yielding (average yield approximately 2.5-3.5 t ha^{-1} under favorable conditions) compared to Dinorado (yield less than 2 t/ha up to 2.7 t/ha under the same management practices). However, milled Dinorado had a local market price of more than a dollar (in Philippine pesos, P45-50 kg^{-1}, with approximate conversion P42/US$1) compared to UPL Ri-5 at P32-P35 kg^{-1}. Higher yielding UPL Ri-5 helps ensure farmers' household food security while the higher market value of Dinorado provides additional income to the farmer. The average yield of Dinorado in Arakan ranged from <1 to 1.5 t ha^{-1} while UPL Ri-5 produced 1 to 2 t ha^{-1}. The national average yield of upland rice was <1 to 1 t ha^{-1}.

Mungbean is a preferred legume of local farmers in Arakan, with a market price similar to Dinorado's (R. F. Hondrade, personal observation). Average yields under favorable growing conditions in the uplands ranged from 0.9 to 1.7 t ha^{-1}. Farmers grow this crop both for market and household food consumption.

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In addition to the analysis of grain yield described above, yield was also used to calculate the corresponding land equivalent ratio (LER) for evaluating the rice mixture and the rice-mungbean intercrops in each subplot. The LER for each subplot was calculated using the following formula, illustrated for a two crop mixture.

$$P_1 \cdot \frac{\text{Yield}_1 \text{ in mixture}}{\text{Yield}_1 \text{ in monoculture}} + P_2 \cdot \frac{\text{Yield}_2 \text{ in mixture}}{\text{Yield}_2 \text{ in monoculture}}$$

where P_i is the proportion of rows planted to Crop i in the subplot being considered (Table 1), and Yield_i is the yield of Crop i calculated based on the dry (air- or sun-dried) weight per row. The LER for the three crop mixtures (with Dinorado, UPL Ri-5, and mungbean) was calculated similarly.

The LER for each mixture is a measure of how well the mixture or intercrop yield compared to the monoculture yield. Pair-wise comparisons between the means of the LER for the four cropping treatments (Table 1) that included more than one type of crop were performed. A one-tailed t-test was performed to see if the four LER means were statistically larger than 1.

Crop disease evaluation and other response variables

In each of the subplots, including the control, the weed biomass was weighed at the end of the season. Visual ratings of common diseases were also collected by an experienced disease observer, as described below. A range of beneficial and pest arthropod species were also counted within the subplots, including rice bug (*Leptocorisa acuta*). The following disease infection and insect pest damage were evaluated at crop maturity. For rice panicle blast (caused by *Magnaporthe oryzae*), three categories of infection were recorded: no visible lesion, lesions on several pedicels or secondary branches, or lesions on few primary branches or the middle part of the panicle axis. Rice leaf blast (caused by *Magnaporthe oryzae*) was evaluated in 2007 and 2008, using a scale of ten possible categories of infection (International Rice Research Institute

1996). Rice brown spot (caused by *Cochliobolus miyabeanus*) was evaluated on a scale of 10 potential levels of severity. Pod rot of mungbean (caused by *Gluconobacter* sp.) was evaluated in 2008 based on percentage incidence, the percentage pods infected. Rice bug damage was evaluated in 2006 by damage category. In general pesticides were not used, with the exception of the Oreta one-year-old rubber farm in 2006, which had no observed rice bug damage.

Analysis of relative yield ranking of treatments, and stability of yield rank across environments

To evaluate the performance of the different cropping systems, regression analysis was used to determine which treatments performed better across the different environments, in an analysis similar to Mundt's (2002) analysis of wheat cultivar mixture performance. The mean yield per row was computed for each treatment in each site for the three years. For each of the twelve site-years, the weighted mean yield across the seven cropping systems (Table 1, excluding the control) was noted, as an index of the quality of that site-year as an environment for crop production ("environment index"). For each site-year, the rank of each treatment mean yield was computed (1 = lowest, 7 = highest), indicating the relative performance of each treatment in each site-year.

The performance of the intercropping systems was evaluated in two ways. First, we used a regression analysis to evaluate the relationship between the environment index (mean yield in each site-year) and the yield ranks for each treatment. The best intercropping system will have the highest mean yield rank. Higher P-values associated with the slope indicate stronger evidence that the performance rank of a cropping treatment changes going from higher mean yield environments to lower mean yield environments. A positive slope indicates higher performance rank in high yield environments, while a negative slope indicates higher performance rank in low yield environments. A relatively small mean square error from the F

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test in the regression analysis indicates that the quality of the environment explains most of the variability in performance rank of a cropping system. We also performed the same type of analysis with the different crops weighted by their relative economic value. The economic value of Dinorado and mungbean was approximately equivalent, and 40% higher than the value of UPL Ri-5, based on typical valuation of these crops. Thus relative economic weights were 1 for UPL Ri-5, 1.4 for Dinorado, and 1.4 for mungbean, and the treatment mean yield per row was adjusted accordingly.

RESULTS

Rubber tree age effects

Rubber tree age did not have a significant effect on cropping system productivity (Table 3). Although the mean subplot yield in one-year-old rubber sites was 1.5 times that in three-year-old rubber sites, the variation among sites was very high (with yield 4.3 times higher in the highest yielding one-year-old rubber site compared to the lowest yield one-year-old rubber site).

Rice and mungbean yield responses to cropping system

Rice yields per row were greater in intercropping systems than in monoculture in some cases, although yields varied widely within and among years (Fig. 2 and Tables 2-5). There was a tendency for rice yields to be higher when rice made up a smaller proportion of the intercrop rows (Figs. 2 and S3). Dinorado yield responded significantly to intercropping treatments only in 2006 ($p = 0.03$), when Dinorado yield per area was significantly higher in 0.8MB than in 0.2MB (Tables 2 and 3). UPL Ri-5 yield also responded significantly to intercropping treatments only in 2006 ($p = 0.001$). UPL Ri-5 yield per area was significantly higher in 0.8MB compared to the monoculture and RM in 2006 (Table 2). There were no significant treatment effects or significant

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mean differences in pairwise comparisons for the two rice varieties in 2007 and 2008 (Tables 2 and 3). As expected, UPL Ri-5 yield was generally higher than Dinorado yield.

Mungbean yield did not respond significantly to intercropping treatments in 2006 (Table 2). Mungbean also showed a tendency for higher yield when mungbean made up a smaller proportion of the intercrop rows (Figs. 2 and S3). There was a significant treatment effect for mungbean yield in 2007 and 2008 ($p = 0.03$; Table 3). There was a significant treatment x year interaction ($p = 0.002$), indicating that the response of mungbean yield to intercropping treatment significantly varied by year. In 2007 and 2008, mungbean yield per area was significantly higher in 0.2MB compared to 0.8MB (Table 2). Mungbean data were missing from one farm in 2006 and there were also other cases of missing data that made mungbean comparisons more difficult. One component of variability in mungbean response was the observed 90% severity of pod rot in one site (P. Roxas) in 2006.

Land equivalence ratios

The estimated LER for the rice mixture varied with year (Fig. 3; Table 4). The intercrop LER estimate for 0.2MB was significantly greater than 1 in all three years, and 0.5MB and 0.8MB were also significantly greater than 1 in two out of three years. The intercropping treatments differed significantly in their effect on LER in 2006 ($p = 0.006$; Table 4). The mean LER was significantly greater in RM and lower in 0.8MB in 2006 (Table 4). Also, the LER for RM was significantly greater than one. In 2007 and 2008 there was a significant intercropping treatment effect on LER ($p = 0.03$). Among the pairwise comparisons, the 0.5MB LER was significantly greater than the RM LER. Also the 0.5MB LER mean was significantly greater than one, but the mean of RM was not significantly less than 1.

Weed responses to cropping systems

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Weeds commonly observed in the experiments were *Ageratum conyzoides, Borreria laevis*, *Calopogonium mucunoides, Chromolaena odorata, Ludwigia octovalvis, Murdannia nudiflora*, and *Rottboellia cochinchinensis,* where *A. conyzoides* was particularly abundant. As expected, all crop treatments resulted in lower weed biomass than the unplanted control (Table 5). The mungbean monoculture had the lowest weed biomass in 2007-2008, and was significantly lower than the weed biomass in the Dinorado monoculture and RM; however, in 2006 the mungbean monoculture did not significantly reduce weed biomass (Table 5), probably because of problems with mungbean establishment in that year. The intercropping treatment effects were significant in both 2006 and 2007-2008. There was also a significant treatment by year interaction in 2007-2008 (Table 5).

Disease and insect responses to cropping treatment

Disease and insect pests were present at fairly low levels overall (Tables 6 and 8). Brown spot, panicle blast, leaf blast, and rice bug were common enough in at least some years to be evaluated for differential responses to the intercropping treatments. Brown spot caused by *Cochliobolus miyabeanus* was generally more severe in Dinorado than in UPL Ri-5, and there was evidence for decreased brown spot in Dinorado in the rice mixture and increased brown spot in Dinorado in the 0.8MB intercrop in 2007-2008 (Table 8). Panicle blast caused by *Magnaporthe grisea* was generally more severe in UPL Ri-5 compared to Dinorado in 2006 (Table 6), but more severe in Dinorado than in UPL Ri-5 in 2007-2008 (Table 8). There was evidence that panicle blast was higher in Dinorado in the 0.2MB intercrop and lower in the 0.5MB intercrop in 2006 compared to other treatments (Table 6). Leaf blast could be evaluated in 2007-2008. Leaf blast severity was generally higher in Dinorado than in ULP Ri-5 (Table 8), but there were no significant cropping treatment effects (Table 9). In 2007-2008 there was a year effect on brown spot and leaf blast in UPL Ri-5 (Table 9). In 2006 there was an effect of rubber age on panicle blast in UPL Ri-5,

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where older rubber trees were associated with higher disease (Table 7). Pod rot of mungbean was observed at one site in P. Roxas in 2007-2008 where severity reached 90%, and the treatment effect was significant (Table 9).

The rice bug, *Leptocorisa acuta*, could be evaluated in 2006 and was generally more abundant in UPL Ri-5 than in Dinorado (Table 6). Rice bugs were significantly less common in Dinorado in all intercropping systems compared to Dinorado monoculture, but were more common in Dinorado in the rice mixture compared to the monoculture (Table 6). Other insect pests observed in some sites were the green leafhopper, brown planthopper, and grasshoppers. The most commonly observed beneficial insects were spiders, wasps, red ants, and lady bugs, but these were observed too infrequently to allow statistical comparison of treatment effects.

Yield rank and stability

In the analysis of yield rank and stability (Table 10), the monoculture UPL Ri-5 had the highest mean yield rank, with little evidence (P = 0.15) for a positive slope, and mean square error 1.95. The second highest mean yield rank was for the rice mixture (RM, 4 rows of Dinorado and 6 rows of UPL Ri-5), with a relatively high mean square error 2.53 indicating higher variability than observed for UPL Ri-5. The next highest ranked cropping systems were the 0.5 and 0.2 MB intercropping systems, with similar performance. Comparing all the treatments, the monoculture mungbean (MB) treatment had the lowest mean yield rank (1.9), a negative slope (-0.000377) and a relatively high mean square error (3.21) reflecting water-logging problems at some sites, particularly in 2006.

The yield rank and stability weighted by economic values (Table 11) showed similar trends. UPL Ri-5 still had the highest ranked performance, but among the weighted ranks there was stronger evidence (P = 0.07) for a positive slope, indicating that the relative performance of UPL Ri-5 was higher in environments with higher mean yield. The mean performance of the 0.5

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MB intercropping system and the Dinorado monoculture was higher when weighted by economic values, tied for second highest rank. For the 0.5 MB system, there was not evidence for a non-zero slope, thus not evidence for a change in yield rank across environments (P = 0.3). For the Dinorado monoculture, there was evidence for a positive slope (P = 0.03), indicating Dinorado yield was less stable in poorer environments (Fig. S5). The Dinorado monoculture also had a somewhat higher MSE than the 0.5 MB intercropping system.

DISCUSSION

As rubber trees age, the mean yield of crops intercropped with rubber may go down, yet the difference in yield between one-year-old rubber and three-year-old rubber was small compared to the differences among one-year-old rubber sites. Crop production in rubber tree plantations appears to be a viable approach for increasing local food production where young rubber plantations are common, and potentially for increasing local household food security. Farmers in the area of these experiments continue to plant rice, mungbean, peanut, or corn in zero- to two-year-old rubber, although they do not commonly use intercropping of crop species, and the practice of planting crop species between tree rows has been adopted in palm oil plantations, as well (R. F. Hondrade, personal observation). Two rice varieties are commonly used, a higher yielding variety and either Dinorado or another traditional variety, depending on market demand (R. F. Hondrade, personal observation). Extension programs can help make farmers aware of options for intercropping in tree crops like rubber; Mindanao had relatively higher rates of technological change in rice production than some other areas of the Philippines, with other contributing factors likely being investment in infrastructure, farm mechanization, and adoption of modern rice varieties (Umetsu et al. 2003). Planting rice with leguminous tree species has been proposed for upland rice production in eroded areas of northern Mindanao, with reports of

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increased UPL Ri-5 yield in eroded sites (MacLean et al. 2003). Farmers in Sri Lanka were more likely to adopt rubber intercropping if they had more extension contacts and higher education (Herath & Takeya 2003). Intercropping with tea has been recommended to improve income in the pre-tapping phase. The conclusion was that farmers in Sri Lanka, where intercropping in rubber can be an important part of household strategies with reported benefits both before and during rubber production (Rodrigo et al. 2001), were more likely to adopt this system if they had incomes above a minimal level, if their income was based solely on their farm, and if the majority of land was suitable for tea cultivation. Technical knowledge of how to intercrop tea and rubber was identified as a limiting factor in adoption (Iqbal et al. 2006).

In comparing the performance of the seven cropping system treatments, a monoculture of UPL Ri-5 had the highest mean yield rank, with or without weighting for economic value. However there was some evidence that the performance of UPL Ri-5 was lower in poorer environments, where household food security may be more problematic. When considering yield weighted for economic value, the next highest mean yield rank was the tied 0.5 MB intercropping system and the Dinorado monoculture, where the 0.5 MB system appeared somewhat more stable (having a non-significant slope in response across environments and lower MSE). The poorer performance of some cropping systems was a result of poor mungbean establishment at some sites, which could potentially be improved through greater farmer experience in mungbean production. The tendency for crops to yield higher when they made up less than 50% of a cropping system suggests there may be more opportunities for developing useful intercropping systems.

Disease and pest levels were generally relatively low in all treatments, and these low levels present an interesting question in their own right. In fact this region of Mindanao has a reputation for having low disease pressure, where the reasons for this are not entirely clear.

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There have been outbreaks of bacterial blight and blast in Mindanao, which might be explained in part by widespread planting of a single rice cultivar (R. F. Hondrade, personal communication). Part of the popularity of Dinorado may be due to its relative disease resistance, in addition to higher economic value. UPL Ri-5 produced higher yields than Dinorado, even when weighted for economic value. There was a tendency for UPL Ri-5 to have lower disease levels when in the mixture with the more resistant Dinorado, consistent with other reports for rice disease in mixtures (Meung et al. 2003; Zhu et al. 2000). There is the potential for mungbean to change the microenvironment for rice, but the difficulties in mungbean establishment may have made this harder to interpret in this experiment. Microclimate (canopy moisture) has probably played an important role in the success of some rice mixtures, where taller susceptible rice plants surrounded by shorter resistant plants experience less leaf surface moisture and so lower disease development (Zhu et al. 2005). Environmental differences among farms may alter the effects of crop mixtures due to altered competition, or to altered epidemic processes (Garrett et al. 2009). Weed species composition in upland rice is particularly variable compared to other rice production systems, and particularly challenging. Imperata control has been identified as an important component of management for Indonesian rubber (Grist & Menz 1996). Potential management by planting rubber at high densities to compete with weeds presents a trade-off in that high-density rubber will making incorporation of food crops more challenging.

There are other possibilities for incorporating agroforestry systems, with the potential for a range of benefits including increased household food security and wider ecosystem services (Cheatham et al. 2009; Jose 2009; Swift et al. 2004). There is the potential to develop longer-term rubber intercropping systems, to buffer fluctuating rubber prices (Cramb et al. 2009; Nath et al. 2013), by altering rubber tree planting arrangements to allow greater resource availability for other crops (Rodrigo et al. 2004), depending on the stage of development of the local systems

(Barlow 1997; Dressler & Pulhin 2010) and the availability of other options for income (Dressler & Fabinyi 2011; Langenberger et al. 2016; Neyra-Cabatac et al. 2012). In such a system, a managed understory can be integrated in place of additional trees. Upland rice presents a trade-off, because it has an important role in crop production for resource-poor farmers, but can present an important environmental cost if fragile ecosystems are converted for upland rice production. If lands are in plantation production, anyway, the environmental cost of adding upland rice is reduced. It will be useful to learn more about the probably complicated relationship between local rates of crop production in rubber plantations and household food security.

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Supplemental Information

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Table 1. Experimental treatments planted in subplots between rows of rubber trees in farmers' fields in Mindanao

Treatment abbrev.	**Subplot treatment between rubber trees** (Applied to subplot with 10 rows)	**Crops appearing in each treatment (rows)**		
		Dinorado	UPL Ri-5	Mungbean
Control	No crops planted			
Dinorado	10 rows rice cv. Dinorado (D)	10		
UPL Ri-5	10 rows rice cv. UPL Ri-5 (U)		10	
RM	Rice mixture: 2 rows D, 3 rows U, repeated twice	4	6	
0.5 MB	2 rows D, 3 rows U, 5 rows mungbeans (MB)	2	3	5
0.8 MB	4 rows M, 2 rows[a] U + D, 4 rows MB	1	1	8
0.2 MB	2D, 2U, 2D, 2U, 2MB	4	4	2
MB	10 rows mungbeans (MB)			10

[a]UPL Ri-5 and Dinorado in fractions of rows

Table 2. Yield (grams/row) of mungbean and two rice cultivars (Dinorado and UPL Ri-5) for eight cropping treatments (Table 2), from intercropping systems in rubber plantations in Mindanao.

Crops	Treatment	2006 Yield		2007-2008 Yield	
		Mean	(SD)	Mean	(SD)
Dinorado	Monoculture	487[ab]	195	697[a]	186
	RM	524[ab]	195	653[a]	186
	0.5MB	626[ab]	195	1075[a]	186
	0.8MB	762[a]	195	878[a]	186
	0.2MB	470[b]	195	643[a]	186
UPL Ri-5	Monoculture	651[a]	226	1053[a]	185
	RM	605[a]	226	928[a]	185
	0.5MB	790[ab]	226	1044[a]	185
	0.8MB	928[b]	226	1252[a]	185
	0.2MB	668[ab]	226	1065[a]	185
Mungbean	Monoculture	218[a]	75	367[ab]	31
	0.5MB	178[a]	75	397[ab]	31
	0.8MB	293[a]	75	348[a]	31
	0.2MB	193[a]	75	430[b]	31

Treatments RM, 0.5MB, 0.8MB and 0.2 MB refer to the intercropping treatments in Table 2.

Superscripts a, b: if treatments are marked by the same letters, then there is no significant difference in the pair-wise comparison. If the means contain different letter, then there is a significant difference at the 0.05 level.

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Table 3. Treatment effects and results of an AOV for yield (grams/row) of mungbean and two rice cultivars (Dinorado and UPL Ri-5) from intercropping systems (Table 2) in rubber plantations in Mindanao.

Crops	2006 yield		2007-2008 yield	
	Effect	F-test P-values	Effect	F-test P-values
Dinorado	Treatment	**0.03**	Treatment	0.51
	Rubber age	0.53	Year	0.21
	Trt*Rubber age	0.85	Trt*Year	0.73
UPL Ri-5	Treatment	**0.001**	Treatment	0.88
	Rubber age	0.84	Year	0.15
	Trt*Rubber age	0.77	Trt*Year	0.07
Mungbean	Treatment	0.45	Treatment	**0.03**
	Rubber age	0.53	Year	0.33
	Trt*Rubber age	0.43	Trt*Year	**0.002**

Bold P-values are significant at the 0.05 level.

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Table 4. The land equivalent ratio (LER) for eight cropping systems (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), from intercropping systems in rubber plantations in Mindanao. Results are given for a t-test of whether the LER is greater than 1.

2006				2007-2008				Overall Mean
Treatment and effects	Mean	(SD)	t-test p-value	Treatment and effects	Mean	(SD)	t-test p-value	
RM	1.53^{b}	0.14	**0.0007**	RM	0.93^{a}	0.08	0.19	1.23
0.5MB	1.13^{ab}	0.14	0.18	0.5MB	1.21^{b}	0.08	**0.009**	1.17
0.8MB	0.99^{a}	0.14	0.47	0.8MB	1.12^{ab}	0.08	0.08	1.05
0.2MB	1.23^{ab}	0.14	0.06	0.2MB	1.13^{ab}	0.08	0.06	1.18
Trt effect				Trt effect				
P-value	**0.006**	–	–	P-value	**0.03**	–	–	–
Age effect				Year effect				
P-value	0.50	–	–	P-value	0.05	–	–	–
Trt*Age				Trt*Year				
P-value	0.22	–	–	P-value	0.70	–	–	–

The Trt effect refers to the four treatments RM, 0.5MB, 0.8MB and 0.2MB. Trt*Age is the four treatments and the rubber age interaction in year 2006. Trt*Year is the four treatments and year interaction in 2007-2008. Superscripts a, b: if the means contain the same letters, then there is no significant difference in the pair-wise comparison. If the means contain different letters, then there is a significant difference at the 0.05 level. Bold p values are significant at the 0.05 level.

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Table 5. Weed biomass in eight cropping systems (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), from intercropping systems in rubber plantations in Mindanao. The square root transformation was used in analysis, where the original unit for weed biomass was g/m^2.

	2006		2007-2008	
Treatment and effects	Mean	(SD)	Mean	(SD)
Control	31.2^{a}	2.5	24.6^{a}	1.4
Dinorado	14.5^{b}	2.5	15.5^{b}	1.4
UPL Ri-5	10.8^{b}	2.5	13.7^{bc}	1.4
RM	11.9^{b}	2.5	15.1^{bcd}	1.4
0.5 MB	13.2^{b}	2.5	13.9^{bcd}	1.4
0.8 MB	13.3^{b}	2.5	13.1^{bcd}	1.4
0.2 MB	12.2^{b}	2.5	12.6^{cd}	1.4
MB	14.7^{b}	2.5	11.7^{c}	1.4
Trt effect				
P-value	**<0.01**	–	**<0.01**	–
Age effect				
P-value	0.36	–	0.09	–
Trt*Age				
P-value	0.78	–	**<0.01**	–

Eight intercropping treatments (Table 2) were compared. The effects of treatments with the same letter superscript are not significantly different. Bold p-values are significant at the 0.05 level.

Table 6. Crop height and disease and pest severity (**2006**) in intercropping systems (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), in rubber plantations in Mindanao. Results of pair-wise comparisons are indicated by superscripts.

Crops	Treatment	Crop Height		Panicle Blast		Brown Spot		Brown leaf spot		Rice Bug	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Dinorado	Monoculture	148.70^{a}	5.08	1.39^{a}	0.20	1.01^{a}	0.09	1.26^{a}	0.07	2.17^{ab}	1.06
	RM	147.05^{a}	5.08	1.33^{a}	0.20	1.12^{a}	0.09	1.26^{a}	0.07	2.83^{ab}	1.06
	0.5MB	133.27^{b}	5.08	1.06^{a}	0.20	1.11^{a}	0.09	1.32^{a}	0.07	1.94^{b}	1.06
	0.8MB	142.31^{ab}	5.08	1.44^{a}	0.20	0.92^{a}	0.09	1.23^{a}	0.07	1.83^{ab}	1.06
	0.2MB	144.26^{ab}	5.08	1.72^{a}	0.20	1.12^{a}	0.09	1.29^{a}	0.07	1.61^{a}	1.06
UPL Ri-5	Monoculture	115.11^{a}	4.31	2.33^{a}	0.21	0.83^{a}	0.36	3.56^{a}	0.21	5.28^{a}	1.44
	RM	117.33^{a}	4.31	1.89^{a}	0.21	1.22^{a}	0.36	3.11^{a}	0.21	4.61^{a}	1.44
	0.5MB	112.55^{a}	4.31	1.94^{a}	0.21	0.89^{a}	0.36	3.67^{a}	0.21	4.94^{a}	1.44
	0.8MB	112.15^{a}	4.31	2.17^{a}	0.21	1.22^{a}	0.36	3.11^{a}	0.21	4.94^{a}	1.44
	0.2MB	112.92^{a}	4.31	2.06^{a}	0.21	1.06^{a}	0.36	3.33^{a}	0.21	4.83^{a}	1.44
Mungbean	Monoculture	62.83^{a}	12.27	—	—	—	—	—	—	—	—
	0.5MB	65.13^{a}	12.27	—	—	—	—	—	—	—	—
	0.8MB	61.22^{a}	12.27	—	—	—	—	—	—	—	—
	0.2MB	59.03^{a}	12.27	—	—	—	—	—	—	—	—

The monoculture treatment refers to the crops in Dinarado, UPL Ri-5 and mungbean alone. Treatments RM, 0.5MB, 0.8MB and 0.2 MB refer to the intercropping treatment in Table 2. Superscripts a, b: if the means contain the same letters, then there is no significant difference in the pair-wise comparison. If the means contain different letters, then there is a significant difference at the 0.05 level.

Table 7. P-values from treatment effects on crop height and disease and pest severity (**2006**) in intercropping systems (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), in rubber plantations in Mindanao.

Crops	Effects	Crop Height	Panicle Blast	Brown Spot	Brown leaf spot	Rice Bug
Dinorado	Treatment	**0.01**	0.20	0.31	0.77	0.06
	Rubber age	0.69	0.76	**0.03**	0.76	0.57
	Trt*Rubber age	0.08	0.63	0.39	**0.042**	0.67
UPL Ri-5	Treatment	0.66	0.53	0.74	0.08	0.83
	Rubber age	0.96	**0.001**	0.50	0.77	0.73
	Trt*Rubber age	0.44	0.17	0.58	0.85	0.24
Mungbean	Treatment	0.48	—	—	—	—
	Rubber age	0.30	—	—	—	—
	Trt*Rubber age	0.94	—	—	—	—

Treatment stands for the 8 intercropping treatments (Table 2). Trt*Rubber age stand for the treatment and rubber age interaction. Bold p values are significant at the 0.05 level.

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Table 8. Disease and pest severity (**2007-2008**) in intercropping systems (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), in rubber plantations in Mindanao. Results of pair-wise comparisons are indicated by superscripts.

Crops	Treatment	Brown Spot		Panicle Blast		Leaf Blast		Pod Rot	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Dinorado	Monoculture	3.22	0.47	1.09	0.23	0.61	0.25	—	—
	RM	2.33	0.47	1.23	0.32	0.78	0.25	—	—
	0.5MB	3.33	0.47	0.75	0.26	0.61	0.25	—	—
	0.8MB	3.50	0.47	1.24	0.26	0.50	0.25	—	—
	0.2MB	2.89	0.47	1.18	0.26	0.72	0.25	—	—
UPL Ri-5	Monoculture	2.44	0.32	0.63	0.27	0.00	0.14	—	—
	RM	2.00	0.32	0.10	0.27	0.14	0.08	—	—
	0.5MB	2.22	0.32	0.09	0.27	0.35	0.11	—	—
	0.8MB	2.17	0.32	0.52	0.20	0.35	0.12	—	—
	0.2MB	1.83	0.32	0.14	0.27	0.35	0.11	—	—
Mungbean	Monoculture	—	—	—	—	—	—	17.22	5.09
	0.5MB	—	—	—	—	—	—	10.56	5.09
	0.8MB	—	—	—	—	—	—	10.83	5.09
	0.2MB	—	—	—	—	—	—	29.61	5.09

There are no significant differences in the means in all pair-wise comparisons.

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Table 9. P-values from treatment effects on disease and pest severity (**2007-2008**) in intercropping systems (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), in rubber plantations in Mindanao.

Crops	Effects	Brown Spot	Panicle Blast	Leaf Blast	Pod Rot
Dinorado	Treatment	0.18	0.49	0.78	—
	Year	0.11	0.98	0.20	—
	Trt*Year	0.38	0.96	0.07	—
UPL Ri-5	Treatment	0.69	0.26	0.20	—
	Year	**0.02**	0.74	**0.0008**	—
	Trt*Year	0.31	0.34	0.20	—
Mungbean	Treatment	—	—	—	**0.04**
	Year	—	—	—	0.08
	Trt*Year	—	—	—	0.10

Bold p-values are significant at the 0.05 level.

Table 10. An analysis comparing the yield performance and stability of intercropping system treatments (Table 2) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), in rubber plantations in Mindanao. Regression analysis using the mean yield of each treatment for each site as predictor and yield ranks (1 = lowest, 7 = highest) of each treatment as response.

Treatment	Mean Rank	Slope	P-values[a]	MSE[b]
UPL Ri-5	6.3	0.0025	0.15	1.95
RM	5	0.0025	0.20	2.53
0.5 MB	4.5	-0.0022	0.13	1.34
0.2 MB	4.2	-0.0001	0.93	0.97
Dinorado	3.8	0.0038	0.06	2.33
0.8 MB	2.4	-0.0027	0.07	1.33
MB	1.9	-0.0038	0.10	3.21

[a] Probability that slope is significantly different from zero based on F-test.

[b] Mean square error of the regression.

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Table 11. An analysis comparing the yield performance (**weighted by relative economic value**) and stability of intercropping system treatments (Table 1) of mungbean and two rice cultivars (Dinorado and UPL Ri-5), in rubber plantations in Mindanao. Regression analysis using the mean yield of each treatment for each site as predictor and yield ranks (1 = lowest, 7 = highest) of each treatment as response.

Treatment	Mean Rank	Slope	P values[a]	MSE[b]
UPL Ri-5	5.3	0.0032	0.07	2.57
0.5 MB	4.8	-0.0015	0.34	2.52
Dinorado	4.8	0.0040	0.03	2.89
0.2 MB	4.3	-0.0004	0.76	1.65
RM	4.2	0.0008	0.64	2.71
0.8 MB	2.6	-0.0027	0.05	1.54
MB	2	-0.0033	0.11	3.85

[a] Probability that slope is significantly different from zero based on F-test.

[b] Mean square error of the regression.

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Figure captions

Figure 1. Planting rice and mungbean in an experimental site in Mindanao with three-year-old rubber.

Figure 2. Yield (g/row) of two rice cultivars (Dinorado and UPL Ri-5) and mungbean grown between rubber tree rows in a Mindanao plantation. The rice and mungbean were grown in monoculture and in a set of mixture and intercropping treatments (Table 1). The white bar indicates the median across all farms, the upper and lower boundaries of the box indicate the 25th and 75th percentiles, the upper and lower extents of the dotted lines indicate the minimum and maximum, with circles beyond these identified as outliers.

Figure 3. The Land Equivalent Ratio (LER) for a rice mixture and three intercropping systems (Table 1) in three years across all rubber plantations studied (without weighting for relative economic value of different crops). The white bar indicates the median across all farms, the upper and lower boundaries of the box indicate the 25th and 75th percentiles, the upper and lower extents of the dotted lines indicate the minimum and maximum, with circles beyond these identified as outliers.

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Figure 1(on next page)

Planting rice and mungbean in an experimental site in Mindanao with three-year-old rubber.

Figure 2(on next page)

Yield (g/row) of two rice cultivars (Dinorado and UPL Ri-5) and mungbean grown between rubber tree rows in a Mindanao plantation

Yield (g/row) of two rice cultivars (Dinorado and UPL Ri-5) and mungbean grown between rubber tree rows in a Mindanao plantation. The rice and mungbean were grown in monoculture and in a set of mixture and intercropping treatments (Table 1). The white bar indicates the median across all farms, the upper and lower boundaries of the box indicate the 25^{th} and 75^{th} percentiles, the upper and lower extents of the dotted lines indicate the minimum and maximum, with circles beyond these identified as outliers.

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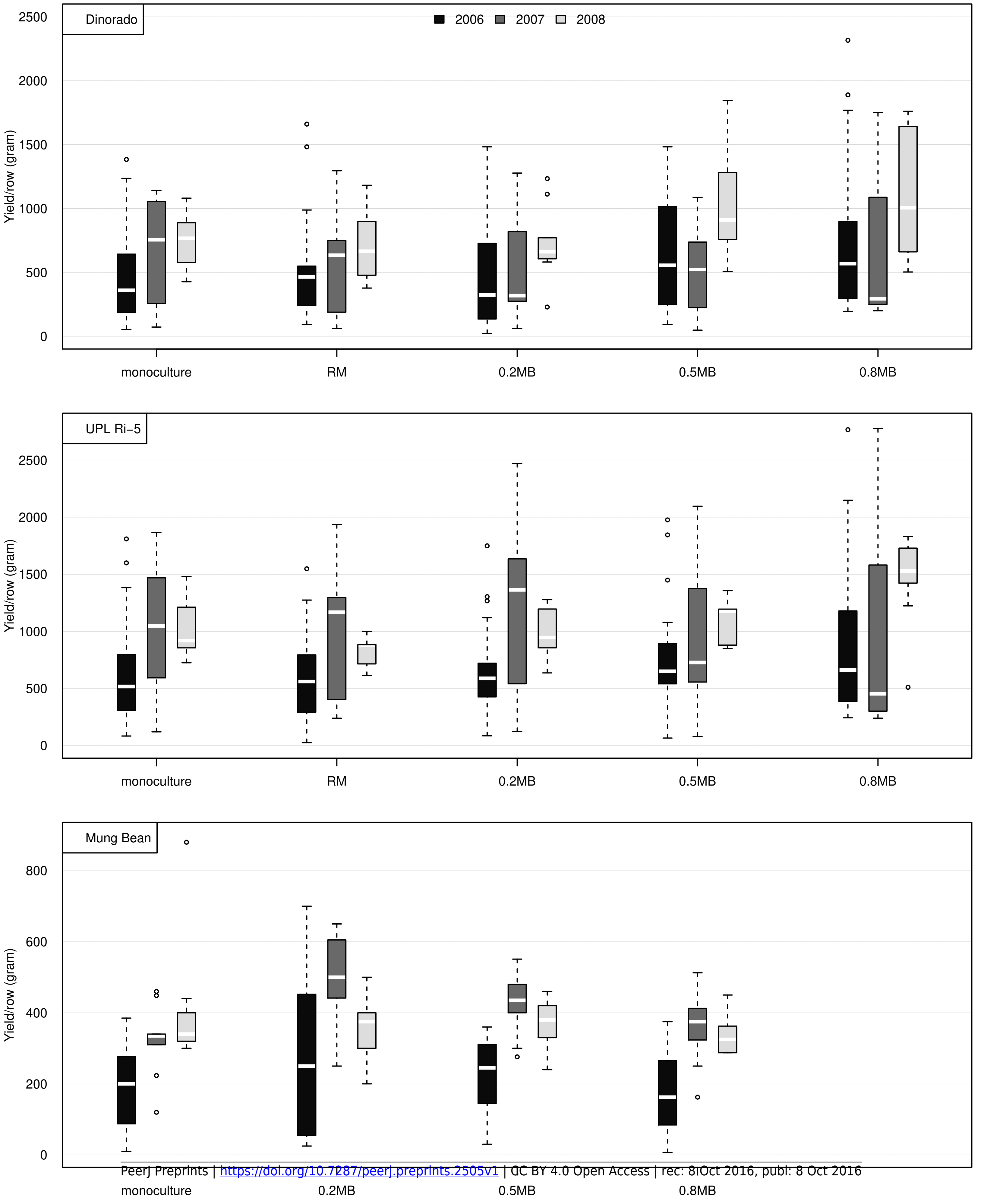

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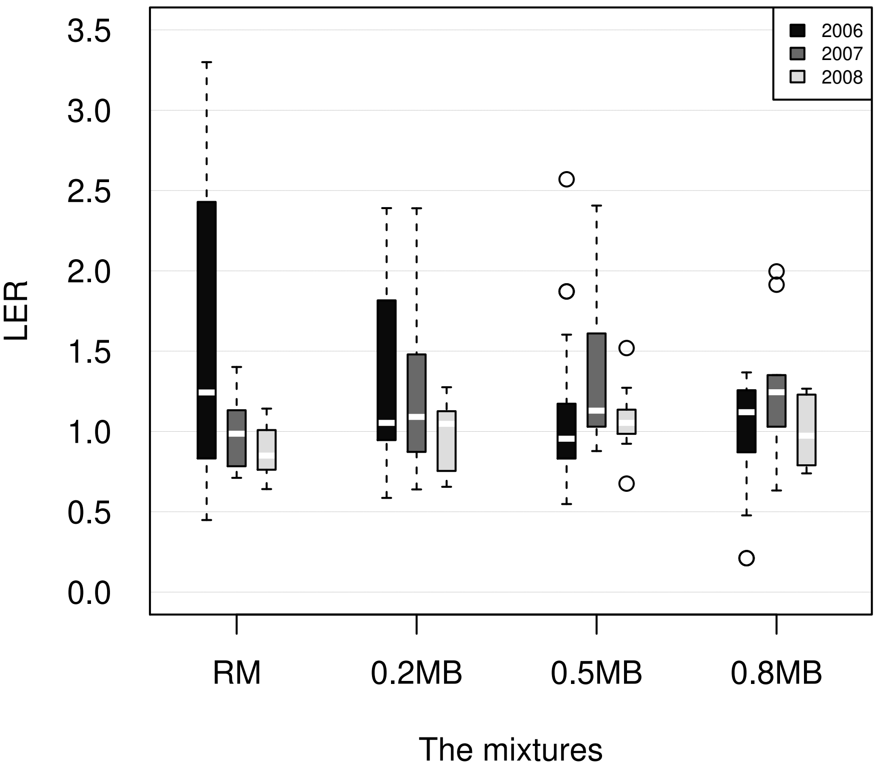
Figure 3(on next page)

The Land Equivalent Ratio (LER) for a rice mixture and three intercropping systems

The Land Equivalent Ratio (LER) for a rice mixture and three intercropping systems (Table 1) in three years across all rubber plantations studied (without weighting for relative economic value of different crops). The white bar indicates the median across all farms, the upper and lower boundaries of the box indicate the 25th and 75th percentiles, the upper and lower extents of the dotted lines indicate the minimum and maximum, with circles beyond these identified as outliers.



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