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Article

Barriers to Agro-Ecological Intensification of Smallholder Upland Farming Systems in Lao PDR

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Abstract: Intercropping of legumes can be a strategy to improve soil fertility and enhance overall productivity while reducing dependency on external inputs in intensified cropping systems. Integration of legumes in maize-based cropping systems is promoted as an agro-ecological intensification option for input-constrained smallholders in uplands of Southeast Asia, but adoption rates in the region remain low. The overall aim of this study was to assess the suitability and trade-offs of integrating ricebean in maize-based smallholder cropping systems in upland areas of Northern Laos. We conducted a researcher-managed field trial to investigate the agronomic performance of ricebean/maize intercropping, and farmer-managed trials combined with surveys (N = 97), and focus group discussions in 10 villages to understand factors influencing farmers' decision making concerning ricebean adoption. Drought, rat infestation and crop damage by grazing livestock were identified as important constraints to the production of ricebeans. Factors facilitating adoption included improvement of soil fertility, the potentially high selling price of ricebeans and the presence of extension agents, while barriers included labour shortage, concerns about competition with maize and lack of a market outlet for the ricebean produce. We conclude that the investigated maize/ricebean intercropping system is poorly suited to the current conditions in the study area, and call for farm-based studies focusing on developing locally adapted legume intercropping systems able to perform under variable rainfall conditions. Initiatives addressing challenges related to free grazing livestock and efforts to link legume producers in remote areas to emerging markets are also needed.

Keywords: agro-ecological intensification; barriers to adoption; facilitating factors; N fixation; intercropping; relay cropping; legumes; ricebeans; maize; Lao PDR

1. Introduction

Shifting cultivation has been the dominant land-use system in the tropics for centuries [1]. However, over the last few decades, a gradual transformation away from shifting cultivation to permanent agriculture has been taking place in the uplands of Southeast Asia as a result of increasing population pressure, government policies and an expanding market infrastructure [2,3]. Laos is one of the countries experiencing such a transformation, with fodder maize (*Zea mays* L.) being one of the commodity crops grown in permanent agricultural systems or intensive shifting cultivation rotations [4,5]. From 2005 to 2014, the area under maize in Laos increased rapidly (183%), as did maize production (279%) [6]. The maize boom in Laos was triggered by the introduction of new hybrid maize cultivars and the opening of cross-border trade in response to high market demand in the neighbouring countries where maize is used as feed for a growing livestock industry [7,8]. In Laos, maize is mainly cultivated by smallholders in upland areas where farmers traditionally have relied on shifting cultivation with long fallow periods to restore soil fertility and reduce weed pressure [9–11]. In these areas, farmers have been drawn into maize cultivation by the relatively high maize prices and at the same time forced out of the traditional shifting cultivation practices that the Lao government considers backwards and environmentally harmful [12]. Hence, the agricultural development policies of Laos are aiming at intensifying the production system and promoting permanent agriculture. This has been done by land use planning restricting the agricultural area allocated to farmers and thereby forcing them to intensify [9]. However, lack of technical and/or financial support for the intensification process has in some cases brought about land degradation and decreased food security as well as instances of indebtedness due to increased need for external inputs [9,13,14]. In response to this (among other things) a series of research and development projects are currently testing and promoting alternative low input cropping systems based on agro-ecological principles in various places in Laos (e.g., Eco-Friendly Intensification and Climate Resilient Agricultural Systems in Lao PDR (EFICAS) and Forestry and Agro-Ecology in Lao Rural Uplands (FORAE)). Integration of legume crops is a central component of many of these low input cropping systems as this can be a strategy to improve soil fertility and enhance overall productivity while reducing dependency on external inputs in intensified systems, due to the ability of legumes to fix Nitrogen (N) from the atmosphere [15,16]. The beneficial effects of legumes on associated crops are well documented [17,18], and studies from Thailand have reported increase in maize yields from maize/legume relay cropping as compared to maize monocropping [19,20]. Successful integration of legumes in maize-based cropping systems has been documented in upland areas of Thailand, where especially ricebean (*Vigna umbellata* L.) has demonstrated potential to be relay cropped into maize-based cropping systems due to its ability to grow in low-fertility upland soils, its suitability for intercropping with maize and marketability [16]. However, even though maize-legume cropping systems appear to have potential for agricultural intensification by input-constrained smallholders in uplands of Southeast Asia, legume adoption by smallholder maize farmers in Laos remains low. Although a few studies have looked into the challenges of legume adoption in upland agriculture in Southeast Asia [16,19], no studies have focused on ricebean integration in subsistence smallholder systems in Laos.

Despite the advantages, there are several challenges associated with introducing a legume crop into maize-based cropping systems, e.g., interspecific competition for light, water and nutrients may occur between the maize and legume crops when grown together. Compared to concurrent sowing, delayed sowing of the legume intercrop has been shown to result in higher maize yields [21]. However, legume crops may be negatively affected if sown too late [22]. This means that there is likely a trade-off between the yield performances of maize and ricebean depending on the ricebean sowing time; one of the goals of this study was to investigate this trade-off.

There is also a gap in our understanding of how sub-optimal biophysical conditions affect the performance of maize/ricebean cropping systems. Most upland soils in the humid tropics have low contents of plant available phosphorus (P), which is an important limiting factor for legume growth and biological N_2 fixation [23]. The availability of P further decreases when soil moisture declines under drought conditions [24]. These two factors affect crop growth, but little is known about how the agronomic performance of maize/ricebean cropping systems is affected by soil P availability and water status. Climate models agree that interannual rainfall variability in Southeast Asia is likely to increase in the future due to climate change [25]; hence, resource-poor farmers who rely on rain-fed agriculture, are likely to be increasingly challenged by dry spells in the future.

In response to the identified research gaps, this study sets out to investigate the agronomic performance of maize/ricebean cropping systems under rain-fed conditions in the uplands of northern Laos, and to examine the factors influencing farmers' decisions concerning ricebean adoption. The study was conducted in villages where the non-governmental organisation Agrisud International (henceforth referred to as Agrisud) has been promoting intercropping systems with ricebean to farmers as a part of a project called Forestry and Agro-Ecology in Lao Rural Uplands (FORAE) since 2015. The project aims to enhance the use of natural resources, improve farmers' livelihoods and contribute to climate change mitigation and adaptation.

We combined a researcher-managed field trial with farmer-managed field trials and a series of surveys and qualitative interviews to (1) examine effects of maize/ricebean cropping systems, P fertilisation and water availability on crop yields and N_2 fixation by ricebean; (2) understand farmers' perceptions of benefits and constraints related to ricebean production and identify barriers to adoption of the maize/ricebean cropping systems; (3) assess the suitability and trade-offs of integrating ricebean in maize-based cropping systems in upland Laos.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Viengkham district, Luang Prabang province, Laos (Figure 1) between May and December 2015. The region has a tropical climate with a wet season from May to September, a mean annual rainfall of 1400 mm and a mean annual temperature of 22 °C [26]. The main agricultural practice in Viengkham district is characterised by short-fallow shifting cultivation systems with upland rice as the main subsistence crop and maize as the main cash crop [27]. Fertilisers are not commonly applied to the fields and there is virtually no mechanisation. The study area has a hilly topography and the soils are classified as Acrisols [28].

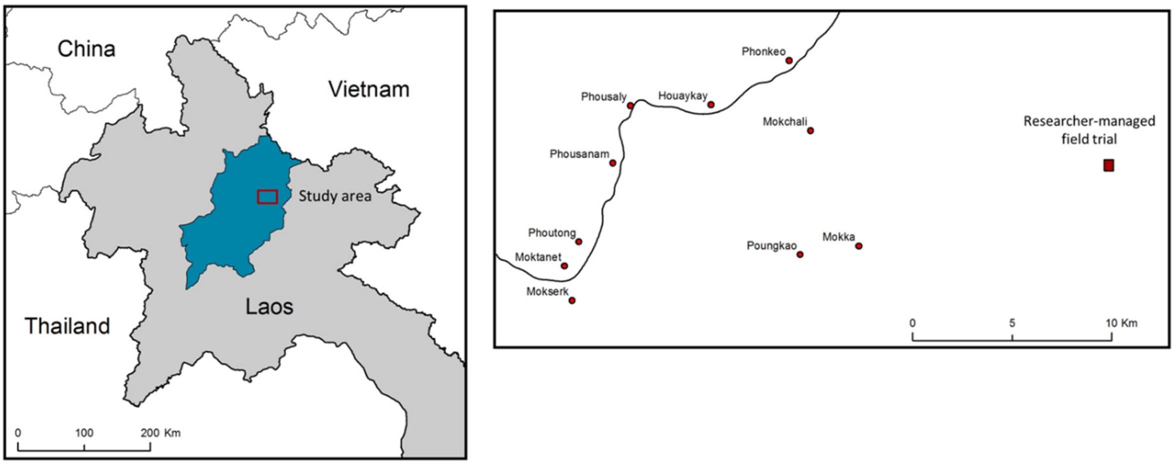

Figure 1. Map of the study area located in northern Laos.

2.2. Researcher-Managed Field Trial

A one-year researcher-managed field trial (RFT) was carried out on a farmer's field in Mouang Mouy village (20°15′ N, 103°3′ E; 500 m a.s.l.). The intention of the researcher-managed field trial was to examine the influence of maize/ricebean cropping systems, P fertilisation and water availability on crop yields and N_2 fixation. The RFT was established in a sloping field that had been cultivated with maize, upland rice and Job's tears (*Coix lacryma-jobi*) n the previous three years; hence, we expected nutrient availability to be relatively low and representative of the situation in the intensified maize production systems. Two plots were set up in the field, one at a lower position (16%–25% slope) and another at an upper position (30%–40% slope) to create a difference in soil moisture content. The lower and upper plots were 42 m apart. The layout and design of the plots are presented in Figure 2.

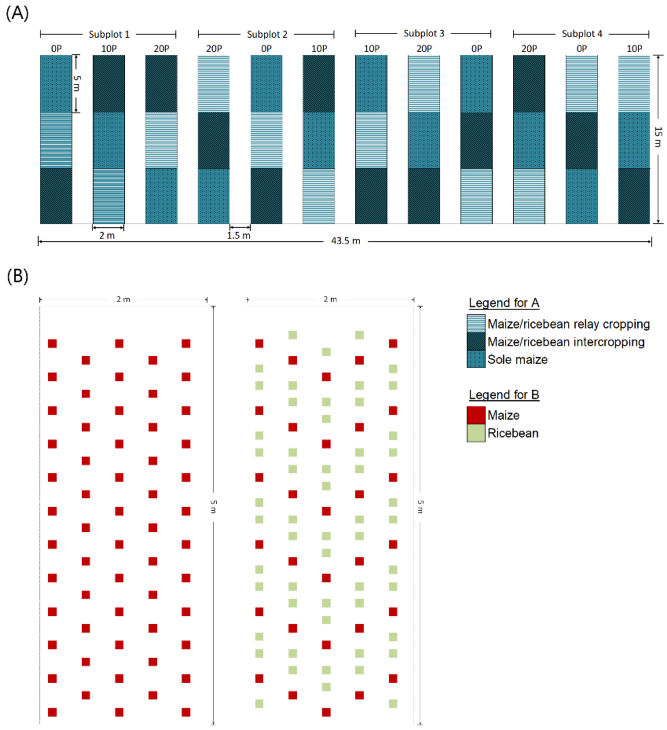

Figure 2. (**A**) Layout of the plot for the researcher-managed field trial (replicated in two positions on the slope of a hill). Each plot was divided into four sub-plots (four replicates), which were further divided into three blocks to represent three P fertilisation levels: 0 (0P), 10 (10P) and 20 (20P) kg P ha ha^{-1}. Each block consisted of three sub-blocks to represent the three different types of cropping systems. (**B**) Design of the sub-blocks for (i) sole maize and (ii) maize/ricebean intercropping and relay cropping systems.

Maize seeds were sown on May 18th in 2015 and in the intercropping system ricebean was sown at the same time, while relay cropped ricebean was sown when the maize crops reached the reproductive stage on August 29th in 2015. These practices were in accordance with the local farming practice in the uplands of northern Thailand, where the biophysical conditions are similar and where maize/ricebean relay cropping has been practised for more than a decade [16]. The Chiang Dao ricebean variety was used as this variety is commonly used in this region, and CP888 maize seeds were used, as this is the most popular hybrid variety in the uplands of Southeast Asia. Sole maize was sown at 0.4 m × 0.4 m spacing. This corresponds to a plant density of 6.25 maize plants m^{-2}. For intercropping and relay cropping, every second maize plant was replaced by two ricebean plants (3.125 maize plants m^{-2} and 6.25 ricebean plants m^{-2}). This substitutive design was chosen because an additive design for intercropping under rain-fed conditions in unpredictable environments can be risky for the farmers, as the increased plant density in additive designed cropping system increase the risk of crop failure in cases of erratic rainfall and severe drought. The same design was used in relay cropping and intercropping to investigate the effects of ricebean sowing time on cropping system performance when all other parameters remained unchanged.

N fertilisers (80 kg ha^{-1}) were applied as a split dressing. Urea (46–0–0) was applied on the 0P block, while a combination of urea and ammonium phosphate (16–20–0) was applied on the 10P and 20P blocks. The P and the first N application was at two weeks after sowing maize, the second N application was at 10 weeks after sowing. Both times the fertilizers were applied as topdressing. Plots were periodically weeded with machetes. Rodenticide (trizinc diphosphide, 85% WP) was applied once at 700 g ha^{-1} and insecticide (carbaryl, Sevin® 85, Bayer) was applied twice at 150 g ha^{-1}. Plots were fenced to protect them from roaming livestock.

Volumetric soil water content was obtained with capacitance sensors (Parrot Flower Power®, Paris, France). Three sensors were inserted into the soil in the lower and upper plots throughout the experiment to collect soil moisture readings. Data were collected continuously and later calibrated with soil of known water content, to give water content in weight per cent.

Soil samples were collected from two depths (0 cm–10 cm and 10 cm–20 cm) at the lower and upper plots (12 points per plot) at the beginning of the experiment. Samples were dried, ground to pass through a 2 mm sieve and analysed for chemical and physical properties. Contents of soil organic C and total N were determined by a CNS analyser (Elementar Vario MACRO, Langenselbold, Germany). Extractable P was determined by the Bray-1 method and measured colourimetrically (molybdate blue) using a flow injection analyser (FIAstar 5000, Foss, Hillerød, Denmark). Particle size distribution was determined by a particle size analyser (Mastersizer Hydro 2000G, Malvern Instruments Ltd., Malvern, UK). Soil pH was measured in a 1:2.5 soil: water solution with a digital pH meter (PHM 210 pH meter, Radiometer, Copenhagen, Denmark).

Maize and ricebean were harvested at maturity. The yields of maize grains and stovers as well as ricebean seeds and haulms were measured from 10 m^2 sub-blocks. Maize ears were harvested, dried and hand-shelled to separate grains from cobs. Mature ricebean vines were harvested, dried and threshed to separate seeds from pods. The weights of maize grains and stovers as well as ricebean seeds and haulms were determined after correcting for moisture by drying the subsamples for three days at 60 °C. Maize stover and ricebean haulm subsamples were then ball-milled and analysed for N concentration and $\delta^{15}N$ composition with an elemental analyser (Elementar Vario PYRO, Langenselbold, Germany) interfaced to an isotope ratio mass spectrometer (IsoPrime100, Isoprime Ltd., Stockport, UK).

2.3. Farmer-Managed Field Trials

Twelve farmer-managed field trials (FFT) were conducted in 10 villages located within 30 km from the RFT, at elevations from 924 to 1272 m a.s.l. (Figure 1). These 10 villages are among the 20 villages in which Agrisud operates. The trial was carried out in 2015; the year in which Agrisud first distributed ricebean seeds to the farmers, hence, captured the first-year effect of ricebean integration.

Each field trial was carried out in a 50 m × 50 m plot nested within a field, managed by farmers. These fields had previously been left fallow for two to five years. Maize was sown at the onset of the rainy season in May. Farmers were encouraged by Agrisud to sow the ricebean seeds 45 days after maize. However, it was observed that most farmers sowed the ricebeans at the same time as the maize. No fertilisers were applied to the plots, which was in accordance with the standard practice of local farmers.

In each plot, three 3 m × 3 m quadrates were sampled and harvested. Maize and ricebean were harvested in October and December, respectively. All plant and soil samplings, measurements and analyses were conducted in the same way as in the RFT.

2.4. Questionnaire Survey and Focus Group Iinterviews

The field trials were supplemented by a household survey and collection of qualitative data to shed light on the criteria affecting farmers' decision making regarding legume adoption. A total of 97 households from the 10 villages were included in the questionnaire survey. These households were among the 256 households who grew maize in 2014 and grew ricebean with maize for the first time in 2015. Information collected in the survey included field conditions, land use history, management practices, labour availability, yield levels of maize and ricebean, perceptions of development in soil fertility and decisions about whether or not to adopt ricebean in the following year, i.e., 2016.

Focus group discussions (FGDs) with maize farmers were conducted to collect qualitative information on the benefits and constraints associated with ricebean production and insights in the facilitating factors and barriers to ricebean adoption. The farmers were divided into two categories: (1) 'adopters'—farmers who grew ricebean in 2015 and would continue in 2016 (eight FGDs across the 10 villages); (2) 'non-adopters'—farmers who grew ricebean in 2015, but would not continue in 2016

(10 FGDs). In each FGD, the participants were asked to discuss the questions and rank the identified factors in order of importance.

2.5. Calculations and Statistical Analysis

The maize yield was expressed in two ways: per land area and per plant. The maize yield per land area was calculated to evaluate cropping system performance, while the maize yield per plant was calculated to evaluate plant performance. Maize yield per plant was calculated as maize yield per land area divided by plant density. Maize yield per land area and maize yield per plant are henceforth referred as 'maize yield' and 'maize yield per plant', respectively.

The maize yield penalty was calculated as the difference in percentage in yield between inter- or relay cropped maize and sole maize; the reported values were calculated based on the average for each cropping system irrespective of the P fertilisation and plot position.

The N_2 fixation by ricebeans was determined using the ^{15}N natural abundance technique. The percentage of N derived from the atmosphere (%Ndfa) for ricebeans was calculated using the following formula [29]:

$$\%Ndfa = 100 \times (\delta^{15}N_{ref} - \delta^{15}N_{ricebean})/(\delta^{15}N_{ref} - \beta) \quad (1)$$

where $\delta^{15}N_{ref}$ and $\delta^{15}N_{ricebean}$ are the $\delta^{15}N$ values of maize stovers (harvested from the sole maize plots) and ricebean haulms, respectively. The β value (-0.91‰) is the $\delta^{15}N$ of ricebean depending exclusively on symbiotic fixation [30]. As the β value was not measured directly, we did a sensitivity analysis to test the influence on altering this value on the %Ndfa and found the impact to be very low.

Statistical tests were performed using SPSS version 24.0. Three-way analyses of variance (ANOVA) were conducted to reveal the interaction effects of P fertilisation, water availability (represented by plot position) and type of cropping system on maize yield and N_2 fixation of ricebean in the RFT. P fertilisation, water availability and type of cropping system served as factors. The assumption of normality was tested using the Shapiro-Wilk test and data on ricebean yield were log-transformed to fulfil this assumption. The assumption of homogeneity of variance of different groups was tested using Levene's test. Multiple comparisons were analysed using the Tukey's Honest Significant Difference (HSD) test at a probability level of 0.05. Descriptive statistics and cross tabulations were used to analyse quantitative data of questionnaire surveys, while Pearson's chi-square test was used to test for association between categorical variables at a significance level of 0.05. Analyses were performed in SPSS version 24.0. Qualitative data from FGDs and interviews were analysed according to themes in this study. The currency used for all monetary values is Laotian kip (1000 LAK ≈ 0.12 USD).

3. Results

3.1. Socioeconomic Characteristics of the Studied Villages

The 10 studied villages each comprised 41–118 households and 260–812 inhabitants mainly of Khmu ethnicity (Table 1). Farmers practised shifting cultivation with one year of cultivation followed by 2–5 years of fallow. Maize, upland rice and sesame were the main crops; while cassava, Job's tears and fruit trees were grown in some villages. Maize was mainly grown as a cash crop. Some households were engaged in livestock production (cattle, buffaloes, goats, pigs and poultry). Respondents on average owned 3.8 plots with a total area of 5.6 ha (Table 2). None of the respondents used irrigation or applied fertilisers or manure to their fields. The majority of the respondents reported labour shortage (64%), practised reciprocal exchange of labour (72%) and did not hire labour (74%). All farmers mentioned 'weeding' as the most labour-intensive agricultural activity. Respondents commonly constructed wood fences around their fields together with owners of neighbouring fields. It took approximately 35 man-days to build a fence for a field of one hectare. After the harvest of main crops, some parts of the fences were often destroyed by termites or used for firewood. At this time, crop residues remaining in the fields were grazed by cattle and goats that freely entered the unfenced fields.

Table 1. Characteristics and major production activities of the studied villages.

Variable	Houay Kai	Mokchali	Mokkha	Mokseuk	Moktaned	Phon Keo	Phousali	Phousanam	Phou Tong	Poung Kao
Population size [a]	397	788	812	260	325	489	612	567	433	288
Number of households	64	97	118	49	53	85	102	82	72	41
Year of establishment	1940	1976	n/a	1945	n/a	1954	1931	1914	1920	n/a
Access to main road	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No
Distance from Viengkham (km) [b]	36	36	44	54	51	32	42	45	50	48
Altitude (m.a.s.l.)	1179	1272	1089	1081	1181	1117	1126	1230	1096	924
Main crop	Maize, upland rice, Job's tears, cassava	Maize, upland rice, sesame	Maize, upland rice, sesame, fruit trees, cassava	Maize, upland rice, sesame, cassava	Maize, upland rice, sesame, cassava	Maize, upland rice, sesame, cassava	Maize, upland rice, sesame, cassava	Maize, upland rice, sesame, cassava	Maize, upland rice, sesame, fruit trees, cassava	Maize, upland rice, sesame cassava

[a] Data obtained from Agrisud. n/a = not available; [b] Data obtained from the Ministry of Public Work and Transport.

Table 2. Household characteristics, management practices and labour availability of the studied villages.

Variable	Value
Household characteristics	
Household size	6.4 ± 1.8 (2–8)
Number of field plots	3.8 ± 0.9 (1–6)
Total land size (ha)	5.6 ± 1.7 (0.5–10.0)
Percentage of household taking loans for agricultural purposes	41 %
Management practices	
Percentage of household practising irrigation	0%
Percentage of household applying fertiliser	0%
Percentage of household applying manure	0%
Labour availability	
Percentage of household experiencing labour shortage	64%
Percentage of household practising reciprocal exchange of labour	72%
Percentage of household hiring labour	26%

3.2. Rainfall Distribution and Soil Characteristics

Compared to the previous five years, the 2015 growing season had an irregular rainfall distribution and low total precipitation (Figure 3; Figure 4A). In 2015, a severe dry spell was observed in May, i.e., the start of the rainy season. This was followed by a rainy period with low rainfall from June to August, and then a slightly drier period from September to November. Compared to other years, 2015 was an unusual year due to strong El Niño conditions [31].

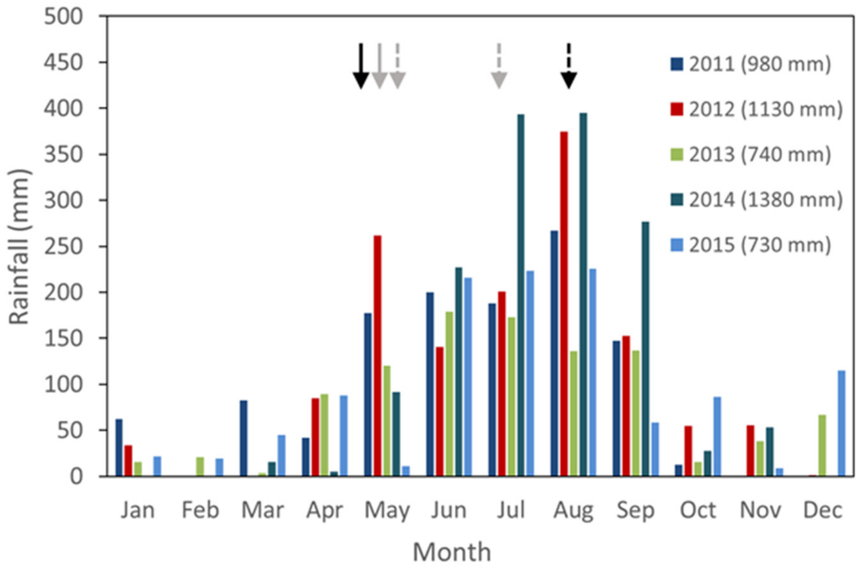

Figure 3. Monthly rainfall from 2011 to 2015 in Viengkham district and cropping seasons for maize and ricebean. Numbers in parentheses are the cumulative rainfall for the maize-growing season (May–September) in the respective years. The black solid and dotted arrows show the sowing dates of maize and ricebean, respectively, in the researcher-managed field trial. The grey solid and dotted arrows show the sowing dates of maize and ricebean, respectively, in the farmer-managed field trials.

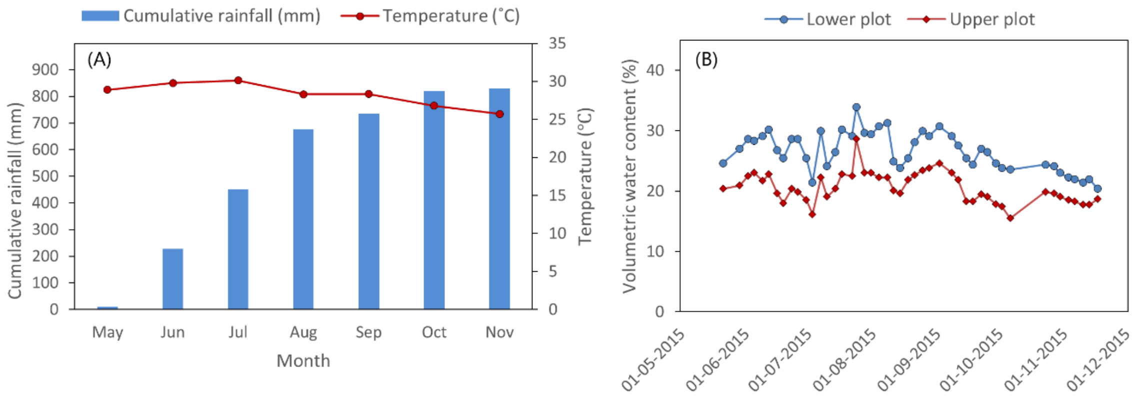

Figure 4. Graphs showing (**A**) monthly mean temperature and cumulative rainfall distributions, and (**B**) volumetric water contents throughout the entire growing season (mid-May to mid-November) of the researcher-managed field trial.

The soil at the RFT was acidic sandy loam with pH values of 4.3–4.5 and consequently concentrations of extractable P in both soil layers at both plots were low (Table 3). The upper plot had significantly lower mean water content than the lower plot throughout the growing season ($p < 0.001$) (Figure 4B). Apart from the lower mean water content and concentration of extractable P in the subsoil at the upper plot, there were no major differences in the measured soil parameters of the two plots. The soils at the FFT were either silty or sandy loams with pH values of 4.6–6.8 and medium contents of extractable P (Table 3).

Table 3. Soil characteristics (mean ± standard error) of the field trials.

Plot Position	Slope (%)	Soil Depth (cm)	pH	Soil Organic C (%)	Total N (%)	Extractable P (mg kg^{-1})	Clay (%)	Silt (%)	Sand (%)
Researcher-managed field trial									
Lower	16–25	0–10	4.5 ± 0.0	2.9 ± 0.1	0.33 ± 0.01	14.3 ± 0.9	4.0 ± 0.4	31.0 ± 2.0	65.1 ± 2.4
		10–20	4.4 ± 0.0	2.0 ± 0.1	0.27 ± 0.01	8.2 ± 1.7^{a}	6.2 ± 1.3	36.1 ± 3.5	57.8 ± 4.8
Upper	30–40	0–10	4.3 ± 0.0	2.9 ± 0.1	0.33 ± 0.01	13.2 ± 1.1	3.9 ± 0.3	28.3 ± 0.8	67.9 ± 1.0
		10–20	4.3 ± 0.0	1.8 ± 0.1	0.26 ± 0.01	4.2 ± 0.3^{b}	6.9 ± 0.6	42.8 ± 1.6	50.4 ± 2.1
Farmer-managed field trials									
-	-	0–10	5.6 ± 0.2	3.6 ± 0.2	0.38 ± 0.01	21.7 ± 3.9	6.3 ± 0.5	50.6 ± 3.1	43.1 ± 3.5
-	-	10–20	5.3 ± 0.2	2.6 ± 0.2	0.31 ± 0.01	19.9 ± 5.1	6.0 ± 0.5	49.0 ± 2.8	45.1 ± 3.2

Different superscript letters on numbers indicate significant differences ($p < 0.05$).

3.3. Crop Yields and Nitrogen Fixation by Ricebean

The average maize yield of all treatments at the lower plot (1.00 ± 0.16 Mg ha^{-1}) was about twice as high as that at the upper plot (0.45 ± 0.14 Mg ha^{-1}) ($p < 0.001$; main effect) (Table 4; Figure 5A). The average maize yield of the intercropping (0.59 ± 0.15 Mg ha^{-1}) was lower than that of sole maize (0.84 ± 0.13 Mg ha^{-1}) ($p < 0.05$; main effect), while the average maize yield of the relay cropping (0.74 ± 0.18 Mg ha^{-1}) did not differ significantly from that of sole maize and intercropping (Figure 5A). A significant two-way interaction between P fertilisation and water availability on maize yield was observed ($p < 0.01$). At the lower plot, the maize yield in the 20P treatment was significantly higher than in the 0P treatment (by 64%) and in the 10P treatment (by 38%), whilst at the upper plot, no significant difference between the P fertilisation was observed. It is, however, noteworthy that the average yields of the sole maize in the 20P treatments of the upper is less than half of that of the other P treatments (Table 4).

Table 4. Maize yield, maize yield per plant, ricebean yield and percentage of nitrogen derived from the atmosphere (%Ndfa) (mean ± standard error), and the results of three-way analyses of variance (ANOVA) at the lower and upper plots of the researcher-managed field trial.

P Level (kg P ha^{-1})	Cropping System	Maize Yield (Mg ha^{-1})		Maize Yield per Plant (g plant^{-1})		Ricebean Yield (kg ha^{-1})		%Ndfa	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
0	Sole crop	0.85 ± 0.12	0.46 ± 0.15	13.6 ± 1.9	7.4 ± 2.4	-	-	-	-
	Relay crop	0.85 ± 0.30	0.48 ± 0.16	27.1 ± 9.6	15.4 ± 5.1	-	-	27.4 ± 8.6	51.5 ± 5.4
	Intercrop	0.64 ± 0.12	0.52 ± 0.25	20.6 ± 4.0	16.7 ± 8.1	1.49 ± 0.66	8.89 ± 5.08	14.8 ± 3.1	41.4 ± 4.1
10	Sole crop	1.12 ± 0.19	0.67 ± 0.11	17.9 ± 3.1	10.7 ± 1.8	-	-	-	-
	Relay crop	0.97 ± 0.25	0.53 ± 0.16	30.9 ± 7.9	16.8 ± 5.2	-	-	29.7 ± 6.9	40.1 ± 8.8
	Intercrop	0.71 ± 0.13	0.34 ± 0.15	22.6 ± 4.1	10.7 ± 4.7	1.88 ± 0.01	4.84 ± 3.77	16.8 ± 4.2	59.2 ± 5.0
20	Sole crop	1.73 ± 0.13	0.21 ± 0.05	27.6 ± 2.2	3.3 ± 0.8	-	-	-	-
	Relay crop	1.21 ± 0.11	0.46 ± 0.15	38.7 ± 3.6	13.5 ± 2.6	-	-	37.5 ± 3.9	48.6 ± 2.0
	Intercrop	0.91 ± 0.10	0.48 ± 0.16	29.2 ± 3.1	13.7 ± 4.6	2.04 ± 0.84	45.53 ± 5.25	34.2 ± 5.6	50.6 ± 8.6
ANOVA ($p < 0.05$)		*P* value		*P* value		*P* value		*P* value	
Cropping system		0.036 *		0.002 **		-		0.700	
P level		0.156		0.300		0.060		0.322	
Plot position		<0.001 ***		<0.001 ***		<0.001 ***		<0.001 ***	
Cropping system × P level		0.760		0.932		-		0.154	
Cropping system × plot position		0.058		0.482		-		0.166	
P level × plot position		0.003 **		0.030 *		0.055		0.606	
Cropping system × P level × plot position		0.242		0.897		-		0.099	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

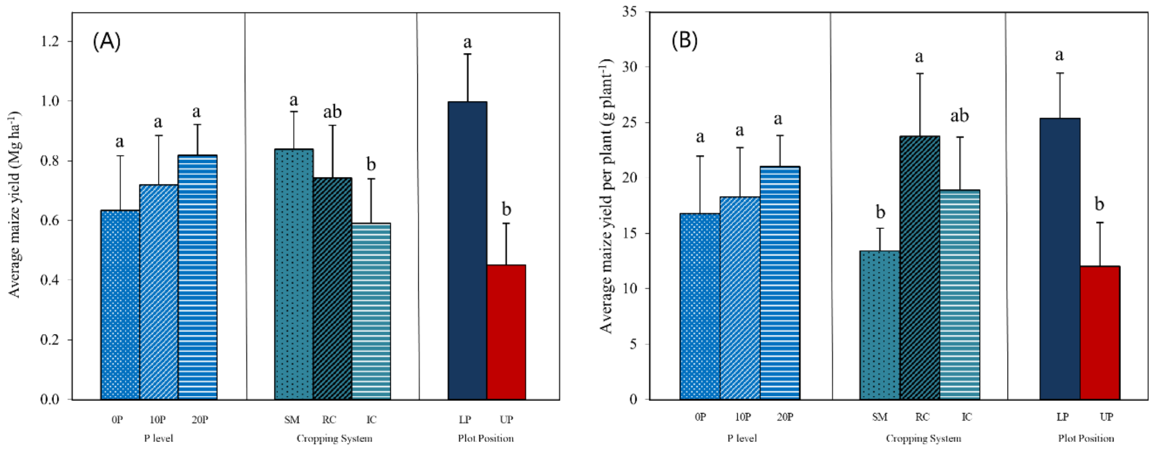

Figure 5. (**A**) Average maize yield and (**B**) average maize yield per plant of all treatments of the researcher-managed field trial. 0P, 10P and 20P represent addition of 0, 10 and 20 kg P ha^{-1}, respectively. SM, RC and IC represent sole maize, relay cropping and intercropping, respectively. LP and UP represent lower plot and upper plot, respectively. Values presented are means with standard error bars (N = 6 for P level and cropping system, N = 4 for plot position). Small letters indicate significant difference between different levels within the studied variables ($p < 0.05$); statistical tests were not performed across variables.

Maize yield per plant showed similar trends as maize yield per land area in terms of the interactions effects between P fertilisation, water availability and cropping system (Table 4; Figure 5B). The average maize yield per plant at the lower plot was about twice as high as at the upper plot (25.4 ± 0.9 g plant^{-1} versus 12.0 ± 0.7 g plant^{-1}) ($p < 0.001$; main effect). The average maize yield per plant in the relay cropping (23.8 ± 5.7 g plant^{-1}) was significantly higher than in sole maize (13.4 ± 2.0 g plant^{-1}) and intercropping (18.9 ± 4.8 g plant^{-1}) ($p < 0.01$; main effect). There was a significant two-way interaction between P fertilisation and water availability on maize yield per plant ($p < 0.05$). At the lower plot, the maize yield per plant was significantly higher in the 20P treatment than in the 0P and 10P treatments (by 56% and 34%, respectively), whilst at the upper plot, no differences between P fertilisation levels were observed (Table 4).

The ricebean yield in the intercropping system varied between 1.5 and 45.5 kg ha^{-1} (Table 4), while the ricebean crop in the relay cropping system failed to produce any yield even though there was substantial vegetative biomass (data not shown). The yield of the ricebean intercrop in the upper plot was significantly higher than in the lower plot (19.8 ± 8.0 kg ha^{-1} versus 1.7 ± 0.7 kg ha^{-1}, $p < 0.001$; main effect). The %Ndfa in the upper plot was significantly higher than in the lower plot (49 ± 6% versus 27 ± 5%, $p < 0.001$; main effect) (Table 4).

The maize yield from the FFTs varied between 0.7 and 3.1 Mg ha^{-1}, with an average of 1.5 ± 0.2 Mg ha^{-1} (Table 5). Ricebean crops performed poorly: of the 12 plots, only four plots produced yields ranging from 12.0 to 60.0 kg ha^{-1} and an average of 25.0 ± 11.7 kg ha^{-1}. The remaining plots were either destroyed by cattle (3) or produced empty pods (5). The same pattern was found in the household survey in which 59% of the respondents experienced failure of the ricebean crop and the remaining farmers harvested ricebean at very low yields (average ricebean yield 9.2 kg ha^{-1}, Tables 5 and 6). According to the survey, the average maize yields in 2014 (the year before ricebean was integrated) were significantly higher ($p < 0.05$) than the average maize yields of 2015 (Table 6).

Table 5. Maize and ricebean yields of the twelve farmer-managed field trials.

	Village	Maize Yield ($Mg\ ha^{-1}$)	Ricebean Yield [a] ($kg\ ha^{-1}$)
1	Houay Kai	3.1	0 (Empty pods)
2	Houay Kai	2.2	0 (Empty pods)
3	Mokchali	1.5	0 (Destroyed by cattle)
4	Mokkha	0.9	16
5	Mokseuk	1.6	0 (Empty pods)
6	Moktaned	1.2	0 (Empty pods)
7	Phon Keo	1.5	0 (Destroyed by cattle)
8	Phousali	1.3	0 (Destroyed by cattle)
9	Phousanam	1.2	12
10	Phousanam	1.5	12
11	Phou Tong	0.7	0 (Empty pods)
12	Poung Kao	0.7	60
Average ± SE		1.5 ± 0.2	25.0 ± 11.7

[a] Out of the 12 plots, only four plots (plots 4, 9, 10 and 12) produced ricebean yields. The remaining plots (plots 1, 2, 3, 5, 6, 7, 8 and 11) were either destroyed by cattle or produced empty pods.

Table 6. Yields (mean ± standard error) of maize and ricebean before (2014) and after (2015) ricebean integration at the studied villages in Viengkham district.

Year	Yield ($kg\ ha^{-1}$)	
	Maize	Ricebean
2014	2000 ± 1400 [a]	-
2015	1600 ± 1200 [b]	9.2 ± 8.0

Different superscript letters on numbers indicate significant difference ($p < 0.05$); statistical tests were not performed across variables.

3.4. Decision-Making Criteria

There were no obvious differences in the ranking of factors affecting ricebean production or adoption between the two focus groups.

In both FGDs, 'improved soil fertility' was mentioned as the most important benefit of ricebean production (Table 7). Farmers elaborated that the soil became 'darker', 'moister' and 'softer' after growing ricebean in the field. 'Food' was mentioned as the second most important benefit and farmers explained that ricebeans are delicious and can be a source of protein for the family. Farmers also mentioned that ricebeans can be used as animal feed, weed control and erosion control.

The same two constraints to production were mentioned by the adopter and non-adopter FGDs—namely, grazing livestock and drought (Table 7). Ricebean crops were easily damaged by grazing livestock because pods were harvested after the maize when livestock would be allowed to roam in surrounding fields, and the fences would often be gone or destroyed by then. Drought was another serious constraint to ricebean production and many farmers reported that the ricebean crops grew vigorously, but no pods were formed, or that the pods were empty, which farmers ascribed to drought.

Table 7. The benefits of and constraints to ricebean production, the facilitating factors and barriers to ricebean adoption and the alternatives to improve soil fertility given by farmers during focus group discussions. The numbers next to each response for benefits, constraints, facilitating factors and barriers represent the sum of ranking values. The responses were listed from the highest to the lowest sum of ranking values.

	Response Given in Focus Group Discussions	
	Adopters	**Non-Adopters**
Benefits	Improve soil fertility (16) Food (11) Weed control (5) Erosion control (3) Animal feed (1)	Improve soil fertility (20) Food (15) Weed control (4) Erosion control (3) Animal feed (2)
Constraints	Drought (20) Grazing livestock (18)	Grazing livestock (26) Drought (24)
Facilitating factors	High selling price (21) Support for other projects (6) Free seeds (4)	High selling price (15) Free seeds (3)
Barriers	Lack of market (9) Increased labour requirement (8) Lack of land (5) Affect maize yield (2)	Affect maize yield (13) Lack of market (11) Increased labour requirement (10) Lack of land (6)
Alternatives to improve soil fertility	Leave field fallow Raise animal for manure Associate with other crops Burn field	Leave field fallow Raise animal for manure Associate with other crops

The selling price of ricebean was mentioned as the most important facilitating factor affecting farmers' interest in adopting ricebean; however, in direct connection to this was the ranking of lack of market as one of the most important barriers in both FGDs. Getting support for other Agrisud-related projects and getting other seeds for free were also mentioned as factors encouraging the adoption of ricebean.

Increased labour requirement came up as an important barrier to ricebean adoption in both FGDs. The farmers elaborated that it was difficult to manage the fields and harvest maize with ricebean crops growing in between the maize crops. Additionally, some farmers complained that the increased labour needed for sowing ricebean resulted in labour shortage for upland rice cultivation.

Notably, 'affect maize yield' was ranked first among the four barriers mentioned in the non-adopter FGDs (Table 7). This was mainly linked to higher incidence of rat infestation as the vigorous growth of ricebean plants provided a good habitat for rats. Furthermore, in some cases the ricebean plants climbed up the maize stalks and made them fall, thus affecting the maize yields.

When non-adopters were asked if they would consider re-adopting ricebean, some said 'no' as they preferred growing other crops; some answered 'yes', provided that more farmers grew ricebean and, interestingly, if Agrisud buys ricebean produce at a high price, gives out free cattle, provides support to build fences and provides more motivation or incentives to adopt ricebean.

Two-thirds of the respondents in the survey said that they would continue to grow ricebean in the following year, whilst the rest would stop growing ricebean. Based on the results of the FGDs, we hypothesised that farmers' decisions about ricebean adoption would be influenced by their perceptions of soil fertility, labour availability and maize yield changes; but the results of chi-square tests showed that farmers' decisions concerning ricebean adoption was not significantly related to any of these factors ($p > 0.05$) (data not shown). After the study we learned that in fact only a single farmer—namely, the headman of Phoutong who was highly supported by Agrisud—continued to grow ricebean in 2016 (Castella, personal communication).

4. Discussion

Due to the El Niño related drought, the yield levels of all plots included in this study were extraordinarily low, which reflects the general situation in Laos in 2015. This situation limits the conclusions that can be drawn from the trials, but there are nevertheless a number of general lessons that can be learned—keeping in mind that El Niño events are likely to become more frequent in the future. In that sense, the results can be viewed as indicative of a future with more variable climate in the region.

First of all, the study shows that soil moisture strongly influences yields and fertiliser use efficiency of rain-fed maize and ricebean. Water deficit during the vegetative and pre-anthesis stages of maize development can have a disastrous effect on maize yields [32] and the dry spell during these critical stages have likely exacerbated the water-stressed condition at the upper plot, possibly leading to a significant reduction in maize yield. The average maize yield in the FFT was within the range of average maize yields in upland areas in northern Laos (1.5–2.5 Mg ha^{-1}) [5]. Ricebean is normally perceived as a drought-tolerant crop, but performs best under an annual rainfall of 1000–1500 mm year^{-1} [33] and the cumulative rainfall of 730 mm during the ricebean growing period clearly brought about yield reducing water stress. The average ricebean yield was only 1.5% of the yield from a village of northern Thailand, where farmers have practised a similar cropping system for more than a decade [16]. Under the wetter soil conditions at the lower plot, the application of P fertilisers led to an increase in maize yield; however, when water was scarce (at the upper plot), the application of P fertilisers had no effect. Hence, the return to investment in P fertilizers under rainfed conditions is very uncertain and in a dry year there may be no benefit at all—or might even have a negative effect. The maize yields of the 20P treatment of sole maize were notoriously low, which could be because the higher availability of P led to greater biomass production early in the season, which used up all the water; thus, there was insufficient soil moisture in the profile during seed development. This 'haying-off' effect is well known from semiarid areas, but as we did not monitor biomass production throughout the growing season it is not possible to document that this was in fact taking place in the RFT.

As expected, maize yields at the RFT were less affected by the presence of ricebean in the relay cropping system than in the intercropping system. This is ascribed to the late sowing of ricebeans in the relay cropping system that allowed maize plants to establish before the legume was introduced into the system, giving the maize plants a competitive advantage that translated into higher yield.

While maize yield per land area showed no significant differences between relay cropping and sole maize, relay cropping produced a significantly higher maize yield per plant than sole maize, irrespective of water availability. The higher plant density in the sole maize system could have led to intraspecific competition, thus a lower maize yield per plant. As shown in the FGDs, a maize yield penalty will discourage farmers to change from maize monocropping to intercropping systems since maize is considered the main crop and an important income source. Conversely, there was no significant maize yield penalty in the relay cropping system, which thus could represent an avenue for the farmers to switch from monocropping to ricebean integration without affecting the maize yield.

However, the maize yield reduction due to rat infestation as reported by the farmers is a challenge that would have to be addressed. This problem was not observed in the RFT, but problems with increased rat infestation in intensified systems have also been reported from elsewhere in the region [34]. The only direct measure being applied by local farmers is rat traps. The problem has been reported to decrease in areas where more farmers are growing legumes, thereby sharing the rat population and reducing the pressure on individual fields (Castella, personal communication), but it is uncertain if this effect would continue if legume cultivation became more common.

The reduced maize yields in the farmer-managed intercropping system are also likely to be related to inappropriate timing of the companion crops, as many farmers did not follow the recommendations given by Agrisud, but distributed the ricebean seeds at the same time as sowing maize. This may have encouraged interspecific competition for resources with effects on yields as observed in the RFT. We did not ask farmers about the reasons for not following Agrisud's recommendations about sowing time, but hypothesise that they are related to the increased labour requirements associated with sowing twice, and that the recommended sowing time in some cases overlapped with the time for sowing and weeding of upland rice which is the staple food and of high cultural importance.

In contrast to the observation for maize yield, a lower ricebean yield was observed in the lower plot of the RFT. This could be because soil moisture acts as a signal for the transition from vegetative growth to reproductive development [35]. The higher water availability in the lower plot may have led to the inclination for late flowering and promotion of vigorous vegetative growth in ricebean plants [36], while water stress stimulated early flowering and inhibited vegetative growth of ricebean at the upper plot. The yield differences may also be associated with a stronger competition with maize for P in the lower plot than in the upper plot. In the lower plot with wetter soil conditions, maize gained an initial advantage of having a head start relative to ricebean and the competitive advantage at the beginning of the growing season translated into better root development, followed by greater nutrient (including P) uptake ability later on in the season. Since P is an essential nutrient for legume performance (%Ndfa increases with P supply) and available P in soil was limited, maize was in a better position to take up P at the onset of the competition; thus, ricebean was more likely to suffer yield loss from competition with maize.

The N_2 fixation of ricebean was influenced by the plot position and relatively poor compared to other studies from the region reporting %Ndfa of 64–86 for ricebean intercropped with maize [30]. This can probably be ascribed to the severe drought and possible nutrient limitation. The %Ndfa of ricebean in the upper plot was about twice that in the lower plot (Table 5), which can be explained by the more intense competition with maize for P at the lower plot as mentioned above. The low levels of N_2 fixation, combined with the fact that most ricebean residues in farmers' fields were grazed by livestock, means that the transfer of N from atmospheric fixation to the soil is likely to be negligible as N allocation studies have shown that only 5%–11% of the fixed N is found in roots [37,38].

Barriers and Facilitating Factors to Adoption of Ricebean

Our results suggest that economic factors are important criteria in farmers' decision-making process, as considerations on selling price and lack of markets came out among the most important criteria. At the time of the study, ricebean was sold at 6000 LAK kg^{-1} in the neighbouring province of Xiengkhouang, while maize was sold at 800–1000 LAK kg^{-1}. However, at the time of the study, no middlemen approached the study villages to purchase the ricebean produce and according to experience from the neighbouring province of Xienkhouang, where a market for ricebeans has emerged, farmers would have to increase the ricebean production to minimum 50 tonnes (equalling one truckload) in order to attract middlemen to the villages (Castella, personal communication). This dilemma could be addressed if Agrisud bought the ricebean production at a minimum price as suggested in some of the FGDs, which is a practice applied by this organisation in relation to the promotion of other crops in other areas. However, in this case, Agrisud's intention was to promote ricebean for household consumption, hence, no efforts were made to facilitate market access. Even though farmers mentioned the culinary and nutritional qualities of ricebean when asked about benefits of the system, consumption was not mentioned as a facilitating factor for adoption. Beans are not a part of the traditional diet in the area and Agrisud's efforts to influence consumption patterns—e.g., by providing ricebean based recipes—seem to have had limited effect.

The fact that 'getting support for other Agrisud-related projects' and 'getting other seeds for free' were mentioned as factors encouraging the adoption of ricebean demonstrate the importance of the presence of an extension agent. Although these factors were not directly related to ricebean adoption, they served as incentives provided by Agrisud in order to encourage adoption and the presence of extension agents promoting maize/legume intercropping clearly affected farmers' behaviour. This was confirmed by an Agrisud trainer who stated that farmers would have stopped growing ricebean if there were no encouragement from Agrisud and by the fact that all but one farmer gave up ricebeans in 2016.

Increased labour requirement was a highly ranked barrier to ricebean adoption in both FGDs and results from the survey points to labour shortage as a general challenge. Increased labour requirement was also identified as a barrier to legume integration by farmers in a study from Thailand and the higher labour input in the intercropping systems was confirmed by calculations of labour productivity in this system versus monocropping of maize [16].

While improved soil fertility was the most frequently mentioned benefit of ricebean production, none of the surveyed farmers perceived declining soil fertility as a problem; hence, this is not likely to be a part of the decision making regarding legume adoption [39]. When asked about other means to improve soil fertility, most farmers mentioned 'leave field fallow' which is an efficient and labour-saving method in situations where this is an option and labour is scarcer than land [11], which seems to be the case for most of the respondents in the area. All of the villages included in this study seem to be in the initial phase of an intensification transition brought about by increased commodification of agriculture and the land zoning policies. This transition has been observed in other villages in the area where it has led to soil degradation and yield declines [14]. Therefore, it is most likely only a matter of time before the farmers in the studied villages start experiencing decreasing soil fertility, and by then the nutrient levels may be so low that it will be not be possible to grow legumes [40].

It is uncertain whether the perceptions of ricebean as soil improver mentioned by the farmers are personal observations or characteristics adopted from Agrisud or other extension services. Given the short history of the crop in the area, it is unlikely that farmers will have witnessed the effects they mention to any great extent. While darker, moister and softer soil are effects one can experience immediately after introducing mulches or cover crops, 'improved soil fertility' is an unlikely observation by a rural smallholder, the first year of legume integration. This points to the limitation of assessing opinions of farmers, in uneven power structures. While during the interviews, our independence of Agrisud was stressed repeatedly, this might not have been sufficient to completely avoid a certain level of willing to present the theoretical, expected effects of legume cultivation over what was actually observed.

Crop damage by grazing livestock was one of the major constraints to ricebean production. Building and maintaining strong fences can protect the crop against livestock, but the construction of fences requires high labour investments. The government of Laos is putting a high priority on increasing livestock production and is currently implementing a smallholder livestock commercialisation project in northern Laos funded by international organisations [41,42]. This has brought about increasing problems with livestock entering and destroying fields—problems that are likely to intensify and complicate any attempts to promote ricebean integration—as well as attempts to grow other leguminous crops outside the main growing seasons. As a part of the livestock promotion programme, efforts are made to ensure that the farmers keep their livestock at designated areas and grow forage crops for feeding it, and a number of initiatives are currently working on implementing landscape level land use plans to address this issue [42].

5. Conclusions

Our findings identify a number of challenges associated with the maize/ricebean intercropping system. The agronomic challenges were to a large extent associated with the occurrence of a drought and while we recognize this as an extreme event, we also clearly show that the maize/ricebean intercropping system is not drought prone; hence, it does not appear to be well-adapted to the increased variability of interannual rainfall and increased frequency of extreme weather events that the future is likely to bring. The expected contribution of the maize/ricebean system to the build-up of soil organic carbon will in theory over time buffer the negative impacts of drought spells and increase climate change adaptation—but at the initial stage, the cropping system itself is fragile and the transition period is a time of high vulnerability of the system.

Relay cropping was superior to intercropping with respect to maize yields; however, ricebean yields were more severely affected by the drought in the relay cropping system than in the intercropping system. As such, farmers are facing a dilemma between fitting the ricebean growing season into the narrow cropping window and minimising the maize-ricebean competition. Therefore, we call for on-farm studies focusing on development of a locally adapted maize/ricebean cropping system that can operate under drought and variable rainfall conditions. This would entail: (1) screening for ricebean genotypes with improved tolerance to drought and low P availability, e.g., a genotype that has a dimorphic root system, (2) identification of optimum ricebean sowing time, and (3) identification of optimum plant density to optimise the overall crop yields.

We identified a number of problems with fitting the system into the local context in which most farmers experience labour shortage, but do not recognize problems with declining soil fertility and hence are not likely to invest labour in soil improvement without any additional benefits. The opportunity of gaining an income from selling the ricebeans would provide such an incentive, but the absence of a market outlet currently prevents this from materializing. Experience from the neighbouring provinces has demonstrated that there is indeed a potential demand for beans in the area, but it appears that efforts to coordinate actors along the value chains are needed to link smallholders in remote areas to these emerging markets. Fitting the intercropping system into the farming systems of the area also poses a challenge, and problems with grazing livestock entering the fields and eating the ricebean before harvest must be addressed before promoting the system. This issue can only be addressed through a community-based landscape level approach that creates enabling conditions for a change of the entire socioecological system. We conclude that the suitability of the maize/ricebean intercropping system in study area is questionable due to the number of agronomic and structural challenges identified in this study.

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