THE EFFECT OF INTERCROPPING DRY RICE WITH SPINACH OR TURNIP ON RICE YIELD AND WEED SUPPRESSION

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Introduction

Rice is one of the staple crops for more than half of the world's population. It is mostly grown in Asia with 90% worldwide production (Childs 2022). Rice (*Oryza sativa*) is an annual grass belonging to the family *Poaceae* and normally cultivated in hot and humid regions with high amount of rainfall from May to September. Rice is best grown in clay or clay loam soils with a high water-holding capacity.

There are a wide range of rice varieties grown in different regions all over the world which are adapted to local weather conditions, however most of traditional rice crops are grown in flooded fields which accounts for 75% of total rice production (Bouman et al. 2001). The purpose of flooding rice fields is to suppress weed emergence, but this cropping system proposes a number of concerns. First, the anaerobic condition accelerates the emission of methane (CH_4) which is a potent greenhouse gas. Methane is produced by the process of methanogenesis under the saturated soil which is then released into the atmosphere via three pathways including diffusion from the soil, diffusion from rice plant micropores, and the release of gas bubbles called ebullition (Gupta et al. 2021). Paddy rice fields are a major source of methane emission with 10-70% of the total anthropogenic methane emission (Agnihotri et al. 1999) and methane is estimated to be 27-30 times more potent than the carbon dioxide over 100 years in causing global warming (United States Environmental Protection Agency (EPA) 2022). The second constraint with this system is high water requirement. In Asia, 80% of the amount of fresh water diverted is irrigated for lowland rice production (Bouman et al. 2001) leading to the shortage of fresh water.

Due to the expansion in global population and the decrease in the total land used for rice cultivation, the global demand for rice consumption is expected to increase by approximately 15% from 2014 to 2030 signifying a need for innovative practices in rice farming to meet the demand

(Mishra et al. 2022). In this context, upland rice has been emerging as an alternative to the lowland system which can address criticism caused by the methane emission and the high-water use. Upland rice is also called dry rice cultivation in which farmers do not flood their rice fields throughout the growing season. Dry rice can be cultivated with both direct seeding and transplanting. It is found that rice grown in dryland required 36-41% less water, compared with traditional flooded system (Belder et al. 2005) which can save water and reduce the release of methane into the atmosphere. Nevertheless, only 8% of total rice cultivation land is upland rice, compared to 92% of lowland rice farming according to data from countries from Asia, Latin America, sub-Saharan Africa (Saito 2018). This can be attributed to the reduced rice yield in upland rice cultivation. Under the unsaturated condition, weeds normally outcompete rice because of their high adaptability and fast growth. Belder et al. also recorded a lower yield of 15-39% in the aerobic rice system (2005). In Korea and West Africa, the loss of rice yield could go up to 100% in direct seeding system due to weed competition (Rao et al. 2007). In Eastern India regions, dry seeded rice grown in rainfed upland ecosystem showed the highest yield loss with more than 180kg ha^{-1}, whereas transplanted rice grown in rainfed deep water ecosystem showed the lowest yield loss with around 70 kg ha^{-1} (Rao et al. 2007). Hence, the loss of rice yield in dry direct seeding system is mostly due to weed competition and a low germination rate at the first stage of establishment. It is important for rice farmers to utilize a sustainable weed management in applying dry rice cultivation either in direct seeding or transplanting systems.

Intercropping is one of sustainable weed management practices in which two or more crops are grown in the same field. There are various forms of intercropping including mixed cropping, companion planting, relay cropping, smother cropping, interseeding, overseeding, or underseeding (Mohler et al. 2019). In addition to weed suppression, the benefits of intercropping are facilitating biological interactions between plants, efficiently utilizing resources such as light, water, and nutrients, increasing biodiversity (Mohler et al. 2019). In comparison with sole crop having low ability to compete weeds, weed biomass was reduced substantially by 58% in intercropping systems (Gu et al.2021). The similar result was found in the wheat-legume mixture with 90% lower weed biomass provided suitable intercrops used (Leoni et al. 2022). As a result, intercropping rice with other crops has been experimented in numerous studies. Intercropping legumes and rice showed a significant reduction of 65% in weed infestation and an increase of 33% in rice yield under the System of Rice Intensification (SRI) (Shah et al. 2021). Habimana et al. stated that rice-spinach intercropping systems had the higher weed suppression, compared with the sole rice system due to the canopy effect of spinach (2019).

Spinach (*Spinacia oleracea*) is a leafy green and cool seasonal crop belonging to the *Amaranthaceae* family. It is an annual plant having leaves variable in size and shapes. Although spinach is best planted in cool weather, it can be grown in Summer for early Fall harvest. Spinach has become an option for an intercrop in rice farming because of its shading effect. Yet, spinach is stimulated to bolt under long-day and warm weather conditions (Government of British Columbia [date unknown]). It is therefore significant to consider spinach varieties which is upright growing and highly resistant to bolting during rice growing season.

Turnip (*Brassica rapa subsp. rapa*) is a root vegetable which is grown in temperate climate belonging to the Brassicaceae family. The turnip root emerges above the ground which varies in color (white, purple, red, or light green). Its leaves develop from the above-ground crown which can cover the ground when they grow bigger. In British Columbia, turnip can be planted early in the Spring for summer harvest and mid-July for fall harvest (Government of British Columbia [date unknown]).

In British Columbia, rice is a 5-months crop starting from May to September and grown in Fraser Valley. There are different varieties of rice grown in British Columbia including sake rice, table rice, and sweet rice. Before Canada started to produce rice, a huge amount of rice consumed in Canada was imported from the U.S. In 2017, Canada was the fourth largest rice importer of the U. S with 209 thousand metric tons of rice (USA Rice 2018). Most of the sake rice was also imported from other producers for sake production in BC (Artisan SakeMaker Inc. 2013). Though it was considered that BC's climate was not suitable for rice farming, there is rice production in the Fraser Valley which has been operated by Mr. Masa Shiroki. Both sake rice and table rice are now grown in Abbotsford, however, those rice fields are flooded (Tourism Abbotsford 2019) that contributes to the global warming and water scarcity. In addition, an increasing demand for rice consumption in British Columbia requires an expansion in rice production in a more sustainable way.

As a result, the aim of this experiment is to compare the efficiency between monoculture and intercropping system in terms of (1) yield of rice, spinach, and turnips; (2) weed suppression; and (3) land use efficiency.

Methods

I. Experiment site

The experiment was conducted at KPU Certified Organic Farm in Richmond, British Columbia, Canada which on the Garden City Lands located at margin of old Lulu Island Peat Bog. The soil at KPU was layered with 70 cm of minerals to conserve the peat soil below. The study was setup in the East Field of KPU Farm along from South to North side.

II. Experimental design

The experimental plot was established using Randomized Complete Block Design with five replicates (five blocks) and three treatments including rice monoculture, spinach and turnip monoculture in succession, and mixture of rice and spinach/turnip succession with a ratio of 1:1. As a result, there were 15 plots in total (Figure 1): 5 rice monoculture plots (1.6 m x 1.6 m), 5 vegetable plots (1.6 m x 1.6 m), and 5 mixture plots (2.6 m x 1.6 m).

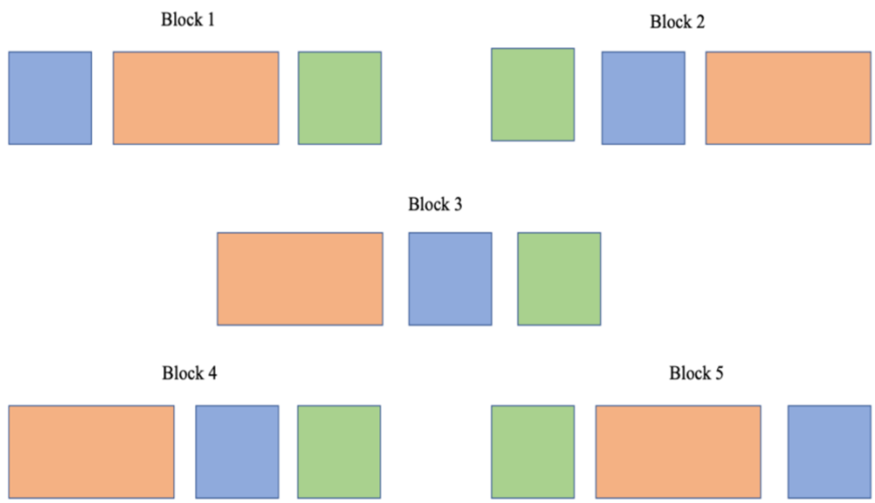


Figure 1. Plot layout

Plot legend

The distance between plots was 30cm, the distance between blocks (buffer zone) was 2.0m, and the distance between plants was 20cm (Figure 2). The harvesting area in monoculture plots was 1m in the centre of the plot and the harvesting area in mixture plots was 2m in the centre of the plot (Figure 2).

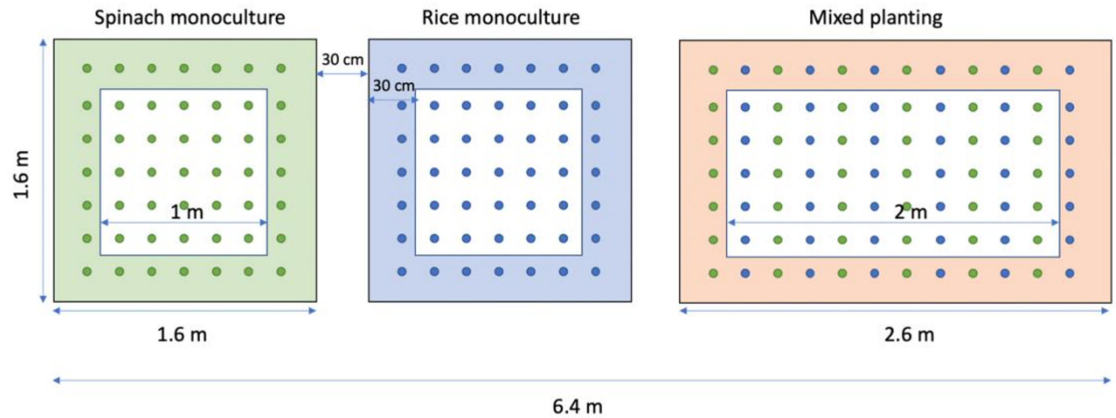


Figure 2. Plot layout

The plot was first mowed and tilled using the tractor on May 18th to loosen the soil, create a smooth and even bed for crops. Five kilograms of blooded meal was applied, and drip irrigation was established with three drip lines on June 2nd. Two more drip lines were added on July 13th after one week of seeding turnip. The irrigation was turned on twice a week and three hours/time for the first three weeks. However, the frequency of irrigation was increased to every other day for three hours/time which was turned off at the end of September.

III. Planting

Rice grains were steeped at 10°C in the germination chamber for 10 days and then dried using paper towel before seeding. Rice was seeded in six crates (200 seeds/crate). Spinach was seeded in eleven trays using soil blocks (2-3 seeds/cell). Three-week-old rice and two-week-old spinach plants were hardened off on May 31st before being transplanted on June 5th. The whole plot was covered using row cover for first three days to protect plants from crows. All plots were hand weeded 1, 2, and 6 weeks after transplanting.

IV. Data collection

Weed pressure was recorded based on the percentage of weed cover which was calculated using Canopeo application. A photo of the plot was taken before weeding and after weeding to determine the percentage of vegetative cover. The difference between before and after weeding was the percentage of weed cover in each plot (Figure 3).

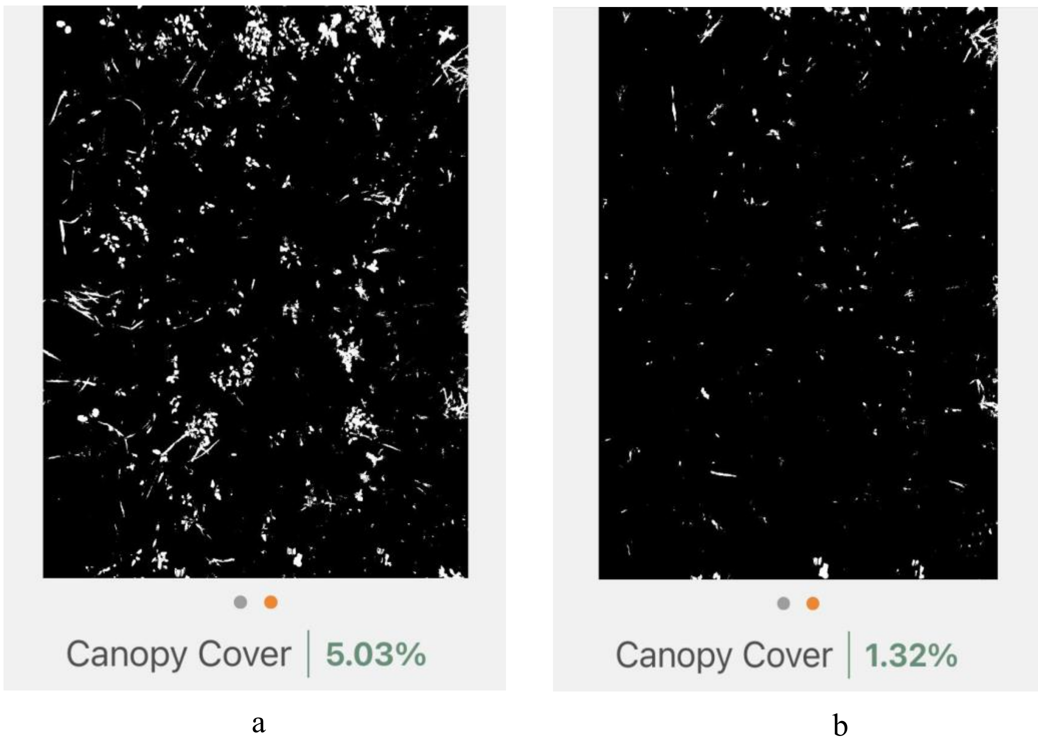


Figure 3. The percentage of vegetative cover in Canopeo application
a) before weeding; b) after weeding

Spinach was hand harvested from the whole plot of each plot on June 28th and the plot was cleaned and prepared before direct seeding turnips (3-4 seeds/hole) on July 7th. Turnip was hand harvested in 1m centre of each monoculture plot and 2m centre of each mixture plot on September 1st. Damaged, undersized, and oversized roots were removed. Fresh weight of spinach and turnip was recorded at harvest.

Rice was hand harvested using clipper in 1m centre of each monoculture plot and 2m centre of each mixture plot on October 22nd and then stored in the cooler. Rice stalks were dried by hanging them over the overhead irrigation line in the dome at the KPU Farm for one week. Rice grains were threshed using a bucket and weed wacker to mimic a thresher on October 31st. Rice grains were winnowed using screening and empty grains were removed using air separator on November 1st, 2023. Dry weight of rice grains was recorded.

V. Data analysis

Land equivalent use was compared using two indicators:

a. Land equivalent ratio (LER) is calculated as following formula developed by Mead and Willey (1980) to determine. If the intercropping is beneficial. It is defined as relative land required in sole cropping to obtain the same yield as in intercropping. LER is greater than 1, intercropping is beneficial to utilize and vice versa.

$$\text{LER} = \frac{Yr}{Sr} + (\frac{Ys}{Ss} + \frac{Yt}{St})/2$$

In which,

Yr, Ys, and Yt is the yield of rice, spinach, and turnip crop obtained in intercropping, respectively.

Sr, Ss, and St is the yield of rice, spinach, and turnip obtained in sole system, respectively.

b. Relative land output (RLO) is calculated to determine the benefits of intercropping as following formula developed by Jolliffe (1997). RLO is obtained to evaluate the advantages when utilizing intercropping in a given amount of land. Monoculture and intercropping system must have a same number of plants.

$$\text{RLO} = \frac{\sum \text{Yi}}{\sum \text{Ym}}$$

In which,

Yi is the sum of rice, spinach, and turnip yield in intercropping

Ym is the sum of rice, spinach, and turnip yield in sole system.

Both LER and RLO are explained in the same way. If LER and RLO are greater than 1, intercropping is beneficial to utilize.

Mixed effects model analysis was used to evaluate the weed pressure

- Fixed factors: treatments and WAT (weeks after transplanting)
- Random factors: block and plot
- Dependent variables: the percentage of weed cover (%)

One-sample student's t-test was used to analyze land use efficiency and ANOVA was used to evaluate crop yield.

Results

I. Weed pressure

The study found no statistically significant difference in the weed cover percentage among treatments with p-value=0.189 (Table 1) showing there was no effect of cropping system on the weed pressure. However, the number of weeks after transplanting indicated an effect on the weed cover with p-value<0.001 (Table 1). Data showed an interaction between treatments and the number of weeks after transplanting found with p-value=0.035 (Table 1).

Table 1. Results of Mixed effects model on the percentage of weed cover (%) after 1, 2, and 6 weeks after transplanting (Significance level of 0.05). Symbol * means the interaction between treatment and the number of weeks after transplanting (WAT)

Fixed Effect Omnibus tests

	F	Num df	Den df	p
Treatment	1.76	2	30.1	0.189
Weeks after transplanting	60.60	2	30.1	<.001
Treatment ✻ Weeks after transplanting	2.98	4	30.1	0.035

Note. Satterthwaite method for degrees of freedom

Weed cover did not differ between treatments during the first two weeks after transplanting, when intercrop was spinach. There was no significant difference in weed infestation between rice monoculture and rice-turnip mixture after six weeks of transplanting with p-value=0.938 (Table 2). Meanwhile, weed cover was significantly lower in turnip monoculture than the rice-turnip intercrop six weeks after transplanting (p=0.028) (Table 2 and Figure 4).

Table 2. Fixed effects parameter estimates on the percentage of weed cover (%) after 1, 2, and 6 weeks after transplanting (Significance level of 0.05) showing. Symbol * means the interaction between treatment and the number of weeks after transplanting (WAT)

Fixed Effects Parameter Estimates

Names	Effect	Estimate	SE	95% Confidence Interval		df	t	p
				Lower	Upper			
(Intercept)	(Intercept)	7.082	0.801	5.51	8.652	4.04	8.8443	<.001
Treatment1	Mixture - Rice	0.914	1.072	−1.19	3.014	30.22	0.8524	0.401
Treatment2	Greens - Rice	−0.986	1.072	−3.09	1.115	30.22	−0.9197	0.365
Weeks after transplanting1	2 - 1	9.072	1.012	7.09	11.056	30.00	8.9615	<.001
Weeks after transplanting2	6 - 1	10.577	1.072	8.48	12.678	30.22	9.8688	<.001
Treatment1 ✻ Weeks after transplanting1	Mixture - Rice ✻ 2 - 1	0.166	2.480	−4.69	5.026	30.00	0.0669	0.947
Treatment2 ✻ Weeks after transplanting1	Greens - Rice ✻ 2 - 1	0.620	2.480	−4.24	5.480	30.00	0.2500	0.804
Treatment1 ✻ Weeks after transplanting2	Mixture - Rice ✻ 6 - 1	0.211	2.695	−5.07	5.493	30.31	0.0782	0.938
Treatment2 ✻ Weeks after transplanting2	Greens - Rice ✻ 6 - 1	−6.223	2.695	−11.51	−0.941	30.31	−2.3090	0.028

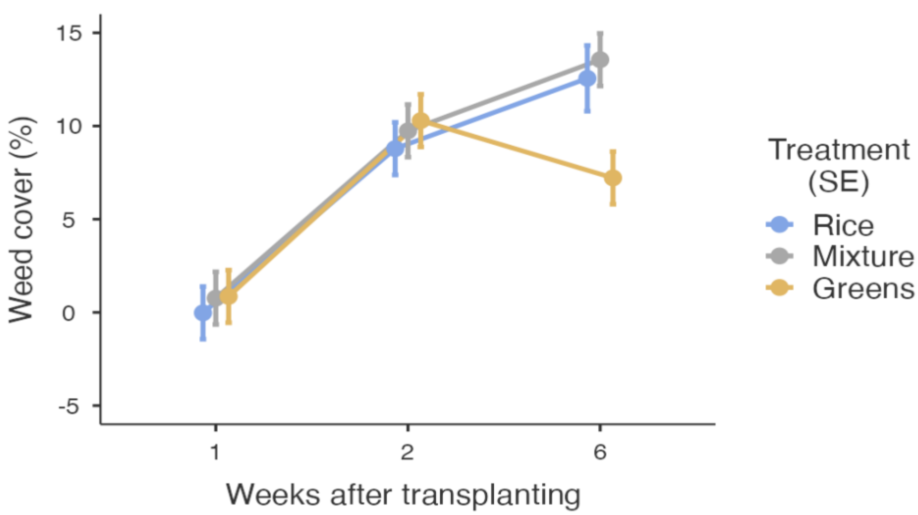
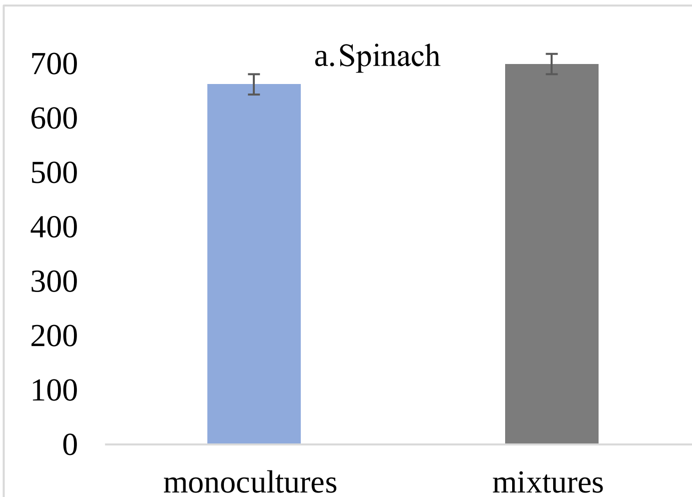
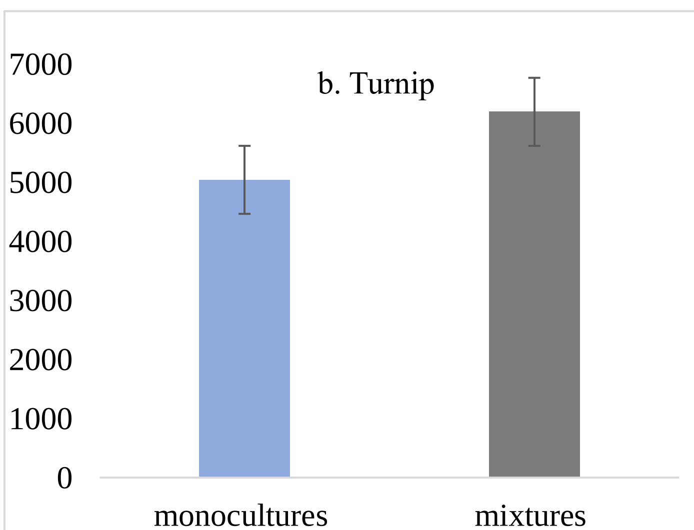


Figure 4. Weed cover removed by hand weeding 1, 2, and 6 weeks after transplanting rice. Error bars denote standard errors around mean.

II. Crop yields

The treatments did not show any statistically significant effect of cropping systems on the average yield of spinach, turnip, and rice. The fresh weight of spinach and turnip in mixture were higher in monoculture plots (Figure 5a and 5b). By contrast, rice yield was approximately 61% higher in monocultures, compared to mixture (Figure 5c).





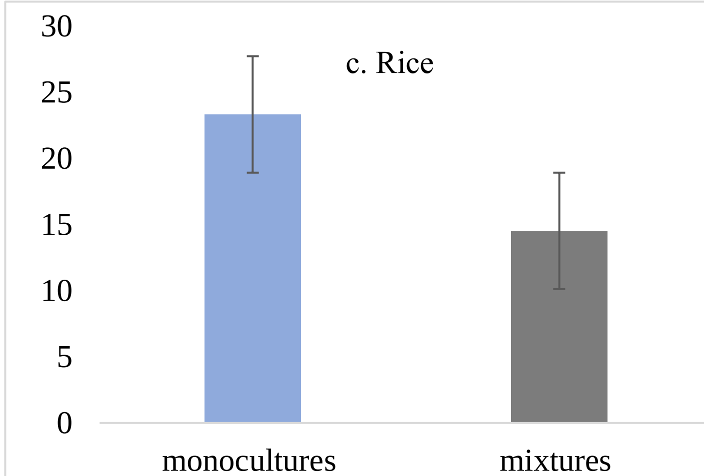


Figure 5. The average yield of spinach, turnips, and rice obtained from monocultures and mixtures. Error bars denote standard errors around mean.

III. Land use efficiency

LER and Square Root Transformed RLO were 1.00 ± 0.26 and 1.13 ± 0.28, respectively which did not significantly differ from 1 indicating intercropping offered no higher land use advantage (Figure 6).

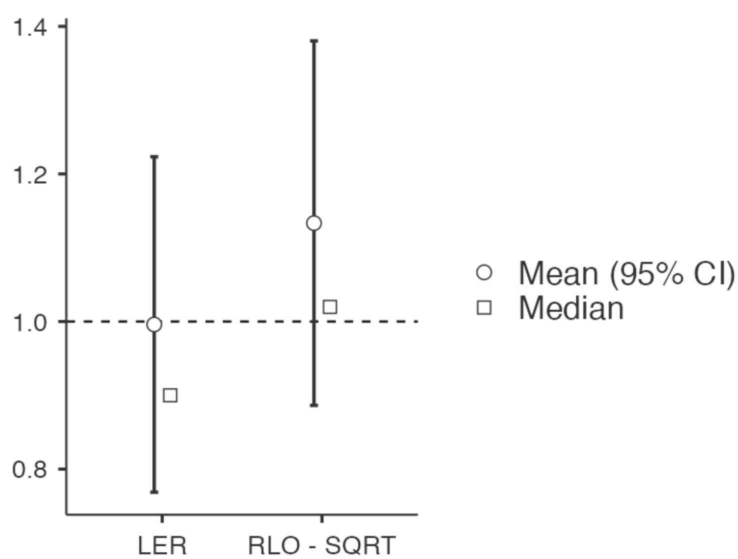


Figure 6. Mixture productivity relative to monocultures, according to the Land Equivalence Ratio (LER) and Square Root transformed Relative Land Output (RLO). Error bars denote 95% confidence interval. Dashed line shows value of one, where mixture and monoculture land use efficiency is equivalent

Discussion

Land use efficiency

The study indicated that intercropping dryland rice with spinach followed by turnip was as efficient as sole cropping. This result might be attributed to the reduced rice yield in mixture plots. Rice yield was approximately 61% higher in the monoculture plots than in the mixture plots. Water deficit was observed in dryland rice during early stages which might negatively affect the initial establishment of rice seedlings. Although rice is more vulnerable to water stress during productive stages, rice yield is decreased by 21-50.6% due to drought during the vegetative phases (Zhang et al. 2018). Water deficit inhibits stomatal opening and photosynthesis which eventually reduces cell division and expansion in rice plants at vegetative stages (Zhang et al. 2018). Two weeks after transplanting, the rice plants were weak and stunted, while spinach plants were well established (Figure 7a) which could give spinach an advantage over the rice plants in mixture plots. The adverse effect of vegetables as intercrops on rice grain yield was mentioned by Rabeya et al. (2018) in which red amaranth or jute had the most influence on rice plant development due to their abundant growth and shading effect, especially at early stages. This effect was also observed in this study when the intercrop was turnips. Turnip tops was extravagantly developed and outcompeted rice plants in the rice-turnip intercropping (Figure 8b). In addition, late planting of rice plants might cause the loss in rice yield. Some rice plants were damaged by the cold weather during the study (Figure 7b). It is mentioned that low temperatures can cause yield loss in rice production due to male sterility in rice plants during the productive stages (Zhang et al. 2014).

a

Figure 7. a) Rice and spinach plants after two weeks of transplanting (Photo taken on June 20th), and b) Cold damage to rice plants

Weed infestation

With p-value=0.189, there was no significant effect of treatments on the percentage of weed cover in all plots. During this study, spinach plants bolted too early in the season due to the high temperature and then was harvested when the rice plants were not able to cover the ground yet (Figure 9) creating an opportunity for weeds to emerge. Nevertheless, the study found a higher weed infestation later in the season with $p<0.001$ and an interaction between the number of weeks after transplanting and treatment. Weed pressure was lower in turnip monoculture than rice-turnip mixture which might be explained by the shading effect of turnip tops. In case of turnip monoculture, turnip leaves were able to entirely cover the ground, shade out, and outcompete the weeds for light, space, and water.

a

b

Figure 8. a) Rice monoculture, and b) Rice-turnip mixture

Figure 9. Photo was taken on July 13th after spinach plants were removed

Conclusion

Mixed planting of rice with spinach followed by turnip did not reduce weed infestation and did not offer higher land use efficiency than monoculture, despite the lower weed pressure in turnip monoculture than in rice-turnip mixture. For future experiments, rice varieties which are highly resistant to drought can be considered in the dryland rice cultivation. A higher ratio of rice and intercrops and choices of intercrop should be further studied to reduce the competition of intercrops in mixture planting.

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