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Integrated Weed Management Strategies Effects on Agronomic Performance of Rainfed and Irrigated Rice

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Abstract: Weeds cause significant production losses estimated at 25% in tropical countries and constitute main factor limiting rice production in Madagascar. This research, which was conducted at Anosibe-Ifanja (Antananarivo, Madagascar), aims to propose the most cost-effective weed management strategies for both irrigated and rainfed rice system to improve rice production. To make the management of these potential rice weeds effective, two cultural practices were tested as good agricultural and farmers' practices on two rice systems. A phytoecological study and a floristic inventory were carried out on test plots, followed by an economic profitability analysis of management strategies. In rainfed rice, a greater number of species were inventoried (42 species in 14 families) than in irrigated rice (37 species in 9 families). The most important families found in both systems were Poaceae and Cyperaceae. But in rainfed rice, two other families are also dominant: Fabaceae and Asteraceae. The study on weed management strategy showed that adoption of in-season and out-of-season tillage combined with regular weeding is effective for weed control in irrigated rice. As far as rainfed rice is concerned, improved farming practice by integrating in-season tillage with aerial ploughing combined with the use of pre-emergence herbicide pendimethalin is more cost-effective. This research has resulted in an in-depth knowledge of rice weeds and weed control strategies that are only feasible with mechanization or animal traction.

Key words: Weed flora, threshold of harmfulness, weeding, rice growing, commune of Anosibe-Ifanja-Madagascar.

1. Introduction

Weeds are one of the main biological constraints affecting agricultural production worldwide and more particularly in developing countries [1]. Indeed, the rate of weed infestation in agricultural plots is considered to be the causes of yield losses [2]. In Africa, this yield loss varies between 28% and 74% in irrigated rice and 48% to 100% in rainfed rice [3] which makes weed control a major issue in rice production. In Madagascar, the absence of weed control leads to a significant drop in the yield of irrigated rice up to a loss of 1.25 t/ha and around 1.0 t/ha for rainfed rice [4]. Therefore, there is a need to improve the effectiveness of control techniques to address these problems. And this management should start before the planting of the main crop until the next sowing [5]. In rice cultivation, manual weeding is the main weed control technique [6] but is becoming less frequent or late due to the increasing shortage of labour growing problem, which is estimated to require about 50 persons/d/ha [7]. In addition, manual weeding is difficult to carry out because of the relatively long labor time, requiring 250-700 man-days (MD) per hectare [8]. Rice farmers are therefore faced with the use of herbicides, which have become an alternative solution. However, chemical control has its limitations due to resistance phenomena and adverse effects on human health and environment [7, 9]. Thus, for weed control, integrated pest management is promoted to meet both the requirements of effective weed control

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and environmental protection. In this study, these Integrated Pest Management (IPM) strategies are based on combination of different soil preparation methods associated with manual weeding or chemical weeding (pre- or post-emergence herbicide). The question is: Does the good soil preparation practice followed by regular weed control provide effective and efficient control of potential weeds in rice? This study evaluates the effect of three weed control methods following two technical itineraries and two cropping systems. It will determine the impacts of control strategies on the rate of weed infested plots, then, to determine the most effective and profitable weed management strategy. The working hypothesis is as follows: the plot weed infestation rate that receives two consecutive tillage operations (in-season and out-of-season tillage or in-season tillage and turning) and regular weed control is low and profitable for rice production.

2. Materials and Methods

Experiment aimed to compare the performance of several weed management methods on two rice production systems, rainfed and irrigated (for the latter system transplanting and direct seeding), by analyzing profitability of each technique tested. The objective was to compare the control effects of mechanical weeding and herbicide integration according to the period of application in the technical itinerary.

2.1 Experimental Design

The survey was carried out in Anosibe-Ifanja area, in the Middle-West of Madagascar, Itasy 18°52′ S and 46°50′ E and 1,050 m mean altitude. It is carried out in Ampokonato village, irrigated rice was planted on rice fields in Mahatsinjo and rainfed rice on tanety soil in Soanavela. This region has a tropical climate with two distinct seasons: a dry period from April to October and a wet period from November to March. The average annual rainfall is about 1,500 mm with an annual temperature varying from 15 to 20 °C. The cultivated land includes different types of soil: red ferralitic soils on hills rejuvenated volcanic soils and sandy soils on banks of rivers, hydromorphic soils in rice fields.

The effects of weed control on two types of cropping systems were compared: rainfed and irrigated rice. In each cropping system, two types of cultivation practices were tested: good practice (GP) and farmers Practice (FP), and four types of weeding: regular weeding (Rw), pre-emergence (Pre) or post-emergence (Post) herbicide and untreated control (UC) (Figs. 1 and 2). To demonstrate the effect of late-season plowing on weeds in irrigated rice, as well as 2nd ploughing in rainfed rice, “Reference” modalities were introduced into the trial. Based on the two cropping systems, two types of reference methods were used: good practice reference (GPR) and farmers practice reference (FPR).

The different modalities are randomly distributed within each block, supposed to be homogeneous. Each elementary plot measures 50 m² or 12.5 m × 4 m and was repeated four times. A distance of 0.5 m separates each plot, a spacing of 1 m for each block and 2 m for each device.

2.2 Setting Up the Experiment

Two types of rice seed are used and vary according to system and cultural management practices. For GPs seeds are certified R1 or first generation from FOFIFA research center or “FOibem-pirenenamombanyFIkarohanaampiharinaho FampandrosoananyAmbanivohitra” and multiplied at the Community Seed Bank (CSB) in Anosibe village. For the farmer practice, they correspond to third generation and come from a single local rice producer. For irrigated rice, variety X265 or “Mailaka” (120-d cycle with 7-8 t/ha of paddy) was chosen because it is grown in all regions of Madagascar [10]. For rainfed rice, the variety Nerica 4 (short cycle of 110-120 d), 4 t/ha and it is a blast resistant variety was used, well adapted to the difficult growing conditions and low fertility of rainfed rice lands [11].

Post	Pre	UC	We	Block 1	Farmers Practice Reference (FPR)	Seasonal ploughing	Post	Pre	UC	We	Block 1	Farmers Practice Reference (FPR)	Seasonal ploughing + late season ploughing
Pre	We	Post	UC	Block 2			Pre	We	Post	UC	Block 2		
Pre	Post	We	UC	Block 3			Pre	Post	We	UC	Block 3		
We	UC	Pre	Post	Block 4			We	UC	Pre	Post	Block 4		
Pre	Post	UC	We	Block 1	Good Practice Reference Transplanting (GPR-T)		Pre	Post	UC	We	Block 1	Good Practice Reference Transplanting (GPR-T)	
Pre	UC	Post	we	Block 2			Pre	UC	Post	we	Block 2		
Post	Pre	We	UC	Block 3			Post	Pre	We	UC	Block 3		
UC	We	Post	Pre	Block 4			UC	We	Post	Pre	Block 4		
Pre	Post	UC	We	Block 1	Good Practice Reference Direct seeding (GPR-DS)		Pre	Post	UC	We	Block 1	Good Practice Reference Direct seeding (GPR-DS)	
Pre	UC	Post	we	Block 2			Pre	UC	Post	we	Block 2		
Post	Pre	We	UC	Block 3			Post	Pre	We	UC	Block 3		
UC	We	Post	Pre	Block 4			UC	We	Post	Pre	Block 4		

Fig. 1 Experimental set-up on control strategies for irrigated rice.

UC: Untreated Control, no mechanical weed control or herbicide treatment.
Pre: Pre-emergence herbicide, Pretilachlor for irrigated rice applied just after transplanting or after emergence for direct seeding and Pendimethalin for rainfed.
Post: Post-emergence herbicide, 15 d after transplanting or emergence, Bensulfuron methyl for irrigated rice and Byspiribac for rainfed rice.
Rw: Regular weeding, weeded mechanically: 15th, 30th and 45th d after rice transplanting or emergence.
GP: Good practice, for irrigated rice, technical data sheets described by Hubert in 1970 [12] and by FAO in 2011 [13]. For rainfed rice, it is adopted from FAO in 1997 [14].
DS: Direct seeding.
T: Transplanting.
FP: Farmer's practice-technical itinerary applied by majority of farmers in Anosibe-Ifanja (based on results of a survey conducted in 2019).
GPR: Good Practice Reference, in irrigated rice, GPR is characterized by the absence of late season tillage, in rainflied rice GPR does not carry turnover ploughing.
FPR: Farmers Practice Reference, in irrigated rice, FPR is characterized by the absence of late season tillage, in rainfed rice FPR does not carry turnover ploughing is to carry out the overturn plowing.

Post	Pre	UC	We	Block 1	Farmers Practice Reference (FPR)	Seasonal ploughing + Turnover ploughing	Post	Pre	UC	We	Block 1	Farmers Practice Reference (FPR)	Seasonal ploughing
Pre	We	Post	UC	Block 2			Pre	We	Post	UC	Block 2		
Pre	Post	We	UC	Block 3			Pre	Post	We	UC	Block 3		
We	UC	Pre	Post	Block 4			We	UC	Pre	Post	Block 4		
Pre	Post	UC	We	Block 1	Farmers Practice (FP)	Seasonal ploughing	Pre	Post	UC	We	Block 1	Farmers Practice (FP)	Seasonal ploughing + Turnover ploughing
Pre	UC	Post	we	Block 2			Pre	UC	Post	we	Block 2		
Post	Pre	We	UC	Block 3			Post	Pre	We	UC	Block 3		
UC	We	Post	Pre	Block 4			UC	We	Post	Pre	Block 4		

Fig. 2 Experimental set-up for rainfed rice control strategies.

Two pre-emergence and two post-emergence herbicides are selected based on the modes of action.

For rainflied rice, pre-emergence herbicide, which has Pendimethalin (400 g/L, Emulsifiable concentrate (EC)) as active substance was used at a rate of 3 L/ha, post-emergency herbicide Bispyribac-sodium (100 g/L, Suspension concentrate (SC)) was used at 0.5 L/ha.

For irrigated rice, pre-emergence herbicide, whose active ingredient Pretilachlor (500 g/L, EC) was used at a rate of 1 L/ha. Post-emergency herbicide Bensulfuron methyl (100 g/kg, Wettable Powders (WP)) was applied with dose 200 g/ha.

For all interventions, water volume was 160 L/ha using a slot nozzle for best efficiency. Three weedings are carried out on the control methods called "regular weeding". Two weeding operations were carried out, on irrigated rice, it was realized with manual weeders (rotary hoe used for weeding) and on rainfed rice using angady (spade iron, rudimentary instrument used manually to turn over the soil, to weed the cultivated fields) at 15th and 30th days after transplanting or emergence, and the third weeding operation was a manual pulling at 45th day after transplanting or emergence. In direct seeding, three manual weeding operations were carried out (15, 30, 45 d after sowing).

2.2.1 Technical Routes

The cropping season began in December 2019 with soil preparation, followed by sowing or transplanting, then weeding and harvesting in May 2020.

For irrigated rice, end-of-season ploughing was done in June 2020. The in-season plowing was done 15 d before transplanting, to a depth of 30 cm. Then rice field was rested for 15 d. Crumbling was done 2 d before transplanting. This was followed by harrowing, which will help to muddy the rice field. To level the seedbed or transplanting, leveling was done. The creation of a belt canal directly precedes transplanting. The 15-d-old rice plants, ready to be transplanted for GP itinerary, came from the nursery in Dapog [12]. The spacing between rice plants was 20 cm for FP and 25 cm for GP.

For rainfed rice, for the FP itinerary, soil preparation is characterized by ploughing to a depth of 15-30 cm, just before sowing with animal-drawn ploughs. Sowing is generally done in piles of 8 grains on average, spaced 20 cm apart. In contrast to FP, GG plots benefited from chemical fertilization. Soil preparation is characterized by a 30 cm deep ploughing carried out at least 15 d before sowing with animal-drawn ploughs, followed by a turning over just before sowing. Sowing is generally done on a flat seedbed and in stacks of 5 grains. Sowing is spaced at 25 cm intervals on each side, with certified seeds.

For two cropping systems, FP used 10 t/ha of manure as a base for fertilization, while GP used NPK 11-22-16 at a rate of 150 kg/ha and 10 t/ha of manure. And 46% of N was applied in two applications, 20 and 25 days after planting (DAP). The standard rate was 150 kg/ha for GP, but it is halved for FP [15, 16].

2.2.2 Method of Observation

Two types' observations were made during experiment. Firstly, the parameters related to weediness and rice production.

At harvest time, the yield on each elementary plot was measured.

The determination of the weed cover rate was done weekly. The evaluation of weed distribution was carried out using overall weed level method based on coefficients that are visually estimated according to scale 1 = 1%, 2 = 7%, 3 = 15%, 4 = 30%, 5 = 50%, 6 = 70%, 7 = 85%, 9 = 100% [17]. And for the evaluation of the cover of each species, Braun-Blanquetscale (1932) adapted by Le Bourgeois [18] was used: 1 < 10% individuals, 2 = 10%-25%, 3 = 25%-50%, 4 = 50%-75%, 5 > 75%.

2.2.3 Methods for Analysis of Weed Parameters

Abundance and frequency are the most effective parameters for measuring weed infestation in crop [19]. Relative frequency (Fr) is used to describe the qualitative floristic richness of each studied modality [18], while abundance is used to analyze the degree of infestation of species [19].

- Fr

Fr is the ratio between the number of individuals of certain weed species and the total population at a given site (1).

$$Fr\ (\%) = 100 \times Fa / Nr \quad (1)$$

Fa: Absolute Frequency or sum of surveys where species is present.

Nr: Total of surveys conducted.

- Abundance/Dominance (ADIm)

ADIm (2) is consequence of cultivation techniques implemented in a given environment.

$$ADIm(e) = \sum ADI(e) / Nrel(e) \quad (2)$$

ADIm(e): Average Abundance-Dominance Index of a species.

ADI(e): Average Abundance-Dominance Index of species calculated.

Nrel(e): Number of surveys where species is present.

Species are divided into two groups based on average abundance:

ADIm(e) ≥ 2 indicates that species are very abundant;

Average ADI < 2 indicates species are low or less abundant.

2.2.4 Statistical Analysis

All data obtained during trial are subjected to Shapiro-Wilk [20] normality test to see if they follow the normal distribution. With regard to paddy yields, they follow normal distribution and are subjected to analysis of variance (ANOVA). The parameters to be followed are: the coefficient of determination (R^2), residual probability (p) and observed frequencies (F). After that, in order to highlight which type of treatment had the biggest effect on the concerned parameter, a multiple pairwise comparison test following the honest significant difference procedure or Tukey's Honestly Significantly Different (HSD) test was performed.

And the data on overall coverage rate do not follow the normal distribution; the obtained means are then subjected to non-parametric Kruskal-Wallis test [21].

The parameters to be followed are: residual probability (p), rank of observations (K).

To analyze sample pairs for significant difference, the Dunn pairwise test with a Bonferroni correction is used.

After pairwise multiple comparison analyses (Tukey (ANOVA) or Dunn (Kruskal-Wallis)), the results of the test indicate groupings according to modalities that are materialized by indexed letters on each graph. Different letters indicate the presence of a significant difference between treatments and vice versa.

2.2.5 Economic Analysis

Economic analysis assesses the economic profitability of weed control methods applied in the trial and to determine which ones are technically based on the basis of reliable indicators. The calculations are based on the context of the rural commune of Anosibe-Ifanja (input prices, labor costs, price of paddy at harvest, etc.). First indicator, gross value added (GVA), provides information on wealth creation by producer (3). The calculation of GVA requires knowledge of gross product (GP) which is defined as the monetary value of the final output while intermediate consumption (IC) corresponds to the monetary value of goods and services fully incorporated into the final product [22].

$$GVA = GP - IC \quad (3)$$

Value-Cost Ratio (VCR) is an indicator of whether an economic modality is profitable [4]. If the VCR is less than 1, practice is not profitable; from 1 to 2, the practice is cost-effective, but needs improvement; if above 2, it is cost-effective and ready to be popularized.

$$VCR = PB/\text{Total load [22]} \quad (4)$$

Value-Performance Ratio (VPR) is daily gross income earned by a person tending one hectare of rice (5). Its increase means that optimization degree of a technique is high. In addition, VPR requires knowledge of the total number of labor hours needed to maintain the crop during a cropping cycle, and labor time is expressed in man-days (MD) [22].

$$VPR = PB/\text{Work time} \quad (5)$$

3. Results

3.1 Floristic Richness according to Cultural Practices

Weed flora in irrigated rice was dominated by 37 species divided into 9 families. Monocotyledons (77.14%) were more important than the dicots (22.86). The most important families were Poaceae (40%) and Cyperaceae (22.86%). The most important species, with abundance greater than or equal to level 2 and a Fr greater than 50%, were: Junglerice-*Echinochloa colona* (Poaceae), Barnyargrass-*Echinochloa crus-galli* (Poacea), Ricefield bulrush-*Scirpus juncoides* (Cyperaceae), Small flower umbrella plant-*Cyperus difformis* (Cyperaceae), Tail-*Leersia hexandra* (Poaceae), Water primose-*Ludwigia adscendens* (Onagraceae), Antelope grass-*Echinochloa pyramidalis* (Poaceae). The weed flora recorded in rainfed rice plots 42 species was divided into 14 families. In rainfed rice, dicotyledons (59.52%) were more numerous than the monocotyledons (40.48%) and with the predominance of Poaceae (29%), Fabaceae (12%) and Asteraceae (17%). The most harmful species, with an abundance greater than or equal to level 2 and a Fr greater than 50%, were: Florida pusley-*Richardia scabra* (Rubiaceae), Hispid Starbur-*Acanthospermum hispidum* (Astaraceae), Small rabbit root-*Ipomoea eriocarpa* (Convolvulaceae), Tropical ageratum-*Ageratum conyzoides* (Asteraseae), Hairy beggar's ticks-*Bidens pilosa* (Asteraseae), Crows foot grass-*Eleusine indica*, Sticky purple cleome-*Cleome hirta* (Cleomaceae), Chaff-flower-*Achyranthes aspera* (Amaranthaceae).

Thus, dicotyledons were more numerous in upland rice than in irrigated rice. The Poaceae family is a major common weed of both rainfed and irrigated rice.

3.2 Effect of Treatments on Overall Weed Cover

To better appreciate treatments' effectiveness, the coverage of last survey in 49 days after emergence or after transplanting is compared to each other. The overall plot coverage indices show significant differences between the different weed control methods. The plot coverage of irrigated rice is statistically high compared to rainfed rice (K = 3.84, p = 0.047). Plot coverage according to GP is higher than FP for both rainfed (K = 3.84; p = 0.009) and irrigated rice (K = 5.99; p = 0.045).

For irrigated rice (Fig. 3), the GPR plots had higher weed cover than GP for both no-till (K = 3.84; p = 0.032) and transplanted rice (K = 3.84; p = 0.019). Similarly for the FP, the FPR has a high weed cover rate compared to the FP (K = 3.84; p = 0.034).

For rainfed rice (Fig. 4), the GPR plots have high weed cover rate compared to the GP (K = 3.84; p = 0.032). For rainfed rice (Fig. 5), the GP plots have a high weed cover rate compared to GP (K = 3.84; p = 0.03), while for the FP, FPR has a low cover rate compared to the FP (K = 3.84; p = 0.005).

According to Figs. 3 and 4, weed cover was higher in the UC than in the weeded plots regardless of method applied.

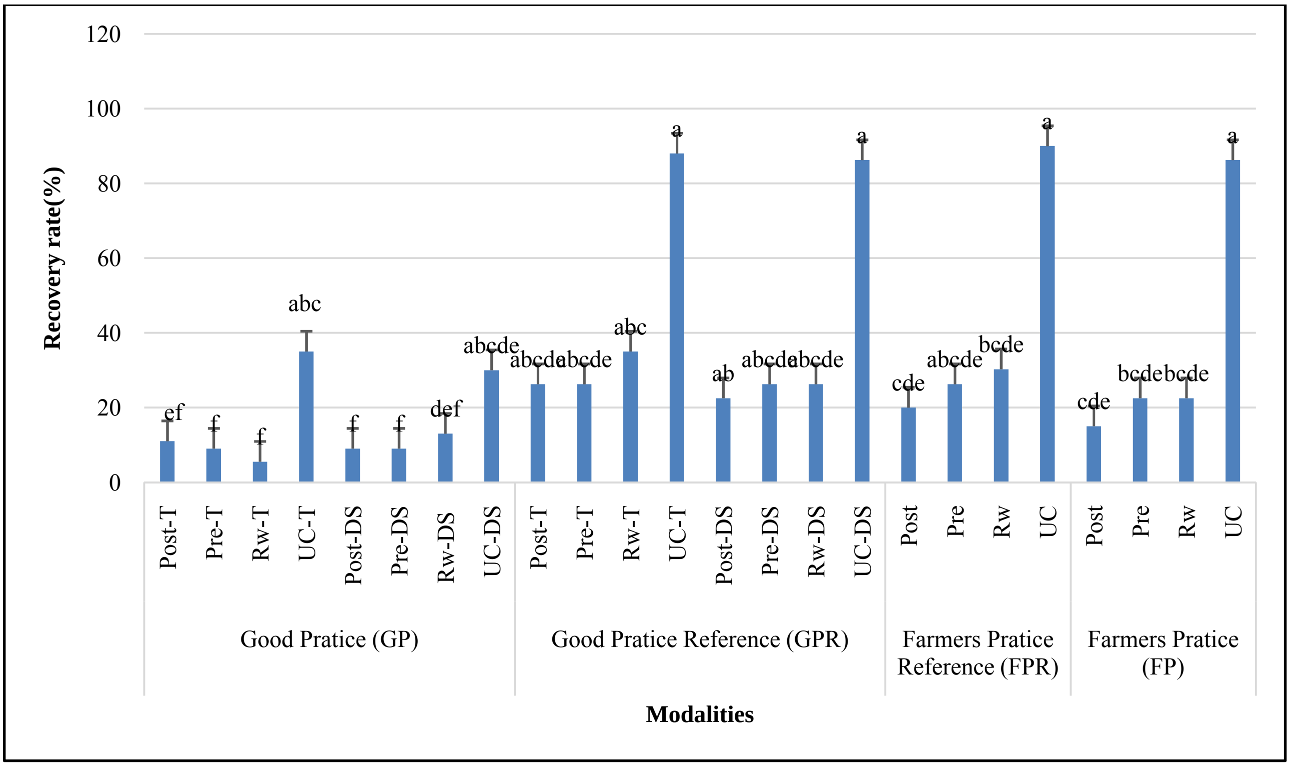

Fig. 3 Treatment efficiencies on weed cover in irrigated rice.
Different letters indicate the presence of a significant difference between treatments and vice versa.

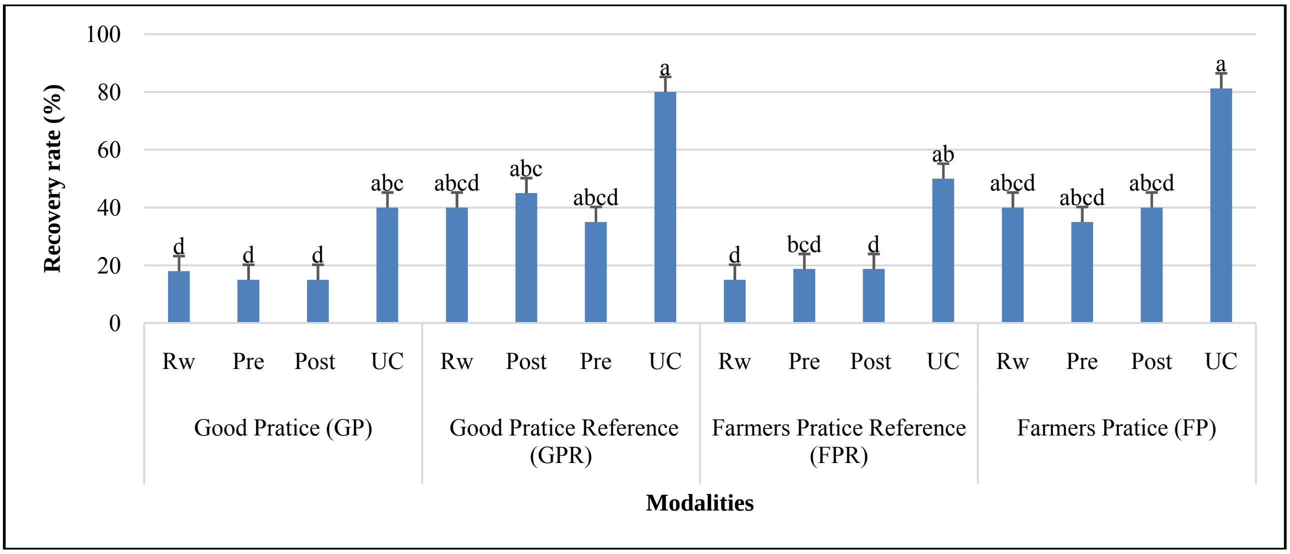

Fig. 4 Treatment efficiencies on weed cover in upland rice.
Different letters indicate the presence of a significant difference between treatments and vice versa.

3.3 Effect of Treatments on Rice Yield

Tables 1 and 2 show statistical results of different modalities on weeds control. When analyzing Tables 1 and 2, a significant difference in yield was found between the GP and FP treatments for both irrigated and rainfed rice.

For both cropping systems, there is a significant difference between the practice reference and modalities conducted under either GP or FP.

On irrigated rice, the GPR has a high yield compared to the GP and FPR with significant lower plot yields than FP (Table 1).

For rainfed rice, the GPR has low yields compared to the GP. But for the FPR, it has a high yield compared to the FP (Table 2).

Comparing weed control strategies and their influence on rice yield, for irrigated rice, analysis of variance (p = 0.001, F = 101.90) revealed significant differences between treatments and controls. GP yields were higher than FP yields in both no-till and transplanted rice (Fig. 5).

Comparing treatments, the GP with Regular weeding (GPT-Rw, GPDS-Rw) for both no-till and irrigated rice, had the highest yield (8.4 ± 0.22 t/ha). The untreated controls had low yields ranging from 0.7 to 1.9 ± 0.04 t/ha. The FP and GPR plots that were conducted without back tillage had low yields compared to the FP and GP plots that adopted back tillage.

Table 1 Statistical result on rice yield in irrigated rice systems.

	GP-T	GP-DS	FP	GP-T	GPR-DS	FPR	FP	GP-T	GPR-T	FPR	GPR-T	GPR-DS
p	0.007			0.001		< 0.0001		0.003		0.145		
F	5.59			13.27		31.30		10.71		2.01		
Significant	Yes			Yes		Yes		Yes		Yes		

Table 2 Statistical result on yield comparison between rainfed rice cropping systems.

	GP	FP	GP	GPR	FPR	FP	FPR	GPR
p	< 0.0001		< 0.0001		< 0.0001		0.001	
F	28.28		26.66		32.88		12.55	
Significant	Yes		Yes		Yes		Yes	

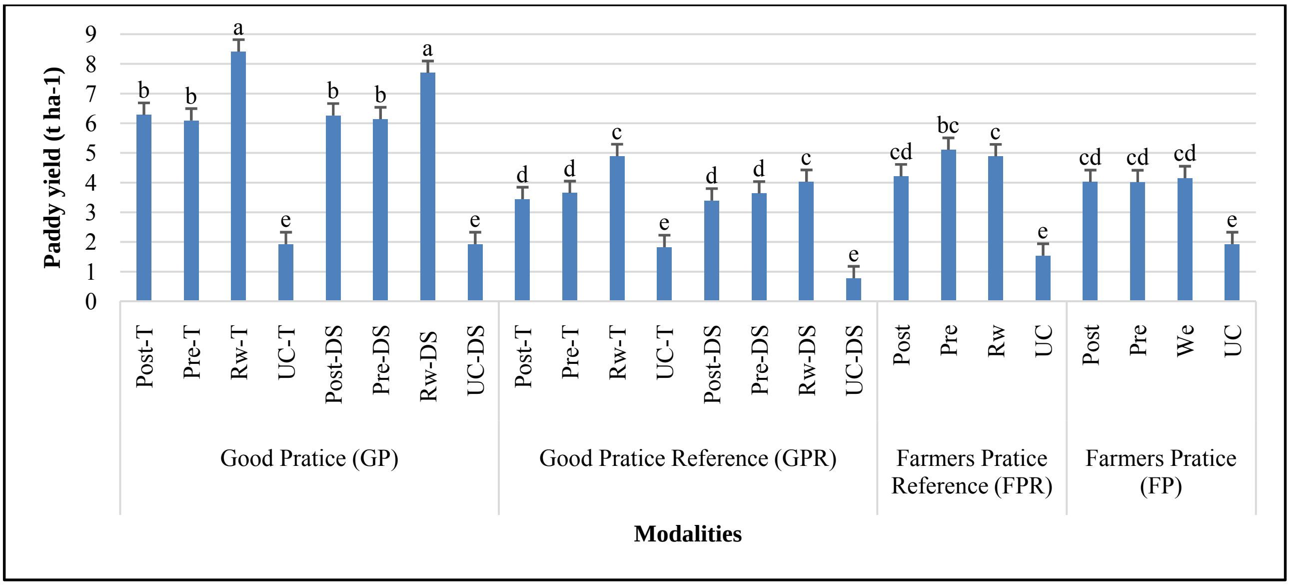

Fig. 5 Comparison treatments effect on the yield of irrigated rice under GP and FP.
Different letters indicate the presence of a significant difference between treatments and vice versa.

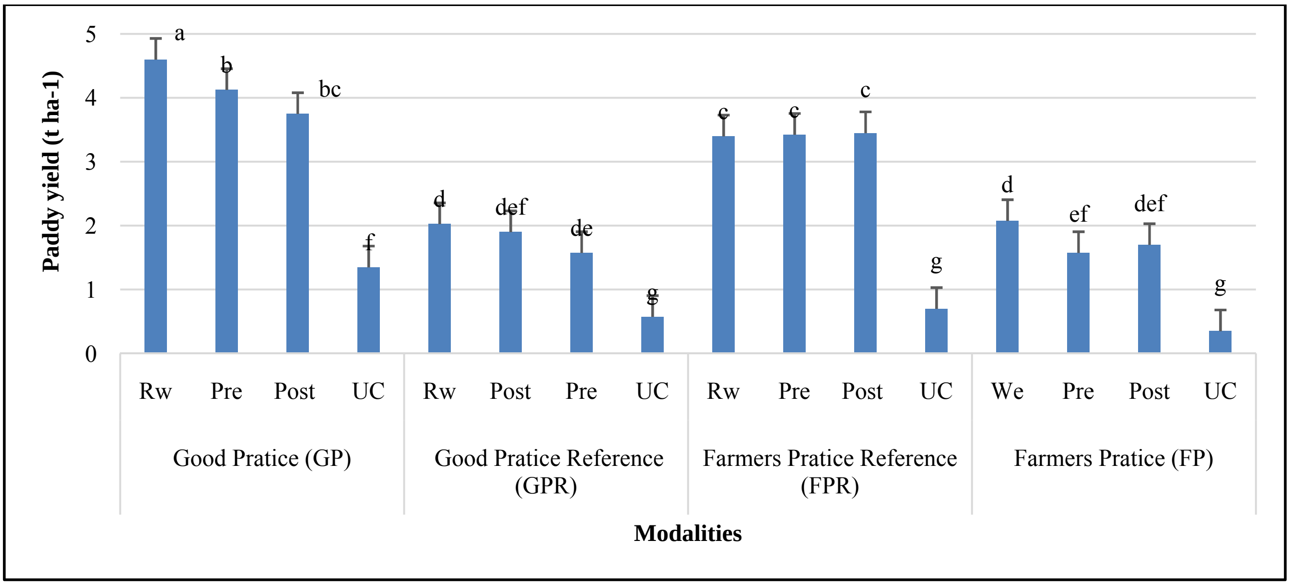

Fig. 6 Comparison of the effect of treatments on rainfed rice yields under GP and FP.
Different letters indicate the presence of a significant difference between treatments and vice versa.

For upland rice, variance analysis ($p < 0.0001$, $F = 69.41$), of paddy yields, shows significant differences between the effects of weed management practices (Fig. 6). Data treatments evoke statistical differences from UC. This shows that all weed management practices have an impact on yield. The best performing modality was the GP-Rw. The GPR where the plots do not undergo a second tillage (GPR) has significantly different yields from plots conducted under GP. FPR that benefited from second tillage had better yields than those of plots conducted under FP.

3.4 Economic Analysis of Different Treatments on Crop Systems

Combination of CVR and VPR analysis allows the identification of the most profitable and least labor-intensive practice suitable for extension (Tables 3 and 4).

For irrigated rice, plots adopting GP have a high VPR compared to FP (Table 3). The control strategy combining in-season and off-season ploughing with regular weeding has high CVRs in both no-till rice (GPDS-Rw) and transplanted rice (GP-T Rw). Their respective CVRs are 2.25 and their VPRs are high, ranging from 2.28 and 23,788 Ariary to 24,232 Ariary. As the CVR value is higher than 2, these control strategies are suitable for extension. However, the labor requirement for these strategies remains high (300 hd/ha).

For FP and FPR, the CVRs are all between 1 and 2, so these techniques need to be improved before being disseminated, and the lower the financial gain, ranging from 12,000 to 16,000 Ariary.

For rainfed rice, FPR with integration of the false seeding technique or 2nd ploughing, combined with use of a pre-emergence herbicide with the active ingredient Pendimethalin (FPR-Pre) has a higher CVR (Table 4). Therefore, this technique is suitable for extension. In addition, the labor time to implement this control strategy is low, 124 hd. Its VPR is the highest at 27,631 Ariary.

4. Discussions

4.1 Weed Cover Rate

Weed cover in rainfed rice is high compared to irrigated rice plots. Weeds in irrigated rice are easier to manage. As soon as crop is established, transplanted rice plants have a head start on weeds since transplanting produces vigorous, well-rooted plants that can compete with weeds [23]. Compared to rainfed rice, weeds can emerge in same time or before rice plants, posing a serious competition problem [24]. In addition, the alternating flooding and drying of rice field is primarily for weed control. Weed seeds that cannot germinate or grow under these conditions cannot

Table 3 Economic results of calculation between weed control techniques for irrigated rice.

Practices	Terms and conditions	GVA (Ariary)	Working time (hd)	VCR	VPR (Ariary)
FP	UC	-1,102,250	309	0.64	6,230
	Pre	1,000,750	310	1.33	13,065
	Post	964,750	310	1.32	12,968
	Rw	1,797,750	349	1.54	14,628
FPR (without late season ploughing)	UC	-1,498,250	281	0.51	5,470
	Pre	900,750	280	1.30	14,107
	Post	1,064,750	280	1.35	14,714
	Rw	902,750	319	1.27	13,197
GP-T	UC	-1,624,750	315	0.54	6,116
	Pre	2,562,250	316	1.72	19,427
	Post	2,683,250	316	1.75	19,829
	Rw	4,680,250	354	2,25	23,788
GP-DS	UC	-1,277,900	247	0.60	7,806
	Pre	2,883,100	248	1.90	24,596
	Post	3,054,100	248	1.95	25,287
	Rw	4,209,100	318	2.28	24,232
GPR-T (Without late season ploughing)	UC	-1,424,750	285	0.56	6,409
	Pre	373,250	286	1.11	12,756
	Post	162,250	286	1.05	12,038
	Rw	1,495,250	314	1.44	15,586
GPR-DS (without late season ploughing)	UC	-2,102,900	217	0.27	3,578
	Pre	745,100	218	1.26	16,751
	Post	489,100	218	1.17	15,602
	Rw	978,100	251	1.32	16,061

Table 4 Economic results of calculation between rainfed rice weeding techniques.

Practices	Terms and conditions	GVA (Ariary)	Working time (hd)	VCR	VPR (Ariary)
FP	UC	- 1,018,000	101	0.26	3,465
	Pre	55,000	109	1.04	14,450
	Post	-40,000	109	0.97	12,844
	Rw	387,000	189	1.23	10,979
FPR (2nd plowing)	UC	-818,000	116	0.46	6,034
	Pre	1,755,000	124	2.05	27,621
	Post	1,490,000	128	1.90	24,532
	Rw	1,602,000	186	1.89	18,280
GP	UC	-1,422,000	116	0.49	11,638
	Pre	101,000	124	1.03	24,395
	Post	588,000	156	1.19	24,038
	Rw	1,168,000	196	1.42	23,469
GPR (without 2nd plowing)	UC	-2,245,000	121	0.20	4,752
	Pre	-1,397,000	121	0.53	13,017
	Post	-1,112,000	141	0.63	13,475
	Rw	-955,000	153	0.68	13,235

develop [20]. The situations imply that weed may not to adapt to frequent changes in their environment [25]. Focusing on rainfed rice, environmental conditions are always favorable for terrestrial weeds throughout the cropping season.

In both rainfed and irrigated rice, GP of sprying herbicide (Pendimethalin and Pretilachlor) has low weed cover. Thus, these treatments effectively control weeds at 49 days after sowing or transplanting. This is due to the adoption of GP that incorporates two successive ploughings in soil preparation before planting which is equivalent to false sowing technique, which reduces the emergence of weed, especially perennials [26]. Furthermore, according to a study on weeds, off-season tillage and the practice of the 2nd tillage technique, at a sufficient depth, could help destroy and dry out underground rhizomes [27]. This technique allows effective management of perennial weeds by extracting responsible organs and then exposing them to solar radiation to destroy them. In addition, several ploughings done with sufficient time interval allow annual weeds seeds to germinate and these will be destroyed by second ploughing pass [28].

Late-season plowing practice combined with in-season plowing with seedbed preparation or transplanting can further eliminate weed vegetation through mechanical action and provides a fine soil and uniform recovery of rice crop [29].

On the one hand, the integration of the GP concept with the use of pre-emergence herbicide significantly reduces weed pressure at the time of upland rice emergence. Thus, this justifies low coverage of the GP treatment with the pre-emergence herbicide, pendimethalin, in rainfed rice. Sylla *et al.* [30] working on lowland rice in central Côte d'Ivoire, obtained similar results to this study with the same active ingredient based on Pendimethalin concentration 500 g/L [30].

On the other hand, manual weeding at 15 d, 30 d and 45 d (manual pulling) after transplanting or sowing justifies very low weediness of plots at full tillering stage (49 d after emergence). Johnson [7] states that competition for nutrients for growth can be unfavorable for rice in early cycle (30 DAR) if weeds are not controlled [7]. Similar results were obtained in Philippines by Gogoi *et al.* [31]. The results of these authors noted that two manual weed controls by hoeing during critical weed period are required to significantly increase grain yield of rice. Moody [32] suggested that two to three manual weed controls are needed during the first two months of rice cycle to achieve good weed control [32]. Similarly, Mballo [33] also showed that two hoeing operations are needed to maintain low weed cover, these are on Day 12 after emergence and Day 48 after emergence in dry season and in wet season on Day 24 after emergence and Day 48 after emergence [33].

Thus, hypothesis that “Weediness rate on plots that received two successive ploughings (season and backward plowings or season and backward plowings) combined with regular weeding is low” is verified.

4.2 Weed Management Strategies Effect on Rice Production and Profitability

On irrigated rice, the untreated farming practice has a low yield of 0.775 t/ha. This is due to increased weed competition. Heavy weed infestations caused a significant reduction in paddy yield. The best yield is obtained by regular weed control on irrigated rice, it is around 8 t/ha. In Philippines, Gogoi *et al.* [31] found that two manual weed controls during critical weed period (15 d, 30 d after sowing) are necessary to significantly increase grain yield in irrigated rice [31].

On rainfed rice, the treatment combining two successive ploughings such as the season ploughing plus a turn-over ploughing combined with a pre-emergence herbicide based on pendimethalin gives high yields of around 3.5 t/ha. Sylla *et al.* [30] found same results with combination of pre-emergence herbicide and combination of pre-emergence herbicide application and regular hoeing weed control [30]. In India, Rekha *et al.* [34] also found the same result, yield increases with herbicide spraying followed by manual weed control [34]. On the other hand, Singh and Angiras [35] stated that the best yields of paddy rice were obtained when herbicide application was complemented by two manual weed hoeing [35].

In terms of cost-effectiveness analysis, on irrigated rice, all weed control treatments positively influenced VPR and CVR ratios. Certainly, CVRs of the good weeding practice modalities are the highest, respectively 2.25 in transplanted rice and 2.28 in direct seeding rice. Thus, the weed management practice integrating the good soil preparation practice combined with regular weeding allows a higher compared to 1 Ariary (1 dollar American = 4,047.35 Ariary) invested in the farm. Moreover, the daily gain generated by these two modalities is the best with about 23,000 Ariary/working day. These results agree with those of Johnson [7], who states that manual weeding remains the main means of weed control in irrigated rice in Africa [7]. In rainfed rice, untreated plots have a low yield of about 0.350 t/ha. Contrary to what farmers think, herbicides are within their financial reach, since the cost of operating plots that adopt herbicide use is equivalent to that of manual weeding, but with less labor time. Thus, combination of turnover plowing with a pre-emergence herbicide resulted in high CVRs. The improved farming practice modality, i.e. the integration of turn-over ploughing associated with pre-emergence herbicide (Pendimethalin), had a CVR of 2.05, higher than the rest of the treatments. The VPR of this modality has the best daily gain around 23,000 Ariary. Thus, as a reference of the FP, the association of two successive ploughings with a pre-emergence herbicide (R-Pre) offers an integrated weed management. Randriamampianina [4] agrees with this study by asserting that the use of herbicides has become essential for most rice producers in Lake Alaotra, attracted by their effectiveness and the savings in time and energy they bring. Also, Andriamahefa [36] agrees with this result, taking the case of the Commune of Ambohibary Sambaina. In addition to these results [36], Le Bourgeois [18] also mentions that herbicides are an important means of weed control in rainfed rice, but their intensive use is exclusively reserved for rainfed rice planted in rotation with cotton, as this type of farmer has access to resources, information, credit and input supply [18]. Thus, hypothesis that “whatever the cropping system and management, combination of two successive plowings (in-season and out-of-season plughings, or in-season and out-of-season plughings) and regular weeding makes rice production profitable" is rejected. In rainfed rice, combination of two successive plughings with use of a pre-emergent herbicide (pendimethalin) is the most profitable, because weeds compete with rice from the beginning of crop, so very early weeding is necessary to obtain an efficient yield.

5. Conclusion

Weed competition is even more important if weeds are present in the plots for a long period of time, which has negative effects on rice growth and yield components. This study highlighted the effect of different weed management practices on irrigated and rainfed rice production in the commune of Anosibe-Ifanja. The results show that in irrigated rice, good management practices with the adoption of regular weed control measures are effective in controlling weed infestation. In contrast, for upland rice, plots that were managed according to farmers' technical itinerary, but improved with the integration of second tillage as a weed control method, and the use of pendimethalin-based pre-emergence herbicides had a high cost-value ratio with a lower production time. However, weed cover remains high in these plots, so further study is needed to complement these results by integrating a second weed control after the use of pre-emergence herbicide (30 or 45 d after sowing). Integrated weed management is therefore of interest for sustainable rice production in this area. Thus, this study analyzed almost all aspects of weed control as applied to rice production. As a follow-up to this study, further research should focus on economic thresholds of weed communities that cause considerable yield losses.

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