

Agroecological Influence on Rice Field Weeds in Anosibe Ifanja Commune (Middle West Madagascar)

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Abstract: Weeds, which cause loss of more than half of production, constitute one of obstacles to development of agricultural production in Madagascar. This study aimed to characterize weed flora and to analyze constraint of weeding irrigated rice with a view to improve control strategy. A phytoecological study of weeds was carried out during 2018-2019 season, on 125 rice plots with an average area of 500 m², in Anosibe Ifanja, Middle-West region of Madagascar (18°52' S and 46°50' E). Surveys on cropping practices and observations on rice field ecology and the importance of weed cover level were carried out in order to establish relationship between factors affecting diversity, distribution and level of weed infestation in rice field. As a result, 47 weed species grouped into about 20 families were identified. Weed cover quantification in each plot, permits to distinguish three major importance species, including Junglerice - *Echinochloa colona* (Poaceae), Tail - *Leersia hexandra* (Oryzoideae), saramollagrass - *Ischaemum rugosum* (Poaceae) and hemp sesbania - *Sesbania rostrata* (Fabaceae). Analysis of agro-ecological factors showed that all production techniques and growing conditions have a role to play in variability of plant cover level. Thus, the main production factors that vegetation cover reduce state are ploughing to a depth of 30 cm, practice of ploughing off-season/in-season and good water control. Ecological factors, especially soil type, soil structure and topography, minimize weed cover in rice fields.

Key words: Weed control, floristic inventory, submerged rice, Madagascar.

1. Introduction

Rice, staple food of more than half of the world's population [1], providing 27% of world's food energy and 20% of its protein intake [2]. At global level, and particularly in some African countries such as Madagascar, its cultivation remains a source of income for producers and therefore contributes to poverty reduction [3]. Ever-increasing consumption of rice [4] correlated with population growth will have to be offset by an increase in rice production, which constitutes a major challenge for many developing

countries such as Madagascar, which depend on this cereal to ensure their food self-sufficiency. In Madagascar, average consumption varies from 118 kg/inhabitant in urban areas to 138 kg/inhabitant in rural areas [5] and cultivates in almost all island regions. However, many factors influence its production, including improved seeds use, fertilization control, irrigation control, animal traction involvement and control of bio-aggressors [6] especially weed control.

In developing countries, weed damage is one of main obstacles to increasing agricultural production [7-10]. Numerous studies have shown that in West Africa, yield reduction due to weed damage ranges from 28% to 74% for irrigated rice [11] and from 48%

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to 100% for rainfed rice [11, 12]. According to some authors such as Noba *et al.* [10], crop losses due to weeding are very high, amounting to 15% in Africa. In Madagascar, rice yields stagnate around 1 t/ha due to losses caused by weed invasion [6, 13] with more than 70% loss without effective control method.

To effectively control this major constraint, it is necessary to know rice flora (harmfulness of species) and weeds behavior (dynamics and effects on crop) towards surrounding factors (cultivation technique and ecology). Indeed, knowledge of weed populations in agrosystems is essential for effective management. In this sense, in Madagascar, several studies have been carried out on weed flora of certain crops such as rainfed rice, irrigated rice, cotton and tansy. This work on weeds has been carried out on taxonomic, phenological and phytosociological aspects but also on pest control by Randriamampianina [13], Rivotiana [14], Mahitasoa [15] and Andriamahefa [16]. On the other hand, little work has been carried out on habitat amplitude, and infestation degree which are important aspects in determining species harmfulness.

Thus, in order to explain the interference between yield loss and the influence of weeds, numerous studies have demonstrated the existence of relationships between the evolution of weeds and the influence of different parameters such as climatic conditions, cultivation techniques used, crop type, type of infestation and weed emergence period [9]. In addition to these factors, the weed flora also evolves quantitatively and qualitatively at the plot level. It is sensitive to changes that depend on the cropping systems in the region [17]. The objective of this study was to assess the importance of the weed flora in irrigated rice through a phyto-ecological study and to determine the influence of agro-ecological factors on the distribution of these inventoried species. More specifically, it focused on weed inventory and description of environmental factors effects [18] and analysis of cultural practice influence on weed level control [9].

2. Materials and Methods

2.1 Study Area and Characteristics

Survey was carried out in Anosibe Ifanja zone, 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 five villages constituting the zone: Anosibe, Ampokonato, Ampahimanga, Ambatolampy and Ambatomenarana. This region is subject to an altitude tropical climate with two distinct seasons, a dry period from April to October and a wet period from November to March. Average annual rainfall is about 1,500 mm with an annual temperature ranging from 15 °C to 20 °C. 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. Soil is very rich in ferric acid, with a high proportion of red ferric acid in the soil.

Study is based on two complementary methods: surveys and observation of their plots to describe ecology and level of grass cover.

2.2 Method of Data Collection and Sampling

Surveys, floristic surveys and observations were conducted and distributed throughout territory to take into account variability effect in ecological and agronomic factors on grass cover level [19]. During survey, sampling was based on total number of households in the region. In this commune, the size of surveyed population is 125 people, or about 5% of theoretical total number of households in the area. To be representative, samples must come from five villages in the commune; each village must therefore provide 25 respondents and their rice fields in order to be able to match data collected.

Each plot corresponding to respondent makes it possible to describe plant diversity on the plot and its context (production technique and plot environment) [20]. Since farmers' rice fields vary in size 0.03 ha to 0.7 ha, it is necessary to determine a minimum

observation area in order to homogenize the observations [18].

Determination of the minimum area by nested square method was carried out during preliminary descent, which consists, in concrete terms, of searching for all species present in a starting quadrat measuring 1 m². The prospecting continues over an area twice as large until no new species is found. The minimum area of observation is defined as cumulative sum of areas from starting quadrat to quadrat following the last survey [21]. Thus, a minimum observation area of 200 m² was obtained for this study.

2.3 Approach of Phytoecological Surveys

Survey is a set of ecological and phytosociological observations concerning a given place [22, 23]. Its location is chosen subjectively so that it is homogeneous [18]. The surface unit chosen is the plot.

2.3.1 Approach Method to Identify Weed Species

Three complementary identification methods are applied: dichotomous keys from three books (*Tropical Weeds* by Merlier and Montegut (1982), *Weeds in Rice in West Africa* by Johnson (1997) and *Weeds of Crops* by Mamarot and Rodriguez, version of ATCA (2014)), the Wikwio IDAO digital platform based on a robot portrait and determination from local herbaria (TAN Tsimbazaza) and two online herbaria (Jstor Global Plant (<https://www.plants.jstor.org/> /collection/TYPSPE) and Tropicos (<https://www.tropicos.org>) herbariums collected in the field).

2.3.2 Approach Method for Floristic Surveys and Weeds Evaluation

Floristic surveys consist of an exhaustive inventory of all the species present in the observation area. During surveys, inventory in a minimum area of 200 m² is applied to ensure homogeneity of sampling.

For each survey, two observations were made: The first observation was made in observation area to note overall herbaceous coverage of plot according to Biological Testing Commission Scale reviewed by Marnotte [24]. The second, more rapid observation

was then made to attribute an abundance-dominance index (ADI) to each species [9]. Quantification scale used is adapted from that of Braun-Blanquet [20], which includes six indices in all (Table 1), rated one to five and indice + for rare species [9, 18, 19, 25]. This is a visual notation integrating both density and coverage. Abundance expresses density, which corresponds to individual's number per unit area. Dominance or cover is the percentage of unit area covered by individuals of a given species [9]. Surveys were conducted and distributed throughout the entire to take into account the variability of ecological and agronomic factors [19].

2.4 Most Parameters

To describe weeds in each study area, following parameters are considered based on grouping:

(1) Ecological parameters based on observations and/or assessment: elevation (m), topography, slope (%), terrain exposure, soil type (soil colour).

(2) Agro-technical parameters (in form of interviews with farmers): crop in progress; cultivation years number; cultivation stage; soil preparation method; different maintenance of cropping plot; maintenance intensity (per year or per crop cycle); fertilisation method.

(3) Floristic parameters: vernacular name; scientific name (if possible); ADI; phenological condition; average height; overall grass cover; average height of overall grass cover.

2.5 Evaluation Period

For each plot, two floristic surveys were carried out in order to follow evolution of floristic composition and weed population dynamic. The first was done before the first weeding, more precisely between 10 d and 21 d after transplanting. And the second inventory was carried out after the farmers had finished all weeding operations, whether manual or mechanical, using rotary hoe, this period was between 10 d and 21 d after all weeding operations.

Table 1 Determination of the cover-abundance coefficient of Braun-Blanquet [20].

Coefficient or abundance-dominance index (ADI)	Percentage (%)	Recovery
+	Present	Rare or very rare individuals, very low coverage
1	< 10	Fairly abundant individuals, but poor recovery
2	10-25	Very abundant individuals or covering 1/20 of the surface area
3	25-50	Individuals covering 1/4 to 1/2 of the surface area
4	50-75	Individuals covering 1/2 to 3/4 of the surface area
5	> 75	Individuals covering more than 3/4 of the surface area

2.6 Data Analysis

It is based on identification of species present and an estimate of infestation degree or overall coverage of each weed obtained by evaluating frequency and cover-abundance in areas of observation. In weed science, according to Barralis in 1976 [26] and Fenni in 2003 [27], study of these two parameters is the most effective way to measure infestation level.

2.6.1 Frequency of a Species

The absolute frequency of a species is expressed as the number of times it appears in all surveys. Absolute frequency of a species is expressed as the number of times it appears in all studies. A parameter called “relative frequency” (Eq. (1)) is more informative than an absolute frequency parameter [9].

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

where, *Fr*: relative frequency, *Fa*: absolute frequency, *n*: number of readings, whose value obtained can be interpreted as follows:

- *Fr* > 50%: very frequent species;
- 25% < *Fr* < 50%: moderately frequent species;
- *Fr* < 25%: infrequent species.

2.6.2 Abundance-Dominance or Cover-Abundance

Abundance expresses the number of individuals that make up the population of the species present in the survey and dominance represents the recovery of all individuals of a given species. ADI (e) is the average ADI of the species across all surveys. ADI m (e) is the ratio of the average ADI of the species to the number of surveys where the species has been present (Eq. (2)).

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

where *Nrel* (e): number of surveys in which the species is present.

2.6.3 Infestation Diagram

Interaction of two parameters, frequency (*Fr*) and abundance-dominance (ADI m (e)), makes it possible to estimate infestation degree. Presentation of weed fouling degree constitutes the main synthetic result of weed infestation level and is only developed [9, 25]. It is presented in form of a scatter plot with *x*-axis representing frequency and *y*-axis representing abundance-dominance, resulting in four possible classes of weeds with their respective characteristics.

Class 1, represents main general species characterized by high frequency and abundance. These species occur throughout most of study area with high recovery rates.

Class 2, includes species that are frequent but not very abundant. There are often only one or two individuals in an area of observation.

Class 3, refers to main local species that are infrequent but very abundant. They are particularly damaging to specific areas.

Class 4, refers to minor species that are infrequent and not very abundant at the same time. They appear occasionally in rice fields.

To facilitate calculation method and result reading of weeds infestation pattern, each species has been given a code called European and Mediterranean Plant Protection Organization (EPPO) code, previously called Bayer code. EPPO code assigned to each species is represented by five letters consisting of the first three letters of genus name, followed by the first two letters of species name.

2.7 Statistical Processing

A qualitative and quantitative analysis of floristic data is performed on XLSTAT.

An Ascending Hierarchical Classification (AHC) is applied to classify weed species according to their importance. It is a method of cluster analysis which seeks to build a hierarchy of clusters. In order to decide which clusters should be combined (for agglomerative), or where a cluster should be split (for divisive), a measure of dissimilarity between sets of observations is required.

Multiple correspondence analysis (MCA) is used to study environmental parameters' influence on weeds cover level. It is used to produce representation maps on which visual observation of proximities allows variables grouping to have a similar effect on weed infestation level. Environmental variables (agronomic and environmental factors) and species recovery are thus represented in the same dispersal space. So, MCA is therefore a method for studying relationship between at least two qualitative variables observed simultaneously on n individuals.

3. Results

3.1 Importance of Weed Species Observed

Weeds recorded include 47 species belonging to 18 families, with broadleaf weeds remaining more diverse than monocot weeds. According to its physiology, the annual and perennial species present similar on all plots (Fig. 1).

Among 47 weed families identified in Anosibe Ifanja, three clearly dominate cultivated study flora: Poaceae (11 species), Asteraceae (eight species) and Cyperaceae (six species) which alone represent 53.19% of observed diversities.

According to the relation of mean abundance and relative frequency, Fig. 2 differentiates three groups based on agronomic parameters.

Class I (red outline), represents very frequent and moderately abundant species, which includes species

generally present in all rice fields (Fig. 2; Table 2). These are four most characteristic species: Junglerice - *Echinochloa colona* (Poaceae), Barnyardgrass - *E. crus-gali* (Poaceae), and Tail - *Leersia hexandra* (Oryzoideae) and Ricefield bulrush - *Scirpus juncooides* (Cyperaceae). The first two species, Poaceae, are characterized with very high capacity to rapidly invaded plots. These species have strong visual similarities with rice plants, especially during seedling stage. Thus, their uprooting often occurs after flowering. On the other hand, Tail - *L. hexandra* (Oryzoideae) is very hardy and conquers both wet and dry environments. The last species, Ricefield bulrush - *S. juncooides* (Cyperaceae) is a classic rice cowpea, but it is easily overcome by rice. In fact, rice plants smother them by filling in holes when tillering.

Class II (blue outline), remains the common but rare species in rice fields (Fig. 2; Table 2). It generally contains species that colonize a specific environment, which may be a group of rice fields with the same conditions. This is the case of Gooseweed - *Sphenoclea zeilanica* (Sphenocleaceae), which occupies rice fields immediately in the east of Anosibe Ifanja village. Apparently, most of these rice fields share the same irrigation water. This is the case of saramollagrass - *Ischaemum rugosum* (Poaceae) which was recently introduced in Anosibe Ifanja.

Class III (green outline), represents infrequent and rare species (Fig. 2; Table 2), which are therefore rarely observed in rice fields and colonize dikes and surrounding irrigated surfaces plots. They occasionally migrate to rice fields when these are regularly drained.

3.2 Cultural Practices Impacts on Weed Infestation

MCA showed that F1 axis carries 27.99% of information and 17.84% for F2 axis. Taking both axes into account at the same time, 45.83% of information explains relationship between states of vegetation cover and cropping practices (Fig. 3).

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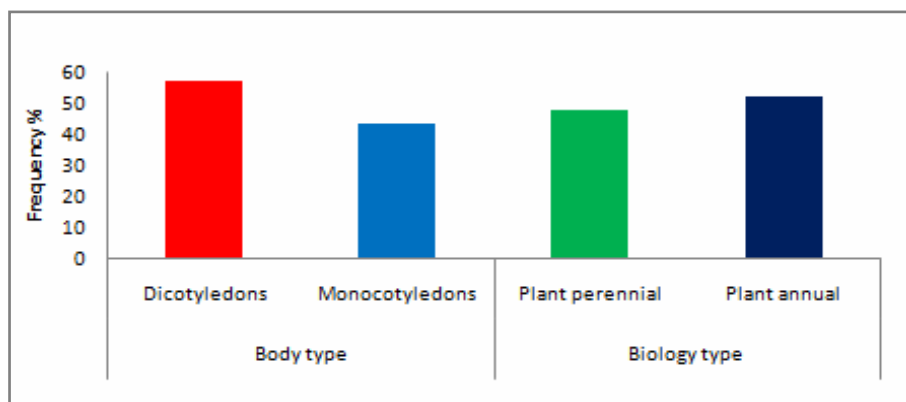


Fig. 1 Weeds' importance in Anosibe Ifanja region.

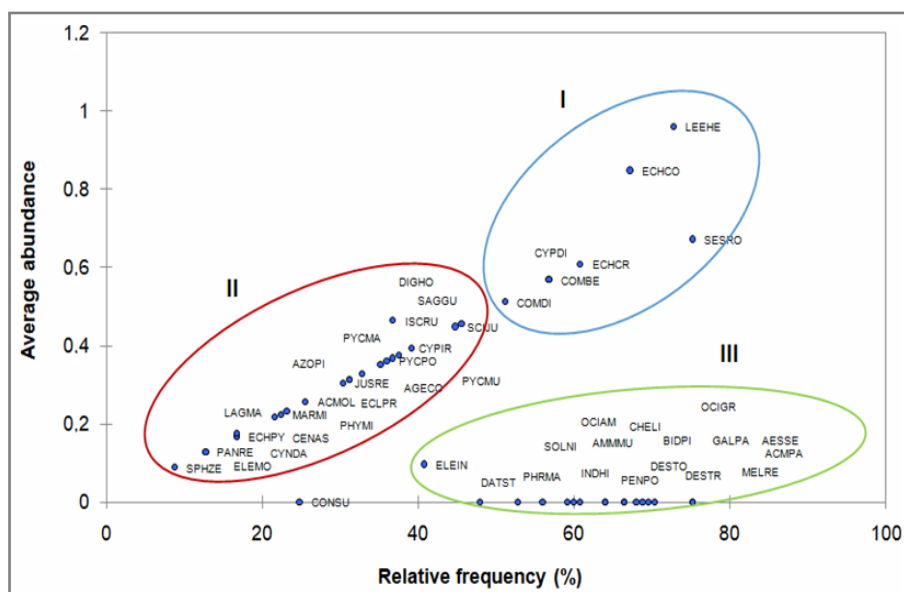


Fig. 2 Mean abundance and relative frequency in the study area of EPPO-coded species ($n = 125$).

Table 2 List of weeds in their respective classes.

Class I	Code EPPO	Class II	Code EPPO	Class II	Code EPPO	Class III	Code EPPO
<i>Echinochloa colona</i>	ECHCO	<i>E. pyramidalis</i>	ECHPY	<i>Ageratum conizoides</i>	AGECO	<i>Aeschynomene sensitive</i>	AESSE
<i>E. crus-gali</i>		<i>Jussiae repens</i>	JUSRE	<i>Acmella oleracea</i>	ACMOL	<i>A. paniculata</i>	ACMPA
<i>Scirpus juncoïdes</i>	SCIJU	<i>Azolla pinata</i>	AZOPI	<i>Conyza sumatrensis</i>	CONSU	<i>Solanum nigrum</i>	SOLNI
<i>Leersia hexandra</i>	LEEHE	<i>C. iria</i>	CYPIR	<i>P. mundtii</i>	PYCMU	<i>Ocimum americanum</i>	OCIAM
<i>Commelina diffusa</i>	COMDI	<i>Pycnus polystachios</i>	PYCPO	<i>Elephantopus mollis</i>	ELEMO	<i>O. gratissimum</i>	OCIGR
<i>C. benghalensis</i>	COMBE	<i>P. macrostachios</i>	PYCMA	<i>Lagarosiphon madagascariensis</i>	LAGMA	<i>Desmodium tortuosum</i>	DESTO
<i>Cyperus difformis</i>	CYPDI	<i>Sphenoclea zeilanica</i>	SPHZE			<i>Galinsoga parviflora</i>	GALPA
<i>Sesbania rostrata</i>	SESRO	<i>Eclipta prostrata</i>	ECLPR			<i>Pennisetum polystachion</i>	PENPO
<i>Digitaria horizontalis</i>	DIGHO	<i>Cynodon dactylon</i>	CYNDA			<i>Melinis repens</i>	MELRE

Table 2 to be continued

Class I	Code EPPO	Class II	Code EPPO	Class II	Code EPPO	Class III	Code EPPO
		<i>Panicum repens</i>	PANRE			<i>Cheirolaena linearis</i>	CHELI
		<i>Ischaemum rugosum</i>	ISCRU			<i>Ammania multiflora</i>	AMMMU
		<i>Sagittaria guyanensis</i>	SAGGU			<i>D. triflorum</i>	
		<i>Marsilea minuta</i>	MARMI			<i>Indigofera hirsute</i>	INDHI
		<i>Centella asiatica</i>	CENAS			<i>Datura stramonium</i>	DATST
		<i>Physalis minima</i>	PHYMI			<i>Phragmites mauritianus</i>	PHRMA
		<i>Eleusine indica</i>	ELEIN				

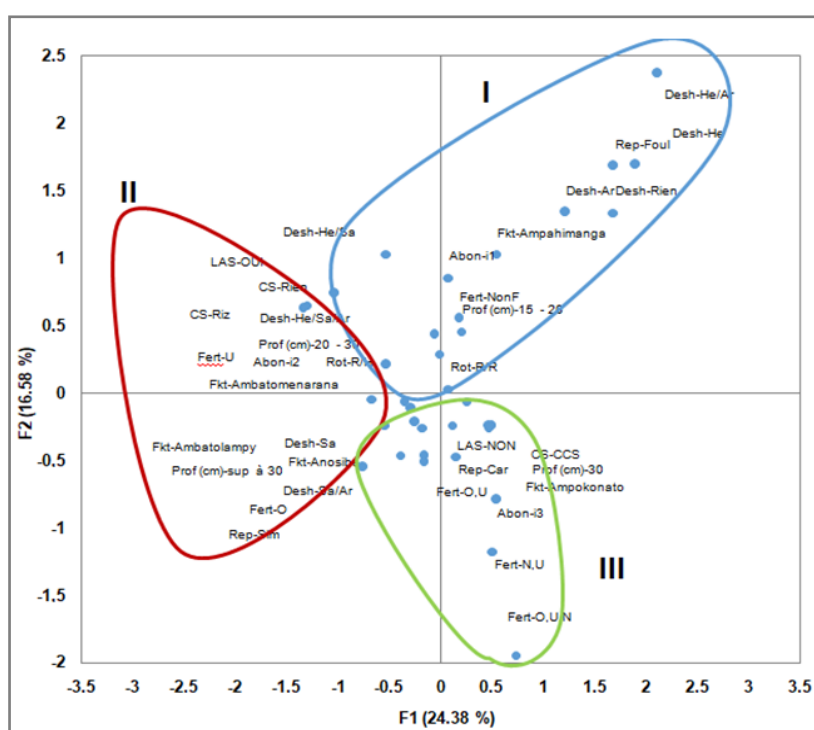


Fig. 3 Relationship between grass cover state and cultivation practices ($n = 125$).

List of abbreviations:

Rot = crop rotation	Depth (cm) = ploughing depth	Des = weeding
R/R = rice	15-20	Her = herbicide
R/H = rice/green	20-30	Sar = weeding
Bean	30	Ar = pulling
CS = off-season	Over 30	He/Sa
CCS = off-season crop	Rep = transplanting mode	He/Ar
Rice = rice	Car = in a square line	He/Sa/Ar
Nothing	Sim = single line	Sa/Ar
LAS = off-season ploughing	Foul = in a crowd	Fkt = villages
Yes	Fert = fertilization	Anosibe
No	NonF = unfertilized	Ampokonato
	O = organic fertilizer	Ampahimanga
	U = urea	Ambatolampy
	N = NPK	Ambatomenarana

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		MH abundance
		i1 = less than 15% recovery
		i2 = recovery of 15%-30%
		i3 = recovery greater than 30%

Three typologies of weed behaviour are highlighted according to cultural techniques (Fig. 3):

Situation 1 (blue outline in Fig. 3), is characterized by a low weed cover, less than 15%. Rice fields in this category benefit from continuous rice cultivation. Technical itinerary remains partially respected: ploughing depth is between 15 cm and 20 cm and does not exceed 30 cm, and rice fields do not receive any fertilizer, either organic or mineral. In fact, fertilizers have the same effect on weeds as on crop, so that fertilizer supply can potentially increase weed infestation. Apparently, use of herbicides such as Pretilachlor also explains this rather low infestation rate. Village of Ampahimaga had majority of rice fields that meet these characteristics.

Situation 2 (red outline in Fig. 3), weed cover is between 15% and 30%. Cropping system constitutes a determining factor in obtaining this coverage type. Most rice fields in this category are planted with off-season crops such as green beans. These vegetable crops require periodic maintenance, particularly in terms of weed control. It therefore allows for growth and elimination of weeds during off-season crop. This contributes to reducing seed stock in soil due to weed management. In addition, farmers who cultivate these rice fields practice back season ploughing. Ploughing reduces germination of weeds because it aims to bury seeds and fragments of weed-spreading organs deep into soil. In addition, single-row transplanting is used for these rice fields. Weeding remains main method used and there is no herbicide treatment. This type of rice field is generally found in village Ambatomenarana.

Situation 3 (green outline in Fig. 3), plots in this situation have a weed infestation with a high level of

grass cover of more than 30%. This situation can be explained by intensive use of plots without crop rotation. In this category, there is an increased use of mineral fertilizers which allows weeds to grow and multiply abundantly. Adoption of square row transplanting does not improve situation because this technique gives more room for weeds to proliferate. In addition, owners of these plots do not practice off-season ploughing or off-season cultivation. As a result, plots in this group give for weeds an advantage of rising, flowering and give seeds for the next generation.

3.3 Environmental Conditions' Influence on Weed Infestation

MCA indicated that F1 axis carries 38.70% of information while 21.26% for the F2 axis. F1 and F2 axes manage to explain 59.96% of relationship between state of grass cover and ecological conditions of rice field (Fig. 4).

Situation 1 shows that (blue diagram in Fig. 4), weed coverage is low as it is less than 15%. These plots have a fragmented texture and are characterized by good water control, which makes it easy to alternate dry and wet periods in rice fields, thus contributing to weed control. However, relatively low weed coverage is mainly due to herbicide treatment applied at the beginning of crop establishment. Ampahimanga site has the largest number of rice field types in this category.

Situation 2 (red outline in Fig. 4), plots presented a relatively average coverage, ranging from 15% to 30%. This situation remains typical of rice fields with water management problems and frequent droughts or floods. With regard to soil conditions, they have a

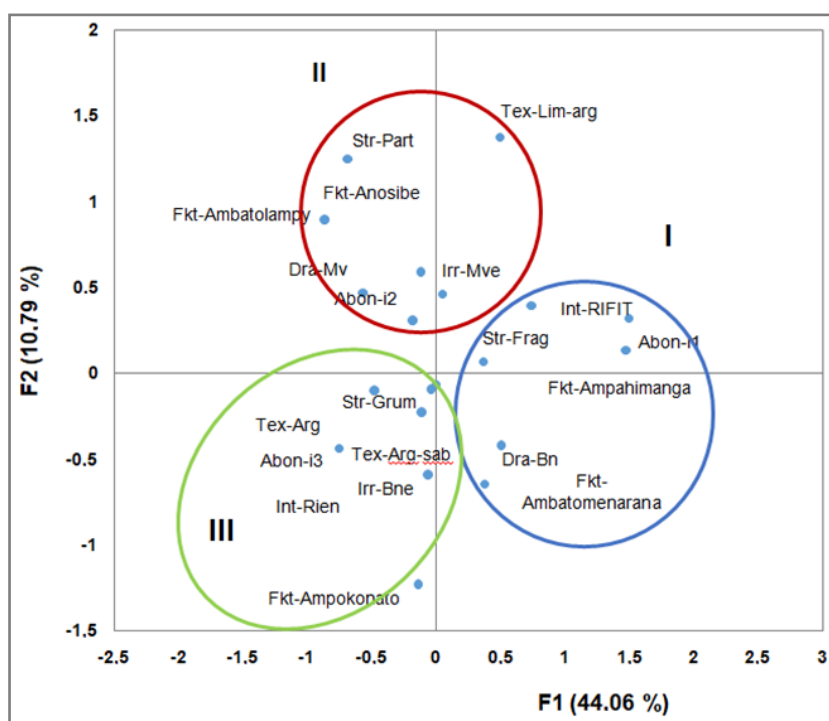


Fig. 4 Relationship between weed status and ecological factors ($n = 125$).

List of abbreviations:

Irr = irrigation	Str = soil structure	Fkt = villages
Bne = good irrigation	Frag = fragmentary	Anosibe
Mve = poor irrigation	Grum = crane	Ampokonato
Dra = drainage	Share = particulate	Ampahimanga
Bn = good drainage	Text = texture	Ambatolampy
Mv = poor drainage	Arg = clay	Ambatomenarana
Int = intervention before observation	Arg-sab = sandy clay	MH abundance
RIFIT	Lim-arg = silty-clayey	i1 = less than 15% recovery
Nothing		i2 = recovery of 15%-30%
		i3 = over 15% recovery

silty-clay texture with a particulate structure. This is the case of plots located near streams and rivers. These rice fields are mainly distributed on the Anosibe and Ambatolampy sites.

Situation 3 (green outline in Fig. 4), shows plots with more than 30% weed cover. This situation can be explained by fact that rice fields are poorly drained. This situation favors proliferation of aquatic weed species. In addition, a soil with a fine texture or lumpy structure and well irrigated is a favorable environment for rice cultivation. But weeds also benefit from this good condition when there is no intervention in the

shortest possible time, such as use of a pre-emergence herbicide treatment.

4. Discussion

4.1 Weeds' Importance for Irrigated Rice

Pressure exerted by weed infestation is a bottleneck for sustainable rice production in any system, especially when certain production techniques are not respected.

Weed assessment results in rice fields of Anosibe Ifanja showed that annual plants are more important than perennial species, which can probably be

explained by the high seed productivity, its faster development cycle and its long life span [28]. Nevertheless, weediness problem by annuals can be easily controlled by deep tillage and good rotation [29]. In addition, rice fields are colonized by a diversity of weeds belonging to about 20 families. Among 47 species recorded, the most dominant are Junglerice - *E. colona* (Poaceae), Barnyardgrass - *E. crus-gali* (Poaceae), Hemp sesbania - *Sesbania rostrata* (Fabaceae), Ricefield bulrush - *S. juncoïdes* (Cyperaceae) and Tail - *L. hexandra* (Oryzoideae). Other species are very devastating, but they are only present in a restricted area such as saramollagrass - *I. rugosum* (Poaceae) case, which colonizes rice fields that have been water submerged and is found near the village of Anosibe. Hannachi [29] confirms this diversity by analyzing all aspects of grassing of cultivated plots of different speculations due to ecological conditions diversity in rice fields, ranging from extremely wet to completely dry conditions. Poaceae family certainly remains the most important in the wettest rice fields, but other families are added when rice fields dry out frequently. However, weed population varies from one region to another. It is therefore evident that results differ in this respect. Merlie and Montégut [30] identified 123 tropical species of spontaneous vegetation on African continent. Previous studies in this study area show that Rivotiana [14] found 89 weed species whose most dominant families are represented by the Poaceae, Asteraceae and Fabaceae, while Mahitasoa [15] in the same study area demonstrated that Poaceae and Cyperaceae were found in all cultures and ecological environments. In comparison with this study, 50% of spontaneous vegetation in this zone is found in rice fields. In addition, Andriamahefa [16] observed 25 weed species in Ambohibary perimeter (located 100 km as crow flies from study area) of which Cyperaceae and Poaceae represent 60% of recorded species [16]. In addition, Randriamampianina in 1984 [13] also mentioned that two weed families are the

most abundant and most frequent in rice fields of Alaotra Lake (located 200 km as crow flies from study area), namely Poaceae and Cyperaceae. Eight major species present in study area (Junglerice - *E. colona*, Barnyardgrass - *E. crus-gali*, Ricefield bulrush - *S. juncoïdes*, Tail - *L. hexandra*, tropical spiderwort - *Commelina benghalensis*, small-flowered umbrella sedge - *C. difformis*) are among the species recorded in Alaotra Lake as well as species inventoried at Ambohimbary Sambaina. Thus, these studies show that although there are differences between regions in terms of geography, climate and cultivation practices, there are at least some species that are considered to be dreaded or common in Madagascar's rice fields. Barnyardgrass - *E. crus-gali* (Poaceae) and Tail - *L. hexandra* (Oryzoideae) represent species most harmful for irrigated rice cultivation throughout development phase [13]. In addition, presence of Poaceae in middle of a crop indicates appearance of more complex competition phenomena in terms of water, nutrient and spatial factors and also makes it more difficult to control these weeds [31].

In comparison with weediness level in irrigated rice cultivation in Africa, weed flora along Senegal River (2018), composed of 179 species divided into 46 families, shows greater diversity [32], whereas Niger flora (2003) has only 45 species in 19 families [33]. These facts can probably be explained by the differences in rice field's topographical position, geographical conditions and climatic conditions.

Furthermore, based on the large morphological groups of weeds, the situation in Anosibe Ifanja (Madagascar) seems to be similar to that in Daloa (Central-Western Côte d'Ivoire) (2017), where dicotyledons (58.10%) are relatively more important than monocotyledons (39.66%), which can be explained by weed management practices in irrigated rice cultivation [34].

In terms of family's importance, Poaceae and Cyperaceae represent the most diversified families, with 36.17% of weeds inventoried. These results are

comparable to those of Halidou [33] with 40% of the listed species and Boraud *et al.* [35] with 45.75% of listed species. However, work of Sylla *et al.* [34] showed the same results in Anosibe Ifanja: Poaceae, Cyperaceae and Asteraceae dominate weed flora in Daloa (Central-Western Côte d'Ivoire) [34]. So Africa weeds remain similar in spite of their geographical situation.

4.2 Factors Influencing the Weediness for Rice Field

This study aimed to understand weed behaviour in irrigated rice. There are those that are adapted to humid environment of rice field such as Junglerice - *E. colona*, *S. juncooides* or Tail - *L. hexandra*. Other species are opportunists that establish themselves in rice field when it is permanently established on dry soil and then adapts when soil is waterlogged or vice versa. As an indication, Goose grass - *Eleusine indica* (Poaceae), American Black nightshade - *Solanum nigrum* (Solanaceae) take advantage of dryness of the rice field while water fern - *Azolla piñata* (Salviniaceae) prefers rice fields submerged in water. Andriamahefa's study (2015) [16] also differentiated weed species of Sambaina Ambohibary, according to their respective ecologies. Saramollagrass - *I. rugosum* (Poaceae) was considered as not important in Sambaina Ambohibary perimeter, unlike Anosibe Ifanja because it is a newly introduced species for study area. Surveys have shown that good irrigation and practice of ploughing in off-season are cure for its devastating infestation [15]. Indeed, cross-checking data showed that changing environmental conditions and production techniques lead to variability in level of weed infestation in rice fields. These facts are confirmed by Bertrand and Doré [17] and Douville [31] by modifying the factors and growing conditions available to them.

Additionally, investigation showed that farmers in Anosibe Ifanja practice ploughing in off-season, which allows for rapid destruction and burial of weed seeds present on surface. They also use animal

traction for rice field work. Thus, depth of their ploughing is between 20 cm and 30 cm. On this subject, Karkour [36] mentioned, however, that deep ploughing already contributes to weed control because it allows them to get rid of a large part of year's seeds and it has been verified that the ideal depth is between 20 cm and 30 cm. In any case, tillage is a means of controlling weeds by Ayeni *et al.* in 1984 in Le Bourgeois [9].

Water is a crucial element for rice cultivation, but it also favors their weeds. Indeed, main objective of flooding rice field is to control weeds in order to select species with a preference for dry soil [37]. Thus, the best way to control weeds is to control water according to stages of rice development and by alternating drying and submergence. Weeds are unable to adapt to this frequent change in their environment, so plots with good water control have low weed infestation rates [38]. If this practice can be used as a control method, it should be applied from early crop stage, that is to say, as soon as rice is at three-leaf stage. In addition, early irrigation can also be used to control annual grasses such as Barnyardgrass - *E. crus-galli* (Poaceae) [39].

With regard to other technical parameters, failure to follow good fertilization practices, such as the correct rate and timing of application, combined with good grass management (herbicide management and rotation integration) [24], directly conditions weed dynamics. With absence of weed control, fertilization only promotes infestation [15, 38]. This situation is frequently observed in the study region in Anosibe Ifanja and, as everywhere in Madagascar agricultural areas. However, action of fertilizers that strengthen rice plants to win potential competitions, they can also harm the crop as poorly decomposed organic matter or, in particular, animal excrements that may contain seeds of fodder species but are considered as weeds in rice cultivation. Finally, transplanting method also helps to the population of weeds in which the rice has a certain growth lead over the weeds. However,

transplanting in crowded and narrow transplanting, as perceived by farmers, makes weeding difficult because weeds always find space to develop, even if they grow exactly at the foot of the rice, unlike row transplanting.

5. Conclusions

In sum, concerns about food self-sufficiency and the perpetual depreciation of rice production in Madagascar are the main reasons for this study. Apparently, weeds are the primary factor limiting rice production. Weeds in irrigated rice cultivation in Anosibe Ifanja plain are characterized by dominance of three families such as Poaceae, Asteraceae and Cyperaceae. Species that stand out for their importance are: Junglerice - *E. colona* (Poaceae), and Tail - *L. hexandra* (Oryzoideae), saramollagrass - *I. rugosum* (Poaceae) and Hemp sesbania - *S. rostrata* (Fabaceae). Abundance of weeds and their harmfulness can vary from one rice field to another, from one village to another, which shows diversity of cases in commune of Anosibe Ifanja. Cultivation practices and environmental factors have a predominant influence on plot weediness. Regarding cultivation practices, back season ploughing and water control reduce level of weed cover in rice fields. Soil type, its texture and structure help to explain distribution of weeds. It would therefore be interesting to continue research on study of harmfulness of weeds in rice cultivation in order to really know yield losses caused by weeds.

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