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Interaction of weed composition and species abundance under different crop rotation pattern

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Key words: Weed composition, Crop rotation, Diversity index, Weed management, Rice-based cropping

Abstract

Weeds are one of the major concerns in agricultural production and weed survey served as baseline information for a strategic weed management system. Four season weed surveys were conducted to assess the effect of different cropping pattern on the weed composition and abundance and identified using different weed reference materials and analyze using PAST software 3.16. The study shows that weed composition in terms of species diversity and abundance varies as affected by the season, crop planted, stage of crop and cropping pattern. Weed species richness and abundance were observed higher in wet season than in dry season and during vegetative stage than in reproductive stage of the crop as affected by crop's canopy cover and available soil moisture. Highest diversity index based on Shannon (H'=2.603) and Simpson (D=0.912) diversity index was found on reproductive stage of rice-corn plot during the 2016 wet season. Also, 2015 and 2016 wet season cropping had a significant difference (p=0.0012) in terms of its weed composition due to the crop rotation scheme. Some weed species were able to adapt different environmental condition that resulted in the complexity of the weed community and their persistence in the field. Lastly, the study revealed that crop rotation does not significantly reduce weed composition but it lowers the weed species abundance and lessens the weed dominance of some noxious weeds found in the field.

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Introduction

One of the major constrain in agricultural production is the presence of weeds. Weeds are the unwanted plants in the agricultural lands that compete for the available resources with the planted crops such as water, nutrients, and light (Oudhia, 2001). It causes significant yield loss when unmanaged due to their competitive and allelopathic behavior (Zahid *et al.*, 2004 as cited by Olorunmaiye *et al.*, 2013). Weeds can also serve as a refuge for harmful organisms for the crops such as alternate host for pathogens, insects and diseases, and can continue its life cycle in the absence of the targeted crops.

Crop rotation is one of the effective weed management practices because it alters the favorable condition for the weed growth and reproduction, thus, reducing weed density (Derksen *et al.*, 1993). This practice is an essential component for integrated weed management systems (Clemens *et al.*, 1994). It is defined as a sequential growing of different crops after every end of cropping season and different from intercropping because intercropping involves cultivation of two or more crops at the same season on the same field (Marenco and Santos, 1999). Crop rotation is observed as an effective weed control as it interrupts a number of weed species development in-terms of its life cycles and surviving types at different cropping density (Simic *et al.*, 2017). Also, the distribution of weed seeds in the soil is highly influenced by the variation of cropping system implied as observed in the crop field (Adesina *et al.*, 2012).

Weed management in a cropping system requires knowledge to the spatial and temporal interaction between weeds, seed losses and seed production (Koocheki *et al.*, 2008) in order to facilitate appropriate weed management strategies (Derkesen *et al.*, 1993). Presence and abundance of weed species in a given crop field are dependent on the type of crop planted, cultural management practices, soil type, available moisture, location, season and cropping patterns (Sit *et al.*, 2007).

In order to attain appropriate weed management strategies, weed survey is essential to understand the weed emergence pattern and problems which may be used for strategic weed management (Olorunmaiye *et al.*, 2013). Thus, the study was conducted to investigate the effects of different crop rotation pattern on the weed composition, abundance and diversity.

Materials and methods

Study site

The experiment was conducted at lot B-12, one of the experimental field of University of the Philippines Los Baňos (UPLB), College, Los Baňos, Laguna (Latitude N14^{o}09.986'; Longitude 121^{o}15.282').

The area was under Type I climate type with two pronounce season: dry season during months of November to April and wet during the rest of the year. Average reported temperature in the area was 27 degrees Celsius and has 16 % exposure to typhoon. Soil type was classified as Lipa Series with brown to dark brown soil color and volcanic tuff parent material. The soil was slightly acidic with a pH of 6.1 and 4.66 % Organic Matter, 83 ppm Phosphorus (Olsen) and 1.60 me Potassium (100g soil) as reported on the soil analysis conducted prior to the field establishment.

Sampling design

Three crop rotations were established at the field namely: Rice-Rice-Rice-Rice; Rice-Corn-Rice-Corn; and Rice-Mungbean-Rice-Mungbean planted in a 10m x 10 m (100m^2) plots.

The plots were planted with rice during wet season and rotated with rice, corn and mungbean in designated plots during dry season. Varieties used were PSB Rc9 (Rice), IPB Var 13 (Corn) and Pag-Asa 7 (Mungbean) with furrows of 25 cm (Rice); 50 cm (Corn) and 50 cm (Mungbean). The experimental design was randomized complete block design with three replicates and separated by 2 m apart. Weed survey was conducted for 4 consecutive seasons (2015WS; 2016WS; 2016DS; 2017DS) using a 1 m x 1 m quadrant randomly placed in each plot.

Sample collection

Weed collection was conducted during the vegetative and early reproductive phase of the crop. The plots were hand-weeded every end of the sampling and followed the required nutrient management to allow the normal growth of the crop and dynamics of the weed population in the field. The field was also irrigated during the dry season as needed by the crop and no chemical input was used during the cropping durations to ensure no effect on the weed composition.

Species identification

Collected weed species were identified up to species level. The reference material used was the Common weeds in Vietnam by Koo *et al.*, (2005) and A Practical Field Guide to Weeds of Rice in Asia by Caton *et al.*, (2010) was used for the weed identification.

Data analysis

Inferential statistics was used to draw a concrete conclusion on the data observed. It was analyzed using different diversity and community structure analyses of weeds in the sampling site. Moreover, One-Way-ANOVA was used to test the significant differences of weed composition between crop rotation, seasons and years across sampling plots. Data were inputted in excel and analyzed through Paleontological Statistics software 3.16 (Hammer, 2017).

Results and discussion

Frequency, Abundance and Density of Weed Species

There were fifteen (15) families out from the twenty-four (24) weed species observed after the first cropping in wet season of 2015 (Table 1).

Table 1. Weed species occurrence in different cropping system after 2015 WS at Lot B-12, Pili Drive, UPLB, College, Los Baňos, Laguna.

Family	Species	Rice /Rice Plot	Corn/Rice Plot	Mungbean/Rice Plot
Amaranthaceae	*Celosia argentea*	√	√	√
Asteraceae	*Ageratum conyzoides*	-	√	√
Asteraceae	*Eclipta prostrata*	√	√	√
Asteraceae	*Synedrella nodiflora*	√	√	√
Asteraceae	*Tridax procumbens*	√	√	√
Asteraceae	*Vernonia cinerea*	-	√	-
Capparaceae	*Cleome rutidosperma*	√	√	√
Commelinaceae	*Commelina benghalensis*	√	-	-
Commelinaceae	*Commelina diffusa*	√	√	√
Commelinaceae	*Murdanniavaginata*	√	√	√
Convolvulaceae	*Ipomoea triloba*	√	√	√
Cyperaceae	*Fimbristylis dichotoma*	√	√	√
Cyperaceae	*Cyperus iria*	√	√	√
Cyperaceae	*Cyperus rotundus*	√	√	√
Euphorbiaceae	*Euphorbia hirta*	√	√	√
Leguminosae	*Mimosa pudica*	√	√	√
Malvaceae	*Urena lobata*	√	-	√
Onagraceae	*Ludwigia octovalvis*	√	√	√
Phyllanthaceae	*Phylanthus niruri*	√	√	√
Poaceae	*Echinocloa colona*	√	√	√
Poaceae	*Cynodon dactylon*	√	√	√
Poaceae	*Digitaria ciliaris*	-	√	√
Poaceae	*Paspalum conjugatum*	√	√	-
Poaceae	*Rottboellia cochinchinensis*	√	√	√
Portulacaceae	*Portulaca oleracea*	√	√	√
Rubiaceae	*Hedyotis corymbosa*	√	√	√
Solanaceae	*Physalis augulata*	-	√	-

The composition and population were varied across the cropping pattern with twenty-five (25) observed weed species from rice-corn plot, and twenty-three (23) from rice-rice plot and rice-mungbean plot, respectively. Increased in weed diversity in rice-corn plot than in rice-rice plot was somewhat favorable as observed by Stevenson *et al.*, (1997) in which the diversity of weed increases under crop rotation scheme than in monoculture.

Table 2. Frequency, abundance and density of different weed species during 2015 Wet Season at vegetative and reproductive stage of the crop.

2015 WS	Rice-Rice Plot			Rice-Corn Plot			Rice-Mungbean		
Weed species	F	A	D	F	A	D	F	A	D
Vegetative stage sampling									
Celosia argentea	3	83	27.67	3	326	108.67	3	135	45
Cleome rutidosperma	3	109	36.33	2	64	32	3	119	39.67
Commelina benghalensis	1	15	15	-	-	-	2	15	7.50
Commelina diffusa	3	63	21	2	91	45.50	3	101	33.67
Euphorbia hirta	2	3	1.50	2	4	2	2	3	1.50
Cynodon dactylon	1	6	6	2	26	13	3	35	11.67
Cyperus rotundus	3	266	88.67	3	134	44.67	3	117	39
Ipomoea triloba	2	84	42	3	54	18	3	87	29
Mimosa pudica	-	-	-	1	12	12	-	-	-
Portulaca oleracea	1	6	6	3	38	38	2	22	11
Roettboellia cochinchinensis	1	9	9	2	11	11	3	10	3.33
Reproductive stage sampling									
Ageratum conyzoides	2	3	1.5	-	-	-	1	1	1
Celosia argentea	2	23	11.5	3	90	30	2	61	30.5
Cleome rutidosperma	3	69	23	2	54	27	3	92	30.67
Commelina benghalensis	-	-	-	1	3	3	2	8	4
Commelina diffusa	3	45	15	2	31	15.5	3	61	20.33
Digitaria cilliaris	2	52	26	3	26	8.67	3	93	31
Digitaria setigera	1	10	10	1	2	2	-	-	-
Echinocloa colona	2	62	31	3	100	33.33	2	26	4
Euphorbia hirta	2	3	1.5	2	51	25.5	3	2	0.67
Cynodon dactylon	1	6	6	2	4	2	3	65	21.67
Cyperus iria	-	-	-	2	13	6.5	1	1	1
Cyperus difformis	3	26	8.67	1	3	3	3	3	1.5
Cyperus rotundus	3	130	43.33	3	89	29.67	3	98	32.67
Fimbristylis dichotoma	2	18	9	-	-	-	-	-	-
Ipomoea triloba	3	24	8	3	17	5.67	2	12	6
Leptochloa fusca	1	3	3	-	-	-	2	14	7
Ludwigia octovalvis	1	6	6	1	3	3	1	2	2
Mimosa pudica	-	-	-	1	12	12	-	-	-
Murdanniavaginata	2	14	7	1	19	19	2	7	3.5
Physalis augulata	1	5	5	1	5	5	1	2	2
Portulaca oleracea	1	6	6	2	14	7	2	10	5
Roettboellia cochinchinensis	2	9	4.5	2	11	5.5	3	6	2
Synedrella nodiflora	1	5	5	1	5	5	1	2	2

The increase in the weed composition was said to decrease the dominations of a few problematic weeds (Macak *et al.*, 2005) such as *Cyperus rotundus* and as observed in the study.

The frequency, abundance and diversity of weeds is dependent on the characteristics of a given weed species, growth habit and life cycle. Based on the weed survey, most dominant weeds species do not vary across season and crop stages consisting of

Cyperus rotundus, *Echinocloa colona* and *Cleome rutidosperma*. Generally, dominant weeds were characterized with a high number of reproduction scheme such as seeds and rhizome (*Cyperus rotundus),* seeds and cuttings (*Commelina diffusa)* and high seed production in which fertilization was self-compatible (*Echinocloa colona* and *Cleome rutidosperma)* (Gbehounou, 2013).

Table 3. Frequency, abundance and density of different weed species during 2016 Dry Season at vegetative and reproductive stage of the crop.

2016 DS	Rice-Rice Plot			Rice-Corn Plot			Rice-Mungbean Plot		
Weed species	F	A	D	F	A	D	F	A	D
Vegetative stage sampling									
Celosia argentea	1	3	3	3	54	18	1	15	15
Cleome rutidosperma	3	203	67.67	3	35	11.67	2	19	9.5
Commelina diffusa	1	2	2	-	-	-	-	-	-
Digitaria ciliaris	-	-	-	1	6	6	-	-	-
Echinocloa colona	3	72	24	3	78	26	3	154	51.33
Eclipta prostrata	1	7	7	-	-	-	1	2	2
Euphorbia hirta	-	-	-	-	-	-	1	6	6
Hedyotis corymbosa	2	9	4.5	-	-	-	3	14	4.67
Cyperus iria	-	-	-	1	19	19	-	-	-
Cyperusrotundus	3	88	29.33	3	156	52	3	180	60
Ipomoea triloba	3	49	16.33	3	83	27.67	2	49	24.5
Ludwigia octovalvis	1	6	6	1	2	2	2	20	10
Mimosa pudica	2	33	16.5	3	7	2.33	2	11	5.5
Murdanniavaginata	1	2	2	-	-	-	2	21	10.5
Paspalum conjugatum	1	25	25	1	6	6	-	-	-
Phyllanthus niruri	2	12	6	2	15	7.5	2	31	15.5
Physalis angulata	-	-	-	1	6	6	-	-	-
Portulaca oleracea	1	4	4	-	-	-	2	39	19.5
Roettboellia cochinchinensis	2	12	6	3	39	13	2	21	10.5
Synedrella nodiflora	2	26	13	2	25	12.5	2	38	19
Tridaxprecumbens	1	13	13	2	16	8	3	31	10.33
Urenalobata	1	2	2	2	3	1.5	3	39	13
Reproductive stage sampling									
Celosia argentea	-	-	-	-	-	-	1	5	5
Cleome rutidosperma	3	119	39.67	3	131	43.67	1	17	17
Commelina diffusa	-	-	-	2	32	16	3	9	3
Echinocloa colona	3	104	34.67	3	24	8	3	57	19
Cyperus rotundus	3	43	14.33	3	103	34.33	3	68	22.67
Ipomoea triloba	3	11	3.67	2	18	9	2	12	6
Mimosa pudica	2	3	1.5	1	2	2	2	12	6
Portulaca oleracea	2	3	1.5	3	39	13	3	9	3
Roettboellia cochinchinensis	-	-	-	3	52	17.33	3	71	23.67
Tridaxprecumbens	2	11	5.5	-	-	-	-	-	-
Urena lobata	-	-	-	-	-	-	1	14	14

These specific characteristics in some weeds help their survival throughout cropping pattern (Olorunmaiye *et al.*, 2013). *Cyperus rotundus* was observed to be the most dominant weed species across the cropping pattern, crop stages and cropping season. *Cyperus rotundus* was reported to be one of the most noxious weed due to its high range of environmental tolerance in which it can grow in all soil condition, can survive under high temperature and produce extensive tuber system that were prolific and difficult to control when established (Holm *et al.*, 1977).

Weeds with the highest occurrence at the field were described below:

Table 4. Frequency, abundance and density of different weed species during 2016 Wet Season at vegetative and reproductive stage of the crop.

2016 WS	Rice-Rice Plot			Rice-Corn Plot			Rice-Mungbean Plot		
Weed species	F	A	D	F	A	D	F	A	D
Vegetative stage Sampling									
Ageratum conyzoides	1	6	6	1	15	15	1	2	2
Celosia argentea	3	101	33.67	2	99	49.5	3	66	22
Cleome rutidosperma	3	60	20	1	85	85	3	54	18
Commelina diffusa	2	16	8	1	14	14	3	48	16
Digitaria ciliaris	2	27	13.5	2	28	14	1	32	32
Echinocloa colona	3	136	45.33	3	94	31.33	3	59	19.67
Eclipta prostrata	2	21	10.5	-	-	-	1	5	5
Cyperus rotundus	3	233	77.67	3	268	89.33	3	429	143
Ipomoea triloba	3	30	10	3	26	8.67	2	29	14.5
Ludwigia octovalvis	2	22	11	-	-	-	-	-	-
Mimosa pudica	-	-	-	2	30	15	1	5	5
Phyllanthus niruri	1	5	5	-	-	-	1	12	12
Portulaca oleracea	2	14	7	1	7	7	2	16	8
Roettboellia cochinchinensis	2	27	13.5	3	39	13	2	41	20.5
Synedrella nodiflora	2	91	45.5	2	43	21.5	2	50	25
Reproductive stage sampling									
Ageratum conyzoides	-	-	-	1	12	12	1	25	25
Celosia argentea	1	4	4	2	20	10	2	24	12
Cleome rutidosperma	1	8	8	3	65	21.67	-	-	-
Commelina diffusa	1	5	5	2	24	12	2	75	37.5
Echinocloa colona	3	98	32.67	2	27	13.5	3	71	23.67
Eclipta prostrata	-	-	-	1	36	36	-	-	-
Cynodon dactylon	1	1	1	1	9	9	1	4	4
Cyperus iria	2	14	7	2	2	1	2	8	4
Cyperus rotundus	3	62	20.67	2	44	22	2	55	27.5
Fimbristylis dichotoma	1	18	18	3	75	25	2	92	46
Ipomoea triloba	-	-	-	1	12	12	1	5	5
Ludwigia octovalvis	2	26	13	3	42	14	2	29	14.5
Mimosa pudica	2	7	3.5	1	5	5	-	-	-
Murdanniavaginata	1	7	7	3	59	19.67	2	13	6.5
Paspalum conjugatum	-	-	-	1	11	11	-	-	-
Phyllanthus niruri	3	24	8	1	11	11	-	-	-
Roettboellia cochinchinensis	2	12	6	1	3	3	1	11	11
Synedrella nodiflora	2	18	9	3	55	18.33	1	11	11
Vernonia cinerea	-	-	-	1	6	6	-	-	-

Table 5. Frequency, abundance and density of different weed species during 2017 Dry Season at vegetative and reproductive stage of the crop.

2017 DS	Rice-Rice Plot			Rice-Corn Plot			Rice-Mungbean Plot		
Weed species	F	A	D	F	A	D	F	A	D
Vegetative stage sampling									
Celosia argentea	2	30	15	3	45	15	2	35	17.5
Cleome rutidosperma	2	49	24.5	3	72	24	3	71	23.67
Commelina diffusa	1	6	6	3	13	4.33	3	20	6.67
Echinocloa colona	3	77	25.67	3	100	33.33	3	79	26.33
Ecliptap rostrata	2	14	7	2	10	5	2	8	4
Euphorbia hirta	1	5	5	1	5	5	1	3	3
Cynodon dactylon	-	-	-	-	-	-	2	4	2
Cyperus iria	1	2	2	-	-	-	2	2	1
Cyperus rotundus	3	97	32.33	3	130	43.33	3	79	26.33
Ipomoea triloba	3	69	23	3	54	18	3	65	21.67
Mimosa pudica	3	38	12.67	1	13	13	3	19	6.33
Murdanniavaginata	2	16	8	2	13	6.5	3	28	9.33
Phyllanthus niruri	2	7	3.5	2	6	3	2	8	4
Portulaca oleracea	2	10	5	2	4	2	3	32	10.67
Roettboellia cochinchinensis	1	14	14	2	12	6	3	16	5.33
Synedrella nodiflora	2	18	9	2	18	9	3	13	4.33
Tridaxprecumbens	2	26	13	1	9	9	-	-	-
Reproductive stage sampling									
Celosia argentea	2	13	6.5	2	14	7	3	32	10.67
Cleome rutidosperma	-	-	-	2	9	4.5	1	9	9
Commelina benghalensis	2	5	2.5	-	-	-	-	-	-
Commelina diffusa	1	5	5	2	14	7	-	-	-
Echinocloa colona	3	41	13.67	3	39	13	2	26	13
Ecliptap rostrata	-	-	-	-	-	-	2	6	3
Euphorbia hirta	2	6	3	1`	3	3	-	-	-
Cynodondactylon	1	3	3	-	-	-	-	-	-
Cyperus iria	-	-	-	1	4	4	2	6	3
Cyperus rotundus	3	40	13.33	3	65	21.67	3	33	11
Fimbristylis dichotoma	3	43	14.33	3	31	10.33	2	26	13
Hedyotis corymbosa	-	-	-	2	3	1.5	-	-	-
Ipomoea triloba	3	17	5.67	2	7	3.5	2	12	6
Mimosa pudica	3	24	8	3	25	8.33	2	8	4
Murdanniavaginata	-	-	-	1	4	4	-	-	-
Phyllanthus niruri	1	4	4	2	5	2.5	1	1	1
Portulaca oleracea	-	-	-	2	3	1.5	1	1	1
Roettboellia cochinchinensis	-	-	-	2	10	5	3	9	3
Synedrellano diflora	3	30	10	2	11	5.5	-	-	-
Tridaxprecumbens	2	13	6.5	-	-	-	2	14	7

Wet Season Cropping

The weed species with highest occurrence value (in terms of frequency, abundance and density) at vegetative stage on the first cropping (2015) was observed in the order of *C. rotundus>C. rutidosperma>I. triloba* for rice-rice plot; *C. argentea>C. rotundus>C. diffusa* for rice-corn plot and lastly, *C. argentea>C. rutidosperma>C. rotundus* for mungbean-rice plot. Whereas, sampling at the reproductive phase with highest occurrence was in the order of *C. rotundus>C. rutidosperma>E. colona* for rice-rice plot; *E. colona>C. argentea>C. rotudus* for rice-corn plot and *C. rotundus>D. ciliaris>C. rutidosperma* for rice-mungbean plot (Table 2).

Table 5. Frequency, abundance and density of different weed species during 2017 Dry Season at vegetative and reproductive stage of the crop.

2017DS	Rice-Rice Plot			Rice-Corn Plot			Rice-Mungbean Plot		
Weed species	F	A	D	F	A	D	F	A	D
Vegetative stage sampling									
Celosia argentea	2	30	15	3	45	15	2	35	17.5
Cleome rutidosperma	2	49	24.5	3	72	24	3	71	23.67
Commelina diffusa	1	6	6	3	13	4.33	3	20	6.67
Echinocloa colona	3	77	25.67	3	100	33.33	3	79	26.33
Ecliptap rostrata	2	14	7	2	10	5	2	8	4
Euphorbia hirta	1	5	5	1	5	5	1	3	3
Cynodon dactylon	-	-	-	-	-	-	2	4	2
Cyperus iria	1	2	2	-	-	-	2	2	1
Cyperus rotundus	3	97	32.33	3	130	43.33	3	79	26.33
Ipomoea triloba	3	69	23	3	54	18	3	65	21.67
Mimosa pudica	3	38	12.67	1	13	13	3	19	6.33
Murdanniavaginata	2	16	8	2	13	6.5	3	28	9.33
Phyllanthus niruri	2	7	3.5	2	6	3	2	8	4
Portulaca oleracea	2	10	5	2	4	2	3	32	10.67
Roettboellia cochinchinensis	1	14	14	2	12	6	3	16	5.33
Synedrella nodiflora	2	18	9	2	18	9	3	13	4.33
Tridaxprecumbens	2	26	13	1	9	9	-	-	-
Reproductive stage sampling									
Celosia argentea	2	13	6.5	2	14	7	3	32	10.67
Cleome rutidosperma	-	-	-	2	9	4.5	1	9	9
Commelina benghalensis	2	5	2.5	-	-	-	-	-	-
Commelina diffusa	1	5	5	2	14	7	-	-	-
Echinocloa colona	3	41	13.67	3	39	13	2	26	13
Ecliptap rostrata	-	-	-	-	-	-	2	6	3
Euphorbia hirta	2	6	3	1`	3	3	-	-	-
Cynodon dactylon	1	3	3	-	-	-	-	-	-
Cyperus iria	-	-	-	1	4	4	2	6	3
Cyperus rotundus	3	40	13.33	3	65	21.67	3	33	11
Fimbristylis dichotoma	3	43	14.33	3	31	10.33	2	26	13
Hedyotis corymbosa	-	-	-	2	3	1.5	-	-	-
Ipomoea triloba	3	17	5.67	2	7	3.5	2	12	6
Mimosa pudica	3	24	8	3	25	8.33	2	8	4
Murdanniavaginata	-	-	-	1	4	4	-	-	-
Phyllanthus niruri	1	4	4	2	5	2.5	1	1	1
Portulaca oleracea	-	-	-	2	3	1.5	1	1	1
Roettboellia cochinchinensis	-	-	-	2	10	5	3	9	3
Synedrella nodiflora	3	30	10	2	11	5.5	-	-	-
Tridaxprecumbens	2	13	6.5	-	-	-	2	14	7

In the second wet season (2016), observed weeds with highest occurrence was in the order of *C. rotundus* > *E. colona* > *C. argentea* for rice-rice plot; *C. rotundus>C. argentea >E. colona* in rice-corn plot and lastly, C. rotundus> *C. argentea* > *E. colona* in the rice-mungbean plot. Whereas, sampling at the reproductive phase with highest occurrence was in the order of *E. colona* > *C. rotundus* > *L. octovalvis*in rice-rice plot; *F. dichotoma* > *C. rutidosperma* > *M. vaginata* for rice-corn plot and *F. dichotoma>C. diffusa>E. colona* for rice-mungbean plot (Table 4).

Dry Season Cropping

The weed species with highest occurrence value (in terms of frequency, abundance and density) at vegetative stage on the first dry cropping (2016) was observed in the order of *C. rutidosperma>C. rotundus>E. colona* for rice-rice plot*; C. rotundus> I. triloba>E.colona*for rice-corn plot and lastly,*C. rotundus>E. colona>I. triloba* for mungbean-rice plot. Whereas, sampling at the reproductive phase with highest occurrence was in the order of *E. colona>C. rutidosperma>C. rotundus*for rice-rice plot; *C. rutidosperma>C. rotundus>R. cochinchinensis* for rice-corn plot and *R. cochinchinensis>C. rotundus>E. colona* for rice-mungbean plot (Table 3).

In the second dry season (2017), observed weeds with highest occurrence at the vegetative stage was in the order of *C. rotundus>E. colona>I. triloba* for rice-rice plot; *C. rotundus>E. colona>C. rutidosperma* for rice-corn plot and lastly, *E. colona>C. rotundus>C. rutidosperma* for mungbean-rice plot. Whereas, sampling at the reproductive phase with highest occurrence was in the order of *F. dichotoma>E. colona>C. rotundus*for rice-rice plot; *C. rotundus>E. colona>F. dichotoma* for rice-corn plot and *C. rotundus> C. argentea> F. dichotoma>E. colona* for rice-mungbean plot (Table 5).

Diversity of Weed Species

Weeds surveyed during wet season were higher than in dry season in terms of weed species richness and abundance. Also, weed abundance was observed higher in vegetative stage than in reproductive stage of the crop.

Highest weed sampling in terms of abundance was collected during the vegetative stage of rice-rice plot consisting of 14 species with 259 individuals. Whereas, lowest count was found on rice-mungbean plot during the dry season of 2017 consisting of 12 species with 57 individuals.

Table 6. Diversity and composition of weed species across seasons, cropping pattern and crop stages.

Season	Cropping	Stage	Abundance	Richness	Dominance	Evenness	Simpson	Shannon
	Rice-Rice	Veg.	213	10	0.243	0.538	0.757	1.682
2015 wet		Rep	168	20	0.122	0.571	0.878	2.436
season	Rice-Corn	Veg.	249	10	0.246	0.569	0.754	1.739
		Rep.	177	20	0.133	0.576	0.887	2.445
	Rice-	Veg.	212	10	0.159	0.711	0.887	2.445
	Mungbean	Rep.	180	20	0.124	0.500	0.876	2.303
	Rice-Rice	Veg.	184	18	0.185	0.460	0.815	2.113
2016 dry		Rep.	95	7	0.313	0.554	0.687	1.354
season	Rice-Corn	Veg.	180	16	0.148	0.576	0.853	2.221
		Rep.	131	8	0.211	0.714	0.789	1.742
	Rice-	Veg.	225	17	0.141	0.609	0.859	2.337
	Mungbean	Rep.	225	17	0.141	0.609	0.859	2.337
	Rice-Rice	Veg.	259	14	0.159	0.609	0.842	2.143
2016 wet		Rep.	100	15	0.160	0.602	0.840	2.201
season	Rice-Corn	Veg.	246	12	0.186	0.632	0.814	2.027
		Rep.	167	19	0.088	0.710	0.912	2.603
	Rice-	Veg.	77	12	0.186	0.633	0.814	2.027
	Mungbean	Rep.	135	13	0.138	0.684	0.862	2.186
	Rice-Rice	Veg.	155	16	0.115	0.687	0.886	2.397
2017 dry		Rep.	77	13	0.123	0.736	0.877	2.258
season	Rice-Corn	Veg.	165	15	0.151	0.590	0.849	2.181
		Rep.	77	16	0.134	0.638	0.866	2.324
	Rice-	Veg.	153	16	0.112	0.676	0.888	2.381
	Mungbean	Rep.	57	13	0.123	0.735	0.877	2.257

The variations in weed composition in terms of richness and abundance between seasons and cropping pattern were highly affected by the canopy cover of the planted crop. Effect of crop's canopy cover on weeds emergence was also reported by Adesina *et al.*, (2012) and Gharineh and Moosavi (2012).

The light penetration on the ground was lower during the reproductive stage as light was the limiting factor for the growth of the weeds. Displacement of some weeds from the vegetative sampling and reduction on the weed density can be accounted that some weeds requires specific light requirement and unable to withstand shaded condition.

Table 7. Comparison across cropping years and crop stages using one-way ANOVA.

	Veg2015WS	Rep2015WS	Veg2016WS	Rep2016WS
Veg2015 WS		0.0031*	1.0	1.0
Rep2015 WS	0.0031*		0.2308	0.0092*
Veg2016 WS	1.0	0.2308		1.0
Rep2016 WS	1.0	0.0092	1.0	

Note: *Significantly difference using Mann-Whitney pair wise (Bonferroni corrected p-value)
Kruskal-Wallis test at p-value=0.001286*

Table 7. Continued.

	Veg2016DS	Rep2016DS	Veg2017DS	Rep2017DS
Veg2016DS		1.0	1.0	0.5002
Rep2016DS	1.0		1.0	1.0
Veg2017DS	1.0	1.0		1.0
Rep2017DS	0.5002	1.0	1.0	

Note: No Significant difference using Mann-Whitney pair wise (Bonferroni corrected p-value)
Kruskal-Wallis test at p-value=0.4178.

Highest diversity index value based from Shannon (H'=2.603) and Simpson (D=0.912) diversity index was found on reproductive stage of rice-corn plot during 2016 wet season. However, the lowest weed diversity was accounted during reproductive state of rice-rice crop in 2016 dry season based from Shannon (H'=1.354) and Simpson (D=0.687) diversity index. Soil moisture is an important factor that affects weed composition and density. Soil moisture differs across season and location. Moreover, water availability was more available in wet season due to rain occurrence and lower field temperature than in dry season. Due to difference in water availability, supplemental irrigation was performed in dry season cropping in the conduct of the study to assure normal crop growth. However, even though it was reported that weeds require more water than most of cultivated crops to produce a unit of biomass (Shen *et al.*, 2014), some of the weeds were still able to adapt to limited water condition by developing waxy leaves (Commelinaceae) and smaller leaf area (grasses and sedges) to reduce transpiration and fibrous root system (monocots) or tap root system (dicots) to efficiently absorb the available water in the field resulting to the complexity of the weed community (Table 6).

Weed Species composition across years, cropping season and crop sampling stage

Weed composition in terms of species diversity and abundance varies as affected by crop planted, stage of crop and cropping season. Moreover, it was also observed that weed species richness was affected by land preparation activities and the year in which the sampling was conducted (Demjanova *et al.*, 2009).

There was a significant difference (p=0.0012) in weed composition surveyed between 2015 and 2016 Wet Season Cropping. In addition, weed composition across crop stage in 2015 wet season had significant differences (p=0.0030) while reproductive stage was also significantly difference (p=0.0091) in 2015 and 2016 wet season (Table 7). The significant difference in the weed composition between the two wet seasons was due to the crop rotation conducted. In 2015 wet season, the field was planted with rice while the succeeding 2017 dry season cropping was planted with rice, corn and mungbean across sampling plots. The variation in the canopy structure, height and maturity of the crops cause probable disruption in the normal cycle of the weeds present in the designated experimental plots. Weeds that were unable to tolerate shaded condition were reduced in terms of its abundance while others were displaced. Whereas, no significant differences on the weed composition in the two dry seasons because weeds that survive the first crop rotation scheme were most likely tolerate a wide range of shaded condition (Table 7).

Conclusion

The study showed that weed composition and weed abundance are affected by cropping pattern. Cropping pattern alters the environment that favors the development of weed community and affecting the weed composition, abundance, and diversity. Two major reasons that dictate the survival of weed species in the field are the effect of shading and soil moisture availability. Weed abundance reduces as crop reaches its maturity but do not cause significant reduction in weed composition while soil moisture availability dictates the weeds composition and its proliferation. Reduction in the weed composition in a cropping pattern was significant in the first crop shift as most of the weeds can adapt and tolerate easily in a shaded condition and most prominent weed abundance reduction was observed on the rice-mungbean cropping pattern at the second dry cropping. *Cyperus rotundus*, *Echinochloa colona*, and *Cleome rutidosperma* were the most abundant weed species in the field regardless of the cropping pattern. *Cyperus rotundus* is still the most dominant weed species in the field despite the cropping pattern in-terms of plot occurrence and abundance. Lastly, crop rotation can only decrease weed abundance but cannot significantly reduce the dominance of the noxious weed in the field.

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