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The Effect of Nutrient Management and Crop Rotation on Weed Dynamics in Rice under Dry Zone (DL1B) of Sri Lanka

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ABSTRACT

The Integrated weed management (IWM) is widely used to manage weeds in diverse cropping systems. Crop rotation and diverse nutrient management strategies are essential components in IWM. However, the effect of crop rotation and nutrient management systems on weed dynamics in Sri Lankan rice-based cropping systems is scarce. Therefore, an experiment was conducted to identify weed density, biomass, and abundance of two different nutrient management systems (Synthetic; SNM and Integrated; INM) and under rice monoculture and rice-maize rotation during four seasons within the farm premises of the Faculty of Agriculture, Rajarata University of Sri Lanka. Rice variety Bg300 and maize hybrid Pacific-998 were cultivated. Growing maize in the *Yala* season increased weed density and weed biomass compared to growing rice in both crop rotation cycles. During the first cycle, weed density was high under INM in the Rice crop phase. However, in the second cycle, both crop phases (rice and maize) had low weed density under INM compared to SNM. A higher density of sedges was reported with the crop rotation in the *Yala* seasons, and grasses were dominant in the mono-cropping in both seasons. Grass biomass did not change with the nutrient management systems, while the biomass of sedges increased with synthetic fertilizer only. High weed density and biomass in maize during the first cycle were substantially reduced in the second cycle for both nutrient management systems. Overall, reducing chemical fertilizer by 50% and incorporating organic matter, INM, substantially supported weed management in both rice and maize crops.

INTRODUCTION

Competition from weeds is one of the main biotic factors for crop yield loss. Weeds compete for resources (Zimdahl, 2007), harbor crop pests (Hassanali, 2008), disrupt water management (Stoa, 2015), and interfere with crop quality (Akbar *et al.,* 2011; Zimdahl, 2018). In arable land, weed growth, abundance, and composition are mainly determined by crop production practices (Bajwa *et al*., 2014) and prevailing environmental conditions. Primarily, fertilizer inputs such as type, amount, time of application, and source influence weed types, abundance, and density either negatively or positively (Barberi *et al.,*1997; Smith *et al.,* 2010). Generally, nutrient availability in a cropping system influences weed emergence, persistence, dormancy, growth rates, dispersion, and biomass. The dynamics of weeds vary according to the type of fertilizer and their respective nutrient element contents (basically nitrogen (N)) (Moody, 1981). Synthetic fertilizers have shown substantial impacts on weed dynamics. In most instances, weed dynamics aligned with the rate of synthetic fertilizer application (Little *et al*., 2021). Guza *et al*. (2008) reported that total weed biomass increases with the increasing rates of N fertilizer application. Hence, judicious nutrient management practices can be a key component in weed management.

Integrated nutrient management in low external input production systems often uses a blend of synthetic and organic fertilizers. The degree of incorporation of organic sources shows invariable dynamics of weed densities and biomasses, thus substantially different outcomes are possible. Studies elucidated that composted manure can reduce weed infestation by altering soil physical and chemical properties, including water holding capacity, aggregate stability, bulk density, and soil temperature (Singer *et al*., 2004), and reduces weed seed bank in soil (Menalled *et al*., 2005). Furthermore, compost limits weed growth by releasing phytotoxic substances and allelopathic effects on germinating weed seeds (Ozores-Hampton *et al*., 1999). On contrary, Blackshaw (2005) showed that fresh manure and compost releases N slowly, which benefits the weeds more than crop plants with the differential ability of competition at resource-limited conditions. Thus, under alternate nutrient management strategies with organic and inorganic sources, weeds are expected to thrive better than a crop without an effective weed controlling technique.

Crop rotation is the most effective long-term weed control strategy that showed a substantial capability in suppressing weeds (Berzsenyi *et al.,* 2000). Rice-based cropping systems in Sri Lanka use cereals, legumes, vegetables, and pulses in rotation with rice allowing the system to follow an alternate wetting and drying strategy aligning with seasonal irrigation possibilities. Rice crop in the wet (*Maha*) and maize in the dry (*Yala*) seasons are the most prominent combination in lowland paddy fields in the Dry and Intermediate zones of Sri Lanka (Karunatilake, 2003). The selection of crops creates a rotation of anaerobic and aerobic soil conditions in the same field and opens up an environment for weeds to compete with spatially and temporally different canopies.

A diversified crop rotation system can prevent weed species from gaining dominance. Theoretically, growing crops that differ in sowing time, competitiveness, time of maturation, soil management, and nutrient requirements would not be able to benefit from a consistently favorable environment (Radosevich *et al.,* 1997; Doucet *et al.,* 1999; Squire *et al.,* 2000; Adler *et al.,* 2006; Ulber *et al.,* 2009; Gaba *et al.,* 2010; Allan *et al.,* 2014). Liebman and Davis (2000) stated that crop rotations substantially lower both above-ground and below-ground weed densities. Crop diversification can change the degree of weed infestations due to changes in tillage, soil nutrients, water management, timing and amount of nutrients applied, seeding, and harvesting time. Crop growth phase and seasonal variations are major factors influencing the dynamics of weeds in lowland rice-based rotations with different crop rotation intensities.

Changes in weed abundance, growth, and composition under rice monoculture and rotation with maize and their interactions with contrasting nutrient management strategies have not been understood. In this study, we hypothesize that differences in the sources and amount of fertilizer inputs due to the differences in nutrient management systems and their interaction with crop type in rotation can differentially affect weed dynamics. The objectives of this study were to determine how crop rotation and nutrient management can influence weed management in rice.

METHODOLOGY

This study was carried out within the farm premises of the Faculty of Agriculture, Rajarata University of Sri Lanka. The site is located at Puliyankulama in the Anuradhapura district of Sri Lanka within the agro-ecological region DL1b at 8°25'18.12" of latitude and 80°24'9.37" of longitude. This area consists of an undulated catenary landscape (Thenabadu, 1988).

Table 1: The sources and the content of different nutrients under SNM and INM.

Nutrient management	Rice				Maize			
	Mineral nutrient (kg/ha)	Synthetic fertilizer rate (DOA 2013) (kg/ha)	Nutrients from organic fertilizer (kg/ha)	Organic fertilizer rate (Mg/ha)	Mineral nutrient (kg/ha)	Synthetic fertilizer rate (DOA 2013) (kg/ha)	Nutrients from organic fertilizer (kg/ha)	Organic fertilizer rate (Mg/ha)
Synthetic Nutrient Management (SNM)	N - 103.5 (Urea 46%)	225 (Urea)	N - 0	0	N - 154.0 (Urea 46%)	325 (Urea)	N - 0	0
	P – 10.5 (P_2O_5 43.7%)	55 (TSP)	P - 0	0	P – 19.1 (P_2O_5 43.7%)	100 (TSP)	P - 0	0
	K - 30.0 (K_2O 60%)	60 (MOP)	K – 0	0	K - 25.0 (K_2O 60%)	50 (MOP)	K – 0	0
Integrated Nutrient Management (INM)	N - 51.8 (Urea 46%)	112.5 (Urea)	N - 25.9	6	N - 77 (Urea 46%)	162.5 (Urea)	N - 38.5	9
	P – 5.25 (P_2O_5 43.7%)	27.5 (TSP)	P - 0.65	6	P – 9.55 (P_2O_5 43.7%)	50 (TSP)	P - 0.97	9
	K - 15 (K_2O 60%)	30 (MOP)	K - 52.5	6	K - 12.5 (K_2O 60%)	25 (MOP)	K - 78.04	9

Table 2: Crop phases during each season under different nutrient management and cropping systems.

		Cycle 1		Cycle 2	
Nutrient management	**Cropping system**	**2018/19 *Maha***	**2019 *Yala***	**2019/20 *Maha***	**2020 *Yala***
Synthetic Nutrients only	Mono Cropping	Rice	Rice	Rice	Rice
	Crop Rotation	Rice	Maize	Rice	Maize
Integrated Nutrient Management	Mono Cropping	Rice	Rice	Rice	Rice
	Crop Rotation	Rice	Maize	Rice	Maize

The study area consists of imperfectly drained Reddish-Brown Earth soils (Soil taxonomic Order - Alfisols, Suborder - Ustalfs, Great Group (hapludalfs) (Mapa *et al.,*2010). The study was conducted in two cycles, cycle 1; 2018/19 *Maha* (September to February) and 2019 *Yala* (March to August), and cycle 2; 2019/20 *Maha,* and 2020 *Yala*. Seasonal rainfall across four seasons were 364.6 mm, 181.6 mm, 962 mm, and 621.7 mm; the mean monthly maximum and minimum temperatures were 35.7 ℃ and 21.6 ℃, respectively (Figure 1).

The experiment consisted of two nutrient management and two cropping intensities. The treatments were established as a split-plot design with three replicates. Two nutrient management practices; (1) Synthetic nutrient management (SNM) and (2) integrated nutrient management (INM) were considered as the main plot factor while the two-cropping systems; (1) monocropping of rice (MC) and (2) crop rotation (CR) with rice and maize were considered as the sub-plot factors. The crop rotation treatments were conducted for two consecutive cycles in the same experimental plots. There were three blocks which included two main plots of $3600m^2$ each and eight sub-plots each at a size of $90m^2$.

In SNM 100% N, phosphorus (P), and potassium (K) were applied using synthetic fertilizers (Urea, Tripple Super Phosphate (TSP), and Muriate of Potash (MOP), respectively, based on the recommendation of the Department of Agriculture (DOA) in 2013. In INM 50% N, P, and K were supplied with synthetic fertilizers and 25% N was supplied with organic fertilizer (compost prepared by incorporating buffalo manure, poultry manure, gliricidia leaves, and sunn hemp plants). The amount of N applied to INM was 25% lower than that of SNM.

These rates were decided considering the losses of N from urea and organic matter while aiming to provide adequate N for crop growth. With this concept, we aimed to enhance the use efficiency of nutrients applied, and explore a sustainable nutrient management plan for rice-based cropping systems. The P and K rates of organic fertilizer were not standardized. The amount of these two elements depended on the number of organic materials used to supply N (Table 1).

Total N of organic fertilizer was analyzed using the Kjeldahl procedure (Bremner and Mulvaney, 1982). Exchangeable K was determined by the ammonium acetate extraction method (Jackson, 1958).

Available P was extracted by 0.5 M sodium bicarbonate solution while the colorimetric method was used to quantify P after Molybdate blue color development in the extraction using UV Visible Spectrophotometer (Model UVD-2960) (Watanabe and Olsen, 1965).

Two crop rotation intensities were established covering both *Maha* and *Yala* seasons (Table 2). In monocropping, rice was cultivated in all four seasons. In rotation, maize was cultivated in both *Yala* seasons in 2019 and 2020. Therefore, during the *Maha* seasons, rice was cultivated in four sub-plots in the main plot of a block. During the *Yala* season, rice was cultivated in two subplots in the main plot of a block while maize was cultivated in the other two subplots in which rice was cultivated during the previous season (Table 2).

For rice, the land preparation was done by impounding water after plowing for two weeks and harrowing followed by fine leveling with the help of a wooden leveler. Pre-germinated seeds of rice variety Bg300 were broadcasted at a rate of 120 kg/ha on the prepared plots. The land was deeply plowed and prepared flatbed with four sub-plots for maize cultivation. The pre-soaked seeds of hybrid Pacific 998 were planted at 45 cm x 30 cm spacing, as two seeds per hill at the rate of 12 kg/ha.

We followed the crop management practices of the Department of Agriculture, Sri Lanka (DOA, 2015). Weed management was carried out in SNM and INM using post-emergence herbicides (Table 3). An adjustable single nozzle knapsack sprayer was used for herbicide application, and the herbicide was carefully administrated ensuring no difference between SNM and INM (Table 3). The irrigation was started one week after the seed sowing and impounded with 5 cm depth of water to keep soil sufficiently moist throughout the rice cultivation period. Flood irrigation method was followed to keep the soil moist for rice. Irrigation was done for two weeks for maize cultivation using flooded irrigation. The drains were opened about 1-2 hours after the flooding of the plot. Deep drains were placed around and in the middle of the plot to minimize flood damage due to heavy rain.

Total weeds of rice and maize plots were counted from four different locations of a single plot selected using the 0.5 m by 0.5 m quadrate at seedling stage of rice and five-leaf stage of maize (20 Days after sowing (DAS)) and grasses, sedges, and broadleaves were counted as types of weeds separately at the heading stage of rice and tasseling stage of maize (60 DAS). Weed dry weight of rice and maize plots were measured at the heading stage of rice and tasseling stage of maize (60 DAS) for grasses, sedges, and broad leaves separately. All weeds per quadrate were carefully uprooted, cleaned, separated, and identified to types. Then, roots were removed and air-dried for two days and then oven-dried until reaching a constant weight at 60 °C temperature.

Data from four seasons were analyzed to identify the impact of different nutrient management, crop phase, cropping season, and growth stages on weed dynamics during the crop period. Data were statistically analyzed using the SAS computer program version 9.0. Seasonal weed data were tested for normality and heteroscedasticity. The data were log-transformed to maintain the homogeneity and normality of residuals. Analysis of variance (ANOVA) was carried out using the repeated measures MIXED model. Fixed variables were nutrient management, crop phases, cropping season, and growth stage. The random factor was the block, while the season was considered the repeated factor. The means were separated using the least significant difference (LSD) method at the 5% probability level.

Table 3: Application of herbicides in SNM and INM during 2018/19 *Maha*, 2019 *Yala*, 2019/20 *Maha,* and 2020 *Yala.*

Season	Crop	Herbicide		Time of Application (Days after sowing)	Rate of application (L/ha)	Dilution (product per 16L of water)
		Generic Name	Trade Name			
2018/19 *Maha*	Rice	Pretilachlor 30% EC	Sofit 30EC	0-4	1.6	64-80mL
		MCPA 60% SL	M60	18-21	1.8	72-89.6mL
2019 *Yala*	Rice	Pretilachlor 30% EC	Sofit 30EC	0-4	1.6	64-80mL
		MCPA 60% SL	M60	18-21	1.8	72-89.6mL
	Maize	Nicosulfuron 40 g/L OD	Topaz Nicosulfuron	10-15	1.25	64mL
2019/20 *Maha*	Rice	Bispyribac sodium 4% + metamipof 10%	Kensolo	10-18 or weed at 2-5 leaf stage	0.1	4-5.12mL
2020 *Yala*	Rice	Pretilachlor 30% EC	Sofit 30EC	0-4	1.6	64-80mL
		MCPA 60% SL	M60	18-21	1.8	72-89.6mL
	Maize	Nicosulfuron 40 g/L OD	Topaz Nicosulfuron	10-15	1.25	64mL

RESULTS AND DISCUSSION

Weather differences

The two major growing seasons have different weather conditions (Figure 1). The major (*Maha*) season received approximately 65% more rainfall than the minor (*Yala*) season. The highest rainfall was received during the 2019/2020 *Maha*, and the lowest was recorded with the 2019 *Yala* season (Figure 1). However, the highest rainfall received in the 2020 *Yala* season second only to the *Maha* season. The monthly mean maximum temperature for all four seasons was 35-36 °C. The monthly mean minimum temperature was recorded as 25 °C in the *Yala* season and around 22 °C in the *Maha* season (Figure 1).

Total weed density

The four-way interaction of nutrient management, crop phase, growth stage, and season did not significantly affect total weed density. However, except three-way interaction of the nutrient management system, crop phase, and growth stages, the other three-way interactions had significant impacts on the total weed density (Table 4). There were no significant changes in crop phase and nutrient management interaction during the first 2018/2019 *Maha* season (Figure 2). This was due to both crops in the *Maha* season being rice (rice-rice monoculture and rice-maize rotation), and it was the starting season, and there was no adequate time to reveal the effect of different nutrient management.

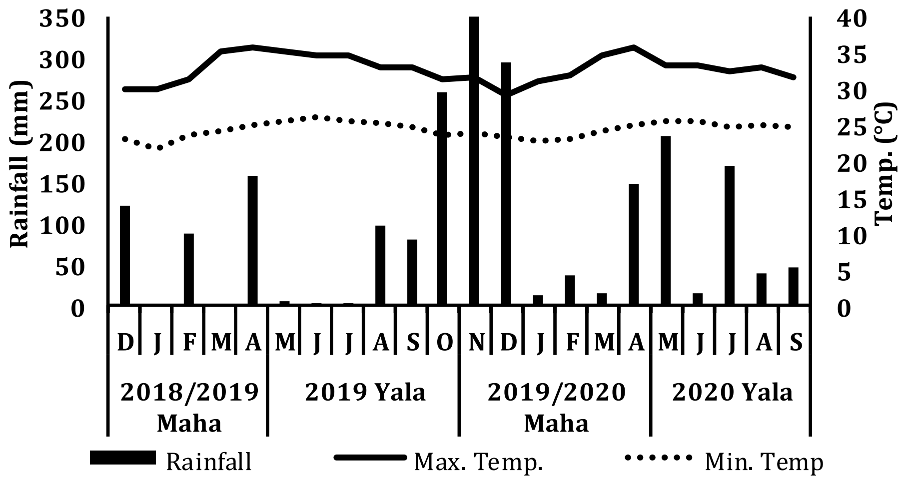

Figure 1: Monthly cumulative rainfall, monthly mean maximum and minimum temperature in the cropping system with different nutrient management experiments in 2018/2019 *Maha*, 2019 *Yala*, 2019/2020 *Maha* season, and 2020 *Yala* seasons.

Table 4: Effects of nutrient management, season, crop phase, growth stage, and their interaction on total weed density and total weed biomass.

Effect	Total weed density	Total weed biomass
Season (SE)	**	**
Nutrient Management (NM)	**	**
Crop phase (CP)	**	**
Growth Stage (S)	**	NA
NM × CP	**	**
NM×SE	**	**
CP×SE	**	**
NM×S	*ns*	NA
CP×S	*ns*	NA
S×SE	**	NA
NM×CP×SE	**	**
NM×CP×S	*ns*	NA
NM×S×SE	**	NA
CP×S×SE	**	NA
NM×CP×SE×S	*ns*	NA

ns-Not significant at $P<0.05$, ** Significant at $P<0.05$, NA-Not applicable

During the *Yala* season in the first cycle (2019 *Yala*), rice was in MC while the maize was in the CR system. The weed density declined in rice in *Yala* compared to the previous *Maha* season (2018/19 *Maha*) in the SNM, but it increased in INM. However, weed density in maize greatly increased compared to the previous *Maha* season with rice crop in the rotation. During *Yala* in the rice crop (MC system), weed density was low in the SNM system compared to INM. However, under maize, INM had low weed density compared to SNM (44%). During the *Maha* season in the second cycle (2019/20 *Maha*), both rice crops (which completed rice-rice and rice-maize rotations) had significantly lower weed density under INM compared to SNM. Interestingly, both these rice crops under INM had lower weed densities compared to the *Maha* season in the first cycle, but higher weed densities under SNM (Figure 2). Increased availability and ability to release N, P, and K from synthetic fertilizer increased weed emergence, weed persistence, weed growth, and weed dispersion (Bajwa *et al.,* 2014) than those observed in INM. This was also due to the low phosphorus content of the INM system due to the non-standardization of the phosphorus and potassium elements. Although phosphorus had a small effect, K did not affect weed communities (Freyman et al., 1989). On the other hand, organic manure may reduce weed infestation by altering soil physical and chemical properties, including water holding capacity, aggregate stability, bulk density, and soil temperature (Singer *et al.,* 2004), reducing weed seed bank in soil (Menalled *et al.,* 2005), and releasing phytotoxic substances in the immediate environment of weed seeds (Ozores-Hampton *et al.,* 1999). Rice crop in 2019/20 *Maha* season under the INM in rice-maize CR showed lower weed density than the MC rice (Figure 2). It was emphasized that the INM system with CR caused less weed infestation than others in *Maha* season. The study of Opeña *et al.* (2014) also revealed long-lasting monoculture pattern led to higher weediness than the crop rotation diversity, and crop rotation caused reduced weed density due to the increase of crop diversification, and it alters the favorable conditions to weed growth in the last season.

As observed in the first cycle, during the second cycle, weed density increased in the *Yala* maize crop compared to having *Maha* rice crop in the rice-maize CR. However, in the MC, rice in the *Yala* season reduced weed density compared to rice crops in the *Maha* season.

The increase in weed density in maize crop during the *Yala* season in both cycles were common under both nutrient management systems indicating the negative effect of having an upland crop in the rotation with rice (Figure 2). It was due to the maize crop, which grew on aerobic condition, grown in more conducive to weed infestation than the rice in lowland conditions.

Generally, maize is classified as an upland crop grown under well-drained soil conditions and rice as a lowland crop grown under semi-aquatic conditions, and it has different influences for weed growth (Jayawardane and Weerasena, 2001). Because of the different establishment methods in different crops, there is more space within maize cultivation than in rice. The weed density in maize cultivation increased due to the influence of high inter-row space, which allows increasing weed density. The agronomy itself was able to control weeds in rice is the main reason for maintaining a uniform weed pattern throughout the cropping period. However, Ghosh *et al.* (2020) also emphasized replacement of synthetic N fertilizers with organic sources may help in weed management in the rice–maize crop rotation.

Although there were no significant differences between nutrient management methods at 20 DAS during the first cycle *Yala* (2019) season, the SNM reported a significantly higher weed density than INM at 60 DAS (Figure 3). Because weeds have access to nutrients through synthetic fertilizers than under the INM system. The enriched seed bank with alternate anaerobic and aerobic conditions (2019 *Yala*) and the accelerated weed emergence with synthetic fertilizer inputs may have led to high weed density in SNM with CR at 20 DAS in 2019/2020 *Maha* (Figure 3). However, due to the maintenance of flooded conditions and application of herbicides, the weeds were minimized (Rao *et al.,* 2007) in 60 DAS in all systems with rice crops of the 2018/2019 *Maha*. During the second cycle *Yala* (2020) season, both nutrient systems reported significantly lower total weed density at 60 DAS than at 20 DAS (Figure 3) due to the impact of herbicide application. The SNM system during the 2020 *Yala* season reported higher weed density at both DAS due to the higher availability of nutrients from synthetic fertilizers (Bajwa *et al.,* 2014).

Concerning season, crop phase, and growth stages interaction, the weed density of the maize in the rice-maize CR system during 2019 *Yala* reported a significantly increasing trend of weed density from 20 DAS to 60 DAS (Figure 4). This was due to the low rainfall in 2019 *Yala* (Table 1) which disrupted the crop growth, and the weed density remained high due to the rapid uptake of nutrients by weeds. On contrary, a significantly decreasing trend was reported from 20 DAS to 60 DAS during 2020 *Yala* (Figure 4). It would be due to the application of herbicides, which suppressed the weed competition (Mehmeti *et al.,* 2012, Triveni *et al.,* 2017 and Kakade *et al.,* 2020). Moreover, with canopy development, the crop could suppress the growth of weeds by restricting radiation availability (Mhlanga *et al.,* 2016). Weed density did not change significantly at 20 DAS during the second cycle (2019/20) *Maha* season rice crop completed rice and maize cultivation during the 2019 *Yala* season (Figure 4). It emphasized that maize crops with the CR or monocropping of rice would not affect the subsequent rice cultivation.

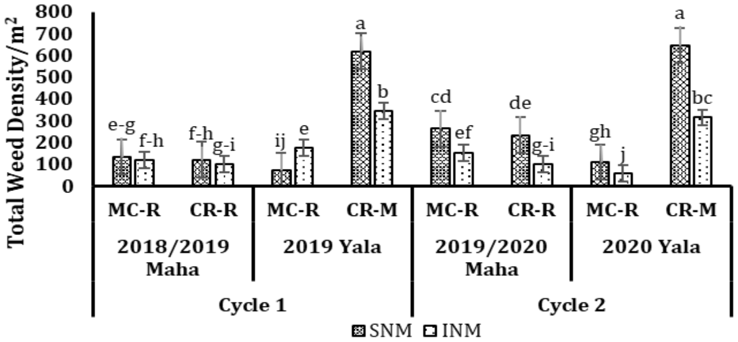

Figure 2: Total weed density as affected by the season, crop phase and nutrient management interaction.

(SNM -Synthetic Nutrient Management; INM -Integrated Nutrient Management; MC-R -Monocropping-Rice; CR-R -Crop Rotation-Rice; CR-M – Crop Rotation-Maize). The same letters in each DAS are not significantly different at P<0.05 (LSD). Bars are standard errors.

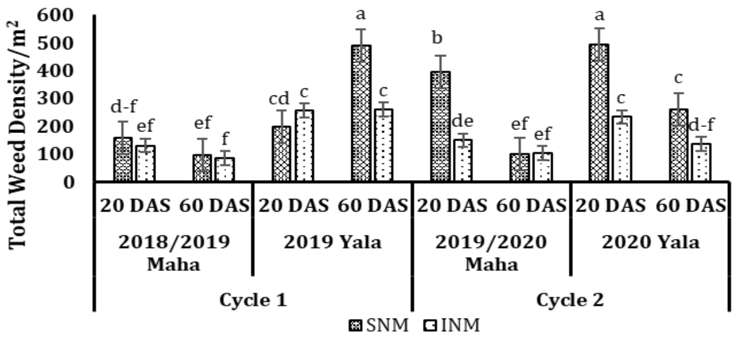

Figure 3: Total weed density as affected by the season, DAS and nutrient management interaction.

(SNM -Synthetic Nutrient Management; INM -Integrated Nutrient Management). The same letters in each DAS are not significantly different at P<0.05 (LSD). Bars are standard errors.

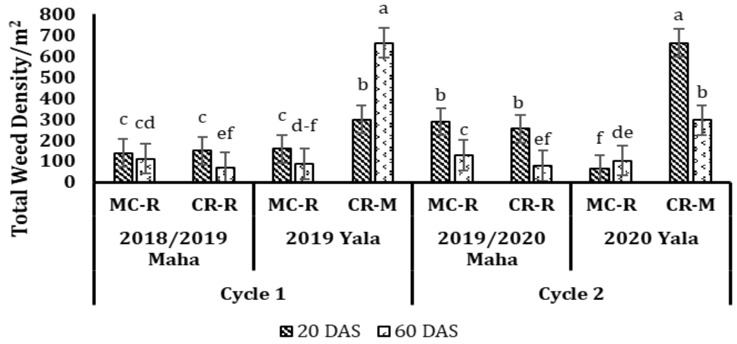

Figure 4: Total weed density as affected by the season, crop phase and DAS interaction.

(MC-R -Monocropping-Rice; CR-R -Crop Rotation-Rice; CR-M – Crop Rotation-Maize). The same letters in each DAS are not significantly different at P<0.05 (LSD). Bars are standard errors.

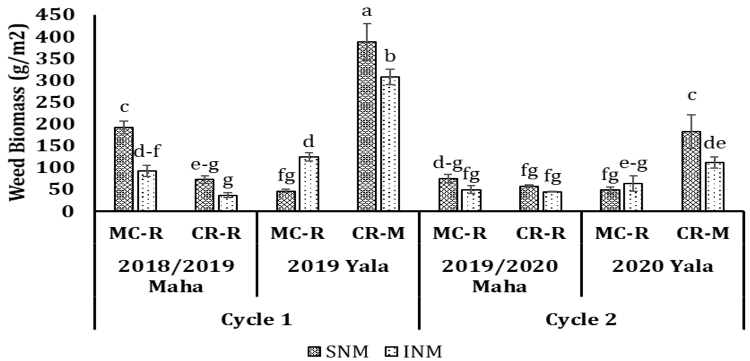

Figure 5: Weed biomass as affected by the season, crop phase with nutrient management at 60 days after sowing.

(SNM -Synthetic Nutrient Management; INM -Integrated Nutrient Management; MC-R -Monocropping-Rice; CR-R -Crop Rotation-Rice; CR-M – Crop Rotation-Maize). The same letters in each DAS are not significantly different at P<0.05 (LSD). Bars are standard errors.

Total weed biomass

Three-way interaction of nutrient management, crop phases, and seasons significantly impacted the total weed biomass variation (Table 4). The first season of the 2018/2019 *Maha* season had higher weed biomass with the synthetic fertilizer application with the impact of instant availability of nutrient elements from the synthetic fertilizers. In contrast, in the 2019 *Yala* season of the first cycle, the monoculture system with the INM system recorded significantly more weed biomass than in the SNM (Figure 5). This phase also had a high weed density. Probably due to the presence of weed seeds in the organic matter applied. Manure and plant materials used to prepare compost can serve as vectors for weed seeds (Liebman and Davis, 2000).

As observed in weed density, weed biomass increased substantially in the maize crop in *the Yala* season under both nutrient management systems, while INM showed comparatively low weed biomass. The phosphorus (Blackshaw et al., 2004) and N (Blackshaw, 2005) content of the INM system were limited, which contributed to the decrease in biomass. No significant changes in weeds were reported between cropping systems and nutrient management during the 2019/20 *Maha* season (second cycle) (Figure 5).

Weed biomass increased significantly with SNM under maize in CR during the 2020 *Yala* season of the second cycle, and MC rice did not change with different nutrient management. 2020 *Yala* in the second cycle showed significantly lower weed biomass than 2019 *Yala* in the first cycle (Figure 5). Overall, the effect of the nutrient management system was more pronounced during the first cycle. During the second cycle, it was mainly identified in the Maize crop in the *Yala* season.

Weed composition

Densities of grasses, sedges, and broadleaves were influenced by the three-way interaction between nutrient management system, crop phase, and season (Table 5). During the 2019 *Yala* of the first cycle, the densities of grasses and sedges in SNM with maize in CR were substantially higher (312 types of grass/m^2, 590 sedges/m^2) than all other treatments combinations (Figure 6 (a), (b)). The increase in grass and sedge densities confirms the efficient nutrient utilization by weeds that were released from synthetic fertilizers. Grasses and sedges contributed 43% and 64% in the SNM under maize in CR, and those were 21% and 68%, respectively in the INM under maize in CR 2019 *Yala*. The abundance of grasses was 12% higher in SNM compared to the INM system, while sedges were more prominent (4%) in the INM system (Figure 6). Grasses are usually the most dominant competitors during the early stages, while sedges dominate in the later stages (Jiang, 1989) also caused high sedges density in the 60 DAS stage (Figure 6). 2019/2020 *Maha* of the second cycle resulted in similar grass density with the cropping system and nutrient management except for SNM with rice in CR. Alteration of wetting and drying conditions influenced grass suppression with the crop rotation system with SNM (Liebman *et al.,* 1993).

In the 2019/20 *Maha* of the second cycle, the CR system with SNM and INM had a lower sedges density than the rice monoculture method. Rice in CR resulted in fewer sedges density than maize in the CR system in the previous *Yala* (2019) season (Figure 6 (b)). The aerobic soil condition under maize-CR in *Yala* was much more favorable for sedges to thrive. During the dry season (*Yala* seasons), the grass in the paddy fields was out of control due to low water availability. The *Yala* season (2020) of the second cycle showed no significant grass density in MC-rice and CR- maize. The SNM with both cropping systems during the 2020 *Yala* season had higher grass density than the 2019/20 *Maha* season. Although rice-MC with SNM during 2020 *Yala* resulted in higher grass density than the 2019 *Yala* season, maize-CR with SNM during 2020 *Yala* resulted in lower grass density than the 2020 *Yala* season. Maize-CR with INM during 2020 *Yala* also resulted in lower grass density compared to the first cycle 2019 *Yala* season (Figure 6a).

Concerning sedges density, maize in CR system with both nutrient management systems during 2020 *Yala* season resulted in lower density than that of the first cycle 2019 *Yala* season. Results of the second cycle interpreted crop rotation with altering wetting and drying conditions were influenced by both grasses and sedges suppression (Figure 6 (b)).

Isachne globose (Batadella) was the most commonly identified high contributed grass type in both rice and maize fields than *Echinochloa glabrescens* (Bajiri), *Ischaemum rugosum* (Gojara), and *Echinochloa colonum* (Godamaruk) throughout the cropping period. *Cyperus rotundus* (Kalanduru) was the most prominent sedge with both crops than *Cyperus iria* (Thunessa), *Fimbristylis dichotoma* (Mahakudametta), and

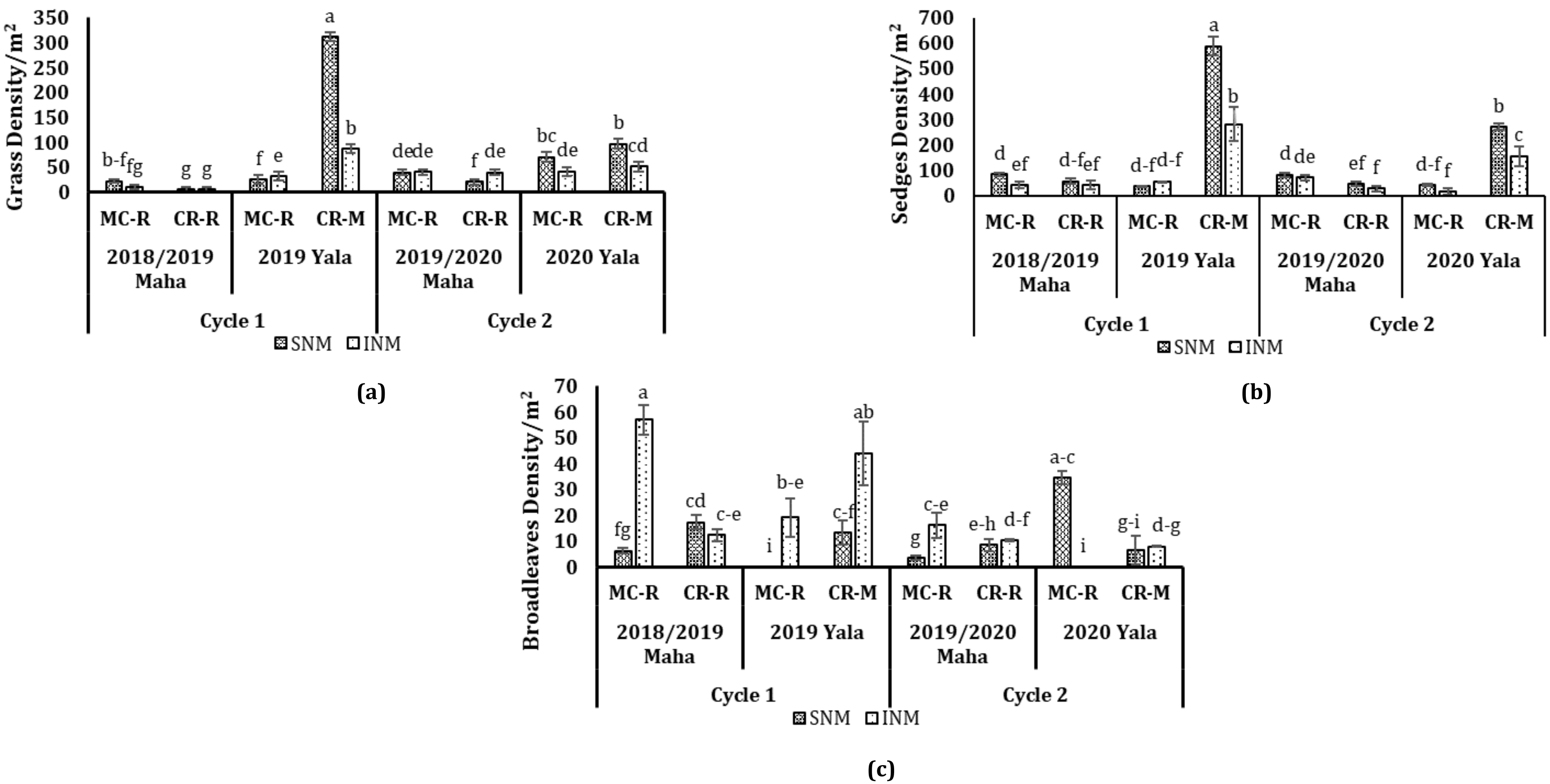

Figure 6: Weed density of (a) grasses, (b) sedges, (c) broad leaves as affected by nutrient management, crop phase and season interaction at 60 DAS.

(SNM -Synthetic Nutrient Management; INM - Integrated Nutrient Management; MC-R -Monocropping-Rice; CR-R -Crop Rotation-Rice; CR-M – Crop Rotation-Maize) The same letters in each weed type are not significantly different at p<0.05 (LSD). Bars are Standard errors.

Fimbristylis miliaceae (Heenkudametta). Even if herbicides were applied, the regenerative part of the underground tuber of *Cyperus rotundus* (Kalanduru) remained and grew back under favorable environmental conditions (Figure 6).

On contrary, broad leaves were low in abundance and were not followed a definite pattern of occurrence. Broadleaves were dominant in rice-MC due to higher water availability and retention of more organic matter in INM (Figure 6 (c)). The most common broadleaves weed was *Marsilea crenata* (Hatharapethiya). Other than that, *Scoparia dulcis* (Walkoththamalli) and *Aeschynomene indica* (Diya siyambala) were also identified with minute density. The diversity and abundance resulted in a comparatively different outcome in different nutrient management than the impact of the total weed density. A cropping system with different crop diversities led to changes in crop management practices and increased diversity of weeds (Doucet *et al.,* 1999).

Biomass of different weed types

The two-way interaction of the crop phase and the season was significant on grass biomass (Table 5). Maize in CR during the first cycle *Yala* (2019) season had higher grass biomass compared to rice in MC. With exception of that, there was no significant difference between rice-MC and maize-CR throughout the cropping period (Figure 7). The lowest rainfall received during the 2019 *Yala* may be the main reason. But grass biomasses were reduced from 2019 *Yala* to 2019/20 *Maha* season irrespective of the effect of cropping systems. Then again, it was increased from the second cycle *Maha* (2019/20) to the *Yala* (2020). Again, the positive impact of rice-maize crop rotation on weed suppression was proved with lower grass biomass during the end of the second cycle than the end of the first cycle (Figure 7).

Two-way interactions of cropping system and season, and nutrient management and season influenced the sedge biomass (Table 5). Sedges in MC were significantly higher initially and then decreased significantly, thus substantially lower in contrast. Biomass of sedges was low in CR in both *Maha* while peaked in both *Yala* (Figure 8).

The changes of the system from inundated *Maha* to aerobic *Yala* favored the abundance of sedges (Figure 9). Hence, the rotation effect on sedges was confirmed, and long-term implementation of such a system may bring rice-based cropping systems weed-free.

High sedge biomass in SNM as evidenced in 2019/2020 *Maha*, may be due to the alternative wetting and drying conditions of the particular season associated with high synthetic fertilizer inputs (Bajwa *et al.,* 2014). However, when continued, sedge biomass was decreased. Sedge biomass in the INM system during the second cycle of the 2019/20 *Maha* season was reduced than the first cycle of 2018/19 *Maha*. Further, the INM system during the 2020 *Yala* season also resulted in a significantly lower value than the 2019 *Yala* season (Figure 9).

The biomass of broadleaves was affected by nutrient management and seasonal interactions (Table 5). Broadleaves biomass reported the highest in the INM in 2019/2020 *Maha* compared to SNM. Despite low numbers of biomasses of broadleaves were in an increasing trend during the study period (Figure 10). However, it was negligible compared to the biomass of grasses and sedges.

Table 5: Effects of nutrient management, season, crop phase, and their interaction on density and biomass of grass, sedge, and broadleaves at 60 DAS.

	Weed Density			Weed Biomass		
Effect	Grasses	Sedges	Broad Leaves	Grasses	Sedges	Broad Leaves
Input System (IS)	*ns*	**	**	*ns*	**	*ns*
Crop phase (CP)	*ns*	**	**	*ns*	**	*ns*
Season (SE)	**	**	**	**	**	**
IS*CP	*ns*	**	*ns*	*ns*	*ns*	*ns*
IS*SE	**	**	**	*ns*	**	**
CP*SE	**	**	**	**	**	*ns*
IS*CP*SE	**	**	**	*ns*	*ns*	*ns*

ns-Not significant at $P<0.05$, ** Significant at $P<0.05$

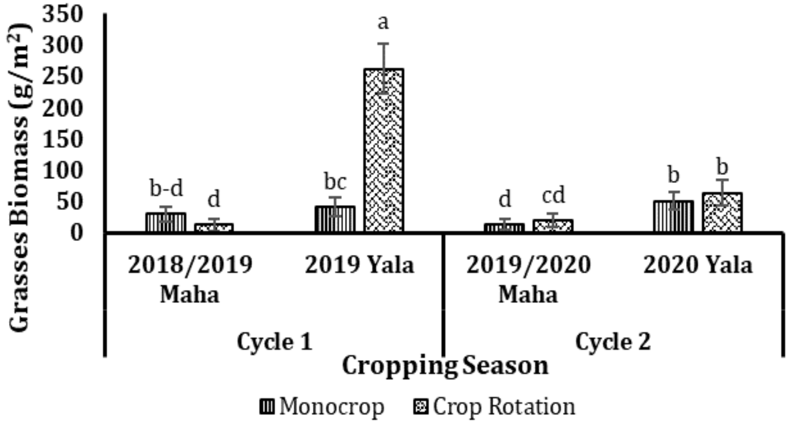

Figure 7: Biomass of grass as affected by the interaction of crop phase and seasons at 60 DAS.

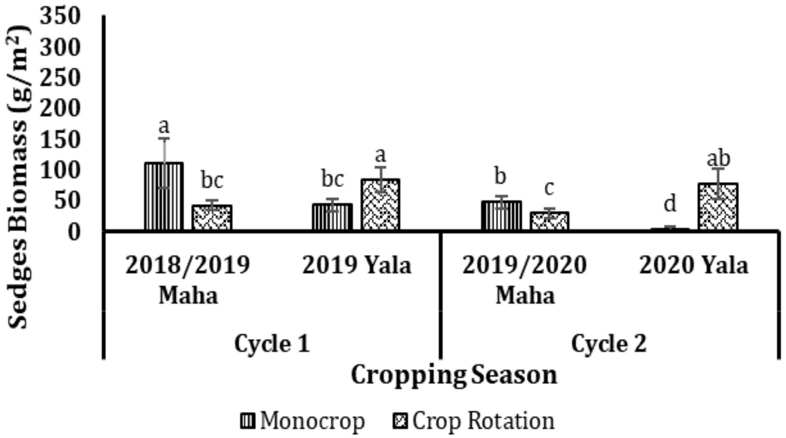

Figure 8: Biomass of sedges as affected by the interaction of crop phase and seasons at 60 DAS.

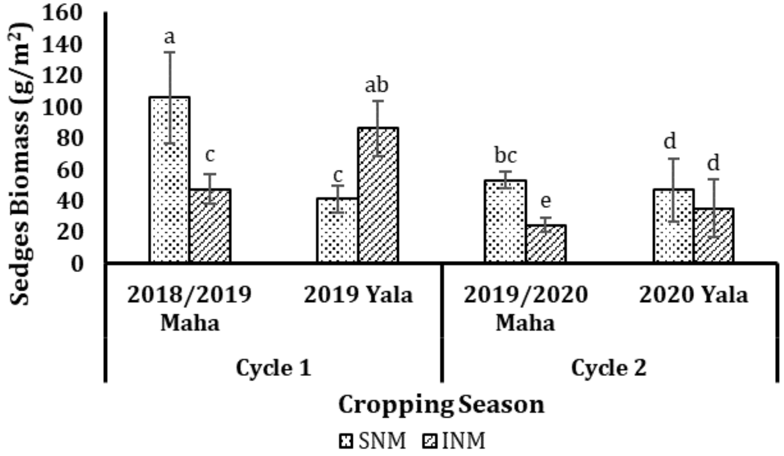

Figure 9: Biomass of sedges as affected by the interaction of nutrient management system and seasons at 60 DAS.

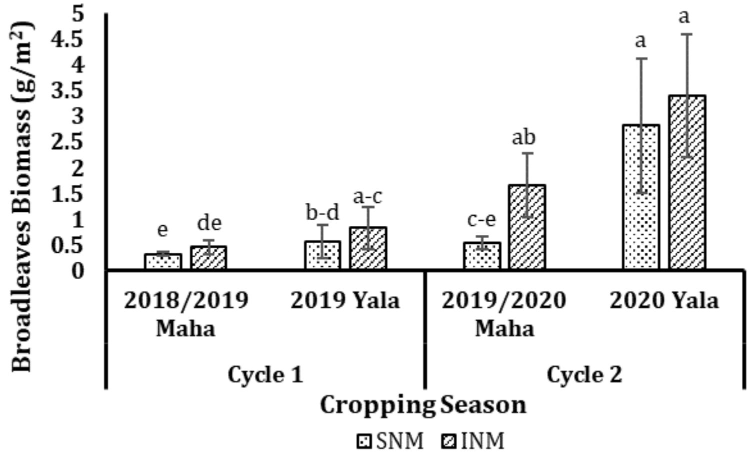

Figure 10: Biomass of broadleaves as affected by the interaction of nutrient management system and seasons at 60 DAS

CONCLUSION

Weed density, biomass, and composition varied with different nutrient sources and crop rotation intensities. Alteration of lowland (rice) and upland (maize) crops contributed to an increase in weed density and biomass under both systems. During the *Yala* season of the second cycle, weed density and biomass decreased drastically, especially with crop rotation systems under both nutrient management systems. Integrated nutrient management systems had low weed density and biomass in most crop phases, and the effect was more prominent during the second cycle. Crop rotation with maize did not affect the weed abundance in subsequent rice cultivation. A high percentage of sedges contributed to the weed density at the CR due to favorable wetting and drying conditions, and a high percentage of grass contributed to the weed density at MC. Although there was a tendency for grass and sedges density to increase from the first cycle to the second cycle due to the rotation of the crop, it was less in the *Yala* season of the second cycle than in the *Yala* season of the first cycle. The INM had less grass and sedges density than SNM. Although nutrient management did not affect grass biomass, sedges biomass remained high during the *Maha* season by applying only synthetic nutrient sources. Because of the low values of the broad leaf's density, biomass was negligible. The effect of increased weeds when maize was grown in the *Yala* season with CR can be controlled by proper weed management in the subsequent rice cultivating seasons. Similarly, weed density and biomass of both cropping systems can be reduced by using INM than using synthetic fertilizers only.

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