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Weed Dynamics as Influenced by Cropping Sequence and Season in Kano River and Hadejia Valley Irrigation Project of Northern Nigeria

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Abstract:
Weeds are the most important biotic constrains to food production in both rainfed and irrigated conditions. Six-season trials were carried out over a two-year period to evaluate the impact of various cropping sequences on weed growth, diversity and composition at the Hadejia Valley Irrigation Project (HVIP) and Kano River Irrigation Project (KRIP) in the Sudan savannah zone of Northern Nigeria. Fifty six weed species of the 71 species found throughout the study were in the maize-based sequence, 54 in the rice-based sequence, and 32 in the cowpea-based sequence. In the wet season, the cowpea-wheat-rice (CWR) rotation sequence recorded the highest biomass (231.4g m^{-2}) whereas the cowpea-onion-rice (COR) rotation sequence recorded the lowest (165g m^{-2}) in cold season. The cowpea-tomato-rice (CTR) rotation sequence recorded 13.4% more weeds density than cowpea-wheat-rice (CWR) and 10.4% higher weeds than cowpea-onion-rice (COR) in rainy season. Maize-wheat-fallow (MWFL) had the most weeds (250.3 m^{-2}) while maize-wheat-cowpea (MWC) had the least (170.5 m^{-2}) in rainy season. In terms of weed biomass, maize-tomato-fallow (MTFL) had the maximum amount (664.8g m^{-2}) during the hot dry season, whereas maize-wheat-cowpea (MWC) had the lowest amount (411.8g m^{-2}). The rice-wheat-maize (RWM) consistently supported more weeds during the rainy (328.87 m^{-2}), cold (291.39 m^{-2}), and hot (271.46 m^{-2}) seasons. In the cold season, rice-wheat-fallow (RTF) rotation sequence showed lower weed biomass (470.1 g m^{-2}), whereas in the hot dry season, rice-wheat-fallow (RWFL) showed the maximum weed biomass (656.3 g m^{-2}). Rotation systems involving legumes, forage, and pasture decreased weed infestation and may be utilized as an alternative method of weed management. The conventional cereal-cereal-cereal rotation sequence encouraged weed infestation and should be discouraged.

Key word: Important value index, weed morphology, weed density, weed biomass

Introduction

Growing a variety of crop species on the same piece of land is known as crop rotation. It is not the same as continuous monoculture, which is the technique of cultivating a single crop species on the same piece of land, or inter-cropping, which is the practice of growing two or more crops simultaneously on the same piece of land. The most common rotations practice, are one-year rotation e.g. maize – mustard, rice – wheat. The use of different crops in rotation sequence can create differences in resource competition and allelopathy leading to the creation of an unconducive environment for growth and development of other plants (Gerasimova and Mitova 2020; Ghaffar et al. 2022).

In the irrigated areas of the Hadejia Valley Irrigation Project (HVIP) and Kano River Irrigation Project (KRIP), a variety of crops are grown under a range of management circumstances, cropping patterns, and production techniques. Crop intensity has increased in irrigated areas as a result of the fast population growth and the ensuing intensification of agriculture brought on by concerns about food security. Inappropriate rotation sequences in agricultural farming systems present a number of difficulties for farmers in KRIP and HVIP. There is also a threat of rapid buildup of pests and diseases associated with the current unorganized rotation system. Weeds and other pests from other crops can spread and affect more crops. To control these widespread pests, farmers apply various pesticides which may seriously affect the ecosystem and rapid buildup of pesticide resistance organisms.

The advent of chemical pesticides and fertilizers, as well as improved cultivars, have all been linked to a decrease in the usage of extended rotation (Butkeviciene et al. 2021). Currently, lengthy rotation is frequently replaced with short-term rotation and extended monoculture. Although these technologies have proven effective, they are regrettably linked to drawbacks such as a rise in weed infestation, among other things. Rotation has had a major impact on weed growth and development. According to Wozniak and Soroka (2018), conventional monoculture had 51.1 times as many weeds and 75% more dry weight than rotation. Monoculture has been shown to worsen a crop stand's phytosanitary condition and increase weed infestation (Wozniak, 2019).

Rotation is the most practical and cost-effective way to reduce weeds and other pests since it breaks the life cycle of weeds (Shahzad et al. 2016). It significantly lessens the need for weed pressure and the likelihood of herbicide resistance, which is a significant worldwide problem in weed control. It offers a more significant shift in the diversity and organization of weed communities (Wozniak and Soroka 2018). The number of weeds in the field increases significantly when monoculture is maintained. Growing crops in succession is one of the most effective ways to control weeds, but little is known about how seasons and rotation sequence affect weed population dynamics under KRIP and HVIP. To provide an alternative solution to these challenges, this study was conceived to determine the effect of rotation sequence and season on weed population and growth under KRIP and HVIP.

Material and Methods

The research was carried out between 2020 and 2021. The trial was carried out in the hot dry season (April–June), cold dry season (December–March), and rainy season (July–November) each year. The sites were situated in the Sudan savannah zone of Northern Nigeria, between latitudes 11°31'N to 11°52'N and longitudes 8°20' E to 8°40'E, at an elevation of 361 meters. They were part of the Kano River Irrigation Project (KRIP) and the Hadejia Valley Irrigation Project. Table 1 provides monthly rainfall, maximum and minimum temperatures obtained from dataset (from the experimental sites) spans the period from January 2020 to December 2021. The area significantly received more rainfall in rainy season with no rainfall recorded in the cold dry season. Higher maximum temperatures were observed in the hot dry season and the lowest temperature in cold dry season.

The trial comprised of 38 rotation treatments as indicated in Table 2. The cropping sequence was selected based on focus group discussions with farmers, community leaders and other stakeholders in the study communities. The selected sequences were categorized into three: cowpea-based (03), maize-based (12) and rice-based (23)

cropping sequences. The traditional rotation pattern carried out by farmers was also considered to serve as a check for the improved systems. The improved rotation patterns were developed based on an extensive literature search. In addition to applying fertilizer optimally for each crop, cultural practices were carried out according to the requirements of each crop in each season. Weeds inside 1 m^2 quadrants were identified (using Akobundu et al. 2016 and the plant biology Department's herbarium unit at Bayero University, Kano), counted, sorted into broadleaf, grasses, and sedges, and then removed

Table 1: Monthly Mean Temperature and Rainfall of the experimental site (averaged over 2020–2021)

Month	T_max (°C)	T_min (°C)	T_mean (°C)	Rainfall (mm)	T Range (°C)
Jan	30.25	12.35	21.30	0.0	17.89
Feb	31.52	13.94	22.73	0.0	17.58
Mar	36.92	19.83	28.38	0.0	17.09
Apr	38.06	22.27	30.17	6.2	15.79
May	37.82	23.68	30.75	49.2	14.15
Jun	34.74	23.41	29.08	87.5	11.33
Jul	29.69	21.64	25.67	290.3	8.05
Aug	28.67	21.24	24.95	314.1	7.43
Sep	29.60	21.21	25.41	187.1	8.39
Oct	31.11	19.40	25.26	11.1	11.71
Nov	29.23	15.37	22.30	0.0	13.86
Dec	27.78	11.94	19.86	0.0	15.83
Annual Mean	**32.12**	**18.86**	**25.49**	**945.6**	**13.26**

Table 2. List of cropping sequence in each season

Cropping Sequence	Treatments	Season of a Year		
		Rainy Season	Cold Dry Season	Hot Dry Season
Rice-based	RWR	Rice	Wheat	Rice
	RTR	Rice	Tomato	Rice
	ROR	Rice	Onion	Rice
	RWC	Rice	Wheat	Cowpea
	RTC	Rice	Tomato	Cowpea
	ROC	Rice	Onion	Cowpea
	RWG	Rice	Wheat	Groundnut
	RTG	Rice	*Tomato*	Groundnut
	ROG	Rice	Onion	Groundnut
	RWS	Rice	Wheat	Soybean
	RTS	Rice	Tomato	Soybean
	ROS	Rice	Onion	Soybean
	RWP	Rice	Wheat	Pasture grass
	RTP	Rice	Tomato	Pasture grass
	ROP	Rice	Onion	Pasture grass
	RWF	Rice	Wheat	Forage Legume
	RTF	Rice	Tomato	Forage Legume
	ROF	Rice	Onion	Forage Legume
	RWFL	Rice	Wheat	Fallow
	RTFL	Rice	Tomato	Fallow
	ROFL	Rice	Onion	Fallow
	RWM	Rice	Wheat	Maize
	RWWM	Rice	Wheat	Watermelon
Maize-based	MWC	Maize	Wheat	Cowpea
	MTC	Maize	Tomato	Cowpea
	MOC	Maize	Onion	Cowpea
	MWG	Maize	Wheat	Groundnut
	MTG	Maize	Tomato	Groundnut
	MOG	Maize	Onion	Groundnut
	MWS	Maize	Wheat	Soybean
	MTS	Maize	Tomato	Soybean
	MOS	Maize	Onion	Soybean
	MWFL	Maize	Wheat	Fallow
	MTFL	Maize	Tomato	Fallow
	MOFL	Maize	Onion	Fallow
Cowpea-based	CWR	Double cowpea	Wheat	Rice
	CTR	Double cowpea	Tomato	Rice
	COR	Double cowpea	Onion	Rice

from ground level prior to each weeding. The weeds were oven-dried at 65 degrees Celsius. Based on the percentage of occurrences, the infestation level of the identified weeds were evaluated as *=1-25%, **=26-50%,

=51-75%, and *=76-100%. Data for weed biomass, weed density and morphological composition of weeds were subjected to analysis of variance using Genstat 17th discovery editions, and significant treatment means were compared using HSD at a 5% level of probability. The Important Value Index (IVI) of a morphological group of weed was computed (Das, 2011) as:

$$\text{IVI} = \text{Relative density (\%)} + \text{Relative frequency} + \text{Relative abundance (\%), where}$$

$$\text{Relative Density (RD)} = \frac{\text{Density of species}}{\text{Total density of all species}} \times 100$$

$$\text{Relative Abundance (RA)} = \frac{\text{Abundance of individual species}}{\text{Total abundance of all species}} \times 100$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency value of species}}{\text{Sum of frequency of all species studied}} \times 100$$

Results

Weed *Species* Composition

Twenty-one grass species, forty broadleaved species, and seven sedges were among the 68 weed species found in the experimental sites (Table 3). Of these, 51 species were found in maize based rotation sequences, 56 in rice based rotation sequences, and 32 in cowpea based rotation sequences. In maize-based systems, 30 species were found during wet seasons, 34 during cold dry seasons, and as many as 39 during hot dry seasons. In systems based on rice, however, 43 species were recorded during the rainy season, 39 during the cold dry season, and 41 during the hot dry season. The rotation sequence based on cowpeas has a total of 14 species in the rainy season, 20 in the cold dry season and 17 in the hot dry season.

In the maize-based rotation sequence, no weed species showed a 100% infestation level during any of the seasons. The only species in this series with highest infestation levels were *C. esculentus, K. erecta,* and *K. squamulatus,* and these only showed up during the wet season. In

Table 3**.** Weed species composition and their level of infestation in rice, maize and cowpea based rotation sequences in Kano-river irrigations

Weed Species	Maize Base rotation sequence			Rice Base rotation sequence			Cowpea Base rotation sequence		
	Rainy	Cold dry	Hot dry	Rainy	Cold dry	Hot dry	Rainy	Cold dry	Hot dry
GRASSES									
Axonopus compressus (Sw.) P.Beauv.	-	-	*	*	-	*	-	-	*
Chloris pilosa Schumach	-	*	*	*	**	*	-	-	*
Cynodon dactylon (Linn.) Pers	**	*	**	***	**	*	*	*	*
Dactyloctenium aegyptium (Linn)P. Beauv.	*	-	-	*	*	*	-	-	-
Digitaria ciliaris (Retz.) Koel.	-	-	*	*	*	**	-	*	*
Digitaria horizontalis Willd	**	*	*	*	**	*	*	*	-
Echinochloa obtusiflora Stapf	-	-	*	*	-	*	-	-	-
Eleusine indica (L) Gaertn	-	*	*	-	-	-	-	-	-

Elytrophorus spicatus (Willd.) A. Camus	*	-	-	-	-	-	-	-	-
Eragrostis ciliaris (Linn.) R. Br.	*	-	-	*	-	-	-	-	-
Imperata cylindricalls (Linn.)Raeuschel var. *Africana* (Anderss) C.E. Hubbard	-	-	*	-	-	-	**	*	**
Leptochloa filiformis (Lam.) P. Beauv	*	-	*	**	-	*	-	*	-
Oryza barthii A. Chev.	**	-	*	***	*	*	*	-	-
Oryza sativa Linn.	-	-	*	-	-	-	-	-	-
Paspalum scrobiculatum Linn. *(=P.poystachyum* R. Br.)	-	-	*	*	-	**	-	-	*
Pennisetum pedicellatum Trin.	-	*	*	-	*	*	-	*	*
Pennisetum polystachion (Linn.) Schult.	-	*	*	*	*	*	-	*	-
Saterea barbata (Lam.) Kunth	*	-	-	*	*	-	*	-	-
Sporobolus pyramidalis P. Beauv	-	*	*	-	-	-	-	-	-
Triticum aestivum Linn.	-	-	-	-	-	*	-	-	-
Zea mays Linn.	-	*	-	-	-	-	-	-	-
BROAD LEAVES									
Acanthospermum hispidum DC.	**	**	**	***	**	**	*	*	*
Ageratum conyzoides Linn.	*	*	*	*	**	*	-	*	-
Amaranthus hybridus Linn.	-	-	-	-	*	-	-	-	-
Amaranthus spinosus Linn.	-	*	*	*	*	**	-	*	-
Amaranthus viridus Linn.	-	-	-	-	*	-	-	*	-
Aspilia bussei O. Hoffm. &Muschl	-	-	*	-	-	-	-	-	-
Bidens pilosa Linn.	-	-	-	*	-	*	-	-	-
Celosia leptostachya Benth	*	*	*	*	*	*	-	-	*
Cyathula prostrate (L.) Blume	*	-	-	-	-	-	-	-	-
Commelina benghalensis L.	-	*	-	*	*	*	*	*	-
Commelina erecta L.	**	*	*	***	*	*	*	*	-
Corchorus olitorius L.	**	*	*	***	*	**	*	*	*
Crotelarea retusa Linn	*	*	*	*	*	-	-	-	*
Chamaecrista mimosoides (L.)Greene	*	-	*	*	-	*	-	-	-
Euphorbia heterophylla Linn.	-	*	*	**	*	**	-	-	-
Euphorbia hirta Linn.	*	-	*	-	-	-	-	-	-
Euphorbia hyssopifolia Linn.	-	-	*	-	-	-	-	-	-
Gomphrena celosioides Mart.	-	*	*	**	*	*	-	-	-
Indigofera spicata Forssk	*	*	-	*	**	-	-	*	-
Ipomea asarifolia (Desr.) Roem. &Schult	-	-	-	*	-	-	-	-	-
Ipomea eriocarpa R. Br.	-	-	-	-	-	*	-	-	-
Ipomea triloba Linn.	-	*	-	-	*	-	-	-	-
Ipomea repens Lam.	*	*	*	**	**	**	*	*	*
Laggera aurita (Linn.f.) Benth. Ex C.B.Cl.	-	-	*	-	-	-	-	-	-
Leucas martinicensis(Jacq.) Ait.f.	*	*	-	**	*	**	-	-	*
Mitracarpus villous (Sw.) DC.	**	-	*	***	*	*	-	-	*
Mimosa pudica Linn.	-	-	*	-	-	*	-	-	-
Nicortonia rustica	*	*	-	**	*	-	-	*	-
Portulaca quadrifica Linn.	-	*	*	-	**	**	-	-	-
Senna obtusifolia (L.) Irwin & Barneby	*	-	-	*	*	-	-	-	-
Senna occenditalis (L.)Link	-	*	-	-	*	*	-	-	-
Solanum lycopersicum L. Carl	-	-	*	-	-	-	-	-	-
Spermacoce verticillata Linn	*	*	*	-	-	-	-	-	-
Sphenoclea zeylanica Gaertn	-	-	-	-	-	*	-	-	*
Striga hermontheca (Del.) Benth	-	-	-	*	-	-	-	-	-
Synedrella nofiflora Gaertn.	-	-	*	*	-	*	-	-	-
Tephrosia linearis(Willd.) Pers.	-	-	-	*	-	-	-	-	-
Trianthema portulacastrum Linn.	*	*	-	*	-	*	-	-	-

Vernonia cinerea (Linn) Less	-	*	-	*	*	-	-	-	-
Vigna unguiculata (L.) Walf	-	-	-	-	-	-	-	*	-
SEDGES									
Cyperus difformis Linn.	**	*	-	****	****	***	-	-	-
Cyperus esculentus Linn.	***	*	**	**	***	****	*	*	*
Cyperus rotundus Linn.	*	*	*	*	****	***	-	-	-
Cyperus iria Linn.	-	-	-	-	-	*	-	-	-
Fuirena ciliaris (Linn.) Roxb	-	-	-	*	-	*	*	-	-
Kyllinga pumila Michx.	***	**	**	*	**	***	**	**	-
Kyllinga squamulata Thorn.ex Vahl	***	*	**	***	**	**	**	-	*

-= 0%; *=25%; **= 50%; ***=75%, ****=100

rice-based systems, infestation levels of *C. difformis* (during the wet and cold dry seasons) and *C. esculentus* (during the hot dry season) reached 100%. Species like as *C. dactylon* (during the rainy season), *O. sativa* (during the cold dry season), *O. birthii* (during the rainy season), *C. oliterus* (during the rainy season), *M. vilosus* (during the rainy season), *C. diformis* (during the hot season), *C. rotundus* (during the hot dry season), *K. squamulatus* (during the rainy season), and *K. erecta* (during the hot dry season) recorded 75% infestation level. None of these species recorded above 50% infestation level in cowpea-based rotation sequence in both seasons.

Effect of Rotation Sequence and Season on Weed Biomass and Density

Table 4 displays the likelihood that weed density and biomass will be affected by the rotation sequence (rice, cowpea, and maize-based rotation sequence) and season (rainy, cold, and shot dry seasons). Weed density and biomass were significantly affected by rotation sequence, season, and their interactions.

Weed biomass

Season and crop sequence had an impact on the weed biomass. In cowpea based rotation sequence, cowpea followed by wheat followed by rice (CWR) recorded the highest weed biomass which was 9.83% higher than cowpea followed by tomato followed by rice sequence (CTR), and 18.03% higher than cowpea followed by onion followed by rice (COR) rotation sequence (Figure 1).

Among the rotation sequences seen in the maize-based system, maize followed by tomato followed by fallow (MTFL) has the highest biomass (Figure 1). Maize followed by wheat followed by cowpea (MWC), on the other hand, had the lowest biomass, which was statistically comparable to that of maize-onion-soybean (MOS), maize-onion-groundnut (MOG), maize-onion-cowpea (MOC), maize-tomato-soybean (MTS), maize-tomato-groundnut (MTG), and maize-tomato-cowpea (MTC).

When compared to other rotation sequences, rice-onion-fallow (ROFL) recorded the highest weed biomass in the rice-based system, while rice-onion-cowpea (ROC) recorded the lowest (Figure 1). Additionally, the data showed that the biomass of weeds in the two rotation sequences were not statistically the same. The results also revealed none of the two rotation sequences had statistically similar weed biomass.

In rotation sequences based on rice and cowpeas, the wet season yielded the most weed biomass. Nonetheless, in the maize-based rotation cycle, greater biomass was noted throughout the hot season (Figure 2).

The rainy season in the cowpea-based rotation sequence had 37.83% and 31.75% more biomass than the hot and cold dry seasons, respectively. The rainy season had

Table 4**.** Summary of mixed effect model analyses testing the effects of crop sequence (S), cropping season (C), and C × S interactions on weed density (plants m^{-2}) and weed biomass (g m^{-2}).

Cropping System	Weed density (plants m^{-2})			Weed biomass (g m^{-2})		
	Sequence	Season	S x C	Sequence	Season	S x C
Rice	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Cowpea	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Maize	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Weed Biomass

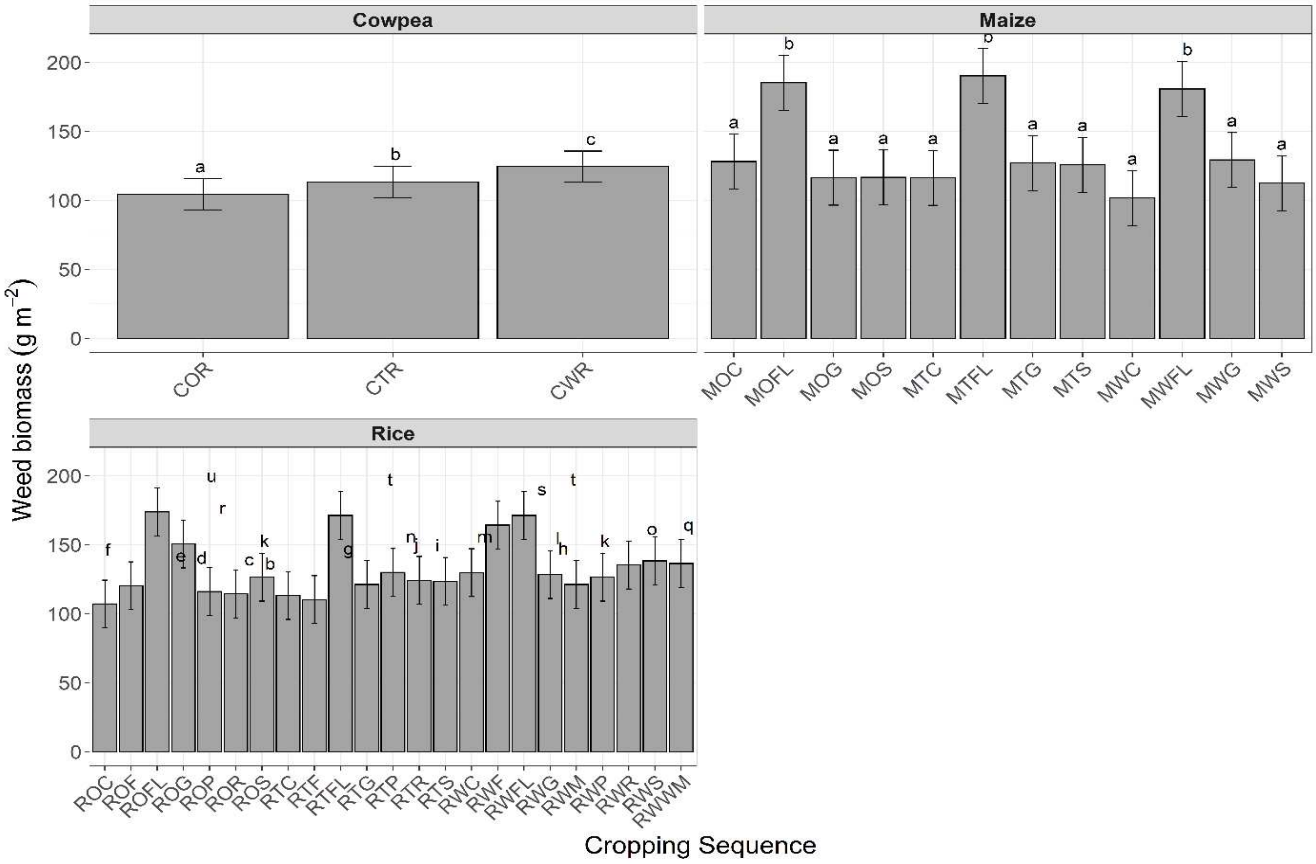


Figure1. Weed biomass of cowpea, maize and rice as influence by cropping sequence. Error bars show the standard error (±) of the mean for the group. Within each panel, different letters show significant differences between means as determined by Tukey's HSD test at the 5% significance level ($p < 0.05$).

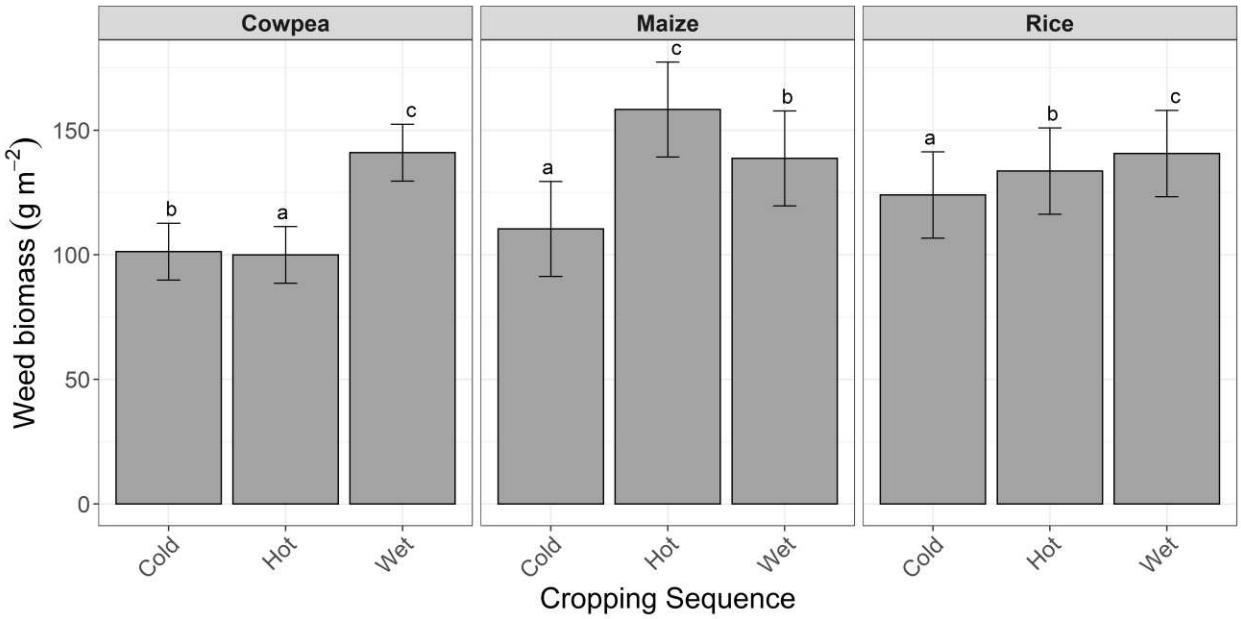


Figure 2. Weed biobass g/m^2 of cowpea, maize and rice as influence by cropping season. Error ba rs show the standard error (±) of the mean for the group. Within each panel, different letters show significant differences between means as determined by Tukey's HSD test at the 5% significance level ($p < 0.05$).

3.4% and 17.24% more biomass than the hot and cold seasons, respectively in rice based rotation sequence. In the maize-based rotation sequence, the hot season recorded 33.9 and 6.4% more weed biomass than the cold and wet seasons, respectively.

In rotation sequences based on rice, maize, and cowpeas, the relationship between season and rotation sequence on weed biomass was significant. The COR rotation sequence in the cowpea-based rotation sequence recorded the lowest biomass in cold and hot dry season which differs from all other rotation sequences (Table 5). Significantly higher weed biomass was observed from CTR, COR and CWR in rainy season compared to other seasons.

During the cold season, weed biomass ranged from 411.8 to 471.1 g m^{-2}, with relatively small differences observed among rotation sequences (Fig 3). Biomass levels were generally moderate and showed no pronounced peaks across treatments. A similar trend was observed during the rainy season, where weed biomass ranged from 465.1 to 503.1 g m^{-2}. Although values were slightly higher compared to the cold season, variation among rotation sequences remained

Table 5. Interaction between rotation sequence and season on weed biomass in cowpea based rotation sequence.

Sequence	Season	Mean
COR	Cold	165.43a
CTR	Cold	199.6bc
CWR	Cold	200.0bc
COR	Hot	179.0ab
CTR	Hot	179.1b
CWR	Hot	203.0bc
CTR	Rainy	222.5c
COR	Rainy	230.3c
CWR	Rainy	231.4c
SE	11.38	

Means followed d by the same letter are not significantly different at 5% level of probability using HSD Turkey's

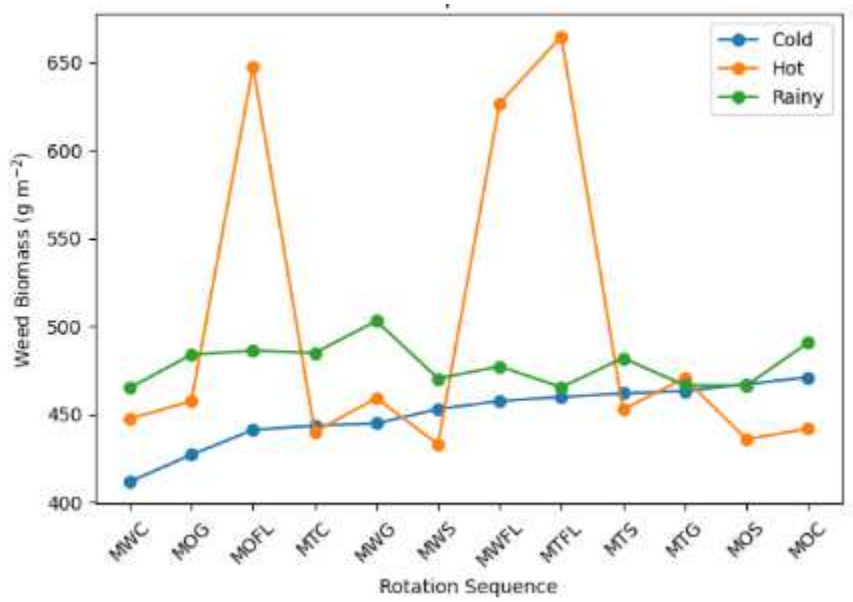


Figure 3. Interaction between rotation sequence and season on weed biomass in maize based rotation Sequence.

comparatively narrow. In contrast, substantial divergence among rotation sequences occurred during the hot season. While several sequences maintained moderate biomass levels (approximately 433–470 g m^{-2}), three sequences viz: MWFL, MOFL, and MTFL recorded markedly higher weed biomass, exceeding 600 g m^{-2}. The highest biomass was observed under MTFL (664.8 g m^{-2}), followed by MOFL (647.6 g m^{-2}) and MWFL (626.8 g m^{-2})

The effect of rotation sequence on weed biomass varied across seasons, indicating a strong Sequence × Season interaction in rice based systems (fig 4). During the cold season, weed biomass ranged from 470.1 to 600.2 g

m^{-2} across rotation sequences. Most sequences exhibited moderate biomass (470–500 g m^{-2}), while the RWF sequence recorded the highest biomass (600.2 g m^{-2}). In the rainy season, biomass values were more evenly distributed, ranging from 472.9 to 572.5 g m^{-2}. Although slightly higher than cold-season values, differences among sequences were less pronounced. In the rainy season, biomass values were more evenly distributed, ranging from 472.9 to 572.5 g m^{-2}. Although slightly higher than cold-season values, differences among sequences were less pronounced. In contrast, the hot season revealed substantial divergence among rotation sequences. Several sequences such as RTFL, ROFL, and RWFL recorded markedly elevated weed biomass, exceeding 600 g m^{-2}, whereas most other sequences remained within the moderate range of 473–500 g m^{-2} The RWS and ROG in the rainy season significantly recorded higher biomass than RWFL, ROC, RTW, RTF, RTC, ROR and ROFL in the season.

Weed density

In both cowpea, maize, and rice-based rotation sequences, the number of weeds per square meter varied with season and rotation sequence. In cowpea-based systems, cowpea-tomato-rice (CTR) had the most weeds, 13.4% more than CWR and 10.4% more than COR (Figure 5). In maize based rotation sequences, MOC had the fewest weeds per square meter, while maize-tomato-groundnut (MTG) had the highest. Numbers of weed m^{-2} were statistically

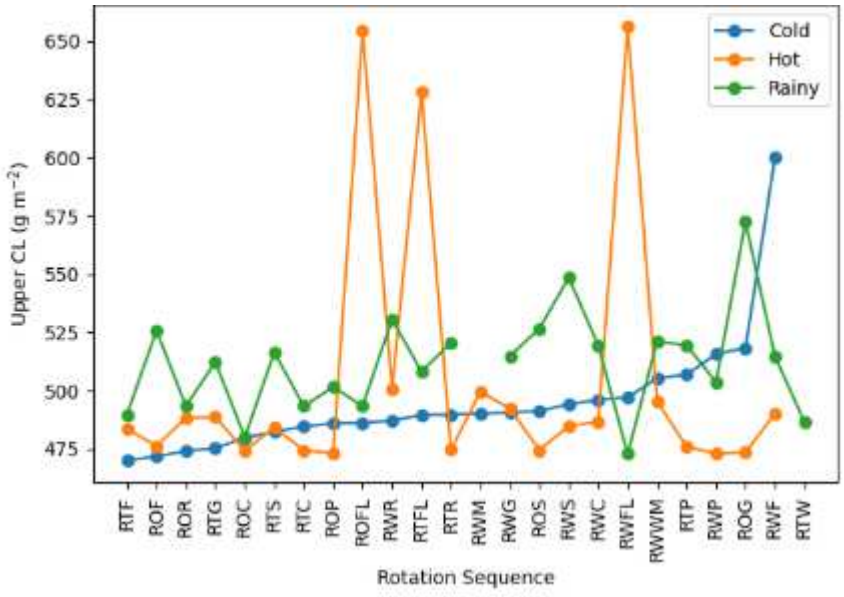


Figure 4: Interaction between rotation sequence and season on weed biomass in rice- based rotation sequence

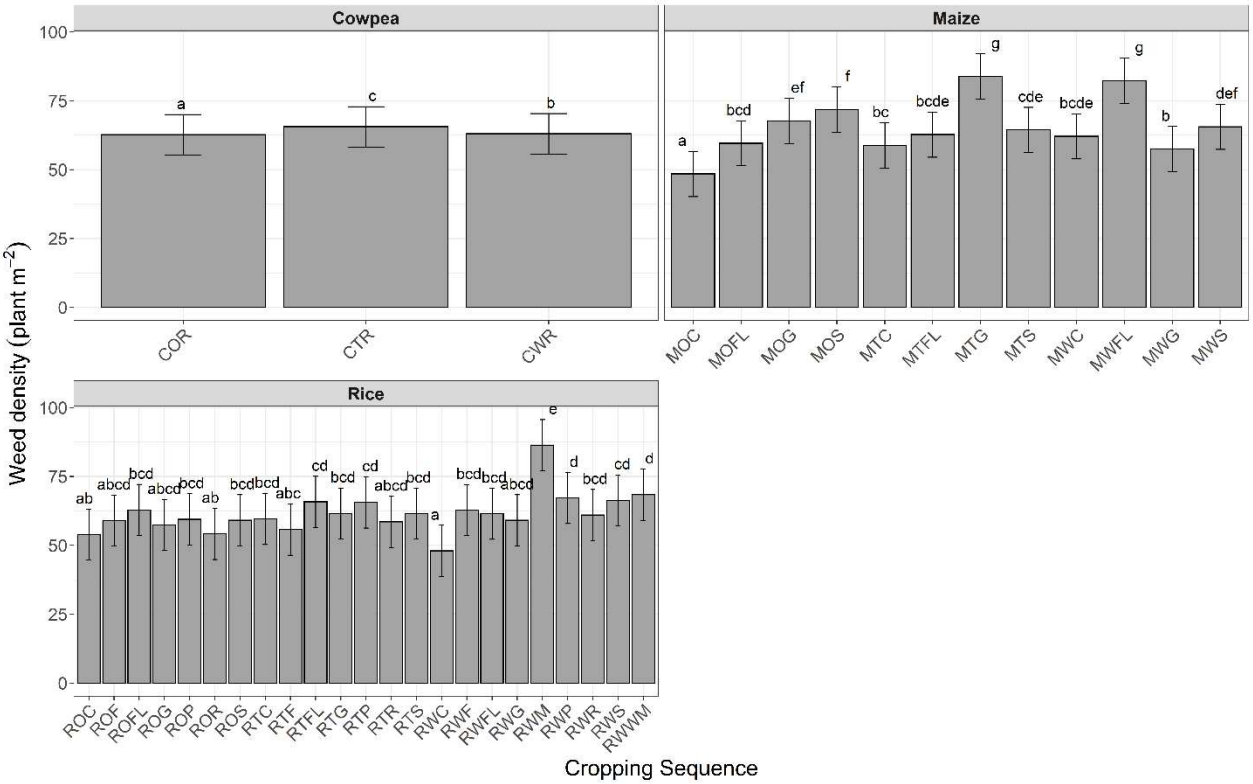


Figure 5. Weed density (plants m^{-2}) of cowpea, maize and rice as influence by cropping sequence. Error bars show the standard error (±) of the mean for the group. Within each panel, different letters show significant differences between means as determined by Tukey's HSD test at the 5% significance level ($p < 0.05$).

comparable for the MOFL, MTC, MTFL, MTS, and MWC. In rice-based systems, rice-wheat-maize (RWM) supported the highest number of weed m^{-2} in comparison to other sequences. The Rice-wheat-cowpea (RWC) rotation sequence registered the lowest number of weeds which was statistically similar to rice-wheat-groundnut (RWG), rice-tomato-rice (RTR), rice-tomato-forage (RTF), rice-onion-rice (ROR), rice-onion-groundnut (ROG), rice-onion-forage (ROF) and rice-onion-cowpea (ROC).

The seasons have a significant effect on the number of weed m^{-2} in cowpea, maize and rice-based rotation sequences (Figure 6). In all the three seasons, the wet season had more weed species than the other two seasons. Rainy season had 60.2% more weeds than the hot dry season and 55.6% more than the cold dry season in cowpea based rotation sequence. However, in maize based sequence, the season (wet) had 46.6% more weeds than the hot dry seasons and 37.78% more than the cold dry seasons. In the rice-based sequence, the rainy season had 68% more weeds than the hot dry season and 55% more than the cold dry season.

The interaction between rotation sequences and season on weed density in cowpea-based rotation systems is displayed in Table 6. The three rotation sequences recorded statistically similar weed density in hot dry season. Similar trend was observed in rainy season. However, CWR significantly recorded higher number weeds in cold

season than COR and CTR that recorded the least in the season. The CTR recorded the highest weed density in rainy season compared to all other treatment combinations while the same sequence did, however, report fewer weeds in colder climates.

A significant interaction between the rotation sequence and the season was observed on weed density m^{-2} in the maize-based rotation sequence (fig 7). The effect of rotation sequence on weed number varied across seasons, demonstrating a pronounced Sequence × Season interaction. During the cold season, weed density ranged from 170.5 to 206.1 weeds m^{-2} across rotation sequences. Most sequences exhibited moderate densities (~170–190 weeds m^{-2}), with a gradual

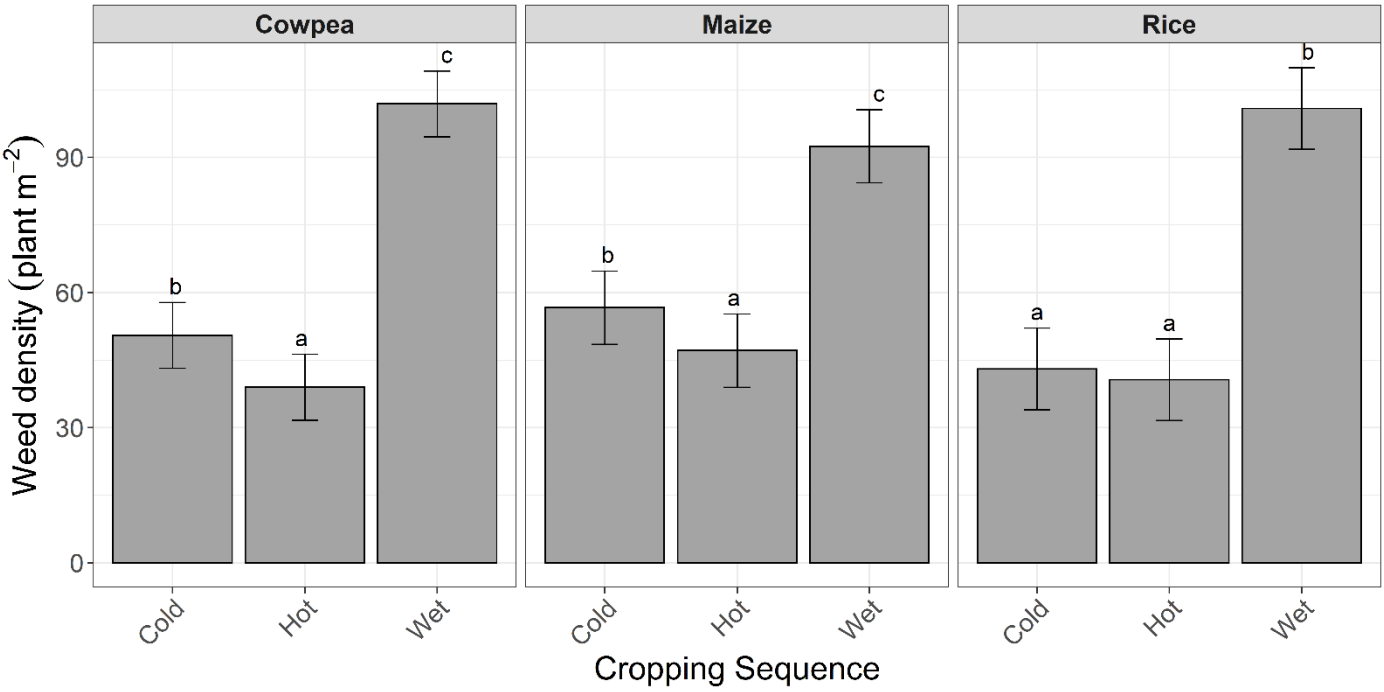


Fig.6. Weed density (plants m^{-2}) of cowpea, maize and rice as influence by cropping season. Error bars show the standard error (±) of the mean for the group. Within each panel, different letters show significant differences between means as determined by Tukey's HSD test at the 5% significance level ($p < 0.05$).

Table 6: Interaction between rotation sequence and season on number of weed m^{-2} in cowpea based rotation sequence

Sequence	Season	Mean
CTR	Cold	100.4ab
COR	Cold	103.5ab
CWR	Cold	115.2ab
CWR	Hot	93.4a
CTR	Hot	94.6a
COR	Hot	96.6a
CWR	Rainy	148.1c
COR	Rainy	155.7c
CTR	Rainy	169.4c
SE±	7.30	

Means followed d by the same are not significantly different at 5% level of probability using HSD Turkey's

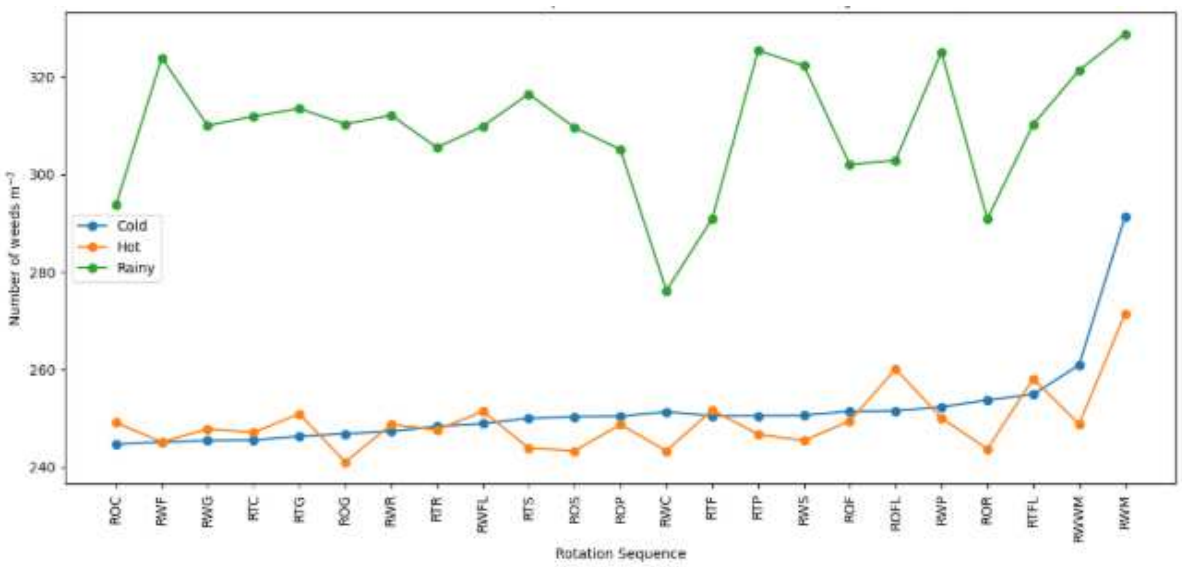


Figure 7 . Interaction between rotation sequence and season on number of weed m^{-2} in rice based rotation sequence

increase observed in MWFL, MWS, MTG, and MOS. In the hot season, weed densities were generally lower than in the cold season for most sequences (161–200 weeds m^{-2}) except MWFL and MTG, which exhibited moderately elevated densities (~195–200 weeds m^{-2}). The rainy season showed the highest weed densities and the largest variation among sequences, ranging from 190.7 to 250.3 weeds m^{-2}. MWFL exhibited the highest weed density (250 weeds m^{-2}), while MTC, MTG, and MOG also showed elevated densities (232–237 weeds m^{-2}). The MWC supported more weeds during rainy than hot and dry seasons. Similar trends were observed in MWFL, MTG and

MTC. In all rotation sequences, weeds were generally more prevalent during the wet season than during the hot and dry ones.

The effect of rotation sequence on weed density varied across seasons, demonstrating a strong Sequence × Season interaction in rice based systems (figure 8). During the cold season, weed densities were relatively uniform across sequences, ranging from 244.7 to 291.3 weeds m^{-2}. Most sequences exhibited moderate densities (245–255 weeds m^{-2}), with the RWM sequence showing the highest density (291.3 weeds m^{-2}). In the hot season, weed densities were generally lower and less variable for most sequences (241–258 weeds m^{-2}), with exceptions of RTFL, ROFL and RWM, which exhibited slightly elevated densities (258–271 weeds m^{-2}). The rainy season showed the highest densities and the largest variation among sequences, ranging from 276.2 to 328.8 weeds m^{-2}. MWFL, RWM, and RWP sequences recorded the highest densities (>320 weeds m^{-2}), while several other sequences remained in the 305–310 range. In general, ROC (in cold season), ROG (in hot dry season) and ROC (in rainy season) recorded the lowest weed density compared to other rotation sequences. More weeds were supported by rice-wheat-soybean (RWS) rotation sequence in rainy than hot and cold seasons. Similar trends were observed on RTF, RWP, RWF, RWM, RWWM, RTS and RTG.

IVI (Important Value Index)

In the cowpea-based system, all of the rotation sequences had higher IVI during the hot dry season compared to the cold and rainy season (figure 9). COR rotation sequence had the highest IVI during the hot, dry season, compare to other seasons. The sequence also supported higher broadleaf species in all seasons with sedges and grasses recorded lower IVI in rainy season. The sedge species were totally absent during the cold dry season in the COR rotation sequence while broadleaf plants consistently exhibited greater IVI in both seasons in the sequence. During both seasons, it was found that grasses had higher IVI in the CTR and CWR sequences, while these species' IVI was lower in the COR sequence in both season. Sedges had higher IVI in CWR rotation sequence during the rainy season compared to COR sequence during the wet and hot dry seasons but completely absent during the cold season.

The effect of rotation sequence and season on important value index of weed species in maize-based systems is presented on figure 10. In comparison to the cold and hot dry seasons, the rotation sequences exhibited higher IVI of both weed groups during the rainy season. In cold seasons, the MOC and MWC sequences had the lowest IVI while the MTG and MTS rotation sequences had the highest IVI during rainy season. In the MTFL sequences during hot dry

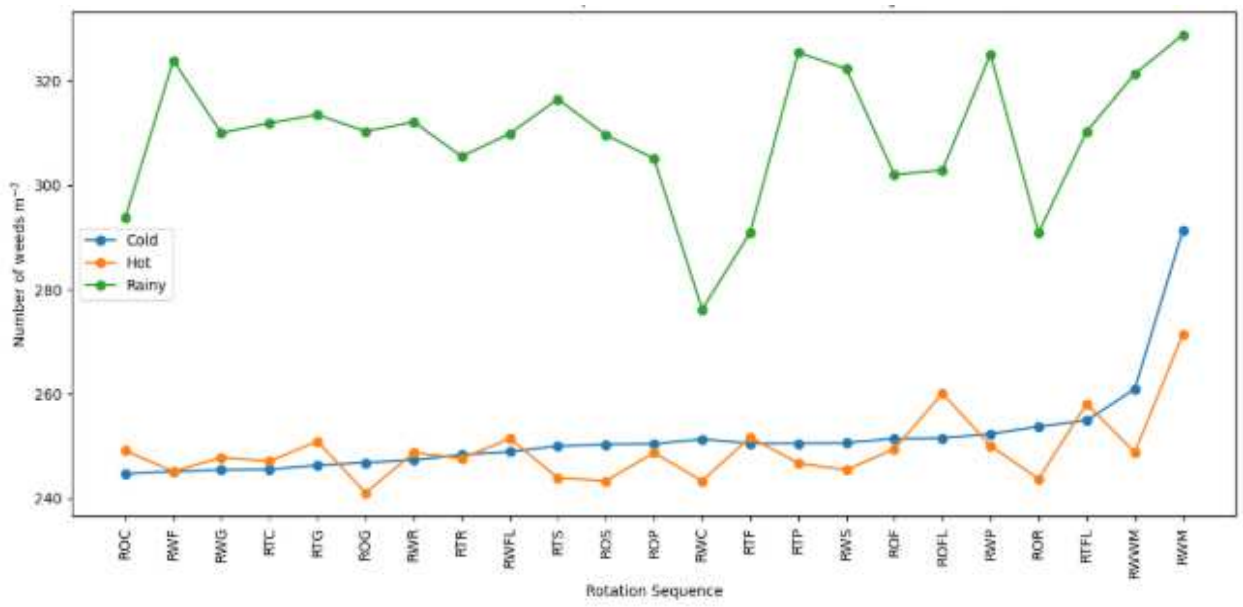


Figure 8 . Interaction between rotation sequence and season on number of weed m^{-2} in rice based rotation sequence

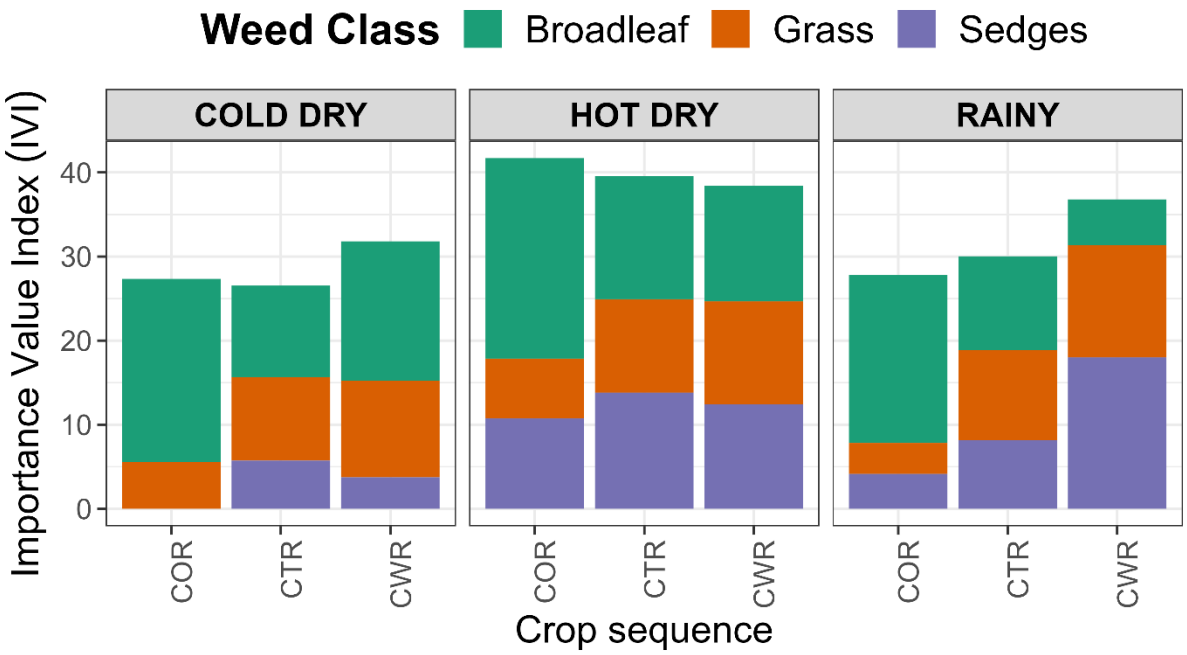


Figure 9. Effect of rotation sequence and season on weed important value index (IVI) in cowpea based rotation sequence

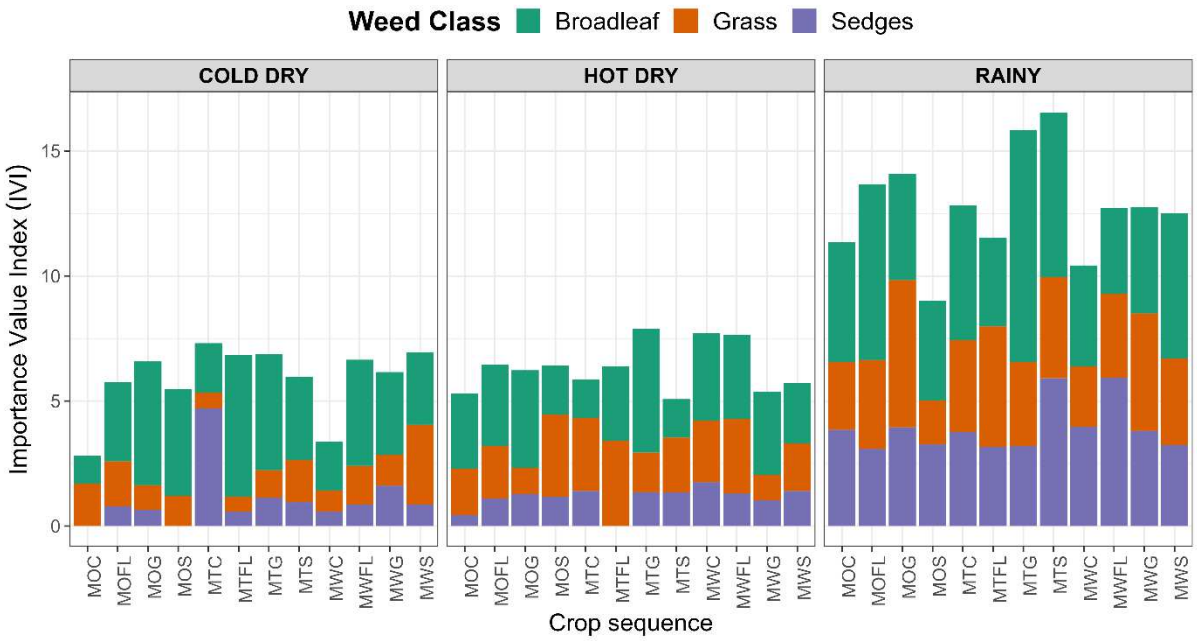


Figure 10. Effect of rotation sequence and season on weed important value index in maize base rotation sequence

seasons and in the MOC and MOS rotation sequences during cold dry seasons, the IVI of sedge species was 0%. In contrast to other morphological groupings of weeds during the cold season, the species' IVI was higher in the MTC sequence. During the wet season, sedges had the highest IVI among the rotation series, with the exception of the MTG and MWS rotation sequences, where grasses outperformed the two morphological groups of weed. Sedge species had the lowest IVI in all the rotation sequence during the hot dry season except in MMG where grass had the lower IVI than sedges.

Figure 11 presents the effect of season and rotation sequence on IVI of grasses, broadleaf and sedges in rice-based rotation sequence. Sedges typically exhibited greater IVI during colder seasons as opposed to hot, dry ones. In every season, the RWM rotation sequence had a higher IVI than any other rotation sequence. Additionally, during the rainy season, the sequence had a higher number of grass and broadleaf species than any other sequence during both seasons. During the hot dry season, sedge species were not supported by the RWG rotation sequence. In the rainy season, ROFL sequences showed fewer broadleaf species, but in the cold season, ROS supported less grass species.

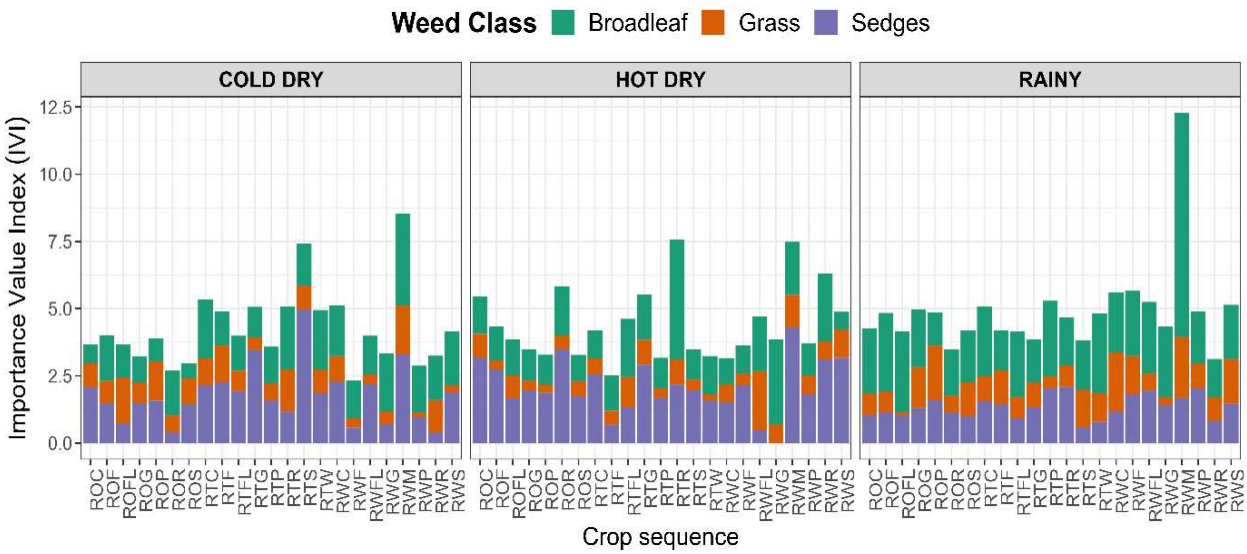


Figure 11. Effect of rotation sequence and season on weed important value index in rice based systems

Discussion

Effect of rotation Sequence on weed dynamics

In comparison to maize and cowpea-based rotation sequences, all categories of weed species were more prevalent in rice-based rotation sequences. This might be explained by the fact that rice is inherently weak for competing with weeds and was cultivated in environments that were more conducive to weed growth than other crops. Additionally, a lot of weed species resemble rice, which makes it easy for them to evade control and survive in rice fields. Das (2011) also noted that several grasses were able to evade numerous weed control tactics since they looked like cereals. Cardina et al. (2002) found that crop type and the timing of weed management measures increased the variety of weed type. Comparing cowpea-based systems to those based on maize and rice, the degree of weed infestation was often lower, suggesting that the new, enhanced rotation systems that incorporate legumes aid in weed control. This implied that improved crop rotation systems (with legumes) were effective approach to weed management, as reported by Shahzad et al. (2021). Cowpea grows faster and provides ground cover to suppress weed growth.

The findings demonstrated that although certain weed species were site-, crop-, and season-specific, others flourished in a variety of environmental settings. It is well established that tillage techniques, cropping schemes, weed management, and other habitat modifications can cause weed movement and density in continuously farmed land (Demjanova et al. 2009). It has been believed that crop rotation increases species diversity and decreases weed density (Wozniack 2019). The lowest weed density observed on the COR sequence (in the cowpea-based rotation system) could be attributed to complete ground cover by cowpea in the rainy season and frequent hoe weeding of the onion during cold dry season. The lowest weed densities found in ROS and ROG in rice and MOS, MOG, and MOC in maize-based systems suggested that they could be employed to limit the establishment and development of weeds.

This corroborated with the finding of Wozniak (2015) who reported that the number and air dry weight of weeds were higher in cereal monoculture than crop rotation. In cereals, crop rotation with crop like soybean can also be used to get rid of troublesome weeds like *Striga hermonthica*. This is due to the fact that involving soybean in the rotation has been shown to promote the *Striga* parasite's suicidal germination (Lado et al. 2018). This suggested that adding soybean to a rice-based rotation sequence could be a useful strategy for getting rid of *Striga asiatiaca*, a parasitic weed of rice that was prevalent in the study area.

Due to their impact on weed density, the results showed that the cowpea-wheat-rice (CWR) sequence supported the largest weed biomass in cowpea-based crops as opposed to cowpea-onion-tomato (COT). The lower weed density observed on MTF compared to higher value observed on MTFL implied that including forage crop in rotation suppressed weed growth better than allowing the field to for fallow. This could be ascribed to the fact that forage crops are aggressive in suppressing weed due to the quick canopy and their allelopathic effect as reported by Mohler, (2009). The lowest weed biomass observed on MWC and RTF implies that inclusion of legumes and forage crops in rotation sequence reduces the level of weed infestation due to their ability to provide quick and complete canopy cover. This corroborated with the findings of Shahzad et al. (2021) that fallow-wheat crop rotation encourages weed growth and biomass. Improved rotation systems with legumes, forage, and pasture reduce weeds infestation because legumes, forage, and pasture cover the entire ground in the corresponding season. This was demonstrated by the lower weed biomass observed on MWC, MWS (in maize-based system) and ROC, ROF, ROP, and RTF in rice based-system. In addition to enhancing the soil's fertility, adding legumes, pasture, and forage crops in rotation sequence, could help in supplying animal feed during shortages. Additionally, this will lessen the recurring disputes between farmers and cattle rearers that arise often in the study area due to the scarcity of animal feed. The higher weed density observed on RMW implied that this rotation sequence involving crop in the same family encourages weed growth and should be avoided. This corroborated with findings of Shahzad et al. (2021) who reported that rice- wheat rotation sequence had higher weed density compared other rotation sequences.

Effect of Season

The ideal weather conditions for weed growth and development during the rainy season, as opposed to hot and cold dry seasons, may be the reason for the higher weed density observed in the rainy season across cropping sequence and rotation systems. According to Olabode et al. (2010), the rainy season created an environment that was conducive to weed seeds breaking dormancy and germination. Due to the early start of the 2021 rainy season, which began prior to the crop harvest, a considerable number of weeds were also aided by the hot dry season. However, according to Das (2011), the cold dry season had the lowest weed density because of the adverse effects of cold weather on weed seed germination, growth and development. Seasonal variations were seen in the number of weeds m^{-2} across all rotation sequences. During the wet and hot dry seasons, a greater number of weed species were seen in all rotation sequences, suggesting that temperature significantly affects infestation. Olabode et al. (2010) had reported higher weed density and dry weight during rainy season than in dry season. In maize based-sequences, the cold dry season had the lowest weed biomass, whereas the hot dry season had the highest biomass across all rotation sequences. In contrast to the cold dry season, when the temperature is low and weed growth is slowed down, the hot

dry season offered a worm temperature and additional moisture from the early onset of rain in 2021, allowing luxuriant weed growth to flourish in all rotation sequences (Das, 2011).

Interaction between season and cropping Sequence on weed dynamic

According to our research, fallow's impact on weed control changed with season. In contrast to permitting the fallow period to occur during the hot dry season, which produced an environment that was favorable for breaking weed seed dormancy and enhancing weed seed germination, allowing it to occur during the wet or dry season may have improved weed control. Gradual increase of weed density observed in MWFL, MWS, MTG, and MOS during cold season in maize base rotation sequence indicates that these sequences slightly favored higher weed establishment even under cooler conditions. In these systems, rotation sequences consisting of cereal-cereal-fallow with sufficient soil moisture and optimal temperature during the rainy and hot seasons promote higher weed growth than during the cold dry season, as indicated by the higher weed biomass on RWFL rotation sequence in the hot season. This could be explained by the fact that weeds may have been able to overcome some physiological hibernation during the hot, dry season by taking advantage of the fallow period. This corroborates with the finding of Ramesh et al. (2017) who reported that weed problems could be aggravated by high temperature, and most significantly by water stress. Compared to COR (cowpea-based systems), CWR rotation supported higher weed biomass regardless of the season. This indicates that the cereal-cereal rotation pattern promoted weed growth and ought to be discouraged. The low dry weight of COR in all seasons further supported the claim that weed growth is prevented crop diversification in any cropping systems.

Weed biomass varied with season in all rotation sequences in rice-based systems. When compared to other sequences during the rainy season, the RWFL rotation sequence had the lowest weed biomass. Higher weed biomass was achieved, though, when the fallow period fell during either the hot or cold dry season. This suggested that the season affects the fallow period's ability to suppress weeds. The dynamics of weed populations in cropping systems have been found to be influenced by a wide range of elements, and the changing climate has made matters more complex. According to Anderson (2015), the arrangement of crops in a series of two cool-season crops followed by two warm-season crops can disturb weed dynamics and cause weed flora to alter during the growing season.

Effect of rotation sequence and Season on IVI of weeds

The hot dry season's comparatively warm temperatures created an environment that promoted weed seed germination and raised the density and frequency of all weed species, leading to a higher IVI. Increased IVI of broadleaf weed species throughout the season demonstrated that this rotation promoted the growth of this weed group throughout the year. During onion cultivation in the COR rotation sequence, frequent manual hoe weeding may have encouraged the sprouting of this group of weed species, increasing their density and frequency and, thus, their IVI. Because the crop itself and the management practices associated with it can produce various habitats for weeds, this demonstrated unequivocally that crop rotation can aid in weed control (Murph et al. 2006; Gerasimova and Mitova 2020; Ghaffar et al. 2022). Our results supported those of Yusuf and Lado (2014), who found that

during the wet season, broadleaf weed had higher IVI (in cereal) than grass and sedges. It's possible that the combination of cold weather during the cold season and frequent tillage throughout the onion growing season contributed to the unfavorable conditions for sedge species growth and development on the COR rotation sequence during the cold season.

It is possible to infer from this study that all weed types were more prevalent during rainy seasons than during cold and dry ones, demonstrating how weather affects weed occurrences throughout all rotation seasons. With the exception of MTC (cold season) and MTS (hot dry season), grasses dominated all rotation sequences (in a maize based systems). The inclusion of soybean (MTS) and cowpea (MTC) in the rotation may have provided a full canopy cover, lowering the frequency and density of grass and, consequently, IVI. The cereal-legume rotation sequence generated more biomass, which aided in weed management, according to Gerasimova and Motiva (2020). Cowpea and soybean may have an allelopathic effect on sedges, which may be more noticeable in colder climates, which explained why sedges were absent in MOC and MOS during the cold season. These may have given grasses a chance to spread, hence increased IVI. These findings supported those of Yakubu et al. (2006), who found that in the Nigerian savannah of Northern Guinea, grasses had the greatest IVI in irrigated carrots.

In RWM, the IVI of grass was rising in every season. This may be due to the fact that maize, wheat, and rice are members of the Poaceae family, which is a family of grasses. The degree of weed infestation may rise if the same crop type is continuously grown. Butkeviciene et al. (2021) found that rye monoculture in the spring had an average of 2.7 times more weed seedlings than rye crops in other crop rotations. In contrast, RTC and RTF saw a complete crop type change throughout the year, which reduced the amount of weed infestation and ultimately resulted in the total eradication of sedge species during the cold season. Additionally, this offered solid proof that the shift in the cropping season contributed to a decrease in weed dominance and occurrence as reported by Ņečajeva et al. (2015). Similarly, Waznoik (2019) have reported wide variations on weed species composition between cereal monoculture and crop rotation at Lubin, south Poland.

Conclusion.

The non-parallel trends across seasons in the interaction plot confirm the presence of a significant interaction effect. Overall, the results suggest that the influence of rotation sequence on weed density is highly season-dependent, with certain sequences exhibiting strong sensitivity to rainfall and others remaining comparatively stable across seasons. Crop rotation is an effective alternative way for weed management expectably in organic agriculture. Continuous cultivation of crop belonging to the same morphological group increases the density of weed species. Improved rotation sequences with legumes and forage crops reduced weed density and dry weight in rice, maize and cowpea based rotation sequence. This provides alternative ways of weed management other than chemical pesticide and provide environmentally health environment. Rainy season provide conducive environment for weed infestations in both rotation sequence in the study area.

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