Original Research Article

CROP MULCHES FOR INCREASED WEED CONTROL AND RICE PRODUCTIVITY

ABSTRACT

A study was conducted to determine the influence of mulches of rice (R), maize (Mz), mucuna (Mc) and cymbopogon (C) on weed growth and rice yield. Twelve mulch treatments included MzRC, RMcC, MzMC, MzRMc, MzRC + one hand rogueing of weeds (hr), RMcC + hr, MzMcC + hr, MzRMc + hr, MzRC + one hand hoeing of weeds (hh), RMcC + hh, MzMcC + hh and MzRMc + hh, 2hh, 3hh, Butanil +1hh and a weedy check in a randomised complete block design (RCBD) with three replicates. The study was conducted both on-station and on-farm (2014). CMcRMz species were each planted in 24 plots under a RCBD replicated thrice and 3 crops uprooted from the plots were combined in equal proportions of different stover into four mulches (MzRC, RMcC, MzMcC & MzRMc). The experimental site was ploughed, divided into 48 plots under RCBD replicated thrice and the mixed mulches were applied (10-12.Mt ha^{-1}) to 12 plots at planting. Higher rice growth was recorded under MzMc than RC mulches with or without a post mulch weed control. RC based mulches most effectively reduced weed density and biomass followed by MzMc mulches. 2hh and MzRMc mulch + 1hr produced similar rice yield but lower rice yield was under RMcC and Butanil + 1hh. Rice growth and tiller development reduced under the weedy check giving zero yields. The highest striga was under Butanil + 1hh (8 striga), followed by 3hh and 2hh (3 & 2 striga). No striga was recorded under cymbopogon mulches and weedy check. The highest returns on investment (ROI) were under 2hh (0.52 & 0.43) at the two sites and MzRMc + hr recorded high ROI (0.47) on station, similar to 3hh on-farm. Maize, rice, cymbopogon and mucuna have high potential to produce bio-herbicides with high rice yields.

Keywords: mulches, grain, growth, striga, yield

1 INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food in many regions of the world and the increasing population pressure, demands that more attention be directed towards improving productivity. [1] reported weeds as the most threatening biological constraint to direct seeded rice cultures with high yield reductions (60%), with even a complete crop failure under heavy weed infestations. Cultural and/or chemical methods are generally employed to control weeds. Hand hoeing, though effective, is getting increasingly unattractive due to labour scarcity, rising wages and its dependence on weather conditions. [2] reported development of resistance to herbicides in some previously susceptible weed species and serious environmental concerns due to high residual effects of herbicides in soil as major drawbacks associated with herbicide usage. Moreover, allowing weeds to reach sufficient size to be rogued, especially perennial species that fragment on pulling is a serious concern [3].

The use of allelopathic crop residues is a promising strategy of achieving cost effective, safe and environmentally friendly weed suppression in arable fields [4]. Allelopathy is described as the ability of plants to inhibit or stimulate growth of other plants in the environment by effects of biochemicals. Weed suppression using allelopathic mulches can be achieved through crop rotation or intercropping. Residues of allelopathic plants may be left on the soil as mulch after harvesting crops in reduced tillage systems [5] or may be incorporated into the soil in conventional tillage systems where they release putative allelochemicals during decomposition [6,5] noted that mulching is only effective against weeds before or during germination and does not provide effective weed control if done after weed emergence. Nevertheless, the use of allelopathic plant residues has been reported to be an effective way of suppressing weeds because the allelochemicals are released in the soil environment in close proximity to weed seeds or the roots of weed seedlings and can therefore be readily absorbed by the receiver plant [7].

There is little literature on use of mulches and cover crops of mucuna, cymbopogon, desmodium, rice and maize for weed control [7,8,9,10]. Related studies have indicated that incorporation (*in situ*) of whole sorghum plants or their various parts alone or mixed with each other was found to suppress weed growth in wheat [11]. [12] reported that sorghum mulch (10-15 Mt ha-^{1}) decreased (38-41%) the dry weight of purple nut sedge relative to the control. [13], however, cautioned about the importance of considering the allelopathic nature of crops before being used as mulches [14] reported that surface mulching with retained cowpea (*Vigna unguiculata* L.) residues suppressed weed emergence between 40-60% under conservation agriculture in Zimbabwe.

Allelochemicals released by crop mulches may also influence plant growth indirectly by altering soil characteristics and inhibiting soil micro fauna [15, 16]. Consequently, accumulation of allelochemicals in the soil results in suppression of seed germination and plant growth, decrease in the volume of primary roots and increased secondary roots, reduced uptake of water and nutrients and subsequently chlorosis ultimately resulting in the death of the plant [17]. [6] reported that combining sorghum, rice and maize mulches with reduced herbicide mixtures increased little seed canary grass mortality up to 98%, significantly reduced dry weed biomass and provided up to 92% weed control efficiency. Increased weed emergence and seedling growth was reported from fields treated with allelopathic mulches which could be partially attributed to the hormetic effects of the allelochemicals at low concentrations [18]. The objective of the study was, therefore, to determine the effect of *Mucuna pruriens*, *Cymbopogon nardus*, *Zea mays* (LONGE 6H) and *Oryza sativa* (NERICA 1) mixed mulches on weed growth and rice productivity.

2. MATERIALS AND METHODS

2.1 Field experiment using crop mulches

2.1.1 Site description

The experiment was conducted at Ikulwe research station and on-farm at Pallisa. Ikulwe is situated at 00^{o} 26' 23.2''N and 033^{o} 28' 40.9'' E and lies 1209 m above sea level. The area received a total of 543 of the 1230 mm mean annual rainfall during the cropping season with mean minimum and maximum temperatures of 18.5 and 30 ^{o}C against the annual temperature of 18.30 and 32 ^{o}C, respectively. Pallisa is located at 1^{o} 13' 33.2''N and 33^{o} 46' 47.2'' E. The total precipitation received was 450 mm and the minimum and maximum temperatures recorded were 19 and 31 ^{o}C, respectively, against the annual rainfall of 990 mm and mean minimum and maximum temperatures of 23 and 33 ^{o}C respectively. Both experimental sites have sandy-loam soils.

2.1.2 Experimental design and treatments

A study was conducted during the rainy seasons at Ikulwe research station and on-farm in Pallisa district in 2014. Cymbopogon, mucuna, rice and maize species were each planted in 24 different plots each measuring 5 x 8 m under a randomised complete block design with three replicates, to provide mulch material and give a site with potential allelopathic effects in the soil for the subsequent study. The crops were uprooted from all the plots at 55 days after emergence (DAE) and combined in sets of three equal proportions of individual stover to give four types of mulches namely maize/rice/cymbopogon, rice/mucuna/cymbopogon, maize/ mucuna/cymbopogon and maize/rice/mucuna. The experimental site was cleared of weeds by slashing and ploughed twice with a tractor. The field was divided into 48 plots (4 x 5 m) arranged in a randomised complete block design with three replicates. At the time of planting rice the mixed stovers were applied as mixed mulches of 3-4 inches thick (10-12.Mt ha^{-1}) under 12 treatments namely maize/rice/cymbopogon, rice/mucuna/cymbopogon, maize/mucuna/cymbopogon, maize/rice/mucuna, maize/rice/cymbopogon + 1 hand rogueing of weeds at 42DAE of rice (hr), rice/mucuna/cymbopogon + 1hr, maize/mucuna/cymbopogon

+ 1hr, maize/rice/mucuna + 1hr, maize/rice/cymbopogon + 1hh of weeds at 28 DAE (hh), rice/mucuna/ cymbopogon + 1 hh, maize/mucuna/cymbopogon +1hh and maize/rice/ mucuna + 1hh. Four treatments under twelve plots, which included 2 hh and 3 hh (14, 28 and 42 DAE), Butanil herbicide (PRE at 2 L ha^{-1}) + 1hh and a weedy check, were located 2 metres outside the preliminary experimental site to avoid any previous allelopathic effects. The treatments were designated as checks.

For comparison the study was conducted in the same year in similar plots (4 x 5 m) not previously planted with the allelopathic crops on a selected farm at Pallisa under a randomised complete block design, replicated thrice. The eight treatments included application of rice/mucuna/cymbopogon mulch + 1hh, maize/mucuna/cymbopogon mulch + 1hh, maize/ rice/mucuna mulch + 1hh, 2hh, 3hh, Butanil (PRE) + 1hh and a weedy check. Application of mulches alone and mulches + 1hr were not administered because of the observed high weed pressure at the site prior to the study. Rice was sown at a spacing of 30 x 12.5 cm (1 plant) within the row in all the plots at both sites. The full N, P and K fertiliser rates used in the experiment were 60 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1}. The N fertiliser was applied in splits at 30 and 55 DAE, respectively and P and K fertilisers were applied at time of planting. The sources of N, P and K were urea (46% N), single super phosphate (16% P_2O_5) and murriate of potash (60% K_2O), respectively.

2.1.3 Data collection

Plant height, number of fully opened green leaves, number of tillers per plant, length and width of longest rice leaves were determined on 20 selected rice plants at 21, 42 and 55 days after emergence (panicle initiation stage) in all the treatments. The species of weeds were established, counted and recorded in 1 x 1 m quadrant for each of the treatments at 21, 42, 55, 63 and 90 days after emergence (Rice harvest). The weeds were oven dried at 80 ^{o}C for 12 hours until constant weight and biomass determined. The number of striga plants within 15 cm radius from the base of rice plants and within five inner rice rows was determined during the same sampling period. The count was expressed as the number of striga per 100 rice plants. At harvest, the total number of panicles, filled panicles per plant, total number of grains per panicle and number of filled grains per panicle were determined on a sample of 20 plants. Rice grain yield was established for the net plots (38 m^2). Data were collected on production costs, gross and net monetary returns per treatment. The economics of weed control was determined as returns on each Uganda shilling investment in the ratio of the net returns to the cost of production in each of the treatments [28].

2.1.4 Data analysis

All data collected were subjected to analysis of variance using 13th edition, 2013 of Genstat software. Fischer's least significant difference (LSD) test at *P*=.05 was used to separate treatment means.

3 RESULTS

3.1 Rice growth parameters on station (Ikulwe)

Application of maize/mucuna based mulches with or without a post mulch weed control technology produced taller rice plants (47-60 cm) with higher leaf number (29-37 leaves) and leaf width (1.8-2.0 cm) than rice/cymbopogon based treatments (Table 1). Hand hoeing after mulching with maize/rice/mucuna mulches significantly (*P*=.05) reduced rice plant height and increased leaf number and leaf width relative to the maize/rice/cymbopogon and rice/mucuna/cymbopogon mulches alone. Maize/rice/cymbopogon mulches alone recorded lower number (4.30 tillers) of tillers per rice plant than other treatments. Leaf length was not significantly affected by treatments. Field observations at Ikulwe station indicated that more weeds germinated in the seeded, un-mulched rice rows, than under the mulched inter-rows. The weedy check recorded the lowest observations.

3.2 Rice and striga growth under different weed control treatments on farm (Pallisa)

Butanil application, hand hoeing twice, hand hoeing thrice and maize / mucuna mulches each followed by hand hoeing once, significantly (*P*=.05) increased the plant height and leaf width relative to rice + cymbopogon mulches (Table 2). Butanil application + hand hoeing once, hand hoeing twice and hand hoeing thrice produced significantly more tillers per rice plant than mulched treatments. Like the weedy check, mulching rice with cymbopogon stover recorded no striga attack. Application of maize + rice + mucuna mulch recorded higher striga weed count (3 weeds) than the cymbopogon mulches. Application of Butanil produced the highest number of striga (8 plants) at the peak count date (63 DAE). This was followed by counts of 3 and 2 striga for hand hoeing thrice and hand hoeing twice respectively. Butanil application, hand hoeing twice, hand hoeing thrice and maize + mucuna + cymbopogon mulch produced significantly more and longer rice leaves than other treatments. Application of rice + mucuna + cymbopogon mulch produced rice with the shortest leaves. The weedy check gave the lowest rice plant height, number of tillers, leaf number, leaf length and width.

Table 1 Rice growth parameters under different weed control treatments on station (2014)

Treatments	Plant height (cm)	Tillers -	Leaf number -	Leaf length (cm)	Leaf width (cm)
Butanil (PRE) + 1hh	59.30a	8.70a	42.00a	37.30a	2.00a
Hand hoeing twice	53.70a	6.70a	31.00a	37.70a	2.00a
Hand hoeing thrice	52.30a	9.00a	39.70b	37.70a	2.00a
Maize/mucuna/cymbopogon mulch + 1hr	47.00ab	10.00a	37.00a	39.00a	1.80a
Maize/rice/mucuna mulch + 1hr	47.10ab	7.00a	36.00a	38.00a	2.00a
Rice/mucuna/cymbopogon mulch + 1hr	47.10ab	9.00a	28.00b	34.00a	1.50b
Maize/rice/cymbopogon mulch +1 hr	47.30ab	8.00a	24.30b	42.00a	1.50b
Maize/mucuna/cymbopogon mulch +1hh	52.00a	5.00a	31.00a	39.70a	1.80a
Maize/rice/mucuna mulch +1hh	38.00b	5.67a	30.00a	33.70a	1.80a
Rice/mucuna/cymbopogon mulch + 1hh	44.00b	6.00a	24.30b	37.30a	1.50b
Maize/rice/cymbopogon mulch + 1hh	44.70b	4.67a	19.00b	34.70a	1.50b
Maize/mucuna/cymbopogon mulch	60.30a	5.00a	29.30a	37.30a	2.00a
Maize/rice/mucuna mulch	60.70a	6.00a	28.20a	39.70a	2.00a
Rice/mucuna/cymbopogon mulch	45.30b	6.00a	26.30b	33.70a	1.50b
Maize/rice/cymbopogon mulch	45.70b	4.33b	17.00b	32.30a	1.20c
Weedy check	20.00c	0.00b	5.70c	30.30a	1.20c
P-value	<0.001	0.05	<0.001	0.76	0.002
LSD (*P*= .05)	13.81	5.37	13.89	NS	0.46
CV (%)	17.20	49.7	29.0	21.2	16.2

Values with different letters in a column are significantly different at *P*=.05, NS = Not significant, hr = hand rogueing, hh = hand hoeing.

Table 2 Rice growth parameters and striga per hundred rice plants on farm (2014)

Treatments	Plant height (cm)	Tillers	SHP (striga)	Leaf number	Leaf length (cm)	Leaf width (cm)
Butanil (PRE) + hand hoeing (hh) once	33.00a	4.33a	8.00a	20.67a	33.67a	1.00a
Hand hoeing twice	30.67a	5.00a	2.00b	20.67a	33.00a	1.00a
Hand hoeing thrice	30.33a	4.67a	3.00b	20.00a	34.33a	1.03a
Maize/mucuna/cymbopogon mulch + 1hh	31.00a	3.33b	0.00c	26.33a	29.67a	1.13a
Maize/rice/mucuna mulch +1 hh	32.00a	3.33b	3.00b	11.67b	25.00b	1.00a
Rice/mucuna/cymbopogon mulch +1hh	26.33b	2.00b	0.00c	7.33b	19.67c	0.83b
Maize/rice/cymbopogon mulch +1hh	29.00b	2.67b	0.00c	11.67b	24.33b	0.80b
Weedy check	11.00c	0.00c	0.00c	3.00c	18.33c	0.50c
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
LSD (*P*=.05)	3.52	1.58	1.66	6.51	4.78	0.26
CV (%)	7.5	32.7	35.4	27.8	10.1	16.9

Values with different letters in a column are different at (*P*=.05), SHP = Striga per hundred rice plants, 1hh = hand hoeing once

3.3 Weed type, species, density and biomass under different mulches on station

The maize/rice/mucuna, rice/mucuna/cymbopogon, maize/rice/cymbopogon and maize/mucuna/cymbopogon mulches inhibited the germination of grasses more than broad leaved weeds at 42 DAE but the weedy check produced the same density (60 weeds m^{-2}) of both broad leaved weeds and grasses (Table 3).

Table 3 Weed types, species, density and biomass under mixed mulches on station (2014)

	Weed Type/Species (42 DAE)			Density (Weeds m^{-2})			Biomass m^{-2} (g)		
Treatments	BLW	Grasses	Species	42DAE	65DAE	90DA	42DAE	65DAE	90DAE
Maize/rice/mucuna mulch	45.00c	1.00d	12.00a	46.00b	74.50b	34.50b	120.00c	148.00c	109.00d
Rice/mucuna/cymbopogon mulch	81.00a	5.00c	12.00a	86.00a	99.00a	49.50b	136.00c	158.00b	142.50c
Maize/rice/cymbopogon mulch	78.00a	12.00b	13.00a	90.00a	87.00a	51.00b	150.00b	178.00b	171.00b
Maize/mucuna/cymbopogon mulch	80.00a	16.00b	12.00a	96.00a	88.30a	69.00a	180.00b	213.00b	188.00b
Weedy check	60.00b	60.00a	14.00a	120.00a	150.00a	122.00a	315.00a	346.00a	283.00a
P-value	<0.01	< 0.01	0.54	0.04	0.11	0.05	0.02	0.02	<0.001
LSD (*P* =.05)	3.63	4.80	NS	38.83	64.32	57.81	38.60	96.70	32.24
CV (%)	2.5	3.0	8.0	12.0	7.0	7.2	18.40	21.00	18.0

Values with different letters in a column are different at (*P*=.05), BLW = Broad leaved weeds, NS = Not significant. DAE = Days after emergence of rice.

Application of maize/rice/mucuna mixed mulches significantly (*P*=0.05) reduced both the broad leaved and grass weeds. Maize/rice/mucuna mixed mulches produced the lowest weed density (46, 75 and 35 weeds m^{-2}) and biomass (120, 148 and 109g m^{-2}) per unit area at 42, 65 and 90 DAE of rice. Application of rice/mucuna/cymbopogon, maize/rice/cymbopogon and maize/mucuna/cymbopogon mixed mulches produced higher weed density (50-99 weeds m^{-2}) and biomass (136-213 weeds m^{-2}) than the maize/rice/mucuna mulches between 42 and 90 DAE. The weedy check recorded the highest weed density (120-150 weeds m^{-2}) and biomass (283-346g m^{-2}) per unit area between 42 and 90 DAE. The number of weed species namely *Digitaria scalarum, Ageratum conyzoides, Gallinsoga parviflora, Commellina bengalensis, Amaranthus ritroflexus, Eleusine indica, Spigelia anthellmisa, Euphorbia hetorophylla, Bracharia scalaris, Portulaca olerace, Bidens pilosa, Eleusine indica and Sorghum halepense* were not influenced by the treatments.

3.4 Weed density and biomass on farm

Application of maize/rice/mucuna mixed mulches significantly reduced the weed density and biomass per unit area at 42, 65 and 90 DAE amongst all treatments. The weed density ranged from 340-840 weeds m^{-2} (Table 4). Maize/rice/cymbopogon, rice/mucuna/cymbopogon and maize/mucuna/cymbopogon mixed mulches produced higher weed density and biomass per unit area at 90 DAE than mixed mulches of maize/rice/mucuna. The weedy check recorded the highest weed density (215-931 weeds m^{-2}) and biomass (150-272g m^{-2}) at 42, 65 and 90 DAE.

Table 4 Weed density and biomass as influenced by mixed crop mulches on farm (2014)

Treatments	Weed Density (Weeds m^{-2})			Weed Biomass m^{-2} (g)		
	42DAE	65DAE	90DAE	42DAE	65DAE	90DAE
Maize/rice/mucuna mulch	105.00c	302.00b	340.00d	126.00b	138.00c	167.00c
Maize/rice/cymbopogon mulch	125.00c	144.00c	345.00d	103.60b	142.00b	190.00b
Rice/mucuna/cymbopogon mulch	158.00b	200.00b	525.00c	129.40b	161.80b	194.00b
Maize/mucuna/cymbopogon mulch	175.00b	233.00b	573.00b	131.00b	154.90b	201.00b
Weedy check (Control)	215.00a	931.00a	840.00a	150.00a	272.00a	249.00a
P-value	0.002	<0.001	<0.001	0.002	<0.001	<0.001
LSD (*P*=.05)	26.96	87.60	26.96	18.18	22.99	18.18
CV (%)	13.0	8.0	8.1	15.3	14.0	12.8

Values with different letters in a column are significantly different at (*P*=.05), DAE = Days after emergence of rice

3.5 Yield parameters and yield on station and on farm

<u>3.5.1 On station (Ikulwe)</u>

The highest number of rice panicles per plant was produced when the plots were hand hoed twice or thrice (Table 5). Mulches of maize/rice/mucuna, rice/mucuna/cymbopogon, maize/mucuna/cymbopogon and maize/rice/cymbopogon each followed by one hand-rogueing of weeds produced similar number of rice panicles per plant to hand hoeing twice or thrice treatments. Hand-hoeing alone and mulching followed by post hand-rogueing had higher number of panicles than application of Butanil followed by hand hoeing. The latter treatment gave similar number of panicles per plant to treatments with or without a post mulch hand hoeing. Application of the different weed control treatments did not significantly influence the filling of panicles per plant. Rice/mucuna/cymbopogon mixed mulch produced the lowest number of grains per panicle among all the treatments. Hand hoeing twice, hand hoeing thrice, application of Butanil + hand hoeing once, maize/rice/mucuna mulch + hand rogueing once and rice/mucuna /cymbopogon mulch + hand-hoeing once treatments produced the highest filled grains per panicle.

Table 5 Yield parameters and grain yield of rice at Ikulwe station (2014)

Treatments	Panicles/plant	PFPP (%)	Grains/panicle	PFGP (%)	Yield (Kg ha^{-1})
Three hand-hoeing (hh)	4.50a	45.00a	117.70a	79.40a	1125.00a
Two hand-hoeing (hh)	6.50a	55.30a	112.50a	85.40a	1031.00b
Maize/rice/mucuna +1hr	4.80a	65.00a	124.80a	72.90a	1037.50b
Butanil-70 (PRE) + 1hh	3.90b	45.50a	130.70a	85.30a	796.00c
Rice/mucuna/cymbopogon + 1hh	3.10b	41.50a	112.80a	70.30a	785.50c
Maize/rice/mucuna +1hh	3.70b	47.30a	114.10a	61.40b	730.00d
Maize/mucuna/cymbopogon +1 hh	3.70b	46.00a	131.60a	46.10b	637.50e
Maize/rice/cymbopogon + 1hh	2.50b	72.90a	112.80a	62.10b	600.00e
Rice + mucuna + cymbopogon +1hr	5.40a	39.70a	124.70a	64.60b	640.90e
Maize/mucuna/cymbopogon +1hr	5.50a	43.30a	123.60a	65.00b	631.00e
Maize/rice/cymbopogon +1hr	4.50a	72.90a	113.50a	64.90b	400.00f
Maize/rice/mucuna	3.50b	42.30a	128.40a	38.00c	626.20e
Rice/mucuna/cymbopogon	3.40b	35.30a	85.10b	43.40c	371.20f
Maize/mucuna/cymbopogon	3.50b	45.70a	128.10a	59.90b	246.20g
Maize/rice/cymbopogon	3.00b	69.70a	113.20a	45.10c	262.50g
Weedy Check	0.00c	0.00b	0.00c	0.00d	0.00i
P-value	0.001	0.02	<0.001	<0.001	<0.001
LSD (*P*=.05)	2.28	37.69	28.58	19.14	45.05
CV (%)	2.0	4.0	4.0	3.0	12.0

Values with different letters in a column are significantly different at (*P*=.05), % = Percent, PFPP = Percent filled panicles per plant, PFGP = Percent filled grains per panicle, hr = hand rogueing.

Application of different mixed mulches without a post weed control operation produced the lowest percent filled grains per panicle. The weedy check produced no panicles and zero grain yields. Hand hoeing thrice gave the highest grain yield (1125 kg ha^{-1}) followed by hand hoeing twice (1031 kg ha^{-1}) and maize/rice/mucuna + hand-rogueing once (1037.50 kg ha $^{-1}$). The grain yield under Butanil (796 kg ha^{-1}) and rice/mucuna/cymbopogon followed by hand hoeing once (876 kg ha^{-1}) were not significantly different. Generally, application of a post-mulch hand hoeing gave higher grain yield than treatments given post mulch hand rogueing except for maize/rice/mucuna followed by one hand-rogueing of weeds. The lowest rice grain yield was recorded under application of mulches without a post mulch weed control operation. The maize/rice/cymbopogon mulch treatments with or without a post mulch weed control option produced lower rice grain yield than rice/mucuna treatment. The weedy check had zero rice grain yields.

3.5.2 On farm (Pallisa)

Hand hoeing twice and hand hoeing thrice produced a higher number of grains per panicle on farm than other treatments (Table 6). Maize/mucuna/cymbopogon mulch followed by hand hoeing once also had higher number of grains per panicle than most treatments. Hand-hoeing thrice and hand hoeing twice gave higher rice grain yield than application of Butanil and rice/mucuna/cymbopogon, maize/mucuna/cymbopogon, maize/rice/mucuna and maize/rice/cymbopogon mixed mulches which gave significantly lower grains per panicle and yield than hand hoeing alone. Maize/rice/cymbopogon mulches produced the lowest rice grain yield and the weedy check yielded no grains.

Table 6 Yield parameters and grain yield of rice on-farm

Treatments	Grains per panicle (Grains)	Percent filled grains per panicle (%)	Yield (Kg ha^{-1})
Hand-hoeing thrice	123.50a	81.70a	1096.00a
Hand-hoeing twice	107.00a	79.60a	969.40b
Butanil (PRE) + 1hh	81.00c	77.30a	485.50c
Rice/mucuna/cymbopogon + 1hh	77.00c	87.50a	539.40c
Maize/mucuna /cymbopogon +1hh	88.50b	76.10a	414.00d
Maize/rice/mucuna +1hh	76.00c	85.20a	461.00d
Maize/rice/cymbopogon + 1hh	66.00c	89.40a	105.60e
Weedy Check	0.00d	0.00b	0.00f
P-value	0.001	0.65	<0.001
LSD (*P*=.05)	25.35	NS	69.23
CV (%)	15.0	18.0	14.5

Values with different letters in a column are significantly different at (*P*=.05), % = Percent, ha = hectare, Kg = Kilogram.

3.6 Economics of weed control methods for rice at Ikulwe and Pallisa

3.6.1 On station (Ikulwe)

Hand hoeing twice, maize/rice/mucuna + hand-rogueing once, hand-hoeing thrice, Butanil + hand-hoeing once, rice/mucuna/cymbopogon + hand-hoeing once gave higher gross and net monetary returns than other treatments (Table 7). The treatments also produced positive returns per shilling investment. Maize/rice/cymbopogon and maize/mucuna/cymbopogon mulches without a post mulch operation gave the lowest monetary gross returns, net returns and returns per shilling investment. Generally, application of maize/mucuna mulches recorded higher returns than rice/cymbopogon crop mulches with or without a subsequent weed control operation. The weedy check gave the lowest (-1.00) net returns on investment.

3.6.2 On farm (Pallisa)

Hand hoeing twice and hand-hoeing thrice gave higher gross returns, net monetary returns and positive returns per shilling invested than application of Butanil + hand-hoeing once and other treatments (Table 8). Application of Butanil + hand hoeing once gave negative returns in investment (-0.21).

Table 7 Economics of weed control methods for rice on station.

Treatments	Production costs (Ush)	Gross returns ha $^{-1}$ (Ush)	Net returns ha^{-1} (Ush)	ROI (Ush)
Two hand-hoeing	1,353,000	2,062,000	709,000	0.52
Maize/ rice/mucuna mulch +1 hr	1,404,000	2,070,000	666,000	0.47
Three hand-hoeing	1,562,000	2,250,000	688,000	0.44
Butanil + 1hh	1,230,000	1,592,000	362,000	0.29
Rice/mucuna/cymbopogon + 1hh	1,151,000	1,571,000	420,000	0.36
Maize/rice/mucuna mulch + 1hh	1,524,000	1,252,000	-271,000	-0.17
Maize/mucuna/cymbopogon +1hr	1,430,000	1,262,000	-168,000	-0.12
Maize/mucuna/cymbopogon + 1hh	1,514,000	1,275,000	-239,000	-0.16
Rice/mucuna/cymbopogon +1hr	1,540,000	1,280,000	-260,000	-0.17
Rice/mucuna/cymbopogon	1,090,000	742,000	-348,000	-0.32
Maize/ rice/mucuna +1hh	1,523,000	1,460,000	-63,000	-0.04
Maize/rice/cymbopogon +1hr	1,390,000	800,000	-590,000	-0.4
Maize/rice/cymbopogon	1.076,000	524,000	-552,000	-0.5
Maize/mucuna/cymbopogon	1,075,000	492,000	-583,000	-0.5
Maize/rice/cymbopogon + 1hh	1,390,000	1,200,000	-190,000	-0.14
Weedy Check	1,050,000	0.000	-1,050,000	-1.00

ROI = Returns per shilling investment, hh = hand-hoeing, hr = hand-rogueing, Ush = Uganda shilling

Table 8 Economics of weed control in rice on-farm

Treatments	Production costs (Ush)	Gross returns ha^{-1} (Ush)	Net returns ha^{-1} (Ush)	ROI (Ush)
2 hand hoeing	1,353,000	1,938,800	585,000	0.43
3 hand hoeing	1,562,000	2,192,000	630,000	0.40
Butanil (PRE) + 1 hand hoeing	1,230,000	971,000	-259,000	-0.21
Rice/mucuna/cymbopogon mulch + 1 hand hoeing	1,151,000	1,078,000	-450.200	-0.39
Maize/rice/mucuna mulch +1 hand hoeing	1,523,000	922,000	-601,000	-0.39
Maize/mucuna/cymbopogon mulch + 1 hand hoeing	1,514,000	828,000	-686,800	-0.45
Maize/rice/cymbopogon mulch + 1 hand hoeing	1,390,000	211,200	-1,317,800	-0.94
Weedy Check	1,050,000	0.000	-1,050,000	-1.00

ROI = Returns on Investment, Ush = Uganda shillings

4. DISCUSSION

4.1 Rice growth under different weed control treatments on station and on-farm

Mulches of maize/mucuna/cymbopogon with or without a post mulch weed control technology, Butanil + hand hoeing once, hand hoeing twice or thrice increased rice plant height, leaf number and leaf width. The improved rice growth parameters under hand weeding and Butanil herbicide application may be attributed to increased uptake of water, nutrients and absorption of solar radiation under conditions of reduced competition between rice and weeds. [19] reported the effects of weeds on rice as reduced yield and quality mostly due to competition for nutrients, water and sunlight. In upland direct seeded rice, yield reductions were reported to range between 35% and 45%. The enhanced rice growth parameters with application of maize/mucuna/cymbopogon mulches may be attributed to additive positive allelopathic effects of the bio-compounds, particularly 1,4-Eicosadiene, 2,5-Di-tert-butylphenol, 3,7,11,15-Tetramethyl-2-hexadecen-1-ol and (9Z)-9-Icosen-1-ol profiled by [20] in the stover of maize and mucuna, on physiological processes such as nutrient uptake that affect rice growth. [18,6] reported increased weed emergence and seedling growth from wheat fields treated with allelopathic mulches which were partially attributed to the hormetic effects of the allelochemicals at low concentrations. [21] reported that allelopathic extracts lethal to young weeds but stimulatory to crops may be attributed to enhanced membrane stability and water relations among other mechanisms.

Treatment with maize/rice/cymbopogon mulch and the weedy check recorded the lowest number of tillers per rice plant. The low number of tillers per rice plant under the mixed mulches may be attributed to antagonistic inhibitory effects of some molecules in the compounds identified in the test plants stover by [20] on rice nutrient uptake, growth and tiller development. [20] identified 1,4-Eicosadiene, 2,5-Di-tert-butylphenol, 3,7,11,15-Tetramethyl-2-hexadecen-1-ol, (9Z)-9-Icosen-1-ol, 1,2,3-Trimethyl-4-[(1E)-1-propenyl]naphthalene and 3,4-Diethyl-1,1'-biphenyl compounds in stover of each of rice and maize and could by additive and synergy actions inhibited rice growth and development processes. The result is supported by [22] who reported that chemicals in a mixture can replace each other on the basis of their biological exchange rate or their ‘‘relative potency’’, and any departure of the effect of mixtures from the ADM is characterized by either reduced (antagonistic) or enhanced (synergistic) effects.

The reduced number of rice tillers under the weedy check could have also resulted from allelopathy or from competitions for light, water, nutrients and other resources between weeds and rice under the weedy check as reported by [19]. Weeds have been reported by [23] as a serious biotic stress in cropping systems that cause a reduction in the growth and yield of crops by interfering with different metabolic processes. Allelopathic inhibitory effects of weeds on crops were observed by [16] who noted that the released allelochemicals by allelopathic weeds cause substantial reduction in germination, growth and yield of the crop plants by altering various physiological processes such as enzyme activity, protein synthesis, photosynthesis, respiration, cell division and enlargement. [15,16] reported that allelochemicals from crop mulches influence crop growth indirectly by altering soil properties and inhibiting soil micro fauna. [24] reported the critical period for weed control in rice to be between 14 and 42 DAE of rice.

4.2 Striga growth

The striga count in Pallisa significantly ($P \leq 0.05$) reduced under treatments with cymbopogon mulches and increased under maize/rice mulch. This suggests that the secondary metabolites produced by cymbopogon mulches have inhibitory effects on striga attachment on rice roots. The major secondary metabolites produced by cymbopogon stover included citronellal, β-Citral, cis-Geraniol, Trans-Carane, eugenol, geraniol acetate, β-Elemen, caryophyllene, α-Gurjunene, γ-Cadinene and citronellyl butyrate [20]. The bio-compounds possibly reduced the quality and quantity of strigolactones; the chemical elements, responsible for successful striga attachment and development. The inhibitory effect of *C. nardus* have been observed on the shoot and root growth of cress, lettuce, rapeseed and Italian rye grass at concentrations ≥ 0.03 g dry weight equivalent extract per milliliter [25]. [26] reported citral of cymbopogon to significantly reduce the chlorophyll and carotenoid contents of barnyard grass. The higher striga count due to maize and rice mulch could be attributed to 4 phenolic compounds namely 2,5-di-tert-butyl-phenol, (9Z)-9-Icosen-1-ol, 3,7,11,15-Tetramethyl-2-hexadecen-1-ol and 3,4-Diethyl-1,1'-biphenyl and two terpenoid namely 1,4 Eicosadiene and 1,2,3-Trimethyl-4-[(1E)-1-propenyl]naphthalene identified as common compounds in both maize and rice stover by [20]. The metabolites could have stimulated the striga attachment in a similar manner to the strigolactones. [27] reported strigolactones from root exudates of rice to stimulate the germination of parasitic plant seeds.

4.3 Weed density and biomass under mulched rice

Mixed maize, rice, mucuna and cymbopogon mulches inhibited the germination of grasses more than the broad leaved weeds. This may be attributed to possible phytotoxic effects of compounds identified by [20] from mixed mulches of maize, rice, mucuna and cymbopogon on enzymic processes involved in the germination and development of grass seeds. Germination of grass seeds is influenced by a chemical effect on amylase enzyme in seeds which catalyses the hydrolysis of starch, following imbibition of water, into simple sugars using Gibberellic acid (GA). This is coupled with the hydrolysis of stored protein into amino acids [4]. The results are supported by [28] who reported that allelopathy influenced seed germination and seedling development by preventing cell division and inhibiting cell elongation. [29] similarly reported that the inhibition of germination and seedling growth by allelochemicals is caused by disturbance in hormonal balance, respiration, photosynthesis and interference in cell growth.

Maize, rice and mucuna mixed mulches reduced the density and biomass of weeds more than cymbopogon based mulch treatment at all crop stages. Inhibitory effects on weed growth by the different mixed mulches may be attributed to higher potency of their allelochemicals on target weeds. Five compounds namely 1,4-Eicosadiene; 2,5-di-tert-butyl- Phenol; 3,7,11,15-Tetramethyl-2-hexadecen-1-ol; (9Z)-9-Icosen-1-o-l and Butylated Hydroxytoluene were commonly identified in the stover of maize, rice and mucuna by [20]. The common metabolites possibly additively inhibited processes that promote the growth of weeds. The cymbopogon based mulch treatments namely maize/rice/cymbopogon, rice/mucuna/cymbopogon and maize/mucuna/cymbopogon, each had four similar compounds namely (9Z)-9-Icosen-1-ol, 2,5-di-tert-butyl-Phenol, 3,7,11,15-Tetramethyl-2-hexadecen-1-ol and (9Z)-9-Icosen-1-ol but had no compound in common with cymbopogon crop mulches. This probably explains the lower control efficacy by cymbopogon based mulches on weed density and biomass which may be attributed to possible antagonistic effects by molecules on processes weed growth and development. Allelopathic effects of bio-compounds in related crop surface mulches indicate that sorghum surface mulch (10-15Mt ha^{-1}) applied at sowing controlled weeds and increased maize yield significantly [12]. [30] reported mixture of sorghum + sunflower (18 L ha^{-1}) to suppress the density and dry weight of weeds.

4.4 Yield parameters

Hand hoeing twice, hand hoeing thrice, maize/rice/mucuna mulches + hand rogueing of weeds once and Butanil herbicide + hand hoeing once produced the highest number of panicles per rice plant, percentage filled grains and grain yield. This may be attributed to lower weed biomass and density that could have led to improved nutrient uptake and reduced competition for crop growth resources. Weeds were reported to reduce yields by 35 to 45 percent by [19] due to competition for nutrients, water and sunlight. [31] found an inverse correlation between the rice grain yields, weed biomass and weed density. [32] observed reduced total weed biomass (68-75%) with an increased corresponding grain yield (119-149%) for the non-treated control under a single application of herbicides. [16] reported that weeds interfere with crops through competition and allelopathy.

Percent filling of panicles per plant was lowest under mulched treatments without a post mulch weed control operation and the weedy check produced zero grain yields. Reduced productivity under relatively weedy conditions may be associated with increased chemical interference of allelochemicals in the mulch and weeds on rice reproductive functions. Results may also be attributed to increased competition between rice and weeds for water, nutrient and solar radiation. [33] reported crop yield reductions of more than 50 percent due to weeds under water stress conditions.

4.5 Economics of allelopathic weed control methods in rice

Treatments of two and three hand hoeing, maize/rice/mucuna mulch + hand rogueing once, Butanil + hand hoeing once and rice/mucuna/cymbopogon mulch + hand hoeing once gave higher gross and net monetary returns than other treatments. The treatments also produced positive returns on investment (ROI) per Uganda shilling investment. The increased gross returns, net monetary returns and high ROI observed may be attributed to higher yields and gross returns under the treatments. Higher ROI were under maize/mucuna than under rice/cymbopogon mixed mulches. This may be associated with the enhanced rice growth with higher leaf number, leaf width and higher grain yields observed under the maize/mucuna treatments by [20]

The reduced growth and yield under rice/cymbopogon mulches are associated with inhibitory effects of the phytotoxins in the mulches on physiological processes vital for growth such as nutrient uptake. Several of the associated compounds could have been among those identified by [20]. The negative ROI under rice/cymbopogon based mulches and other mulched treatments were due to the low yields associated with the poor rice growth, low yield and yield attributes under the treatments. The weedy check produced no grain yield and gave the lowest returns on investments. [34], recorded higher returns on investment under pre-Atrazine + hand hoeing once and hand hoeing twice (180%), followed by post Atrazine + hand hoeing once (167%) in maize. The no weeding treatment registered the lowest value (67%). [35], reported the traditional method of growing rice as more expensive (Rs.14014.54 per acre) than improved SRI method (Rs.12154.63 per acre)

4.6 Conclusion

Hand hoeing twice, hand hoeing thrice and application of Butanil followed by hand hoeing once increased rice growth, yield parameters, yield and returns on investment (ROI) relative to other treatments. Rice/cymbopogon based mulches most effectively controlled weeds including the noxious striga in upland rice, but maize/mucuna mulches had higher rice growth, grain yield and ROI than under rice/cymbopogon mulches. Cymbopogon based mulches effectively controlled striga and other weeds and the lowest effects were with maize and rice mulches. All mulches controlled grasses much more than broad leaved weeds. Maize, rice, cymbopogon and mucuna have the potential to produce bio-herbicides for weed control in the drylands.

REFERENCES

1. Phuong LT, Denich M, Vlek PLG, Balasubramanian,V. Suppressing weeds in direct seeded lowland rice.

Effects of methods and rates of seeding. *Journal of Agronomy and Crop Science,* 2005*;*191:185-194.

2. Rehman A, Cheema Z A, Khaliq A, Arshad A, Mohan S. Application of sorghum, sunflower and rice water extract combinations helps in reducing herbicide dose for weed management in rice. *International Journal of Agricultural Biology,* 2010;12:901-906.

3. Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer A M. Weed management in direct seeded-rice. *Advances of Agronomy*, 2007;93:153-255.

4. Jacobsen JV, Chandler PM. Gibberellin and abscisic acid in germinating cereals. In: Davies PJ, editor. Plant Hormones: Physiology, Biochemistry and Molecular Biology. Boston, MA: Kluwer, 1995;164-193.

5. Ashraf R, Sultana B, Yaqoob S, Iqbal M. Allelochemicals and crop management: A review. *Current Science,* 2017*;*3:1-13.

6. Abbas T, Nadeem MA, Tanveer A, Ali AA, Farook N,. Role of allelopathic crop mulches and reduced doses of tank-mixed herbicides in managing herbicide resistant *Phalaris minor* in wheat. *Crop protection,* 2017, In press..

7. Xuan, TD, Shinkichi T, Khanh TD, Min CI. Biological control of weeds and plant pathogens in paddy rice by exploiting plant allelopathy: an overview. *Crop Protection,* 2005;24:197-206.

8. Pickett JA, Hamilton LM, Antony M, Hooper AM, Khan ZR, Charles AO, Midega OA. Companion cropping to manage parasitic plants. *Phytopathology* 2010;48:161-177.

9. Kato-Noguchi H. Rice allelopathy and momilactone. *Pakistan Journal of Weed Science Research,* 2012;18: 1289-296.

10. Jabran K, Mahajan G, Sardana V, Chauhan BS. Allelopathy for weed control in agricultural systems. *Crop Protection*.2015;72:57-65.

11. Cheema ZA, Khaliq A. Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agriculture Ecosystems and Environment*, 2000;79:105-112 .

12. Cheema ZA., Khaliq A, Saeed S. Weed control in maize (*Zea May.* L) through sorghum allelopathy. *Journal of Sustainable Agriculture*, 2004;23(4):73-86.

13. Cheng, ZH, Xu. P. Lily (*Lilium* spp.) root exudates exhibit different allelopathy on four vegetable crops. *Acta Agriculturae Scandinavica***,** 2013**;**63:169-175.

14. Mtambanengwe F, Nezomba H, Tauro T, Chagumaira C, Manzeke M, Mapfumo P. Mulching and fertilization effects on weed dynamics under conservation agriculture-based maize cropping in Zimbabwe. *Environments,* 2015*;*2: 399-414.

15. Kobayashi Y, Ito M, Suwanarak K. Evaluation of smothering effect of four legume covers on *Pennisetum polystachion* ssp. *setosum* (Swartz) Brunken. *Weed Biology and Management* 2003;3:222-227.

16. Zohaib, Ali & Abbas, Tasawer & Tabassum, Tahira. Weeds Cause Losses in Field Crops through Allelopathy. Notulae Scientia Biologicae. 2016;8.47-5647. 10.15835/nsb.8.1.9752.

17. Narwal SS, Palaniraj R, Sati SC. Role of allelopathy in crop production.*Herbologia*,2005;6(1):4-23.

18. Belz RG, Hurle, K. Differential exudation of two benzoxazinoids one of the determiningfactors for seedling allelopathy of Triticeae species. *Journal of Agricultural and Food Chemistry,* 2005;53:250-61.

19. Labrada R 2003. Weed management in rice, in: Auld, B.A. & Kim, K.U. eds. FAO Plant production and protection paper No. 139: 2003;259-272, FAO, Rome.

20. Kaiira MG, Allelopathic interactive effects of rice, cymbopogon, desmodium, mucuna and maize. PhD thesis, Department of Land Resource Management and Agricultural Technology, University of Nairobi, Kenya; 2019.

21. Munir R, Evaluating the role of allelopathy in improving the resistance against heat and drought stresses in wheat, MSc thesis, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan; 2011.

22. Morse, PM. Some comments on the assessment of joint action in herbicide mixtures. *Weed Science*. 1978;26:58-71.

23. Hajizadeh R, Mirshekari B. Interference of wild oat (*Avena fatua*) with wheat cultivars. *Journal of Food, Agriculture and Environment,* 2011;(3-4):398-399.

24. Touré A, Jean, SM, Mawuena, Y, Gumedzoé D. The critical period of weed interference in upland rice in northern Guinea savanna: Field measurement and model prediction. *African Journal of Agricultural Research,* 2003;8(17):1748-1759.

25. Prapaipit S, Piyatida P, Kato-Noguchi H. Allelopathic activity of *Cymbopogon nardus* (Poaceae). *Journal of Plant Studies,* 2013: 2 (2) doi:10.5539/jps.v2v2p1.

26. Poonpaiboonpipat T, Pangnakorn U, Suvunnamek U, Teerarak M, Charoenying P, Laosinwattana C. Phytotoxic effects of essential oil from *Cymbopogon citratus* and its physiological mechanisms on barnyardgrass (*Echinochloa crus-galli*). *Indian Crop Production,* 2013;41:403-407.

27. Pandey, A., Sharma, M, Pandey, GK., Strigolactones in plant stress and development.*Frontiers in Plant Science*, 2016;7:434. doi: 10.3389/fpls.2016;00434.

28. Iman A, Wahab S, Rastan M, Halim M. Allelopathic effect of sweet corn and vegetable soybean extracts at two growth stages on germination and seedling growth of corn and soybean varieties. *Journal of Agronomy,* 2006;5:62-68.

29. Li ZH, Wang Q, Ruan X, Pan CD, Jiang DA. Phenolics and plant allelopathy. *Molecules*, 2010;15:8933-8952.

30. Cheema, ZA, Khaliq A, Iqbal. J. Use of allelopathy in field crops in Pakistan, *Pakistan Journal of Botany*, 2010;40(6):2383-2392..

31. Devasinghe D, Premarathne KP, Sangakkara UR. Weed Management by rice straw mulching in direct seeded lowland rice (*Oryza sativa* L.). *Tropical Agricultural Research,* 2011;22(3):263-272.

32. Punit KA, Agarwal PK, Yavad P, Mondal S. Economic analysis of cost and return Structure of paddy cultivation under Traditional and Sri method: A comparative study. *International Journal of Agriculture Sciences*, ISSN: 09753710 & E-ISSN: 0975-9107, 2018;10 8:5890-5893

33.. Abouziena HF, Haggag WM. Weed control in clean agriculture: A Review *Planta Daninha*, 2016; 34(2) 377-392.

34. Kaiira M, Kagoda F, Gidoi R. Exploring cost-effective maize integrated weed management approaches under intensive farming systems. *Uganda Journal of Agricultural Sciences,* 2014;15 (2):191-198. ISSN 1026-0919.

35. Mahajan G, Chauhan BS. Herbicide options for weed control in dry seeded aromatic rice in India. *Weed Technology,* 2013;27(4):682-689.

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