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Effect of Improved Fallows and Phosphorus Application on Weeds and Maize Yield in Smallholder Farming System of Western Kenya

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Abstract: Little is known about the weed control potential of integrated soil fertility management practices that combine improved fallows with fast growing trees and shrubs and phosphorus fertilizer application in low-input smallholder farming systems. Consequently, a study was carried out to compare the effect of four land-use systems on weed biomass and species composition and maize yield in 1998. The experiment was conducted at two sites namely, Osita farm and Khwisero farm in western Kenya. The four land-use system treatments studied were: continuous maize cropping, *Crotalaria grahamiana* fallow, *Tithonia diversifolia* fallow and natural fallow. A randomized complete block design with four replications was used. The fallows established without phosphorus (P) application were cut clear and planted with maize after 10 months. Results showed that at the time of cutting the fallows at Osita farm there were no weeds, perhaps due to the higher standing tree biomass of 8.8 t ha^{-1} for tithonia and 13 t ha^{-1} for crotalaria. The trees at Osita showed better canopy than those at Khwisero farm which had biomass of 4.2 t ha^{-1} for tithonia and 6.7 t ha^{-1} for crotalaria. Nevertheless, continuous maize system and natural fallow had weed biomass of 0.2 to 2.1 t ha^{-1} in both sites. Because of the good weed control by the fallows at Osita farm, weeding frequency was reduced to two instead of three times for the continuous maize and natural fallow systems. However, tithonia fallow had seedlings germinated from seeds of the tree species at the first weeding. At Osita farm, the crotalaria and tithonia fallows significantly controlled some problematic weeds in particular *Richardia brasiliensis* up to the third weeding stage. This was not the case at Khwisero where the weed load was higher. Tithonia fallow had the largest striga count at Osita with no striga at Kwhisero. Application of P did not have an effect on fallow biomass, however, weed biomass in natural fallow land use system increased with application of P at both sites. It was concluded that improved fallows with fast-growing trees in rotation with crops offer promising prospects for controlling weeds in addition to improving soil fertility.

Keys words: Improved fallows · Crotalaria · Tithonia · Weeds · Maize

INTRODUCTION

Potential maize yield in western Kenya is often limited by low soil fertility, which is confounded by the presence of weeds. Difficult-to-control weeds such as *Richardia brasiliensis* (ricardia), *Digitaria abbyssinica* (couch grass) are common in this region and they contribute to the already low yields of maize, the staple food crop in this densely population region of the country. Maize grain yields under farmers conditions typically average 1.0 ton per ha^{-1}. Significant losses of weeds to crops are often overlooked because they substantially reduce yield without obvious signs of damage. Weeds cause crop losses averaging 30%, however losses of 50% or more are common especially with weeds such as *Striga* spp, *Oryza* spp (wild rice) or *Cyperus* spp [1]. Crops are killed because weed species thrive at the expense of crops by competing for soil moisture, nutrients, light and space [2].

Under these conditions, agroforestry interventions may provide a solution to the problem [3], for instance observed that the potential weed suppression ability and the positive influence on the soil fertility of alley cropping systems could lead to greater acceptance of the systems which integrate trees and cause them to be widely used in farm practice. Unruh [4] indicates that the management of the fallows may serve to speed soil nutrient recovery, inhibit the spread of exotic weeds and grasses and

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provide economic products. A number of agroforestry technologies have been developed and adopted to combat the crucial problem of soil fertility decline [5]. Such technologies include improved fallow with N-fixing trees and shrubs such as *Sesbania sesban*, *crotalaria grahamiana* and non N-fixing shrub such as *Tithonia diversifolia*. Crotalaria is a fast growing leguminous shrub which is able to produce more than 7 t ha^{-1} six months after planting. However, the weed control benefits of these technologies have so far received little attention. In phosphorus deficient soils such as those in western, the application of phosphorus through commercial fertilizers is essential for improving crop yields [6]. How this will affect weed dynamic (biomass production and species composition) under conditions of improved fallows is unclear. And so are the attendant impacts of maize yields. The objective of the study is to determine the impact of improved fallow species and phosphorus application on biomass and composition weeds and maize yields.

MATERIALS AND METHODS

The study was conducted at two sites in western Kenya (Osita and Khwisero Farms in Vihiga and Butere districts, respectively) during the 1997 "short- rains" (October 1997 to January 1998) and 1998 "long rains" (February to August) seasons. Osita farm is in west Bunyore location (latitude of 0° 06`N, 34°34`E and altitude of 1420 m) while Khwisero farm is in Khwisero location (latitude 0° 30' N, 34° 30' E and altitude of 1400 m above sea level). Mean annual rainfall at both sites is 1800 mm with reliability of 60% and bimodally distributed over two growing seasons per year [7]. Osita farm had lower soil fertility compared to Khwisero. Osita farm which had been under maize continuously for 8 years without fertilizer application while Khiwisero farm had been cropped for two years.

The soil in both sites is classified as very fine, kaolintic, isohyperthermic Ferralsol [8]. These soils are well-drained, very deep, dark red to yellowish red, friable to firm, sandy clay with acid humic topsoil. On both sites the soil had no physical or chemical barriers to rooting in the top 4 m. Four land-use systems namely: continuous cropping, crotalaria fallow, tithonia fallow and natural fallow were arranged in a complete randomized block design. These land-use systems were split and phosphorus applied to one split and the other did not receive. The experiment was replicated four times with the treatment combinations are described in Table 1.

Tithonia and crotalaria fallows were established in June 1997 while maize was still in the field. The fallows were cut back to ground level in February 1998 and planted maize. The sub-plots were plus or minus P, applied to maize at a rate of 50 kg ha^{-1}. Weed species were identified visually in the entire area of each experimental plot measuring 6 m x 6 m. Dominant species were determined based on their biomass and the area they covered. Weeds that were hard to identify in the field were classified at the nearby National Agroforestry Centre Maseno. Weed were sampled and identified before establishment of fallow species and at the first, second and third weeding of maize crop. Immediately after weed identification, the weed biomass was assessed by cutting the weeds at the base for all dominant weeds followed by other weed species and recording their biomass weight. Weed samples were dried in a drought oven at 70°C to constant weight and dry matter determined.

Tree biomass assessment was done for each plot at three different locations each covering a 3 x 3 m area. The trees were cut to ground level and leaf biomass separated from the wood, which was considered a woody material if its thickness was greater than 2 mm. The tree biomass from the three locations was mixed and total fresh weights determined. A random sample of the leaf biomass (500 g) was oven dried at 70°C for 48 hours and

Table 1: Treatments combinations in Kwhisero and Osita Farms, western Kenya during season 2 (1997 Short Rains) and 3 (1998 Long Rains)

Treatment number	System	P source	P rate	Season 1 1997 (LR)	Season 2 1997 (SR)	Season 3 1998(LR)
1	Continuous maize	No P	0	M	M	M+- P
2	Continuous maize	TSP	50	M+P	M	M+- P
3	Crotalaria fallow	No P	0	M/F	F	M+- P
4	Crotalaria fallow	TSP	50	M/F + P	F	M+- P
5	Tithonia fallow	No P	0	M/F	F	M+- P
6	Tithonia fallow	TSP	50	M/F+P	F	M+- P
7	Natural fallow	No P	0	M	NF	M+- P
8	Natural fallow	TSP	50	M+P	NF	M+- P

P = P application; F = fallow; NF = natural fallow; Tr. = Treatment M=Maize; SR=Short Rain; LR=Long Rain dry matter determined. The remaining trees were cut (including the border trees) in the plot and placed over the entire plot where they dried and leaves fell on their own. After the tree was dry, the leaves, pods and the small twigs were shaken off and remained in the field. The wood fraction was removed, weighed and a sample taken to obtain oven dry weight. The second sample was used to verify the accuracy of the first wood biomass assessment.

Maize (Katumani H 512 Variety) was grown in both sites (Osita and Khwisero). Maize was planted at a spacing of 75 between rows and 25 cm between plants, giving a stand density of 53000 plants ha^{-1}. Weeding was done 2-3 times manually using a hoe during the season at both sites. Tithonia and crotalaria were established in maize after the last weeding using cuttings and seeds, respectively.

Analysis of Variance (ANOVA) was used to test treatment differences of weed biomass using Genstat [9]. Separate ANOVA was carried out for each site because the timing and frequency of weeding differed between sites. Standard error of differences (SED) was used to make comparison of treatment means. Before conducting the ANOVA, data were first tested for normality and variability using the Genstat package. The Striga data was square root transformed before subjecting it to analysis because it was count data. Square root transformation of the data stabilized the variances and the distribution of the residuals. The α-level was set at 0.05.

RESULTS AND DISCUSSIONS

Effect of Land-Use Systems on Biomass Yield of Fallow Species: Land-use system had a significant effect on biomass yield of fallow species. Crotalaria yielded higher than tithonia at both sites: 13.1 vs. 6.7 t ha^{-1} at Osita and 8.8 vs. 4.2 t ha^{-1} at Khwisero (Figure 1) respectively. These differences (48% at Osita and 60% at Khwisero) are explained by poor growth of maize at Osita where the trees had a denser canopy than at Khwisero. Osita soils were low in fertility because this site was being cropped continuously for 8 years without fertilizer application, which might have resulted, to low weed load, Khwisero was on a second year under cropping. Crotolaria is N fixingi species while tithonia is a non-N fixing species, this may also explain differences in their biomass accumulation.

Effects of Land-Use Systems on Weed Species Biomass and Composition: Natural fallow produced 93 and 62 percent Osita and Khwisero, respectively, of the total weed biomass at the cutting of the fallows. Crotalaria and tithonia fallows had no weeds at Osita farm while Khwisero had some weeds at the cutting of the fallows (Table 2). Fallow species had dense canopy cover at Osita farm while the canopy at Khwisero was sparse leading to high weed biomass. The reduction in weed biomass in improved fallows compared to continuous cropping and natural fallow was due to shading imposed

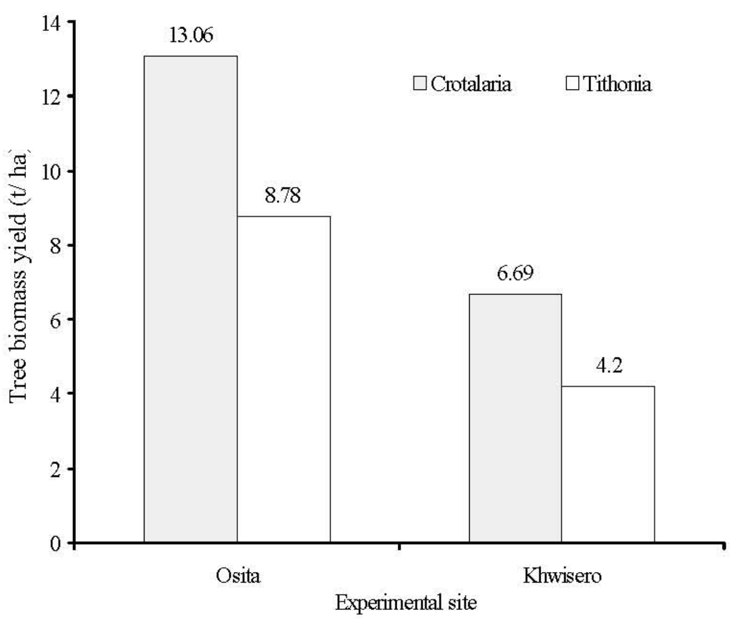

Fig. 1: Total Tree biomass yield (leaves+ Litter +wood) after fallow at Osita and Khwisero, Long rains 1998

Table 2: Effects of four different land-use systems on total weed biomass at Osita and Khwisero during 1998 long rains season

Farm experimental site	Land-use systems	Weed biomass (kg ha^{-1})				
		Cutting fallow	1st weeding (18 DAS)	2nd weeding (30 DAS)	3rd weeding (60 DAS)	Total
Osita	Continuous maize	252b	0.0a	114a	116a	482a
	Natural fallow	3328c	40.2b	259b	138ab	3765b
	Crotalaria fallow	0a	0.0a	141a	87a	228a
	Tithonia fallow	0a	29.9b	88a	186b	303a
	SED	967	8.08	44.6	32.8	62.5
Khwisero	Continuous maize	186a	Nw	150a	184a	521a
	Natural fallow	2066b	Nw	436b	270a	2772d
	Crotalaria fallow	740a	Nw	1013c	301a	2054c
	Tithonia fallow	335a	Nw	531b	251a	1117b
	SED	319.5		116.7	61.2	153.0

Note: Land-use system with the same letter along the column in each site means that they are not significantly different (P > 0.05) using LSD method of separating means. Nw =No weeding

Table 3: Effect of improved fallows on dominant weed species composition at Osita and Khwisero during 1998 long rains

Site (Farm)	Treatment	*Initial weed species*	Ceas. Fallow	1st weeding	2nd weeding	3rd weeding
Osita	Cont.Maize	*Galinsoga parviflora* *Richardia brasilensis*	*Galinsoga parviflora* *Senecio abyssinicus*	No weeds	*Richardia brasilensis*	*Richardia brasilensis*
	Natural fallow	*Digitaria abyssinica* *Richardia brasilensis*	*Guizotia scabra* *Digitaria abyssinica* *Cynodon nlemfuensis*	*Digitaria abyssinica*	*Digitaria abyssinica* *Richardia brasilensis*	*Richardia brasilensis*
	Crotalaria fallow	*Galinsoga parviflora* *Richardia brasilensis*	*No weeds*	No weeds	*Crotalaria grahamiana* *Richardia brasilensis*	*Richardia brasilensis*
	Tithonia fallow	*Galinsoga parviflora* *Richardia brasilensis*	*No weeds*	*Tithonia diversifolia* *Xanthium pengeus*	*Tithonia diversifolia* *Richardia brasilensis*	*Richardia brasilensis*
Khwisero	Cont.Maize	*Richardia brasilensis*	*Richardia brasilensis*	Insignificant weed load	*Richardia brasilensis*	*Richardia brasilensis*
	Natural fallow	*Richardia brasilensis*	*Richardia brasilensis* *Digitaria longiflora* *Digitaria abyssinica* *Guizotia scabra* *Digitaria ternata*	Insignificant weed load	*Richardia brasilensis*	*Richardia brasilensis*
	Crotalaria fallow	*Richardia brasilensis*	No weeds	Insignificant weed load	*Crotalaria grahamiana*	*Richardia brasilensis*
	Tithonia fallow	*Richardia brasilensis*	*No weeds*	Insignificant weed load	*Richardia brasilensis*	*Richardia brasilensis*

by tithonia and crotalaria species that resulted in reduced germination of weeds. Both tithonia and crotalaria fallows had dense canopy cover at Osita compared to Khwisero.

Dense canopy cover results to low temperatures that limit germination and subsequent development of weeds. This is in agreement with the findings of Terry [10] who reported that seeds of tropical grasses germinate optimally at temperatures ranging between 15° and 35°C. The author emphasized that shading by fallow species contributes to a major modification of microclimate below, reducing weed biomass. Also, Jama *et al.* [11] reported weed biomass reduction in a closed canopy of trees and attributed it to reduced photosynthetically active radiation (PAR) reaching the soil surface. Teasdale [12] concluded that weed germination and establishment are related to the modifications of radiation. These findings partly explain the delayed emergence of some weeds, such as richardia, at the Osita site (Table 3).

Maize crop was weeded three times viz, 18, 30 and 60 days after seeding (DAS) at Osita. However, the 18 DAS weeding was not carried out at Khwisero. At first weeding at Osita farm (18 DAS), continuous maize cropping system and crotalaria fallow had no weeds while the weed biomass of the natural fallow system had the highest weed biomass (40.2 kg ha^{-1}) followed by tithonia fallow (29.9 kg ha^{-1}). At this weeding, the predominant weeds in the natural fallow were couch grass while in the tithonia fallow were tithonia seedlings and *Xanthium pungens* (Table 3). Both tithonia seedlings and *Xanthium pungens* are beneficial ones because they easily controlled and decompose fast while digitaria is a problematic one. The absence of weeds in continuous maize cropping plots could be attributed to repeated removal of weeds before reaching seeding stage. This explanation is supported by reports of Terry [9] that concluded that repeated weeding and use of similar production practices impose a selection pressure on any weeds present. Also, Mloza-Banda [13] reported that continuous cropping of maize exerted selection pressure on some weed species in Malawi.

Natural fallow (259 kg ha^{-1}) had higher weed biomass than other land-use systems during the second weeding (30 DAS) at Osita farm. However, there were no differences in weed biomass of the continuous maize cropping (114 kg ha^{-1}), crotalaria fallow (141 kg ha^{-1}) and tithonia (88 kg ha^{-1}). Weed biomass in the continuous cropping and natural fallow were lower than that of tithonia (186 kg ha^{-1}) during the third weeding (57 DAS) at Osita farm. However, there were no differences in weed biomass in continuous maize cropping (116 kg ha^{-1}), crotalaria fallow (87 kg ha^{-1}) and natural fallows (138 kg ha^{-1}) land-use systems. Total weed biomass of continuous cropping (482 kg ha^{-1}), crotalaria fallow (228 kg ha^{-1}) and tithonia fallow (203 kg ha^{-1}) were not significantly different but were all lower than natural fallow (3765 kg ha^{-1}). The lower weed biomass in continuous cropping systems compared to natural fallows could have depleted the weed seed bank in continuous cropping whereas in natural fallow it was replenished. The continuous removal of weeds before reaching seeding stage reduced the seed bank in the soil and resulting in comparable weed biomass between continuous cropping and crotalaria and tithonia land-use systems.

First weeding was omitted at Khwisero Farm because there were no weeds. At this farm, crotalaria fallow had higher weed biomass (1013 kg ha^{-1}) than tithonia (531 kg ha^{-1}) and natural fallow (436 kg ha^{-1}) during the second weeding. While continuous maize cropping (150 kg ha^{-1}) had lowest. The lower weed biomass under continuous cropping was due to continuous removal of weeds when the other systems were in fallow. The main weed species under continuous cropping was richardia, which also had the highest proportion (52 % of the total biomass), compared to other land-use systems. Crotalaria fallow had the highest weed biomass, followed by tithonia fallow, probably because of the higher tree biomass returned to the soil contributing more nutrients especially nitrogen and phosphorus. Weed biomass from all the four land-use systems were not different during the third weeding continuous cropping had the lowest total weed biomass followed by tithonia at Khwisero (Table 2). The litter falls and ability of crotalaria to fix nitrogen and improve soil fertility might have contributed to high total weed biomass.

Effect of Land Use System on Weed Species: Richardia was the most dominant weed species in most of the treatments and in the two sites (Table 3). This is not a native species in the study area but was introduced from tropical America [14]. It is considered problematic and difficult-to-control by the farmers. The reappearance of some of the noxious weeds could be attributed to the characteristics of weeds such as production of large amounts of seeds, efficient dispersal mechanism and the close proximity of plots. For the effect to be felt the distance between plots must be large. The postponement of emergence of some of the noxious weeds such as richardia and couch grass in the crotalaria and tithonia fallows at Osita (Table 3) compared to Khwisero is an indication that better establishment of fallow species can help in the management of these weeds. This suggests that control for some of the noxious weeds depends on how well the fallow trees established. Therefore, one season fallow with dense canopy cover seems to be able to control richardia that is regarded as a serious weed by farmers. Also, if fallows are left for a longer duration, then these weeds could be completely controlled. This was clearly seen during the cutting time of the fallows at Osita where this weed was absent in the improved fallow plots, probably because of intense competition between fallow species resulting in disappearance of weed species over time.

The diverse results of Khwisero and Osita indicate that weeds are unpredictable and change with sites and location within them. The probable reason for high variability in both biomass and occurrence of weeds in the two sites is that weeds depend on the initial seed pool. Nokes *et al.* [15] reported that weed biomass data exhibited large variations between plots, which were attributed to heterogeneity inherent in weed growth.

The most critical factor that determined the weed biomass and species in this study could be PAR and temperature. Although no measurements were taken, observations indicated that shading of crotalaria and tithonia lowered both PAR and temperature at ground

Table 4: Effects of land-use system on striga counts for 1998 long rains season in Osita and Khwisero farm sites

Farm site	Land use system	Number of striga per m^2
Osita	Continuous maize cropping	99.5a
	Natural fallow	95.2b
	Crotalaria fallow	109.8c
	Tithonia fallow	209.7d
Khwisero	Continuous maize cropping	0e
	Natural fallow	0e
	Crotalaria fallow	0.2e
	Tithonia fallow	0e

Note: Land use system with the same letter a long the column in each site means that they are not significantly different ($P > 0.05$) using LSD method of separating means

level thus suppressing weed development particularly at Osita farm. Other factors that could contribute to differences in weed biomass between the fallows and other land-use systems could be allelopathy. Allelopathy effect, as explained by Terry [10], could also be responsible for the weed reduction in both crotalaria and tithonia fallows at Osita. Crotalaria is known to release allelopathic substances from both above-ground biomass and from decaying roots [16]. Nagarajah and Nizar [17] have shown that tithonia to produces secondary metabolites that are harmful to other plants under it. These mechanisms could be responsible for the reduced weed growth in the improved fallows with these two species.

Effect of Land Use System on Striga Count: The number of striga weed count per square meter ranged from 94 in P applied plots of natural fallow to 221 per square meter in no P level of tithonia at Osita (Table 4). There was a site by treatment interaction on striga weed count. The interaction was due to low of striga count in the crotalaria fallow at Khwisero farm. At Osita farm, all land-use systems were highly infested by striga weed. The higher number of striga counts in tithonia fallow compared to the other land-use practices (Table 4) shows that tithonia plant stimulates germination of striga seeds in the soil seedbank. Stimulation of weed seeds to germinate by other plant species is well documented [18]. The high germination of striga could have led to depletion of its seed bank in the soil and hence contribute to the control of this noxious weed. Although striga density was greater in tithonia fallows, maize yield (data not shown) was higher in this land-use system than in the continuous maize and natural fallows probably due to increased soil fertility in improved fallow land-use systems that could have decreased the effect of striga on maize. Increased soil fertility increases the levels of cytokinin and gibberellic acid in the host plant that increase resistance to striga attack [19]. In addition, the higher population of striga in tithonia fallows suggests that if the fallows are on the farm for a longer time without planting maize, they might stimulate striga germination. Therefore, in the absence of the host there will be suicidal germination hence the seed bank will be depleted resulting in lower striga populations. This explanation is in agreement with that of Oswald *et al.* [18] who found that multipurpose trees grown on farms may have ability to increase soil fertility and/or cause suicidal germination of striga seeds and thereby help to reduce striga infestation.

Effect of Land-Use Systems on Maize Yield: Maize yield from crotalaria and tithonia fallows land-use systems were higher than from continuous cropping and natural fallow land-use systems at both Osita and Khwisero (Table 5). Increased maize yield from improved fallows were as a result of their ability to suppress weeds [20] and production of fast decomposing residues that release nutrients for subsequent crops. In crotalaria fallow, it is also likely that crotalaria's ability to fix nitrogen (ICRAF, 1996) increased maize yields in crotalaria fallow compared to continuous cropping or natural fallow system. Low or absence of weeds in the improved fallow land-use systems during first weeding improved maize yields because of lack of competition.

Effect of Phosphorus Application on Tree Biomass, Maize and Total Weed Biomass: Addition of phosphorus did not significantly increase the amount of tree biomass in both sites (Table 6). However, there was an increase of maize yield and weeds due to application of phosphorus (Table 7). The fallow tree may have had extensive rooting

Table 5: Maize yield at Osita and Khwisero during the 1998 'long' rain harvest

Farm site	Land use system	Maize yield (Kg ha^{-1})
Osita	Continuous maize	1233a
	Natural fallow	1482a
	Crotalaria fallow	3812c
	Tithonia fallow	2268b
	SED	326
Khwisero	Continuous maize	1674a
	Natural fallow	2532ab
	Crotalaria fallow	4111c
	Tithonia fallow	3092b
	SED	454

Note: Land use system with the same letter a long the column in each site means that they are not significantly different (P > 0.05) using LSD method of separating means

Table 6: The effect of phosphorus on total trees biomass at Osita and Khwisero farms

Farm site	Fallow species	Phosphorus rate	Tree biomass
		---------- kg ha^{-1} ----------	
Osita	Crotalaria fallow	0	13250ab
		50	8380b
	Tithonia	0	9000a
		50	11420a
Khwisero	Crotalaria fallow	0	6690a
		50	5350ab
	Tithonia	0	4200ab
		50	3280b

For each site, the column of tree biomass followed by the same letter are not significantly different at P < 0.05

Table 7: The effect of P on maize yield and total weed biomass at Osita and Khwisero farms

Farm (Site)	Fallow species	P rate	Maize grain yield	Weed biomass
		----------	Kg ha^{-1}	----------
Osita	Cont. maize	0	1040a	180a
		50	1430ab	280a
	Natural fallow	0	1140a	330a
		50	1340ab	570b
	Crotalaria fallow	0	3480de	190a
		50	4140e	270a
	Tithonia	0	2240bc	320a
		50	2790cd	290a
Khwisero	Cont. maize	0	1140a	190a
		50	2201abc	480a
	Natural fallow	0	1990ab	480a
		50	3080bcd	940b
	Crotalaria fallow	0	3140cd	970b
		50	5090e	1660c
	Tithonia	0	2680bcd	540a
		50	3500d	1030b

For each site, the column of tree biomass followed by the same letter are not significantly different at P < 0.05

systems that were able to extract soil nutrients well that resulted no effect of P on tree biomass. Plant needs phosphorus for growth, nuclear formation and cell division. Phosphorus is easily trans located with plants.

CONCLUSIONS

This study demonstrates that improved fallows that promote vegetative soil cover may reduce weed recruitment due to attenuation of soil temperature and shift in light quality at soil surface, which may decrease weed biomass and alter the number of weed species. This, therefore, offers farmers with an alternative method of controlling weeds while increasing soil fertility, thus giving higher maize yields among other benefits. Improved fallow of *Tithonia diversifolia* and crotalaria may decrease striga seed from the soil seed bank by encouraging seed germination hence lead to low striga weed and other noxious weeds like richardia. Improved fallows of long duration can control both noxious and economical weeds in Western Kenya. While P application may enhance weed biomass and induce a higher weeding frequency than normal for crops, the use of improved fallows with fast-growing trees in rotation with crops may mitigate this problem.

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