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Effect of *Lablab purpureus* L. cover crop and imidazolinone resistant (IR) maize on weeds in drought prone areas, Kenya

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ABSTRACT

Weeds compete for nutrients and soil moisture resulting to low maize yields in dry lands. A three year field study was initiated in 2009 at Kenya Agricultural and Livestock Research Organization, Kiboko to evaluate the effect of dolichos bean (*Lablab purpureus* L.) and open pollinated imazapyr herbicide coated imidazolinone-resistant (IR)[1] maize on weed species composition, density, and maize yield. Initially, weed species were identified, and then controlled using glyphosate at 1.6 kg ai ha^{-1}. Twenty four plots were marked, each measuring 4 × 5 m. Six treatments 1) IR-maize coated, 2) IR-maize coated + brown dolichos, 3) IR-maize coated + black dolichos 4) IR-maize uncoated, 5) IR-maize uncoated + brown dolichos, 6) IR-maize uncoated + black dolichos were laid out in a randomized complete block design replicated four times. IR-maize was planted at a spacing of 90 × 45 cm and 2 seeds per hole. Weeds were sampled from a one meter squared quadrat 21 and 42 days after planting (DAP). The data was subjected to analysis of variance using Genstat version 12.0. Eighteen (18) weed species were prevalent before the experiment. Interaction of dolichos and herbicide coated IR-maize had no significant ($P > 0.05$) effect on weed species composition and density. Dolichos significantly ($P < 0.05$) reduced the density of *Portulaca quadrifida* L. and *Paraknoxia parviflora* L., and increased *Eleusine indica* L. Weed species composition decreased by 14% (21 DAP) and 33% (42 DAP) in plots with dolichos compared to no cover. Maize yields were significantly ($P < 0.05$) higher in plots with dolichos than without. From the findings, this study recommends dolichos integration with coated IR-for weed management and increased maize yields in drylands.

1. Introduction

Worldwide, maize (*Zea mays* L.) produces the highest yields among cereals. The East and Central Africa (ECA) region produces an average yield of 1.8 t ha^{-1} (FAO, 2008). These yields are relatively low compared to the potential yield of 4.5–7.0 t ha^{-1} in ECA region (Mwangi et al., 2011). It is the most important staple crop in Kenya. It is an important cash crop vegetable (baby corn and green maize) and seed/grain. Maize is very sensitive to weeds in vegetative, reproductive and maturity growth stages. Maize planted in fields heavily infested with weeds resulted in substantial yield reductions even when rainfall is adequate (Abdin et al., 2000). Development in *Striga* weed management (Kabambe et al., 2008; Kanampiu et al., 2003, 2002) has indicated that imazapyr herbicide coated imidazolinone-resistant (IR-maize) seeds absorbed part of the herbicide from the coat. Absorbed herbicide moved systemically through phloem and xylem and controlled any attaching *Striga species*. Imazapyr slowly tightly binds onto Acetohydroxyacid synthase (AHAS) enzyme and inhibits synthesis of branched amino acids (leucine, valine and isoleucine) resulting to plant death from lack of needed proteins for growth (Muhitch et al., 1987). IR-maize is naturally resistant to imazapyr herbicide (an imidazolinone). The herbicide not absorbed by the seed diffused into the soil and killed *Striga* seeds in the soil. Apart from controlling *S. hermonithica*

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[1] Imidazolinone – resistant (IR) maize contains gene conferring tolerance to imazapyr an imidazole herbicide.

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species, it also left 2–5 cm surrounding maize clear of any weeds (Kabambe et al., 2008). The herbicide dissipating from coated maize seeds does not affect root zone of legume intercrops 15 cm from coated seeds (Kanampiu et al., 2003, 2002). Research (Shrestha et al., 2002) has indicated that many factors influence the weed community interaction. This has implications on weed density and diversity. The question is what is the effect of imazapyr coated IR-maize on weed species composition surrounding maize in a drought prone area under conservation agriculture? The objective of this study was therefore to evaluate the effect of dolichos and imazapyr herbicide coated IR-maize on weed composition, weed density and maize yield in Machakos County of Kenya.

2. Materials and methods

2.1. Study area

Field trials were conducted for two years (2009–2011) at Kenya Agricultural Livestock Research Organization (KALRO) Kiboko. This is a crops research Station located in Makindu Division, Makindu District in Makueni County. It is located 155 km from Nairobi along Mombasa highway, at latitude 2.15°S, longitude 37.75°E and altitude 975 m above sea level. It lies in agro-ecological zone (AEZ LM 5) (Roselt, 2011). Soils are classified as orthic ferralsols with a sandy clay loam texture in top 20 cm (according to FAO soil classification). The ecosystem has fragile soils. Soil tests prior to planting showed that the soil pH ranged from 7.3–8.3. The region has two wet seasons: a long rain season (March to May) and a short rain season (October to December); with an annual average rainfall of 600 mm based on more than 70 years Meteorological data, Makindu Station. Rainfall is erratic and unreliable. Infiltration rates vary from moderate to rapid. It has a potential evaporation of 2000 mm. It is a hot dry region with a mean annual temperature of 22.6 °C, mean annual maximum 28.6 °C and mean annual minimum of 16.5 °C (Roselt, 2011).

2.2. Plant materials

Imazapyr herbicide coated IR – maize (Imazapyr 30 g ha^{-1}) open pollinated variety (OPV) (WS 303) and uncoated IR – maize (*cv.* 303) was obtained from Western Seed Company. Black dolichos (*var.* HB 1002) and brown dolichos (*var.* Rongai) were obtained from KALRO seed unit.

2.3. Treatments and experimental design

To prepare the site in 2010, weeds were identified, slashed and glyphosate applied at 1.6 kg ai ha^{-1} (equivalent of 400 ml per 20 L) using a knapsack sprayer with a low volume nozzle to control emerged weed seedlings.

Twenty four (24) plots were demarcated, each measuring 4 × 5 m and furrows made at a spacing of 90 cm. There were six (6) treatments 1) IR-maize coated, 2) IR-maize coated + brown dolichos, 3) IR-maize coated + black dolichos 4) IR-maize uncoated, 5) IR-maize uncoated + brown dolichos, 6) IR-maize uncoated + black dolichos. These treatments were laid out in a randomized complete block design (RCBD) and replicated four times to minimize variability between and within plots. Maize was planted at a spacing of 90 × 45 cm and 2 seeds per hole. In the cover crop treatments, two rows of dolichos were planted between two rows of maize with intra-row spacing of 45 cm. During planting, compound fertilizer (NPK 23:23:0) was applied at 60 kg ha^{-1} P_2O_5 (equivalent to 13.8 kg N ha^{-1} and 6.02 kg P) respectively. After planting, all treatments were irrigated for 3 h to field capacity (320–355 mm) and after every 3 days (at uniform intervals) between 6.00 pm and 6.00 am. This ensured adequate water expected to dissipate herbicide from coated IR-maize and meet water requirements for increased yield. All treatments were top-dressed with fertilizer nitrogen (N) applied at 31.2 kg N ha^{-1} as calcium ammonium nitrate (CAN 26% N) fertilizer at 120 kg ha^{-1} 21 days after planting (DAP). The treatments were not weeded manually. The experiment was repeated in the same plots in 2011.

2.4. Data collection

2.4.1. Determination of interaction effect of herbicide coated IR-maize and cover crops on weed species composition

Weed species composition and density assessments were done 21 and 42 DAP. A meter squared quadrat was placed randomly in each plot. Within the quadrat growing weed species were identified, counted and recorded. Blocking, replicating and randomizing treatments were expected to minimize variability in the field.

2.4.2. Determination of effects of herbicide coated IR-maize and cover crops on maize yield

At physiological maturity, two middle rows out of the five maize rows were harvested. The whole maize plant was cut from ground level, tied with sisal twine, weighed using a spring balance and weight recorded, ears were counted, and cobs weight recorded. Thereafter, maize was shelled and grain dried to an average moisture content of 12.5% and weighed using top load balance. Three grain moisture readings per sample were taken using a multigrain moisture meter and their average moisture content recorded. Yield (at 12.5% grain) = Grain yield x (100-actual grain moisture %)/87.5 (Badu-Apraku et al., 2012).

2.5. Data analysis

Effect of herbicide coated IR-maize and cover crops on weed species composition was compared 21 and 42 DAP in 2010 and 2011. The data for weed and maize were subjected to Analysis of variance (ANOVA) using GenStat statistical package, Version 12.0. Where treatment effects were significant, further analysis (logical comparisons and contrasts of means) was done using Student Newman Keuls (S–N–K) test at 5% significance level.

3. Results

3.1. Effect of interaction among herbicide coated IR-maize, cover crops and time on weed species composition

A total of 18 weed species formed the composition in the field before trials were established. Majority (15 species) were broadleaf while 3 species were grasses. Annual broadleaf dominated (12 species), perennial broadleaf were few (3 species) while the annual grasses were 3 species. The effect of herbicide coated IR-maize and cover crops on weed species composition and weed density (count m^{-2}) was evaluated 21 and 42 DAP.

The ANOVA result showed that there was no significant ($P > 0.05$) interaction effect among the herbicide coated IR-maize, cover crops and time on the weed species composition (count m^{-2}). The number of species (count m^{-2}) was not influenced by treatment. In addition, the ANOVA showed that there was no significant ($P > 0.05$) interaction effect among the herbicide coated IR-maize, cover crops and time on weed density (count m^{-2}).

Further ANOVA on individual weed species showed that the interaction among herbicide coated IR-maize, cover crops and time had a significant ($P < 0.05$) effect on *Boerhavia diffusa* L. and *Eleusine indica* L. The effects were weed species specific.

3.1.1. Effect of herbicide coated IR-maize, cover crops and time (Days after Planting-DAP) on B. diffusa

The density of *B. diffusa* was significantly ($P < 0.05$) lower in plots with coated IR-maize and cover crop than in uncoated IR-maize and no cover crops 21 DAP. The density of *B. diffusa* in herbicide coated IR-maize plots decreased with time (from 21 to 42 DAP) compared to uncoated IR-maize.

3.1.2. Effect of interaction of herbicide coated IR-maize and cover crops on E. indica

The interaction between herbicide coated IR-maize and dolichos cover crops significantly ($P < 0.05$) increased the annual grass weed *E. indica*. Plots having herbicide coated-IR-maize and cover crop had significantly ($P < 0.05$) higher density of *E. indica* compared to coated IR-maize alone. The density of *E. indica* was higher in uncoated IR-maize with no cover crop compared to coated IR-maize with no cover. The dolichos shading effect reduced the effects of herbicide coat on *E. indica*. The density of *E. indica* was significantly ($P < 0.05$) different across the treatments (Fig. 1).

3.2. Effect of herbicide coated IR-maize on weed species composition

ANOVA showed there was no significant ($P > 0.05$) effect of the herbicide coated IR-maize on weed species (count m^{-2}). However, the weed species composition varied across treatments.

3.3. Effect of cover crops on the weed species (count m^{-2}) in the composition

ANOVA showed there was no significant ($P > 0.05$) effect of the dolichos on the weed species (count m^{-2}) 21 and 42 DAP. However the weed species varied across treatments. Further ANOVA on dolichos effects on individual weeds showed significant ($P < 0.05$) effects on three weed species, *P. quadrifida* L., *P. parviflora* (Stapf ex Verdc.) and *E. indica*. Dolichos effect significantly ($P < 0.05$) reduced the density (count m^{-2}) of two annual broadleaf weed species (*P. parviflora* and *P. quadrifida*) and significantly ($P < 0.05$) increased one annual grass (*E. indica*) (Table 1).

3.4. Effect of time on weed species composition

ANOVA showed that time (DAP) had a significant ($P < 0.05$) effect on the number of weed species (count m^{-2}). There were more species (7.3 count m^{-2}) 21 DAP compared to 5.5 count m^{-2} 42 DAP (Fig. 2).

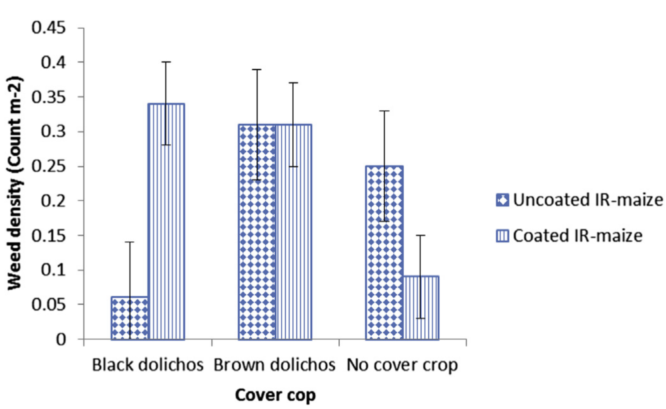

Fig. 1. Effects of Imazapyr herbicide coated IR-maize and cover crop on mean density (count m^{-2}) of *Eleusine indica* L.

Table 1
Effect of cover crop on the mean density (count m^{-2}) of *Portulaca quadrifida L.*, *Paraknoxia parviflora* (Stapf ex Verdc.) and *Eleusine indica* L. Gaertn.

Weed species	Weed species mean density (count m^{-2})			
	Black dolichos	Brown dolichos	No cover crop	SE
P. quadrifida	0.23	0.06	0.38	0.08
P. parviflora	5.63	6.09	12.02	1.74
E. indica	0.20	0.31	0.17	0.05

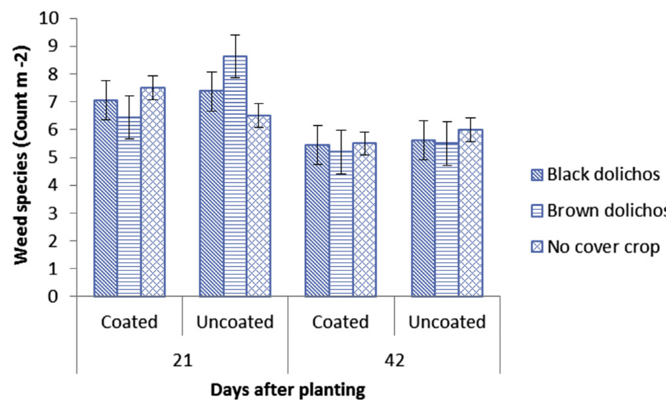

Fig. 2. Diversity of weed species (count m^{-2}) 21 days after planting (DAP) compared to 42 DAP.

3.4.1. Effect of time (days after planting) on individual weed species in 2010 and 2011

Further ANOVA on effect of time on individual weed species showed there was a significant ($P < 0.05$) effect on the density (count m^{-2}) of 10 annual weed species (*Bidens pilosa*, *B. diffusa*, *Euphorbia hirta*, *P. parviflora*, *Oxygonum sinuatum*, *Sonchus oleraceae*, *Tridax procumbens*, *Trichodesma zeylanicum*, *Dactyloctenium aegyptium* and *E. indica*). Majority (8) of the species were broadleaf while (2) were grasses. The weed species density (count m^{-2}) 21 and 42 DAP in 2011 were significantly higher than 2010 respectively except for *D. aegyptium*, *E. indica* and *O. sinuatum* (Table 2).

3.5. Effects of herbicide and cover on maize yields (kg ha^{-1})

ANOVA showed that there was no significant ($P > 0.05$) interaction effect between herbicide and cover crop on maize yield (kg ha^{-1}); however yields differed between 2010 and 2011.

3.6. Effect of herbicide coat on IR-maize yields (kg ha^{-1})

ANOVA showed there was a significant ($P < 0.05$) effect of herbicide coat on mean IR-maize grain yield (kg ha^{-1}). Herbicide coated IR-maize had significantly ($P < 0.05$) less grain yield (kg ha^{-1}) than uncoated IR-maize (Table 3).

3.7. Effect of cover crops on IR-maize yields (dry grains in kg ha^{-1})

ANOVA showed that dolichos had a significant ($P < 0.05$) effect on IR-maize grain yields and components (kg ha^{-1}). Dolichos significantly ($P < 0.05$) increased grain yields in herbicide coated IR-maize compared to no cover crops which had the lowest grain yield (kg ha^{-1}) in 2010 and 2011 respectively (Table 3).

Table 2
The mean density of weed species present 21 and 42 DAP in 2010 and 2011.

Time		Weed species mean density rank									
Year	DAP	BP	BD	DA	EI	EH	OS	PP	SO	TP	TZ
2010	21	0.75[c]	0.47[a]	19.33[a]	0.42[a]	0.61[b]	0.42[a]	0.81[c]	0.17[b]	0.17[b]	0.19[b]
	42	0.69[c]	0.47[a]	3.75[b]	0.53[a]	0.47[b]	0.36[b]	0.81[c]	0.14[b]	0.14[b]	0.11[b]
2011	21	34.78[a]	3.78[a]	0.53[b]	0.0[b]	6.14[a]	0.0[c]	8.44[b]	4.14[a]	4.14[a]	54.81[a]
	42	3.19[b]	0.58[a]	0.53[b]	0.0[b]	1.06[b]	0.0[c]	19.86[a]	1.36[b]	1.36[b]	9.03[b]

Means in the same column followed by the same superscript letter do not significantly differ at ($P < 0.05$) according to Student Newman Keuls test.
Key: DAP = Days after planting, BD = *Bidens pilosa*, BD = *Boerhavia diffusa*, DA = *Dactyloctenium aegyptium*, EI = *Eleusine indica*, EH = *Euphorbia hirta*, OS = *Oxygonum sinuatum*, PP = *Paraknoxia parviflora*, SO = *Sonchus oleraceae*, TP = *Tridax procumbens* and TZ = *Trichodesma zeylanicum*.

Table 3
Comparing maize yield (grain and components kg ha^{-1}) in 2010 and 2011.

	Maize dry matter (t ha^{-1})		Ears (count ha^{-1})		Ears weight (t ha^{-1})		Grain yield (t ha^{-1})	
	2011	2010	2011	2010	2011	2010	2011	2010
No cover uncoated	6.3[a]	4.2[a]	27,625[a]	28,920[a]	3.4[a]	2.4[b]	3.0[a]	2.0[b]
Black dolichos uncoated	5.8[ab]	6.5[a]	25,875[a]	27,094[a]	3.4[ab]	3.9[a]	2.9[ab]	3.3[a]
Brown dolichos uncoated	5.4[ab]	4.7[ab]	26,625[ab]	27,880[ab]	3.2[ab]	2.6[b]	2.6[ab]	2.2[ab]
Black dolichos coated	4.9[bc]	6.2[a]	21,125[bc]	22,120[bc]	2.7[bc]	3.9[a]	2.3[bc]	2.5[ab]
Brown dolichos coated	4.0[c]	5.5[ab]	19,875[c]	20,812[c]	2.2[c]	3.1[ab]	1.9[c]	2.5[b]
No cover coated	2.0[d]	1.4[c]	18,706[d]	19,588[d]	1.2[d]	0.8[c]	0.9[d]	0.6[c]
CV %	14.9	25.4	14.8	14.8	17.4	27.9	19.5	25.8

Means in the same column followed by the same superscript letter are not significantly different at 5% significance level according to Student Newman Keuls.

4. Discussion

4.1. Effects of herbicide coated IR-maize and cover crops on weeds

The interaction effect of treatments on number of weed species was not significant probably because the effect was weed specific, meaning that it increased some species while it decreased others which may have resulted to equal count m^{-2}. The interaction effect of herbicide coated IR-maize and dolichos significantly ($P < 0.05$) increased the density of *E. indica* (0.31) compared to uncoated IR-maize alone (0.17) implying that probably dolichos biomass accumulation supported the growth of *E. indica*. *E. indica* a small seeded weed showed intensive resource uptake capacity overtaking slow growing dolichos resulting higher density probably due to greater early dependence on external soil nutrient sources. In addition *E. indica* has a large absorptive area per unit mass compared to *P. quadrifida* and *P. parviflora*, whose density was reduced by cover crops. This could explain why dolichos significantly ($P < 0.05$) increased *E. indica* density compared to no cover crop.

Dolichos reduced the number of weed species (count m^{-2}) by 33% at 42 DAP and 14% 21 DAP compared to no cover implying that the more live cover crop vegetation which had accumulated was more effective in inhibiting light mediated germination. This is because it lowers red to far red ratio of light as Teasdale and Mohler (1993) have reported. The number of weed species (count m^{-2}) observed 21 and 42 DAP could hence be attributed to seed longevity, species specific germination patterns and other complex processes that contribute species shifts over time as reported (Higginbotham et al., 2000; Shrestha et al., 2002).

This study showed that *B. pilosa*, *B. diffusa*, *E. indica*, *E. hirta*, *P. parviflora*, *S. oleraceus*, *T. procumbens* and *T. zeylanicum* density was not significantly different 21 and 42 DAP, however weeds were more stunted 42 DAP compared to 21 DAP in 2010. This implies that probably dolichos canopy cover 42 DAP physically blocked sunlight resulting to stunted weeds, but same density. Under the dolichos shading effects 42 DAP, *O. sinuatum* density increased probably because it had more seed mass which supported its growth requirements meaning that 1) dolichos effect 42 DAP was weed species specific 2) stunting of weeds indicates a possible loss of species potential to reproduce over time 3) and reduced speed at which weed patches could expand across the field as Fabian (2008) has indicated. This study showed that shading effect contributed to suppression of *P. parviflora* and *P. quadrifida* (which were the most prominent) implying that given adequate time, dolichos cover crop could effectively manage weeds in the maize field.

This study has shown that use of cover crops/plant residue mulches, increased maize yields differentially (much more for uncoated IR-maize than coated maize) probably implying that weeds had more negative effect on coated-IR than uncoated before they were suppressed. Probably weeds could be characterized, their differential responses used innovatively so that weeds/residues will benefit maize. This requires evaluation of target weed species within a smaller area (0.25 m^{-2}) where coated IR-maize apparently had effect compared to 1 m^{-2} quadrat assessed in controlled experiment.

4.2. Effects of coated IR-maize and dolichos cover crop on maize yields

Uncoated IR-maize with black dolichos produced significantly ($P < 0.05$) higher yields than with brown dolichos probably due to the high black dolichos biomass (10–22 t ha^{-1}) and additional leaf litter (1.7 t ha^{-1}). The implication is heavier canopy had more weed suppression compared to low brown dolichos biomass (4–10 t ha^{-1}) and foliage droppings dry matter (0.7 t ha^{-1}). In addition, foliage droppings could have contributed to mulching and improved soil water retention contributing to increased maize yield. Coated IR-maize with no cover crop plots were covered by weeds dry matter (0.3 t ha^{-1}) and had the lowest grain yield in both 2010 and 2011. This implies that weeds were more competitive than herbicide coated IR-maize hence depressed yields. In addition, the study found that freshly coated IR-maize produced higher dry grain yields in 2010 compared to same seed planted in 2011. This implies that other than weed management factor, planting reserved herbicide coated IR-maize seeds (from 2010 season) contributed to reduced yield potential hence the low yields in 2011 compared to 2010.

In 2011, yield increase in uncoated maize could be associated to ecological benefits including reduced moisture loss and water runoff hence more infiltration (Gachene and Mwangi, 2006; Karuma et al., 2011). With no dolichos, the weed species consequently formed residue mulch (after they were desiccated with glyphosate) and increased yields. This implies that weeds formed a valuable ecosystem component that could be tapped to provide services complementing those of cover crops to increase maize yield as indicated (Bivadar, 2012). The high yields from uncoated IR-maize with no dolichos in 2011 implies that use of prevalent weed species could contribute to an appropriate weed management plan (Schonbeck, 2012).

5. Conclusion

This paper shares knowledge on the effects of integrating dolichos with herbicide coated IR-maize on the number of weed species, weed density and maize yields. The study demonstrated that the weed density was significantly ($P < 0.05$) higher in 2011 than 2010, and significantly ($P < 0.05$) more 21 DAP than 42. In addition, weed species were more 21 DAP than 42 DAP. This was probably due to management effects, inherent differences in species, and environment (soil and water). The interaction effects of coated IR-maize and dolichos were weeds' species specific (increasing or decreasing some weed count m^{-2}). Dolichos reduced the density of *P. parviflora* and *P. quadrifida* while it increased *E. indica 42* DAP.

Dolichos significantly increased herbicide coated and uncoated IR-maize grain yield than no cover. Black dolichos significantly increased IR-maize yields (uncoated/coated) more than brown and no cover respectively, and contributed to sustained increase in yields. With no dolichos coated IR-maize yield reduced by 25% $year^{-1}$. Uncoated IR-maize yield increase (with dolichos or weed residue mulch) in 2011 demonstrated that weed residue mulch is a resource that could supplement cover crops. The question is could all weed species contribute equally to increase maize yield?

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References

Abdin, O.A., Zhou, X.M., Cloutier, D., Coulman, D.C., Faris, M.A., Smith, D.L., 2000. Cover crops and interrow tillage for weed control in short season maize (*Zea mays* L.). Eur. J. Agron. 12, 93–102.

Badu-Apraku, B., Fakorede, M.A.B., Menkir, A., Saogo, D., 2012. Conduct and Management of Maize Field Trials. IITA, Ibadan, Nigeria, 59 pp. ISBN 978-978-8444-02-2. Available at. www.iita.org/c/document_library/get_file?.

Bivadar, S.R., 2012. Green weeds as a source of manure used for production of maize vegetation. Int. J. Sci. 1 (1), 46–48.

Fabian, D.M., 2008. Weed Seed Bank Dynamics and Integrated Management of Agricultural Weeds. A self-learning Research from Montana State University Extension guide. Mont guide pdf. www.msuextension.org.

Food and Agriculture Organization, (FAO), 2008. Investing in Sustainable Agricultural Intensification. The Role of Conservation Agriculture.

Gachene, C.K.K., Mwangi, H.W., 2006. Green manure/cover crops for soil erosion control and conservation agriculture in Central and Eastern Highlands of Kenya. In: Joseph, G.M., Jane, W.W., Charles, K.G., Marjatta, E. (Eds.), Enhancing Agricultural Productivity in East Africa. Kenya Agricultural Research Institute, pp. 145–170. KARI/LRNP ISBN 9966-879-71-4.

Higginbotham, S., Leake, A.R., Jordan, V.W., Ogilvy, S.E., 2000. Environmental and ecological aspects of integrated, organic and conventional farming systems. Asp. Appl. Biol. 62, 15–20.

Kabambe, V.H., Kanampiu, F., Ngwira, A., 2008. Imazapyr (herbicide) seed dressing increases yield, suppresses *Striga asiatica* and has seed depletion role in maize (*Zea mays* L.) in Malawi. Afr. J. Agric. Biotech. 7 (18), 3293–3298.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K., Gressel, J., 2003. Multi-site, multiseason field tests demonstrate that herbicide seed coating herbicide-resistance maize controls *Striga spp*. and increases yields in several African countries. Crop Prot. 22, 697–706. Elsevier Science.

Kanampiu, F.K., Ransom, J.K., Dennis, F., Gressel, J., 2002. Imazapyr and pyrithiobac movement in soil and from seed coats to control *Striga* in legume intercropping. Crop Prot. 21, 611–619. Elsevier Science.

Karuma, A., Gachene, C.K.K., Gicheru, P.T., Mwang'ombe, A., Mwangi, H.W., Clavel, D., Verhagen, J., Von Kaufmann, R., Francis, J., Ekaya, W., 2011. Effects of legume cover crops and subsoiling on soil properties and Maize (*zea mays* L.) growth in semi-arid area of Machakos District Kenya. Trop. Subtrop. Agroecosyst. 14, 237–243.

Muhitch, M.J., Shaner, D.L., Stidham, M.A., 1987. Imidazolinones and acetohydroxyacid synthase from higher plants. Properties of the enzyme from maize suspension culture cells and evidence for the binding of imazapyr to aceto hydroacid synthase invivo. Plant physiol. 83, 451–456.

Mwangi, H.W., Mgonja, F., Admassu, H., Opio, F., Rwomshana, I., Karau, J., Kimani, V., 2011. Up Scaling of Soil Water Management Technologies and Drought Tolerant Varieties for Increased Maize Productivity in ECA Countries. Availablewww.asareca,org/resources/reports/ASARECAGApaper.2011.pdf.

Roselt, 2011. Kibwezi-Kiboko Observatory Baseline Progress Report. L'Observatoire du Sahara et du Sahel (OSS). Roselt.www.oss-online.org/sites/…/05.pdf. 69pp. Downloaded 10-6-2014.

Schonbeck, M., 2012. Twelve Steps towards Ecological Weed Management. Available Online: In. www.extension.org/paper/18539-in-twelve-steps-toward-ecological-weed-management-in-organic-vegetables. Downloaded on 12-04-2013.

Shrestha, A., Knezevic, S.Z., Roy, R.C., Ball-Coelho, B.R., Swanton, C.J., 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. Eur. Weed Res. 42, 76–87.

Teasdale, J.R., Mohler, C.L., 1993. Light transmittance, soil temperature and soil moisture under residue of hairy vetch and rye. Agron. J. 85, 673–680.