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Full Length Research Paper

P Application And Intercropping Of Maize And Sorghum With Lupinus Albus Inhibits Striga Hermonthica Emergence And Arbuscular Mycorrhiza Fungal Colonization

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Abstract

Recent data suggest a direct correlation between low soil phosphorus, arbuscular mycorrhiza fungi colonization and high *Striga* infestation due to production of *Striga* germination stimulants by the host plant. In this work, we investigated the tri-partite interaction between *Striga*, AMF, and host crops – maize and sorghum in the following experiments. i) The effect of applying P, and cultivation with AMF species on sorghum and maize cultivars that are either tolerant or susceptible to *Striga hermonthic*a, ii) the effect of inter-cropping maize or sorghum with a P fixing legume – *Lupinus albus* on *Striga* infestation in naturally and artificially *S. hermonthic*a infested soils. We report that colonization by either *Glomus mosseae or G. intraradicus* AMF species was inversely proportional to P application in both *Striga* sensitive and tolerant cultivars. In addition, low P negatively affected plant biomass accumulation while adequate P application at 31ppm leading to increased plant biomass. Phosphorous levels between 77 and 102 ppm inhibited biomass accumulation in both maize and sorghum irrespective of whether the cultivars were susceptible or tolerant to *S. hermonthic*a. Maize intercropped with *L. albus* revealed higher biomass accumulation and less *Striga hermonthic*a emergence. From this study, the control of parasitic plants can potentially be achieved by manipulating P levels to generate low germination stimulant producing crops that do not 'attract' *Striga* by either *L. albus* intercropping or artificial P application. Integrated *S. hermonthica* management in sorghum and maize and indicate that P manipulation through either artificial P application or intercropping with P efficient plants like *L. albus*, could stimulate plant growth, suppress *S. hermonthic*a emergence and affect abundance and persistence of AMF.

Key words: Sorghum, Maize, arbuscular Mychorrhiza fungi, Phosphorus, *Orobanche*, *Lupinus albus*

INTRODUCTION

Poor soil fertility and *S. hermonthic*a (Del.) Berth are major constraints to optimum cereal production in Sub-Saharan Africa (SSA) (Berner et al. 1995; Ejeta 2007). Phosphorus (P), is an essential plant nutrient but very sparingly accesible in Kenyan soils (Okalebo et al. 2006; Sanchez 2002). The problem of low P in soil is further exacerbated because maize and sorghum are poor in P mobilization in the rhizosphere and this result in P deficiency symptoms that have been positively correlated with heavy *S. hermonthica* infestation in the field (Duff et al. 1994; Estabrook and Yoder 1978; Yoneyama et al. 2007). Application of mineral fertilizers is unaffordable to the majority of resource-poor farmers and hence not an option for remedying to the low P levels in soils in the

region (Odongo and Abayo 1999). Colonization of cereals with arbuscular mycorrhiza fungi (AMF) is known to improve plant access to P in the soil and some earlier studies have simultaneously associated AMF colonization with production of root exudates containing *Striga* germination induction chemical volatiles known as strigolactones (Yoneyama et al. 2007). Another possible mechanism for making P available to crop plants is intercropping with high P mobilizing plants. The white lupin (*Lupinus albus L*), a non mychorrhizal legume exhibits high level of success in P deficient habitats due to its ability to secrete copious amounts of acid phosphatases that mobilize/liberate inorganic phosphate from organic and sparingly inorganic compounds (Duff et al. 1994; Tadano and Sakai 1991; Vance et al. 2003). To date, the response of *Striga* tolerant and susceptible maize and sorghum cultivars to different AMF strains at different soil P levels has not been determined in Kenya. Such a study could provide useful information on biotic-abiotic interaction of these cultivars with native AMF isolates and P levels. *Lupinus albus* was found attractive in this study because : i) it has remarkable tolerance to P deficiency, ii) it is a legume and so a good candidate for improving soil Nitrogen content, and iii), it can be used as fodder and also for human consumption (Sujak et al. 2006). It was hypothesized that if *L. albus* is intercropped with maize, it could possibly improve the nutrition status of maize in P deficient soils and that low *S. hermonthica* germination may be recorded as a ripple effect. In general this study aimed at:- i) Investigating AMF infection rates in *Striga* susceptible and tolerant maize and sorghum cultivars at different P application rates ii) Determining suppression, if any, of *S. hermonthica* infestation by *L. albus* intercropping with maize and sorghum.

Materials And Methods

Description of plant materials and Arbuscular mycorrhiza fungi

A susceptible maize cultivar H514 and a tolerant maize cultivar KSTP' 94 were used. For sorghum the susceptible cultivar was CRN335 while the tolerant one was SRN 39. All the sorghum cultivars were provided by Dr. Santie De Villiers of ICRISAT-Nairobi while the maize cultivars KSTP 94 and 514 were purchased from Simlaw seed store in Nairobi-Kenya and Kakamega research station Kenya respectively. *Striga hermonthica* seeds were collected from Kibos research station Kenya. *Lupinus albus* seeds were provided by Prof. Doug Huggh of Plant and Environmental Sciences Department, University of California-Davis USA. The inoculum for two pure AMF isolates *Glomus mosseae* and *G. intraradices* were obtained from Dudu Tech Kenya Limited.

Plant growth conditions

This experiment was conducted in a Biosafety Level II glass house in the Plant Transformation Laboratory at Kenyatta University, Kenya. The design was a Randomized Complete Block Design as follows, Sorghum or maize (tolerant or resistant) were planted into pots treated with P in the form of Di Ammonium Phosphate (DAP) at the rates of 0, 2.5, 5 or 10g. About 1500 spores of either *Glomus mosseae* and *G. intraradices* were independently inoculated in separate pots with sterile soil. Sterile soil was purchased from Kenya Plant Health Inspectorate Service-Nairobi Kenya. The soil comprised of autoclaved forest soil mixed with course sand and ballast in the ratio soil 1:1:1 respectively. The soil was well homogenized with spores and fertilizer. Four seeds of either sorghum or maize were planted per pot. The seeds were thinned to one per pot at 28 days after planting. Calcium Ammonium Nitrate (CAN) a nitrogen fertilizer was applied in all pots at the rates of 2.5g/pot at 28 days after planting.

Determination of soil fertility level at Planting

One kilogram of soil sample treated with 0, 2.5, 5 or 10g of DAP fertilizer were sampled from each treatment before planting. On soil analysis for P level at Kenya Agricultural Research Institute at the National Agricultural Research Laboratories in Nairobi these p application rates translated into 2, 31, 77 and 102 ppm.

Measurements of Plant performance

To measure biomass, a destructive harvest method was applied at 90 days after planting. Plant height was taken from the first node to the tip of the plant shoots. The plants were then separated into shoot and roots. A random sample of fine roots was collected more or less equally from each replicate for AMF colonization scoring. Plant roots and shoots were separately packed in paper bags for oven drying at 70 ^{o}C for 7 days or until constant dry weight was obtained before weighing.

Determination of Mycorrhiza colonization

To determine if AMF colonization and P availability are closely linked, the random sample of fine roots previously collected was analyzed. The roots were washed and rinsed in several changes of tap water. Roots were soaked in ten percent KOH was added and left at 90 ^{o}C for one hour in oven. The roots were then acidified in 1% HCL for 5 minutes. The HCL was decanted and 0.05% trypan blue in lacto glycerol added and allowed to simmer at 80 ^{o}C for 10 minutes. The stain was decanted. Root pieces were then stored in glycerol acidified with a few drops of HCL until they were examined for the presence or absence of mycorrhizae within 14 days. In case the roots were highly pigmented, after KOH treatment, alkaline hydrogen peroxide was added and roots put in

oven (Phillips and Hayman 1970). The roots were assessed for mycorrhizae by placing root pieces on glass slide followed by application of few drops of glycerol and covering with a cover slip. Presence or absence of external hyphae, vesicle or arbuscles was examined using the slide method (Mcgonigle et al. 1990). Arbuscular mycorrhiza fungi colonization was determined by estimating overall root colonization by internal hyphae, external hyphae, vesicles or arbuscles as a percentage of the entire roots area (Mcgonigle et al. 1990).

Effect of *Lupinus albus* on maize biomass and *Striga hermonthica* emergence

To test the effect of *L. albus* on maize and on *S. hermonthica* emergence, a pot experiment was designed with non *S. hermonthica* infested soil from Kenya Plant Health Inspectorate Service-Nairobi Kenya and *Striga* infested soil from Alupe in Western Kenya. For the non *S. hermonthica* infested soil, soil was infested with about 5 grams (approximately 1000 seeds) *S. hermonthica* seeds in pots where either maize H514 only or maize and *L. albus* intercrop were to be planted. The pots were watered daily for one week before planting to precondition the *S. hermonthica* seed for germination. This experiment was performed using four replicates per treatment. Non-intercropped maize acted as the control. Data on maize height and number of emerged *S. hermonthica* was collected at 90 days after planting. The data analysis was performed using Statistical Analysis Software (SAS) package. Data was subjected to Analysis of Variance and means separated using Standard Error. Confidence limits were set at over 95% ($P<0.05$).

Results

Soil analysis of the 0, 2.5, 5 and 10gms P application rates translated into 2, 31, 77 and 102 ppm of soil P respectively. In both maize and sorghum P application significantly ($P=0.0001$) affected plant height, root weight, Shoot weight and AMF colonization (Figures 1 to 4). An ANOVA on sorghum data revealed P level significantly ($P=0.0001$) affected plant height, root weight, shoot weight and AMF colonization. AMF colonization also differed significantly ($P=0.05$) between sorghum cultivars as well as at different P application rates (Figures 2 and 4). In the absence of artificial P application, AMF fungi colonized both maize and sorghum at higher rates and the responsiveness was inversely related to the soil P level for both susceptible and tolerant maize and sorghum cultivars. Such response cut across the two AMF isolates used (Figure 1 to 4). For instance, At 0 P application *Glomus mosseae* colonized maize cultivar KSTP 94 up to 83.75% but this dropped to 70% when it came to cultivar H514. *Glomus mosseae* colonization dropped to below 2.5% when P levels were 31ppm applied as 2.5g of DAP. The *Glomus mosseae* colonization with higher P application at 77 ppm and 102 ppm levels were 7.5% and 0% respectively (Figures 1 and 2).

For sorghum, *Glomus mosseae* retained the same trend as maize and revealed 83.75% colonization in cultivar SRN 39 and 72.5% colonization in CRN335 at 2 ppm of P. At 31ppm P level, SRN 39 recorded 35.5% while 8% colonization was recorded in CRN335. The *G. mosseae* colonization at 77 and 102 ppm P fell between 11% and 0% respectively in sorghum although the drop was less gradual than what was observed in maize colonized with *G. mosseae* (Figure 1 and 2). Contrary to the results reported with *G. mosseae* colonization, *G. intraradices* was less infective on both tolerant and susceptible maize and sorghum cultivars. At 2 ppm of P KSTP 94 recorded 75.5% colonization, while H514 recorded 78% colonization. At 31ppm P level AMF colonization dropped from 35% to 0% in maize cultivars H514 and KSTP 94 respectively. Interestingly for this AMF species, there was an increase in KSTP 94 to about 3.33% although it finally dropped to 0% in both sorghum cultivars at 102 ppm of P. The fall in the colonization of maize was sharper in *G. intraradices* than *G. mosseae*. For sorghum, SRN 39 and CRN 335 recorded 30 and 33.3 % colonization at 2 ppm P respectively. The colonization fell to 0 and 2.5 % for SRN 39 and CRN335 respectively. At 77 ppm the colonization unexpectedly increased to 8.75% and 7.5% for SRN 39 and CRN 335 respectively. At this stage a lot of variation was seen as evidenced by the mean standard error bars. No *G. intraradices* colonization was observed in sorghum and maize at 102 ppm (Figure 3 and 4). The AMF features scored included vesicles, arbuscules, intercellular hyphae, external hyphae and internal hyphae. The dominant features were the vesicles.

In the *L. albus* maize intercrop experiment the pots without *L. albus* recorded significantly higher numbers of *S. hermonthica* emergence. Twelve and nine *S. hermonthica* plants were the highest and lowest respectively to emerge from maize pots with naturally infested soil. This was contrary to what was recorded in pots where maize was intercropped with *L. albus*. In *L. albus* intercropped pots the lowest *S. hermonthica* emergence was 0 while the highest was 4 (Figure 5 A). For artificially infected soils, the highest and lowest *S. hermonthica* emergence was in pots planted with maize only and were 14 and 10 respectively. Pot with maize and *L. albus* intercrop recorded arrange of 1 - 4 *S. hermonthica* plants (Figure 5B). Maize plants intercropped with *L. albus* visually appeared healthier and taller compared to those grown in pots without *L. albus* and this result was evident in both artificially and naturally *S. hermonthica* infested/inoculated pots (Figure 6A to D).

Discussion

In this study P level affected AMF colonization in both sorghum and maize. The poor performance at low P level in maize and sorghum could have been due to P

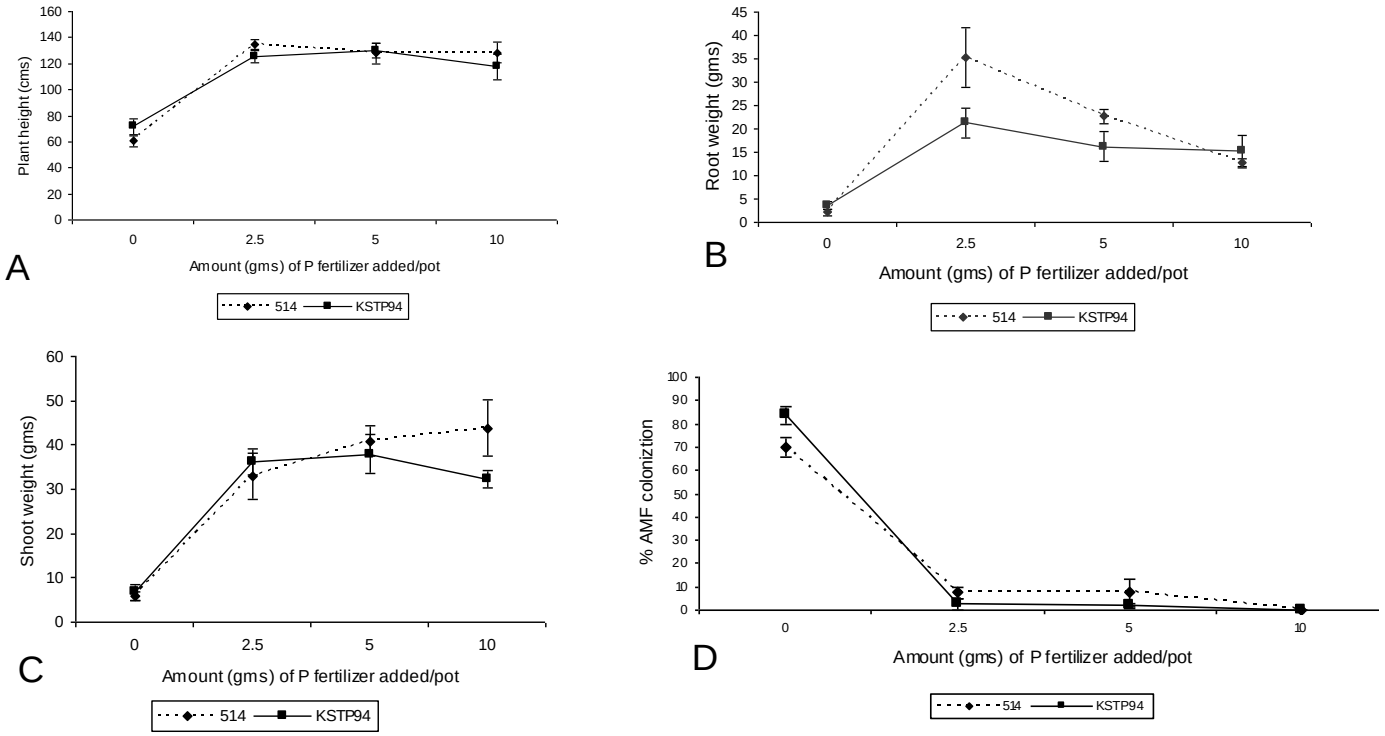

Figure 1. Effect of P levels and *G. mosseae* on growth parameters in *Striga* tolerant and susceptible maize. A. Plant height B. Root weight C. Shoot weight D. Percentance *G. mosseae* colonization. Bars represent standard error means.

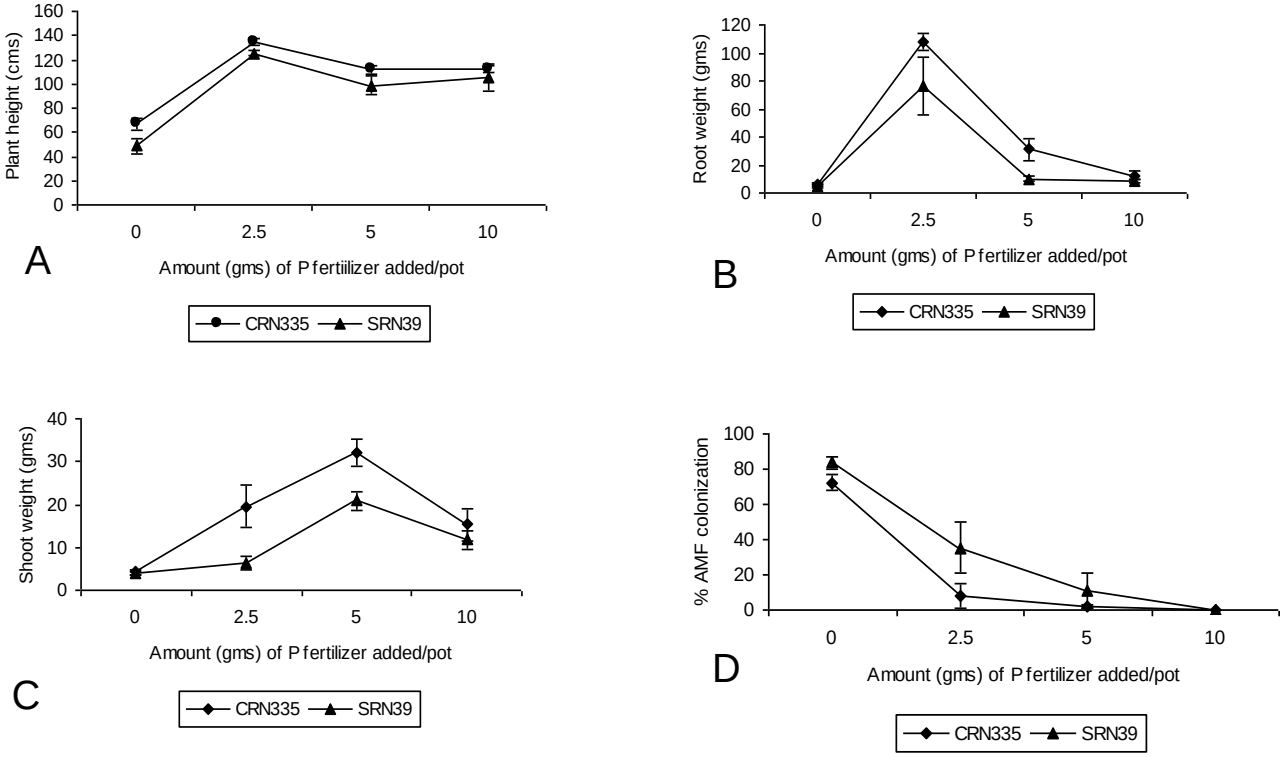

Figure 2. Effect of P levels and *G. mosseae* on growth parameters in *Striga* tolerant and susceptible sorghum. A. Plant height B. Root weight C. Shoot weight D. Percentage *G. mosseae* colonization. Bars represent standard error means.

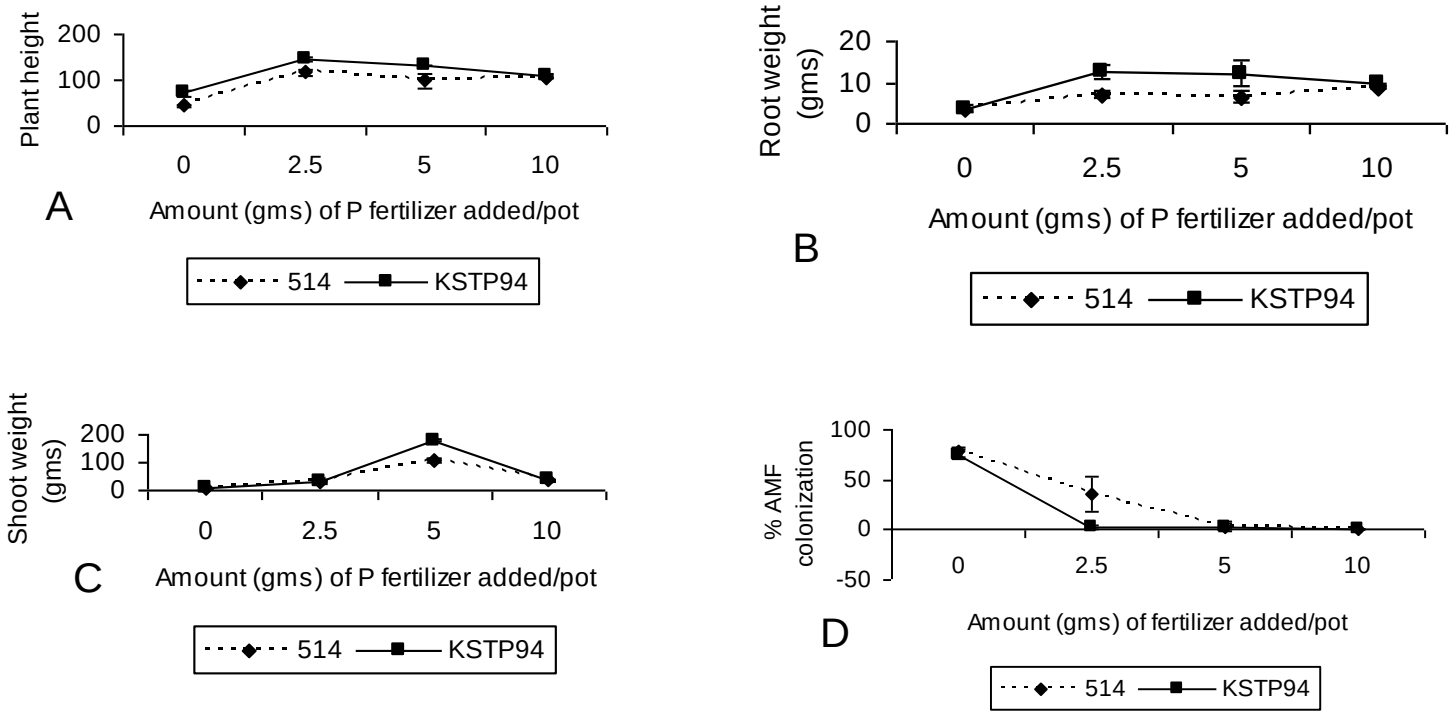

Figure 3. Effect of P levels and *Glomus intraradices* on growth parameters in *Striga* tolerant and susceptible maize. A. Plant height B. Root weight C. Shoot weight D. Percentance *G. intraradices* colonization. Bars represent standard error means.

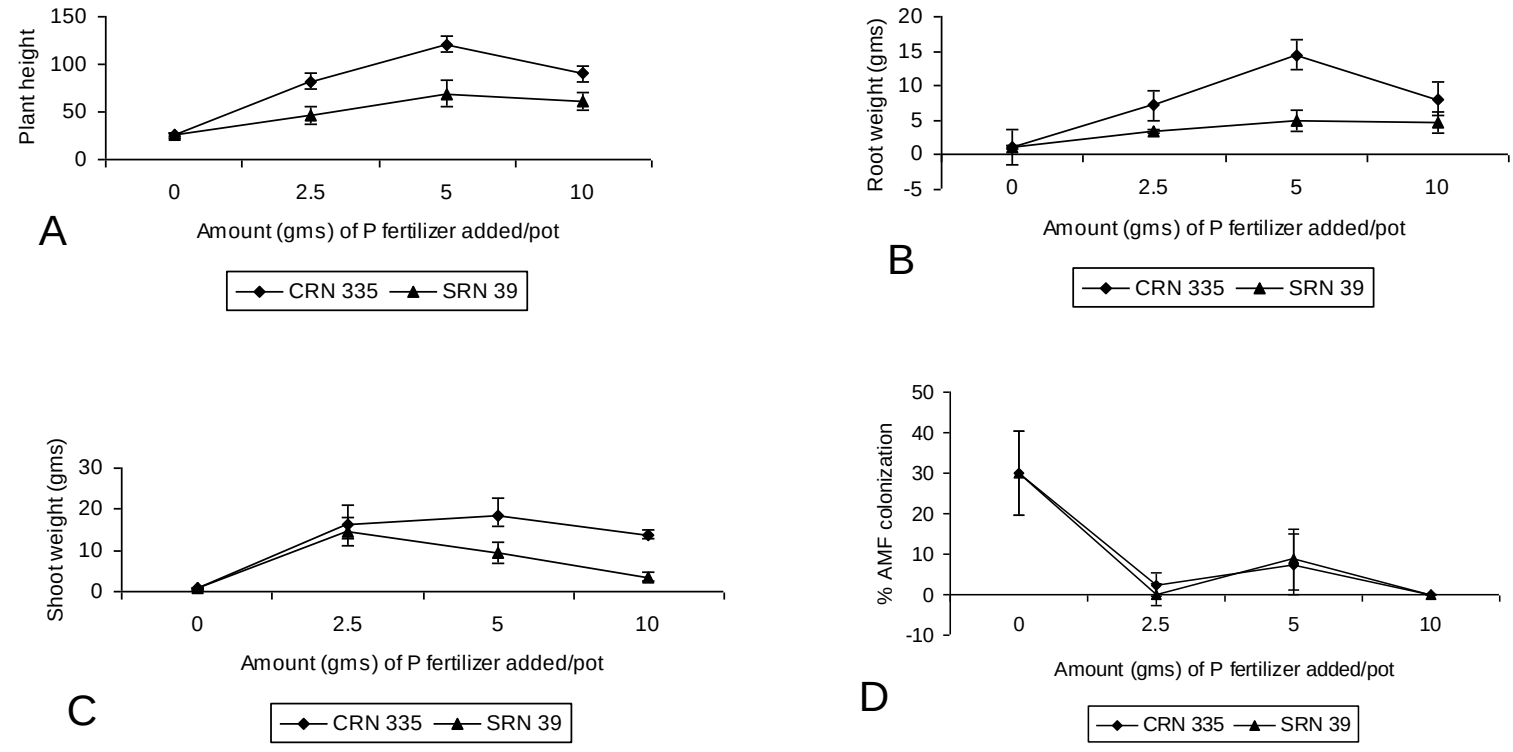

Figure 4. Effect of P levels and *Glomus intraradices* on growth parameters in *Striga* tolerant and susceptible sorghum. A. Plant height B. Root weight C. Shoot weight D. Percentance *G. intraradices* colonization. Bars represent standard error means.

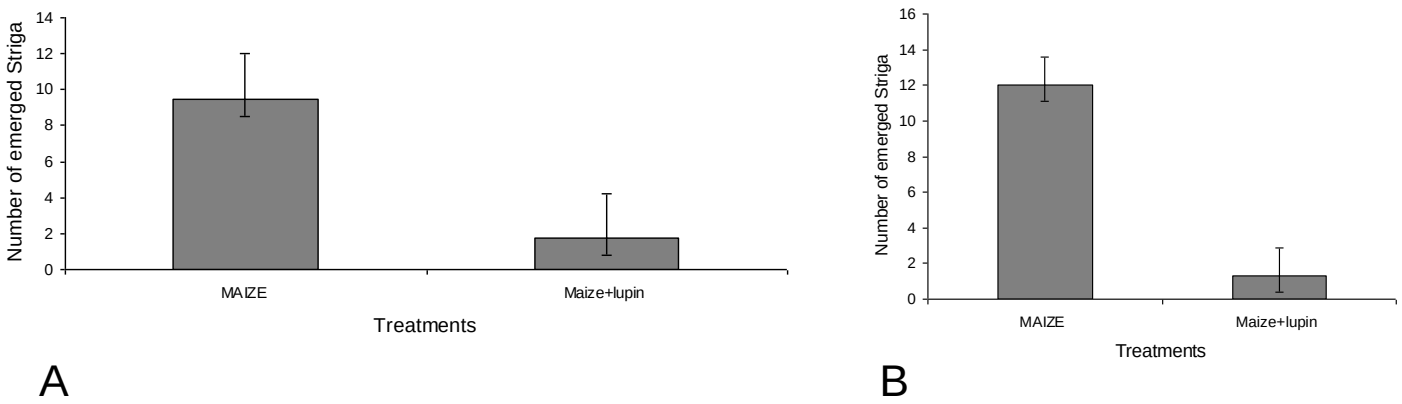

Figure 5 *Striga hermonthica* emergence data when maize was grown singly or when intercropped with Lupin. Panel A) *Striga hermonthica* emergence in naturally infested soil grown with maize monocarp or maize +lupin intercrop. B) *Striga hermonthica* emergence in artificially infested soil grown with maize monocarp or maize + lupin intercrop. Bars represent standard error means.

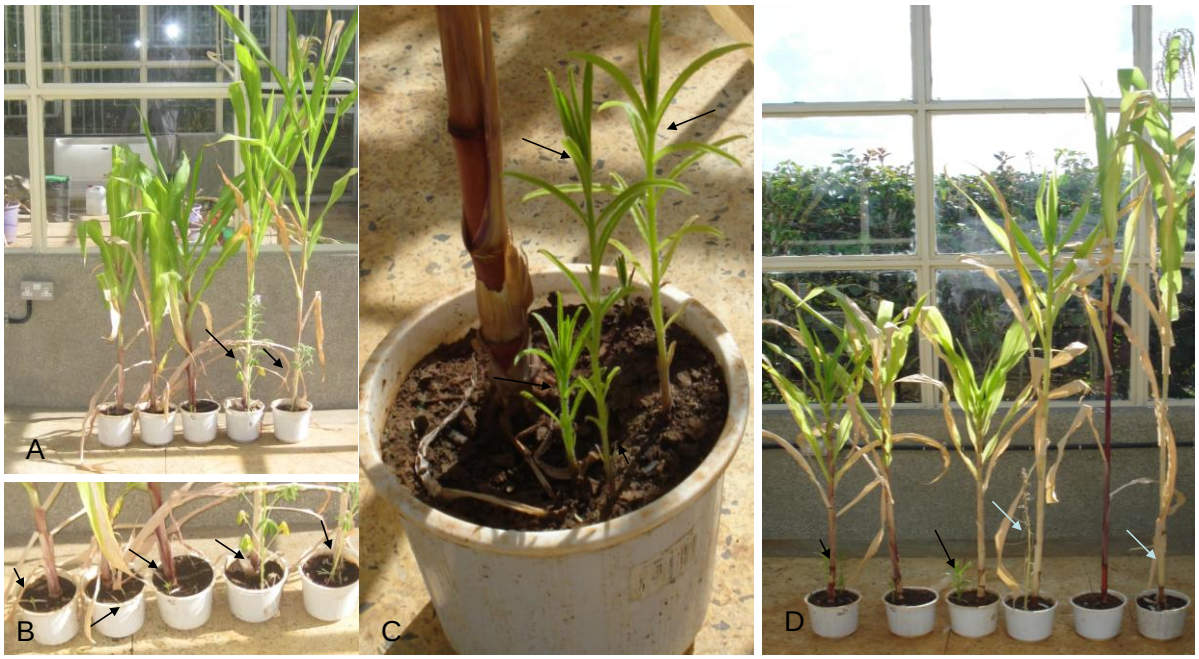

Figure 6: Plant vigor and *S. hermonthica* emergence with and without Lupin intercrop with maize variety 514 in *S. hermonthica* infested soils. Panel A and B. Show naturally infested soil pots, the first 3 pots from left having maize and *S. hermonthica* beginning to emerge, pot 4 and 5 show maize intercropped with lupin without *S. hermonthica* emergence. Panel C show an artificially infested soil pot with maize with lots of *S. hermonthica* emergence. Panel D, shows artificially infested soil pots at 90 days after planting with the first 3 pots having maize and emerged *S. hermonthica* beginning to flower (see black arrows) , Pot 4 to 6 indicate maize and lupin remnants with no *S. hermonthica* emergence (see white arrows).

deficiency stress that suppressed many essential plant processes. For instance, P has been reported to play numerous biological functions, it is a structural element in phospholipids and nucleic acids, is key in energy metabolism, the regulation of enzymatic activities, and in signal transduction cascades (Raghothama 1999; Rausch and Bucher 2002. When P was applied at somewhat adequate levels (31 ppm), the plant biomass accumulation picked up in both sorghum and maize. This could be because the key roles played by P were turned on and the plant was able to function normally hence prompting biomass accumulation. Above this optimum P level (more that 31 ppm) the plant again accumulated less organic matter as revealed by the plant height, root weight and shoot weight data at 77 and 102 ppm in both sorghum and maize and perhaps this can be ascribed to

P toxicity. When plants are exposed to abiotic stress, like very high nutrient level they tend to spend lots of their resources on countering the stress through homeostatic pathways to the extent that important plant physiological processes are sacrificed. Together these results indicate that the tolerance of both maize and sorghum to high or low P is limited. Only optimum P application rate is beneficial to the plant and should be applied. P susceptibility appears to cut across genotypes irrespective of their tolerance or susceptibility status to *S. hermonthica*.

The findings of this study indicate that in maize and sorghum, AMF colonization is high at low P levels but drops drastically when P is applied. This observation applied to both sorghum and maize. Apparently, the soil P status has strong influence on AMF colonization. Application of P fertilizers has a significant impact on the colonization of maize and sorghum by AMF. The results were consistently observed with both *G. mosseae* and *G. intraradices*. This could indicate that in areas where intensive agricultural production is practiced, application of P fertilizer beyond the crop requirement may lower AMF colonization due to the build up of excess P in the soil. Kahiluoto et al (2001) and Jensen and Jakobsen (1980) have recorded similar results where reduced AMF colonization of roots and AMF spore density in soil was inversely correlated with increasing P fertilization. Johnson (1993) also postulated that other than reducing colonization and propagule numbers, fertilization may also select AMF species that are inferior in terms of providing a benefit to the host (Jensen and Jakobsen 1980; Johnson 1993; Kahiluoto et al. 2001). Though only single isolates were used in the current study, there is consistency in the results showing that AMF colonization declined in sorghum and maize in soil when adequate P (31ppm or higher) was applied. The decline in AMF colonization could be due to a number of factors: i) a decrease in secretion of strigolactone germination stimulants by sorghum and maize ii) The presence of AMF-inhibitory compounds in or in the vicinity of sorghum and maize roots produced by the plant itself during adequate P supply and finally iii) presence of inhibitory compounds produced by microorganisms in the distorted rhizosphere. Whenever plants are colonized by AMF the benefits include increased access to water, nutrients and tolerance to biotic and abiotic stresses (Lendzemo et al. 2007). Enhanced biotic and abiotic tolerance is thought to result from improved nutritional status and induction of defense-related genes (Harrison 2005; Johanson et al. 2004; Kuster et al. 2004; Lendzemo et al. 2007; Pozo et al. 2002).

In the maize and *L. albus* intercropping experiment, lupin, a P efficient and leguminous species, was intercropped with maize; the latter appeared healthier and were taller than mono-cropped maize plants. This result indicated that the efficiency in P-acquisition and N fixation of *L. albus* in the rhizosphere of maize led to more biomass being produced by maize perhaps due to synergized nutrient acquisition ability in the crop. This result agrees with some previous studies and also differs with earlier studies, for instance Kamh et al. (1999); Nuruzzaman et al. (2005) and Weisskopf et al. 2008 have associated improved maize yield with *L. albus* while El Dessougi et al. (2003) associated reduced yield with *L. albus* depleting P in the shared rhizosphere (El Dessougi et al. 2003; Kamh et al. 1999; Naruzzaman et al. 2005; Weisskopf et al. 2008).

It is not clear how intercropping improved the P acquisition abilities of maize but a number of adaptive strategies have evolved in plants that alleviate or help them overcome P deficiency. Such strategies may include change in gene expression which involves transcriptional factors, SPX sub-family proteins, non coding RNAs, protein modifiers like phosphorylation, dephosphorylation and protein translocation (Misson et al. 2005; Wasaki et al. 2003; Wu et al. 2003). Whether any of these mechanisms was displayed by either maize or lupin or both is not known and was not investigated by the current study. The significant reduction in *S. hermonthica* emergence in pots where *L. albus* and maize were intercropped indicated that some antagonistic mechanism(s) against *S. hermonthica* seed germination and/or emergence existed. Such antagonistic mechanism(s) could either be due to change in P and N levels or change in the concentration or type of volatiles and metabolites in the maize rhizosphere that could possibly influence *S. hermonthica* seed germination and/or emergence. Currently, no *S. hermonthica* resistant maize cultivars exist (Ejeta 2007) and this result points to the existence of a viable *S. hermonthica* inhibition machinery that may prove beneficial to resource limited farmers and infested SSA soils. Perennial mono-cropping and *S. hermonthica* have greatly low cereal yields in SSA (Ejeta 2007). Unfortunately, the resource-poor farmers, the majority in the region, pay the price that comes with penalties of nutrient depletion and *S. hermonthica* infestation by either buying the expensive inorganic fertilizers and herbicides, planting without fertilizer, or abandoning their farms (Sanchez 2002). The latter two worsen the food security situation in Africa and hence call for intensified exploration efforts for viable *S. hermonthica* control, soil fertility restoration, and maintenance strategies.

Conclusions

This study demonstrated that P application rates affect maize and sorghum plant vigor. In addition low soil P favors colonization by *G. moseae* and *G. intraradices* while application of P fertilizers discourages *G. moseae* and *G. intraradices* colonization in maize and sorghum. It was also noted that intercropping *L. albus* and maize can lead to improved maize growth and vigor. Finally it was

noted that *L. albus* and maize intercropping can suppresses *Striga* emergency from the soil irrespective of whether the *Striga* inoculum was naturally or artificially applied.

Recommendations

The *L. albus* and maize intercropping, if adopted, can relieve the pressure to apply commercial inorganic fertilizers by resource-poor farmers, who make up the majority in SSA. Long term field and pot experiments on the effects of *L. albus* on *S. hermonthica* emergence and phosphorous availability need to be conducted. Finally research to elucidate the exact mechanism (s) by which *L. albus* suppresses *S. hermonthica* germination and or emergency and simultaneously improves intercropped maize need to be conducted.

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