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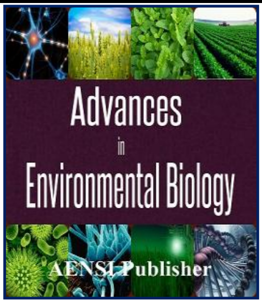

Cowpea (*Vigna unguiculata*) and bacterial inoculation: A plausible components of an integrated management strategy for the root parasitic weed *Striga hermonthica* on sorghum

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ABSTRACT

Two sets of greenhouse experiments were conducted to investigate the effects of i) sorghum intercropping with cowpea genotypes and seeds level of *Striga* on *Striga* incidence on sorghum Wad Ahmed, ii) intercropping of cowpea, bacterial strains and inorganic phosphorus on *Striga hermonthica* parasitism and sorghum growth. Treatments were arranged in a randomized complete block design with four replications. In the first greenhouse experiment, irrespective of intercropping, *Striga* emergence progressively increased with seed bank size. Intercropping, significantly, reduced *Striga* emergence and dry weight. Base on the overall means of *Striga* emergence, intercropping of B301 and T100K-901-6 cowpea genotypes with sorghum reduced Striga emergence by 95- 45% and 96-52% at 1 – 16mg/pot of Striga seed bank, respectively as compared to control. A consistent progressive decline in sorghum height, leaf area and dry weight was evident in sole sorghum crop with increasing Striga seed bank size. , Intercropped sorghum, invariably, improved sorghum growth than sole sorghum. In the second experiment, intercropping with cowpea, inoculated with *Rhizobium leguminosarum* alone or in combination with phosphorus, delayed and repressed *Striga* emergence, significantly in comparison to sole sorghumwith a reduction ranging between 98 and 92%, respectively. However, significant increments of leaf area were only attained when sorghum intercropped with *Rhizobium* inoculated cowpea, alone or in combination with phosphorus at 92 kg ha^{-1} by 56 and 50%, respectively. Intercropping with cowpea inoculated with *Rhizobium* alone or in combination with phosphorus at46 kg ha^{-1}increased sorghum dry weight significantly as compared with the corresponding control. In conclusion, cowpea genotypes inoculated with the bacterial combination, invariably achieved the highest reductions in *Striga* emergence as well as the highest increase in the measured sorghum growth attributes.

KEYWORDS: cowpea, sorghum, bacterial strains, phosphorus, incidence, *Striga* seeds size

INTRODUCTION

Intercropping is a potential beneficial system of crop production. It offers a better utilization of natural and labor resources, provides safe guards against failure of single crop, gives greater yield and return per unit area, and minimizes the spread of pests and diseases [1].Phosphorus is one of several elements which affect nitrogen fixation, and along with nitrogen, it is a principal yield-limiting nutrient in agricultural production [2]. The application of phosphorus could thus, enhance maximum exploitation of the advantages of biological nitrogen fixation (BNF) mechanism by legumes. Hence, the use of grain legumes in smallholder cropping systems is being widely promoted and has received substantial attention across Africa as an alternative strategy to enhance soil fertility and improve grain yields [3].

High illiteracy among farmers, lack of awareness of the *Striga* life cycle and the unavoidable low crop productivity arising from the damage the parasite inflicts while subterranean, makes farmers reluctant to accept and/or adopt post-emergence control measures [4]. Depletion of the soil seed bank of *Striga* by suicidal germination, which involves germination of the seeds in absence of or away from the host roots, is a potential control option and has been strongly advocated by several authors [5, 6]. Hence there is a need to look for simpler techniques as components of an integrated *Striga* control package which is adaptable to the African situation. Legume rotation operates through two major mechanisms, suicidal germination of *Striga hermonthica* seeds in the soil and improvement of soil fertility. Sibhatu [7] observed that *Striga* infestation decreased with increasing organic matter of the soil and that organic matter content seemed to be the most important factor which preserved the soil fertility. Since soil microbial biomass flourishes better in a medium rich in organic matter, organic or inorganic soil amendments may increase soil suppressiveness to *Striga hermonthica* and also improve soil conditions to increase yield of subsequent cereal. In this work, two greenhouse experiments were conducted to study the effects of intercropping of selected cowpea genotypes and *Striga* seed level on *Striga* parasitism and sorghum growth as well as the suppressive effects of cowpea inoculated with rhizobia, BMP, inorganic phosphorus each alone or in combination on *Striga* parasitism and sorghum growth.

MATERIALS AND METHODS

Seeds:

Sorghum cultivar Wad Ahmed was obtained from the Agricultural Research Corporation, Sudan. Tow cowpea genotypes B301 and T100K-901-6were obtained from the International Institute of Tropical Agriculture (IITA) Ibadan Nigeria. *Striga hermonthica,* seeds were collected from sorghum infested fields.

Microbial Bio-fertilizers:

The bacterial strains (*Rhizobium leguminosarum* and *Bacillus megatherium* var. *phosphaticum* (BMP)) (selected on basis of their ability to suppress *S. hermonthica* germination.) were obtained from Environment and Natural Resources and Desertification Research Institute (ENRDRI), National Centre for Research (NCR), Khartoum, Sudan. Autoclave sterilized (for 20 min at 15 bars and 121 ^{0}C for 20 min) yeast extract mannitol and meat peptone broth media were inoculated by *Rhizobium leguminosarum* (TAL 1399 and *Bacillus megatherium var. phosphaticum* (BMP), respectively.

General:

Two sets of green- house experiments were conducted at the College of Agricultural Studies (CAS), Sudan University of Science and Technology, In both experiments, unless otherwise mentioned, pots (36 cm i.d. and 32 cm in height), perforated at the bottom, were filled with 7 kg sand mix (2:1) prepared by mixing soil collected from CAS farm with river sand. *S. hermonthica* seeds were mixed with the top 10 cm of soil in each pot. Sorghum Wad Ahmed seeds (5/pot) were planted. Cowpea genotypes B301 and T100K-901-6seeds (7/pot) were planted as a companion crop. Sorghum and cowpea seedlings were thinned to 2 and 3, respectively, 7 days after emergence. Sole sorghum, *Striga* infested and *Striga* free sorghum intercropped with cowpea were included as controls for comparison. All pots were irrigated at 2–3 days intervals throughout the growing period. Weeds other than *S. hermonthica* were removed by hand. Emergent *Striga* plants were counted weekly starting three weeks after crop emergence. *Striga* count and sorghum height were determined 30, 60 and 90 days after sowing (DAS). Leaf area was estimated by multiplying the length of the second leaf from top by half of maximum width of the leaf at 30, 60 and 90 DAS. At harvest, sorghum and *Striga* shoots, each, were cut at ground level, air-dried and weighed.

First experiment, effects of intercropping and level of Striga seeds on Striga incidence and sorghum growth:

Soil was inoculated with different levels of *Striga* seeds (0, 1, 2, 4, 8, 16 and 32mg/pot). Sorghum seeds (5/pot) were planted at *Ca*. 2 cm. soil depth. Cowpea B301 and T100K-901-6 seeds (7/pot) were planted as a companion crop. Sorghum and cowpea genotypes were thinned as described above. *Striga* emergence, sorghum heights, leaf area, sorghum and *Striga* dry weights were measured as described above.

Second experiment, effects of intercropping, bacterial strains and inorganic fertilizer on Striga incidence and sorghum growth:

In the green house experiment intercropping was integrated with inoculation of *Rhizobium leguminosarum* TAL1399, phosphorus solubilizing bacterium (*Bcillus megatherium var phosphaticum*)as well as inorganic phosphorus. Soil infested with *S. hermonthica* seeds, placed in plastic pots, was sown withsorghum cv. Wad Ahmed and cowpea T100K-901-6 as described above. Cowpea seeds were either inoculated with *Rhizobium leguminosarum* and *B. megatherium* each alone or in combinations with inorganic fertilizer. Aliquots (15 ml each)of each of the respective bacterial suspensions ((10^{-4} dilution) were injected, within the root zone, at each pot. Irrigations were carried out every 2 days. Phosphorus was applied at two doses 46 kg ha^{-1} and92 kg ha^{-1}, immediately after sowing. The experiment was conducted in a RCBD with four replications. Data of sorghum leaf chlorophyll content were taken at 30, 45, 60 and 75 DAS by using a SPAD-502 Chlorophyll Meter (Minolta). Leaf area was measured at 30, 45, 60 and 90 DAS. *Striga* emergence, sorghum height, leaf area and shoot dry weight of sorghum and *Striga* were measured as described above.

Results:

Greenhouse experiments:

First experiment, effects of intercropping and level of Striga seeds on Striga incidence and sorghum growth

Effects on Striga emergence:

Striga emergence, on sorghum, irrespective of intercropping, increased with time and seed bank size. At 30 DAS, average *Striga* emergence on sole sorghum at the lowest seed bank size was 3 plants/pot (Table1). Increasing *Striga* seed bank to 8 or16 mg/pot further increased the parasite emergence, albeit not significantly. At the highest seed bank size (32mg/pot),*Striga* emergence increased significantly (Table 1).Sorghum intercropped with cowpea B301 at the lowest seed bank size (0.3 plant/ pot) displayed the lowest emergence (Table 1). Increasing *Striga* seed bank size to 8 or more /pot increased *Striga* emergence significantly in comparison to the lowest seed bank size. While, no any *Striga* emergence was observed in sorghum intercropped with cowpea T100K901 at the lowest seed bank size. However, a progressive, albeit non-significant increase in emergence was observed up to a seed bank of 8 -16mg/pot. Increasing *Striga* seed bank size to 32mg per pot, further increased *Striga* emergence by more than 4-fold (Table 1).

At 60 DAS, *Striga* emergence, irrespective of seed bank size, showed considerable increase in comparison to that recorded at 30 DAS (Table 1). At 90 DAS, *Striga* emergence showed a similar trend. The average *Striga* emergence at the lowest and highest seed bank were 13.3 and 25 plants /pot, respectively (Table 1). Sorghum intercropped with cowpea B301 and T100K-901-6, increasing *Striga* seed bank size to 16 and 32mg per pot further increased *Striga* emergence by more than 2-to-4-fold, respectively (Table 1). In the overall mean, *Striga* emergence on sorghum intercropped with cowpea B301 and T100K-901-6 genotypes reduced *Striga* emergence by 95- 45% and 96-52% at 1- 16mg/pot, respectively as compared to the respective control.

Dry weight:

Striga dry weight, irrespective of intercropping, progressively increased with increasing seed bank size (Table 2). On sole sorghum, *Striga* dry weight progressively increased with seed bank size. Increasing *Striga* seed bank to 2 mg per pot increased *Striga* dry weight by 74.9%. At *Striga* seed bank size of 4, 8, 16 and 32 mg per pot the increase in *Striga* dry weight was 133.7, 216, 257, and 275.7%, respectively in comparison to the lowest seed bank size (Table 2).*Striga* dry weight on sorghum intercropped with cowpea B301, albeit progressively increased with seed bank (Table 4.9). Increasing seeds bank size to 16 and 32 mg/pot resulted in significant increase in dry weight. *Striga* on sorghum intercropped with cowpea T10K-901-6 displayed 19 g at the lowest *Striga* seed bank size. A Further increase in seed bank to 8, 16 and 32 mg increased *Striga* dry weight by 52.6, 75.3 and 84%, respectively. Across the seed bank size, sole sorghum sustained the highest *Striga* dry weight followed by sorghum intercropped with cowpea B301 and T100K-901-6 (Table 2).

Effects on sorghum height:

Sorghum height, irrespective of intercropping, displayed a progressive decrease with *Striga* seed bank size and increased with time (Table3). In general, sorghum intercropped with cowpea, irrespective of the latter genotype or *Striga* seed bank size, displayed better growth than sole sorghum. *Striga*free sorghum, when intercropped with cowpea, irrespective of genotype or date of observation, displayed an increase in height of 27.7-64.5% in comparison to the corresponding sole sorghum treatment. In sole sorghum at 30 DAS, *Striga* seed bank at 1-8mg/pot inflicted insignificant (5.1-20.9%) decrease in height (Table 3). Increasing *Striga* seed bank size to 16 and 32 mg per pot reduced sorghum height by 27.2and39.9%, respectively (Table 3). *Striga* seed bank 1 or2 mg per pot reduced sorghum height, albeit not significantly. Increasing *Striga* seed bank size to 4 mg per pot or more resulted in significant reductions in sorghum height. While, sorghum intercropped with cowpea

T100K-901-6 did not show a significant reduction in height at the lowest level. The highest reduction (36.5%) was observed at the highest *Striga* seed bank (Table 3). At 60 DAS, reduction in sorghum height followed more or less similar trends. At 90 DAS, *Striga* seed bank size at 2 and 4 mg per pot reduced sorghum height by 2 and 17.1%, respectively. Increasing *Striga* seed bank size to 8 mg per pot or more, reduced (24.5-36.7%) sorghum height significantly. In cowpea B301 and T100K-901-6, a seed bank of 4 mg /pot or more resulted in significant reductions. The highest reduction (31.7 and 45%) was observed at the highest levels, respectively (Table 3).

Leaf area:

Sorghum leaf area, irrespective of intercropping or time, decreased with increasing *Striga* seed bank size (Table 4).At 30 DAS, sole sorghum, invariably, showed a progressive decline in leaf area with *Striga* seed bank size in comparison to the *Striga* free control (Table 4). The reductions in leaf area at *Striga* seed bank of 8, 16 and 32mg/pot were 47.8, 54.9, and 66.4%, respectively. Sorghum intercropped with cowpea genotypes did not show significant reduction in leaf area, irrespective of the parasite seed bank size. At 60 DAS, the leaf area of sole sorghum showed a progressive increase in comparison to the records made at 30 DAS, irrespective of *Striga* seed bank size (Table 4).At 90 DAS, leaf area showed more or less the same trend, a progressive decline with *Striga* seed bank size. Intercropping with cowpea B301 and T100K-901-6, irrespective of *Striga* infestation increased sorghum leaf area in comparison to sole sorghum (Table 4). A consistent progressive decline in leaf area was invariably affected with increasing *Striga* seed bank size. However, the overall effect across *Striga* seed bank levels was a progressive decline with increasing seed bank size with significant reductions attained at the highest *Striga* infestation levels (16 and 32 mg/pot). Sorghum intercropped with cowpea T100K-901-6, irrespective of time, showed a consistent decline in leaf area with *Striga* seed bank size (Table 4).

Dry weight:

Sorghum dry weight irrespective of intercropping decreased with increasing *Striga* seed bank size (Table 5). *Striga* seed bank size at 1and 2 mg/ pot reduced sorghum dry weight by 7.7 and 22.5%, respectively. Increasing *Striga* seed bank size to 4, 8, 16 and 32 mg/ pot reduced sorghum dry weight by 31.9, 39.3, 54.8 and 60.7 %, respectively in comparison to the respective *Striga* free control.

Intercropped sorghum invariably showed significantly higher dry weight than the sole crop (Table 5). However, it showed more or less the same trends in reduction with *Striga* seed bank as sole sorghum in comparison to the respective *Striga* free control (Table 5). *Striga* free sorghum intercropped with cowpea B301 and T100K-901-6 displayed a dry weight of 134.8 and 150g, respectively (Table 5). *Striga* at the lowest seed bank reduced sorghum dry weight by 2 and 4 %, the observed reduction was not significant. Increasing *Srtiga* seed bank to 8, 16 and 32 mg/ pot decreased sorghum dry weight by 60.7- 70.3 %, and 57.7-67.3%, respectively and the observed reductions were significant.

Second experiment, effects of intercropping, bacterial strains and inorganic phosphorus on Striga incidence and sorghum growth:

Effects on Striga:

Result revealed that most of treatments decreased *Striga* emergence considerably in comparison to the control (Table 6). Furthermore, *Striga* emergence progressively increased with time. At 30 DAS, *Striga* emergence was very low as only 0.33 *Striga* plants emerged on the untreated control. However, no any *Striga* emergence was observed on sorghum intercropped with cowpea T100K-901-6 genotype alone or in combination with *Rhizobium*, BMP and phosphorus at the highest dose. At 60 DAS, *Striga* emergence increased, substantially, and was highest on the unfertilized un-inoculated control (7 *Striga* plants/ pot). Intercropping with cowpea inoculated with each of *Rhizobium* alone or or BMP each alone or in combination with phosphorus at 92 kg ha^{-1} reduced *Striga* emergence in the range of 93-100%, respectively. At 75 DAS, *Striga* emergence on sole sorghum showed similar trend as in 60 DAS. Cowpea intercropping treated with *Rhizobium* plus phosphorus at the highest dose completely inhibited *Striga* emergence. At 90 DAS, intercropping with cowpea, previously inoculated with *Rhizobium* alone or in combination with phosphorus at 92 kg ha^{-1}reduced *Striga* emergence by 92 and 96%, respectively as compared with the corresponding control. The *Striga* emergence date was delayed by 75 days in cowpea previously treated with *Rhizobium* plus phosphorus at 92 kg ha^{-1}, compared to the control.

Effects on sorghum height (cm.):

Sorghum height, irrespective of treatment, displayed progressive increase with time and decreased with *Striga* infestation (Table. 7).In general, the majority of the treatments resulted in heights comparable to the corresponding control (*Striga* infested sole sorghum). Sole sorghum displayed better growth than sorghum intercropped with cowpea, in presence or absence of *Striga*. At 30 DAS, cowpea inoculated with *Rhizobium* alone or in combination with phosphorus, BMP plus phosphorus resulted in a significant increase in plant height comparable to the corresponding control. Among other treatments, sorghum intercropped with cowpea, previously inoculated with the combination of BMP plus *Rhizobium* plus phosphorus at 46 kg ha^{-1} or 92 kg ha^{-1}, displayed the highest growth. At 60 DAS, sorghum intercropped with cowpea inoculated with the combinations of *Rhizobium* plus BMP plus phosphorus at 92 kg ha^{-1},*Rhizobium* plus BMP plus phosphorus at 46 kg ha^{-1}, sustained the highest growth as compared to the corresponding control. At 90 DAS, *Striga* reduced sorghum height significantly as compared with the corresponding control. Among all treatments, *Rhizobium* alone or in combination with phosphorus plus BMP were the most stimulatory effect on sorghum growth. Sorghum height was negatively correlated with *Striga* emergence.

Chlorophyll content:

At 30 DAS, there were significant differences between the treatment means with regard to sorghum chlorophyll content (Table 8). Among treatments, sorghum intercropped with cowpea T100K-901-6, previously inoculated with BMP plus phosphorus at the highest dose displayed the highest chlorophyll content. At 60 and 90 DAS, SPAD value declined with time as well as *Striga* infestation.

Leaf area:

Leaf area, irrespective of intercropping or time, decreased with *Striga* infestation (Table 9).Sorghum free *Striga* plant in the control pot had the highest leaf area. At 30 DAS, sole sorghum, invariable, showed a progressive decline in leaf area with *Striga* albeit not significantly, in comparison to the *Striga* free control. Intercropping with cowpea inoculated with *Rhizobium* plus phosphorus at 92 kg ha^{-1}increased sorghum leaf area by 70% in comparison to sole sorghum. At 60 DAS, leaf area of sole sorghum showed a progressive increase in comparison to the records made at 30 DAS. Intercropping with cowpea inoculated with the combination of *Rhizobium* and BMP plus phosphorus at 92 kg ha^{-1} increased sorghum leaf area by 9%, in comparison to sole sorghum. At 90 DAS, leaf area showed more or less the same trend, a progressive decline with *Striga* infestation. However, significant increments were only attained at sorghum intercropped with cowpea inoculated with *Rhizobium* alone or in combination with BMP plus phosphorus at 92 kg $ha^{-1}$by 56 and 50%, respectively.

Dry weight:

There were significant differences among the treatment means with regards to total sorghum biomass (Tables 10). Sorghum dry weight irrespective of intercropping decreased with *Striga* infestation (Tables 10). *Striga* free sorghum and infested crop showed root dry weight of 68 and 36/pot, respectively (Table 10). Intercropped sorghum invariable showed higher dry weight than the sole crop. All treatment increased root dry weight significantly as compared to the control. Cowpea inoculated with *Rhizobium* increase sorghum root dry weight significantly as compared to sole sorghum control. Almost all treatments increased shoot dry weight as compared to the control. Among other treatments sorghum intercropped with cowpea inoculated with BMP alone or in combination with *Rhizobium* plus phosphorus at 46 kg ha^{-1} sustained the highest shoot dry weight.

Discussion:

Soil fertility depletion is the major limiting factor in crop production in Arid and semi-arid lands [8]. Continuous mono-cropping of cereal crops without fallowing has worsened the situation. *Striga hermonthica*, a parasitic weed, has long been believed to be correlated with the declining soil fertility status. Legumes hold great potential as sources of high protein food and feed [9]. They also enhance N uptake and plant capacity to withstand drought [10]. Normally, for optimal legume-*Rhizobium* symbiosis to occur, a sufficient amount of phosphorus is required, while cereals need considerably large amounts of both N and P for optimal growth [11]. It is noteworthy that a plant species may produce several strigolactones which differ significantly in their germination inducing activity (GIA) and that the main strigolactone from sorghum and cowpea were reported to be sorgolactone and alectrol, respectively [12]. Cowpea is not parasitized by *S. hermonthica*, however, it is a host for the closely related species *S.gesneriodies*. In the present work a holistic approach was adopted with the objectives of providing information on intercropping in greenhouse experiments where intercropping was integrated with inoculation of *R. leguminosarum* and *B. megatherium var phosphaticum***,** a phosphorus solubilizing bacterium and inorganic phosphorus. In the first greenhouse experiment, irrespective of intercropping, *Striga* emergence progressively increased with seed bank size (Table 1). However, intercropping with cowpea, irrespective of time and seed bank size delayed and repressed *Striga* emergence, significantly in comparison to sole sorghum where the reductions varied between 50 and 100% and 1and 30 % at the lowest and highest seed bank size, respectively. The reduction in the parasite emergence could be as pointed out by Parker and Riches [5], in similar situations, due to induction of germination by the advancing cowpea roots away from those of sorghum and/or competition between cowpea roots and those of sorghum for the juvenile *Striga* germilings. Nitrogen fixed by the legumes has also been pointed as a reason for *Striga* control. Incidence of *Striga* is known to negatively correlate with soil fertility, particularly nitrogen availability [13]. *Striga* dry weight, invariably, increased at a faster rate on sole sorghum than intercropped plants (Table 5). At the lower seed bank size, *Striga* dry weight from under sorghum intercropped with cowpea T100K-906-1 reduced by 22.8%. At *Striga* seed bank size of 4 - 32 mg/pot intercropping with cowpea B301 and T100K-906-1 reduced *Striga* dry weight by 39.5- 49.2.% and 59.5 – 61.7%, respectively. The reduction in *Striga* dry weight is consistent with the reductions in emergence instigated by intercropping with cowpea. The high transpiration rate enhances transfer of host xylem sap into the parasite. Intercropping shades the soil and lowers the temperature. Furthermore reduced transpiration and photosynthesis of the parasite resulting from shading by the intercrop, as reported in similar situations [4, 5], could account, at least in part, for a considerable proportion of the loss in dry weight. Sorghum height, irrespective of intercropping, displayed a progressive decrease with *Striga* seed bank size (Table 3). However, the intercropped sorghum with cowpea genotypes appeared to display better growth than sole sorghum. Leaf area, irrespective of intercropping, decreased with *Striga* seed bank size (Table. 4). Leaf area was invariably higher for intercropped sorghum. As indicated by the magnitude of the reduction in leaf area with time it would appear that limited recovery in leaf area occurred with time. Sorghum intercropped with cowpea genotype T100K-901-6 displayed less reduction in leaf area than the one intercropped with cowpea B301 and sole sorghum crop. Sorghum dry weight, irrespective of intercropping, progressively declined with *Striga* seed bank. However, dry weight of intercropped sorghum, irrespective of *Striga* seed bank size, was invariably higher than that of sole sorghum. The dry weight of intercropped *Striga* free sorghum was about 2-fold that of the respective *Striga* free sole sorghum. Such a difference could be attributed, at least in part, to differences in the genotypes used. In the present study cowpea genotypes with prostrate and spreading habit were employed. Furthermore, cowpea is a legume and a nitrogen fixer. Transfer of nitrogen and possibly phosphorus from legumes to neighboring non-leguminous plants from decaying cowpea roots and nodules has been reported by [12, 14]. Gbehounou and Adango [14] pointed out that intercropping with cowpea leads to higher yield, and that this may be related to the benefits of nitrogen fixation under cowpea cropping, as well as a reduction in leaching of soil nutrients by cowpea cover.

In the second experiment, treatments comprising sorghum intercropped with cowpea T100k-901-6, inoculated with *B. megatherium***,** *R. leguminosarum*, phosphorus or their combinations sustained and maintained significantly less *Striga* emergence than sole sorghum (Table6). At early season, reductions in *Striga* emergence on sorghum intercropped with cowpea T100k-901-6 inoculated with *B. megatherium***,** *R. leguminosarum* and their combination were 43,89 and 69%, respectively, in comparison to that on sole sorghum. However, the reduction was increased in presence of phosphorus alone or in combination of bacterial strains (54 -100%). It is noteworthy, albeit differences between the individual treatments were often not significant, that inoculating cowpea with the bacterial combinations and phosphorus were the most effective in suppressing the parasite emergence. However, intercropping with cowpea, inoculated with *R. leguminosarum* alone or in combination with phosphorus, irrespective of time, delayed and repressed *Striga* emergence, significantly in comparison to sole sorghum where the reduction varied between 98 and 92%, respectively. The reduction in the parasite emergence could be as pointed out by Parker and Riches [5], in similar situation, due to induction of germination by the advancing cowpea away from those of sorghum and/or competition between cowpea roots and those of sorghum for the juvenile *Striga* germilings. Further reduced transpiration and photosynthesis of the parasite resulting from the shading by the intercropped plants [5]. These findings agree with Musyoka [15]. *Striga* emergence was delayed in cowpea treated with *Rhizobium* plus phosphorus at 92 kg ha^{-1}. Intercropping cowpea genotypes may cause suicidal germination of some of *Striga* seeds whereas the bacterial inoculum would inhibit *Striga* germination and/or emergence [16]. Suppression of *Striga* emergence, dry weight and the increase in sorghum dry weight and the association of the maximum increments with the combination of *R. leguminosarum* plus *B. megatherium* and phosphorus are consistent with reports by Musyoka[15] who observed over 2-3-fold increase in sorghum and grasses growth attributes on intercropping of sorghum with cowpea inoculated with a commercial *Rhizobium* strain together with further supplementation of inorganic phosphorus. They attributed the improvement of cowpea intercropped sorghum and grasses in legume/grass pastures to increased availability of nitrogen through biological nitrogen fixation. Furthermore, *Striga* infestation and damaging effects are also linked with low soil fertility and that nitrogen and phosphorus play key roles in the parasitic syndrome [4]. The use of legumes together with inoculation with *Rhizobium* as revealed by Musyoka[15] and phosphorus solubilizing bacteria as shown in this study may provide the cheapest viable option to the resource- constrain sub-Saharan African farmers to improve soil fertility and consequently improve crop performance and *Striga* management. These results demonstrated that *Striga* bio-control based on bacterial inoculum incorporation and the intercropping system constitute each an effective control method against *S. hermonthica* and their synergistic effect is more effective to reduce the parasite infestation. Soil microorganisms and intercropping interfering with early developmental stages were thought of as possible alternatives and/or viable supplements to other control methods [17].

Conclusions:

The technical and economic feasibility of integrating intercropping with cowpea genotypes B301 and T100K-901-6, inoculated with *R. leguminosarum* TAL1399and the phosphorus solubilizing bacterium *B. megatherium var phosphaticum* with existing measures of *Striga* management should be considered and evaluated under farmer's field conditions adopting an efficient participatory approach. Further studies are needed to understand the impact of farmer management practices on *Striga* infestation and soil fertility.

Table 1: Effects of sorghum intercropping with cowpea and seed level of *Striga* on *Striga* incidence (*Striga* emergence)

Striga seed level (mg/pot)	*Striga* emergence (plant/pot) Time after crop sowing (Days)			
	30	60	90	Mean
a-Sole sorghum				
1	3.0 (±1.1) c	7.0 (±1.6) d	13.3 (±1.9) d	7.8 d
2	6.5 (±0.6) bc	12.0 (±1.5) c	17.5 (±1.0) cd	12.0 c
4	7.5 (±0.6) b	13.5 (±0.6) bc	21.3 (±0.9) abc	14.1 bc
8	9.5 (±0.6) b	15.0 (±0.4) bc	20.0 (±1.1) bc	14.8 b
16	10.0 (±2.7) b	16.3 (±1.3) ab	23.0 (±1.6) ab	16.4 b
32	14.3 (±0.9) a	18.5 (±0.6) a	25.0 (±1.8) a	19.3 a
Mean	8.5 c	13.7 b	20.0 a	
b-cowpea B301				Mean
1	0.3 (±0.3) d	0.5 (±0.3) d	0.5 (±0.3) d	0.4 e
2	0.8 (±0.5) cd	1.5 (±0.6) d	1.8 (±0.6) cd	1.3de
4	1.5 (±1.0) cd	2.3 (±0.9) cd	2.5 (±0.9) cd	2.1 d
8	3.3 (±0.5) c	4.5 (±1.6) c	5.5 (±1.3) c	4.4 c
16	6.8 (±0.9) b	8.8 (±0.9) b	11.8 (±1.5) b	9.1 b
32	13.0 (±1.5) a	16.8 (±1.0) a	24.8 (±2.5) a	18.2 a
Mean	3.6 a	4.9 a	6.7 a	
ccowpeaT100K901-6				
1	0.0 (±0.0) c	0.5 (±0.5) c	0.5 (±0.5) c	0.3 d
2	0.8 (±0.5) bc	1.3 (±0.8) c	1.0 (±0.4) c	1.0 d
4	1.8 (±0.8) bc	2.3 (±1.1) c	2.5 (±1.3) c	2.2 cd
8	3.3 (±1.8) bc	4.0 (±1.5) c	4.5 (±1.7) c	3.9 c
16	5.3 (±1.3) b	9.0 (±0.8) b	9.5 (±1.6) b	7.9 b
32	10.0 (±3.1) a	17.0 (±2.2) a	19.0 (±2.4) a	15.3 a
Mean	3.0 a	4.9 a	5.3 a	

Table 2: Effects of sorghum intercropping with cowpea and seed level of *Striga* on *Striga* dry weight

Striga seed level (mg/pot)	*Striga* dry weight (g)			
	Sole Sorghum	B301	T100K-901-6	Mean
1	24.3 (±2.4) d	30.5 (±2.3) c	19.0 (±2.3) c	24.6 d
2	42.5 (±6.2) cd	32.0 (±0.9) c	21.8 (±1.5) bc	32.1 cd
4	56.8 (±7.4) bc	34.5 (±5.0) bc	23.0 (±3.1) bc	38.1 bc
8	76.8 (±15.9) ab	40.8 (±4.2) abc	29.0 (±3.5) ab	48.8 ab
16	86.8 (±2.5) a	44.0 (±5.3) ab	33.3 (±4.7) a	54.7 a
32	91.3 (±2.4) a	46.3 (±3.1) a	35.0 (±) a	57.5 a
Mean	63.0 a	38.0 b	26.8 c	42.6

Table 3: Effects of sorghum intercropping with cowpea and seed level of *Striga* on sorghum growth (sorghum height)

Sorghum height (cm) Time after sowing (Days)				
Striga seed level (mg/pot) a- Sole sorghum	30	60	90	Mean
0	15.8 (±1.8) a	19.0 (±2.0) a	24.5 (±2.6) ab	19. a
1	15.0 (±2.2) ab	18.8 (±1.9) a	26.3 (±1.8) a	20 a
2	14.0 (±0.9) ab	18.8 (±1.5) a	24.0 (±1.6) abc	18.9 ab
4	15.5 (±1.0)a	18.3 (±1.3) a	20.3 (±1.3) bcd	18 ab
8	12.5 (±1.0) abc	16.5 (±0.6) ab	19.8 (±0.9) cde	16. abc
16	11.5 (±0.6) bc	15.8 (±0.5) ab	18.5 (±0.6) de	15. bc
32	9.5 (±1.0) c	13.3 (±0.9) b	15.5 (±0.6) e	12. c
Mean	13.4 c	17.2 b	21.3 a	

b-cowpeaB301 0	24.8 (±2.9) a	27.8 (±3.4) a	31.3(±2.4) a	27.9 a
1	22.8 (±3.1) ab	24.3 (±3.0) ab	30.5 (±1.7) a	25.8 ab
2	18.8 (±1.1) abc	22.3 (±2.1) abc	26.5 (±2.5) ab	22.5 bc
4	20.5 (±1.3) bc	21.8 (±1.4) bc	24.5 (±1.8) bc	22.25 bc
8	18.3 (±0.9) bc	19.3 (±0.5) bc	22.3 (±1.1) bc	19.9 c
16	17.5 (±0.6) bc	19.0 (±0.7) bc	21.5 (±1.3) bc	19.3 c
32	15.3 (±0.9) c	17.5 (±0.6) c	20.0 (±0.7) c	17.6 c
Mean	19.8 b	21.7 b	25.2 a	
c- T100K-901-6				
0	26.0 (±1.5) a	30.3 (±1.3) a	34.5 (±1.7) a	30.3 a
1	24.3 (±3.1) ab	29.3 (±1.5) ab	30.5 (±1.6) ab	28.0 ab
2	21.0 (±1.5) bc	28.3 (±1.2) ab	29.0 (±0.7) ab	26.1 abc
4	20.0 (±1.1) bc	27.0 (±3.0) abc	27.5 (±3.3) b	24.8 bc
8	19.3 (±0.8) c	23.8(±2.7) bcd	25.0 (±2.6)bc	22.7 cd
16	18.0 (±1.1) c	21.5 (±2.6) cd	24.3 (±2.1) bc	21.3 cd
32	16.5 (±0.6) c	19.0(±1.7) d	19.0 (±2.4) c	18.2 d
Mean	20.7 a	25.6 a	27.1 a	

Table 4: Effects of sorghum intercropping with cowpea and seed level of*Striga* on sorghum leaf area

Leaf area(cm^2) *Striga* seed level (mg/pot)Day After Sowing (DAS)	30	60	90	means
a-Sole sorghum				
0	45.0 (±6.1) a	53.3 (±5.3) a	73.6 (±6.7) a	57.3 a
1	38.1 (±5.9) ab	54.0 (±9.3) a	69.9 (±6.4) ab	54.0 ab
2	32.9 (±7.6) abc	46.0 (±11.0) ab	60.7(±10.8)ab	46.5 ab
4	28.1(±7.5) bcd	43.2 (±9.6) ab	58.1(±9.4) bc	43.1 abc
8	23.5 (±5.3) bcd	39.2 (±8.4) ab	55.8(±7.9) bc	39.5 abc
16	20.3 (±4.2) cd	37.4 (±6.7) ab	50.7 (±4.8) bc	36.1 bc
32	15.1 (±2.4) d	23.1 (±2.8) b	36.1 (±4.0) c	24.8 c
Mean	29.0 c	42.3 b	57.8 a	
b-B301				
0	141.8 (±30.3) a	170.4 (±27.1) a	176.8(±19.0)a	163.0 a
1	130.1 (±15.0) a	160.0 (±8.7) ab	173.5(±31.3)a	154.5 ab7
2	123.4 (±14.6) a	143.8(±12.5) bc	166.1(±16.7)a	144.4 abc
4	117.5 (±15.3) a	139.6(±7.3) abc	149.4(±25.1)a	135.5 abc
8	114.6 (±13.9) a	130.4(±10.4)abc	134.1(±21.0)a	126.4 abc
16	104.1 (±15.1) a	126.6(±12.4) bc	118.4(±17.8)a	116.3 bc
32	95.6 (±13.4) a	106.8 (±12.7) c	116.4(±18.6)a	106.0 c
Mean	118.1b	139.6 a	147.8 a	
c-T100K-901-6				
0	157.4 (±19.8) a	171.8 (±11.5) a	182.9 (±13.2) a	170.7 a
1	154.3 (±17.4) a	157.6 (±9.2) a	163.5 (±17.5) a	158.5 ab
2	142.0 (±14.0) a	150.7 (±9.9) a	155.6 (±16.8) a	149.4 ab
4	138.2 (±29.4) a	148.1 (±20.2) a	155.2 (±26.3) a	147.1 ab
8	124.2 (±18.4) a	144.6 (±16.1) a	144.9 (±21.9) a	137.9 ab
16	118.7 (±21.7) a	131.7 (±7.2) a	142.1 (±11.7) a	130.8b
32	104.2 (±23.4) a	128.3 (±31.1) a	138.3 (±24.0) a	123.6 b
Mean	134.1b	147.5 ab	154.6 a	

Table 5: Effects of sorghum intercropping with cowpea and seed level of *Striga* on sorghum dry weight

Striga seed level(mg/pot)	Sorghum dry weight(g)			
	Sole sorghum	B301	T100K-901-6	Mean
0	67.5 (±11.2) a	134.8 (±19.4) a	150.0 (±16.6) a	117.4 a
1	62.3 (±7.6) ab	131.8 (12.7) a	144.0 (±13.5) ab	112.7 a
2	52.3 (±4.9) abc	104.8 (±11.6) ab	116.3 (±12.2) bc	91.1 b
4	46.0 (±8.9) bcd	73.0 (±18.1) bc	84.3 (±13.0) cd	67.8 c
8	40.3 (±4.8) cd	53.0 (±8.3) c	63.5 (±8.8) de	52.3 cd
16	30.5 (±1.4) d	52.5 (±4.3) c	58.0 (±3.4) de	47.0 cd
32	26.5 (±3.5) d	40.0 (8.4) c	49.0 (±4.3) e	38.5 d

Mean	46.5 b	84.3 a	95.0 a	

Table 6: Effects of sorghum intercropping with cowpea, bacterial strains and inorganic fertilizer, on *Striga* emergence Days after sowing (DAS)

Striga emergence day after sowing (DAS)			
Treatments	30	60	90
I.C s(+)	0.0000 A	2.3333 A	6.3333 AB
sorghum s(+)	0.3333 A	7.10 A	16.000 A
I.C +P1	0.6667 A	2.0000 A	2.3333 B
I.C +P2	0.0000 A	2.6667 A	4.6667 AB
I.C+ rizo	0.0000 A	0.6667 A	2.0000 B
I.C +rizo+P1	0.3333 A	3.6667 A	4.6667 AB
I.C +rizo+P2	0.0000 A	0.0000 A	1.0000 B
I.C + BMP	0.6667 A	7.3333 A	10.000 AB
I.C + BMP+P1	0.6667 A	5.3333 A	4.0000 B
I.C + BMP+P2	0.0000 A	7.0000 A	8.6667 AB
I.C +BMP+Rizo	0.0000 A	3.6667 A	4.0000 B
I.C +BMP+Rizo+P1	0.6667 A	3.6667 A	3.0000 B
I.C +BMP+Rizo+P2	0.0000 A	1.3333 A	6.0000 AB
Standard error (±)	0.57	4. 42	5.56

I.C.: Sorghum intercropped with cowpea;P1 and P2: Phosphorus at 46 kg ha^{-1} and 92 kg ha^{-1}, respectively. rizo: *Rhizobium leguminosarum*:BMP*: B.megatherium*; +: in presence of *Striga*; -: in absence of*Striga*

Table 7: Effects of sorghum intercropping with cowpea, bacterial strains and inorganic fertilizer on sorghum height

Sorghum height (cm) day after sowing (DAS)			
Treatments	30	60	90
I.C s(-)	78.50 A	80.83 AB	76.00 ABCD
sorghum s(-)	73.28 AB	86.36 A	92.94 A
I.C s(+)	54.17 BC	62.08 E	71.17 ABCD
sorghum s(+)	54.67 BC	73.5 ABCDE	69.78 ABCD
I.C +P1	63.00 ABC	64.33 DE	52.50 BCD
I.C +P2	54.75 BC	73.8 ABCDE	67.17 ABCD
I.C+ rizo	70.33 ABC	70.1 BCDE	78.00 ABC
I.C +rizo+P1	75.00 AB	69.75 BCDE	49.83 CD
I.C +rizo+P2	75.67 AB	78.00 ABC	75.17 ABCD
I.C + BMP	62.67 ABC	66.75 CDE	60.79 BCD
I.C + BMP+P1	50.50 C	60.88 E	57.02 BCD
I.C + BMP+P2	71.33 ABC	70.91 BCDE	49.17 D
I.C +BMP+Rizo	67.83 ABC	68.58 BCDE	64.33 ABCD
I.C +BMP+Rizo+P1	76.83 A	76.25 ABCD	77.00 ABCD
I.C +BMP+Rizo+P2	76.83 A	80.50 AB	80.67 AB
Standard error (±)	10.51	6.44	14.07

I.C.: Sorghum intercropped with cowpea;P1 and P2: Phosphorus at 46 kg ha^{-1} and 92 kg ha^{-1}, respectively. rizo: *Rhizobium leguminosarum*:BMP*: B.megatherium*; +: in presence of *Striga*; -: in absence of*Striga*

Table 8: Effects of sorghum intercropping with cowpea, bacterial strains and inorganic fertilizer, on chlorophyll content on sorghum

Chlorophyll content Day After Sowing (DAS)			
Treatments	30	60	90
I.C s(-)	36.600 AB	27.667 BC	21.36 ABC
sorghum s(-)	39.167 A	37.933 A	29.367 A
I.C s(+)	30.500 C	24.20 BCD	14.76 BCD
sorghum s(+)	35.633 AB	30.067 AB	23.700 AB

I.C +P1	36.200 AB	20.80 BCD	10.967 CD
I.C +P2	35.900 AB	24.33 BCD	12.86 BCD
I.C+ rizo	35.23 ABC	30.067 AB	20.93 ABC
I.C +rizo+P1	34.53 ABC	21.96 BCD	7.767 D
I.C +rizo+P2	36.133 AB	27.800 BC	21.50 ABC
I.C + BMP	34.200 BC	17.333 D	5.167 D
I.C + BMP+P1	35.06 ABC	19.733 CD	13.90 BCD
I.C + BMP+P2	38.133 AB	19.267 CD	12.300 CD
I.C +BMP+Rizo	37.100 AB	18.433 CD	12.80 BCD
I.C +BMP+Rizo+P1	35.567 AB	20.46 BCD	20.95 ABC
I.C +BMP+Rizo+P2	35.13 ABC	21.66 BCD	11.967 CD
Standard error (±)	2.3678	4.8214	5.3467

I.C.: Sorghum intercropped with cowpea;P1 and P2: Phosphorus at 46 kg ha^{-1} and 92 kg ha^{-1}, respectively. rizo: *Rhizobium leguminosarum*:BMP*: B.megatherium*; +: in presence of *Striga*; -: in absence of*Striga*

Table 9: Effects of sorghum intercropping with cowpea, previously inoculated with bacterial combination and P, on sorghum leaf area

Leaf area(cm^2) Day After Sowing (DAS)			
Treatments	30	60	90
I.C s(-)	138.75 B	292.50 B	199.94 B
sorghum s(-)	165.19 AB	383.88 A	329.38 A
I.C s(+)	55.78 B	135.06 E	148.25 BCD
sorghum s(+)	158.76 AB	207.16 CD	115.29 CD
I.C +P1	82.50 B	168.06 DE	107.38 D
I.C +P2	110.75 B	200.88 CD	142.25 BCD
I.C+ rizo	95.94 B	170.63 DE	179.69 BC
I.C +rizo+P1	83.75 B	159.88 DE	163.50 BCD
I.C +rizo+P2	280.94 A	197.88 CD	128.50 BCD
I.C + BMP	97.19 B	159.31 DE	114.19 CD
I.C + BMP+P1	88.00 B	160.00 DE	156.75 BCD
I.C + BMP+P2	109.38 B	184.25 CDE	150.69 BCD
I.C +BMP+Rizo	94.19 B	169.31 DE	121.44 CD
I.C +BMP+Rizo+P1	103.13 B	210.63 CD	155.06 BCD
I.C +BMP+Rizo+P2	121.94 B	225.44 C	172.88 BCD
Standard error (±)	61.28	25.83	35.19

I.C.: Sorghum intercropped with cowpea;P1 and P2: Phosphorus at 46 kg ha^{-1} and 92 kg ha^{-1}, respectively. rizo: *Rhizobium leguminosarum*:BMP*: B. megatherium*; +: in presence of *Striga*; -: in absence of *Striga*

Table 10: Effects of sorghum intercropping with cowpea, bacterial strains and inorganic fertilizer, on sorghum root dry weight

	Dry weight (g)		
Treatments	*Striga*	Shoot	Root
I.C s(-)	-	68.333 A	75.000 ABC
sorghum s(-)	-	68.000 A	92.667 A
I.C s(+)	2.0667 A	39.533 AB	38.667 BCDE
sorghum s(+)	1.6667 A	36.333 AB	26.000 E
I.C +P1	11.0000 A	41.667 AB	53.333 BCDE
I.C +P2	11.000 A	39.000 AB	38.667 BCDE
I.C+ rizo	10.867 A	38.333 AB	76.000 AB
I.C +rizo+P1	4.7000 A	26.667 B	63.667 ABCD
I.C +rizo+P2	3.0000 A	40.000 AB	25.000 E

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I.C + BMP	5.3333 A	49.000 AB	31.667 DE
I.C + BMP+P1	4.0000 A	22.000 B	36.333 DE
I.C + BMP+P2	2.3333 A	34.333 AB	37.333 DE
I.C +BMP+Rizo	4.0000 A	23.000 B	37.667 CDE
I.C +BMP+Rizo+P1	0.6667 A	33.667 AB	45.333 BCDE
I.C +BMP+Rizo+P2	5.2333 A	49.000 AB	54.000 BCDE
Standard error (±)	5.5619	17.535	18.315

I.C.: Sorghum intercropped with cowpea; P1 and P2: Phosphorus at 46 kg ha^{-1} and 92 kg ha^{-1}, respectively. rizo: *Rhizobium leguminosarum*:BMP*: B.megatherium*; +: in presence of *Striga*; -: in absence of *Striga*

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