Review Paper:

Correlation between *Striga spp* and soil fertility prominence

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Abstract

Witch weed (Striga), a root parasite, has become a major biological constraint to cereal production with severe yield losses of about 85% reported in semi-arid areas of sub-Saharan Africa. S.hermonthica, S .asiatica, S. forbesii and S. gesnerioid are the most dominant and troublesome Striga species. Therefore, a review was carried out with the following objectives to determine the level of Striga threat to crop production related to soil fertility and to determine the effect of fertiliser application to soil fertility-Striga paratism relationship using secondary data. Literature showed nitrogen is negatively related to Striga production.

Adding nitrogenous fertilizers is one of the popular Striga control strategies. Fertilizer applications improve grain yield and farm manures also significantly improve grain yield. This calls for a fertilizer-based soil management approach in which mineral fertilizers, organic fertilisers, green manures and crop rotations are recommended for commercial and small holder use.

Keywords: Striga, Sub-Sahara, Nitrogen, Farm manure, soil fertility, Strigolactones.

Introduction

Striga spp, known as witch-weed, is among the most troublesome and damaging weeds in the world. *Striga* is a genus of parasitic plants widely distributed over Africa parts of Asia Australia (50). The majority of Striga species (e.g. *S. hermonthica*, *S. asiatica*, *S. aspera*, *S. forbesii*) infest cereals such as sorghum, millet, fonio, teff, maize and rice.[42,55,77]

These crops represent the staple food of millions of poor rural families in Africa. Indeed, S*triga* is the major and most persistent biotic threat to production of these crops mostly grown by poor smallholder farmers in marginal areas of sub-Saharan Africa[42].

Most soils in sub-Saharan Africa are infertile due to increased cases of land degradation, climate change, poor resources farmers who are not able to buy mineral fertilisers. This has triggered opportunity for *Striga* to become popular in low soil fertility lands around the region. Increased *Striga* has been contributed by cereal mono-cropping and soil decline in soil fertility[20,41,55,67] in smallholder farming systems.

In Zimbabwe, complete crop failure has been reported by Mabasa[44]. The weed is said to cause yield annual losses estimated to be in excess of US$ 10billion.[13,20,48] The parasite is a major constraint to subsistence agriculture in Zimbabwe such that sometimes resource poor farmers are forced to abandon their fields with grave consequences to their families[48]. According to Tirnko et al[75] and Mandumbu et al,[48] losses from *Striga* are compounded because of the tendency of crops grown under severe moisture and poor fertility conditions to show significant predisposition to *Striga*.

The relation between poor soil fertility and prevalence of *Striga* has often been assumed. The review aimed to search for scientific literature to compile the evidence confirming or declining correctness of this assumption. The review was conducted to demonstrate the truth or existence of this assumption. The findings of the study will assist small holder farmers to design agronomic practices that can be adopted to mitigate impacts of *Striga* in crop yield.

***Striga* Species:** According to Gurney et al[30], *Striga* causes an estimated crop loss of around US $ 7 billion annually in the process affecting the livelihoods of around 300 million people. It has been reported that five of the *Striga spp* cause devastating effects on crops: *S. hermontica, S. asiatica, S. forbsii, S. aspera* and *S. gesnerioides*[79]. Table 1 shows the distribution of *Striga* in Africa and *S. asiatica* is said to have a wide world geographic distribution as compared to others[75]. According to Larsson[42], there are about 23 species of *Striga* found in Sub-Saharan Africa.

Striga Biology: According to Parker et al[60], *Striga's* life cycle consists of a number of steps such as seed germination stimulation, attachment organ initiation (haustorium), host root penetration and the connection with the host xylem and further growth and development as shown in figure 1.

Striga seeds become responsive after a pre-incubation period (pre-conditioning) of moist and suitable temperatures ranging from 30 to 35 ° C, ideal for germination[80] cited by Mandumbu et al[48]. Continuous exposures to specific exogenous signalling molecules exuded by the roots of their host promote germination. The *Striga* roots and some nonhosts can produce various germination stimulants and release them. Strigolactones, however, are known to be the most powerful stimulant leading to germination in many Striga species seeds.

After germination, the growing *Striga* radicle attaches to the host root and develops a haustorium. Host attachment occurs via the haustorium. Once formed, the organ penetrates the host tissues, ultimately forming a vascular connection for parasitism[59]. After connection, the haustorium attacks the host epidermal cells, enters into the root cortex, continues to form a xylem-to-xylem association with the host afterward begins to procure the hosts supplements and water. The parasite tubercles grow underground for several weeks or several months before emergence of the flowering shoots.

The parasite produces a large number of seeds which remain viable for many years in the soil. Each *Striga* plant is capable of producing numerous seeds of about 50 0000 to 500 000.[42] The seeds of *S. hermonthica* are said to be extremely small about 0.2x 0.3mm, weighing about 0.7µg[72].

Table 1
Distribution and occurrence of Striga spp. in sub-Saharan Africa[6,34,40,48,50,75]

Striga species	**Host plants**	**Distribution**
S. aequinoctialts		Guinea, Angola, Siera Leone,
S. angolensis		Angola
S. angustifolia	Sorghum, Sugarcane	Malawi, Tanzania, Zambia, Zimbabwe
S. asiatica	Rice, Sorghum	Angola, Kenya, Lesotho, Malawi, Mozambique, Sudan, Namibia, Tanzania, Madagascar, South Africa, Zanzibar, Zambia, Botswana, Burundi, Democratic Republic of Congo
S. aspera	Rice, Maize, Sorghum, Finger millet, Wild grasses, Sugarcane	Burkina Faso, Cameroon, Central African Republic, Ethiopia, Gambia, Guinea, Cote divore, Nigeria, Niger, Mali, Ghana, Senegal, Sudan
S. bilabiata		Burundi, Guinea Bissau, Niger, Nigeria, Guinea, Angola, Uganda, Democratic Republic of Congo, Mali, Zambia, Malawi, Cameroon, Burkina Faso, Ethiopia, Central African Republic, Kenya, Tanzania, Cote divore
S. brachycalyx		Burkina Faso, Democratic Republic of Congo, Ghana, Cote divore, Nigeria
S. chrysantha		Central African Republic
S. dalzielii		Guinea, Mali, Nigeria
S. elegans		Angola, Botswana, Kenya, Mali, Namibia, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe
S. forbesit	Sugarcane, Maize, Sorghum, Rice	Angola, Botswana, Democratic Republic of Congo, Ethiopia, Kenya, Malawi, Mozambique, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe
S. gastonii		Chad, Central African Republic
S. gesnerioides	Cowpeas, Wild Legumes	Angola, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Democratic Republic of Congo, Ethiopia, Sierra Leone, Senegal, South Africa, Tanzania, Zimbabwe, Gambia, Ghana, Kenya, Malawi, Mali, Mozambique, Somalia, Nigeria, Rwanda, Uganda, Zambia
S. hermonthica	Maize, Sorghum, millet, rice	Kenya, South Africa, Tanzania, Zimbabwe

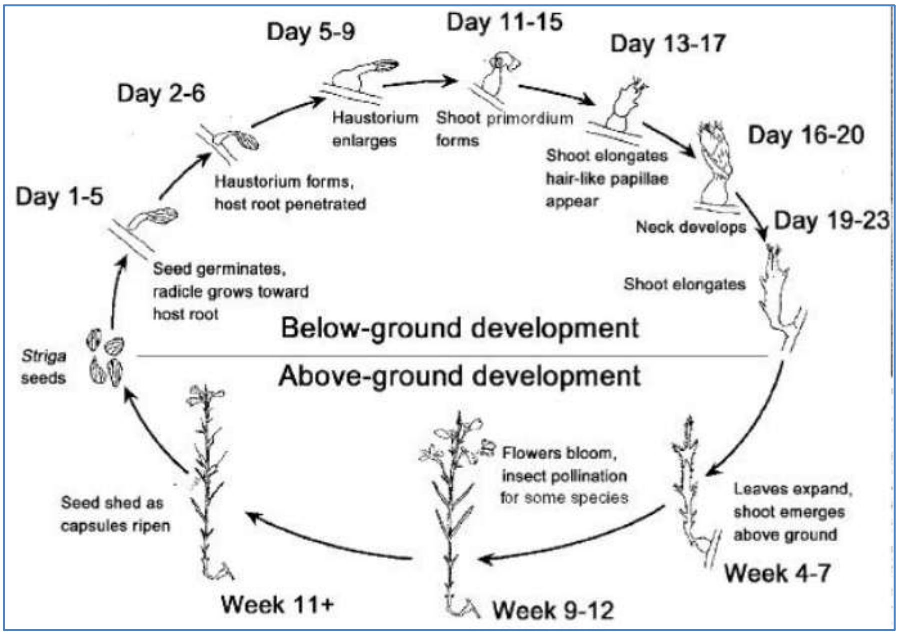

Figure 1: General life cycle of *striga spp*.[10]

There has been a report on increased secretion of strigolactones by root of hosts under phosphorous and nitrogen deficient conditions[43,81]. Jamil et al[32] suggested that application of N and P containing minerals such as NPK and Diammonium hydrogen phosphate could be useful in reducing *S. hermonthica* infection by indirectly inhibiting strigolactone secretion. Use of trap crops stimulates suicidal germination of Striga by releasing strigolactones as indicated by several authors[11,15,31].

Control measures for *Striga* through soil fertility manipulation: Infestation of *Striga* has been boosted by poor soil fertility in most African soils especially in the smallholder farming areas[42]. Improving soil fertility has capacity to reduce *Striga* infestation[42,67,72]. Low soil fertility in SSA has been contributed by poor resources farmers who are unable to by mineral fertilisers[16,51,55,76,83]. Quality of organic manures used by smallholder farmers is also poor due to poor quality of forages consumed by animals in these regions.

Nitrogen is the most limiting nutrient in soils in SSA and this has contributed to *Striga* infestation[42]. This is because N has the effect of reducing strogolactone production from host plants and inhibits germination of *Striga* weeds, so its limitation favours *Striga* infestation. N has capacity to increase vegetative growth of plants and allows them to fight against *Striga* effects.

Poor soil fertility has been attributed to poor soil bio-physio-chemical properties which lead to moisture stress making *Striga* more competitive to crop[72]. The use of N fertiliser and soil moisture conservation techniques such as tied ridges, infiltration pits and tied contours improves soil moistures and has been revealed to cause low *Striga* infestation. Soil with low C:N ratio reduces *Striga* seed density as compared to soils with high C:N ratio (42) and accumulation of N in soil has the capacity to reduce *Striga* infestation[42]. Studies show that application of N fertilisers reduces *Striga* seed germination through inhibition action.[8] The results also show that application of high rates of chicken manure suppresses *Striga* in sorghum fields,[8] this was caused by high N content in chicken manure.

Crop production in smallholder farming areas is commonly done in soils of low fertility, this has been caused by lack of resources by farmers to buy inorganic fertilisers[14,51,55] and this encourages *Striga* infestation. *Striga* infestation is high in soils of low fertility and it outcompetes crops such as sorghum, maize and wheat. In SSA farmers grow small grains (sorghum and millet) in lands with low soil fertility exposing these crops to *Striga* challenges which reduce growth and final yields. To improve soil fertility, farmers can use leguminous tree prunings as means of improving N in the soil[47,55] as well as managing *Striga*.

Derje et al[18] found that intercropping sorghum with groundnut suppressed *S. hermonthica* emergence as compared to other intercrop (soybean) as nitrogen is released by legumes. This study recommended intercropping groundnut in 1:1 proportion and simultaneous planting for the control of Striga by small-scale farmers for sustainable crop production. Emechebe et al[23] conducted a survey in Nigeria and found that farmers mentioned control methods such as hand rouging and hoe weeding, application of inorganic fertiliser, crop rotations and early planting. Trap crops such as groundnut (*Arachis hypogea*, soybean *(Glycine max*), cow pea (*Vigna unguiculata*) and sesame (*Sesame indicum*) have been in use to encourage suicidal germiation[11,15,31].

Economic consequences of *Striga* in Africa: Maize, sorghum and millet are common crops in Africa and are the staple food for most households. The weed *Striga* has become a big problem and causes severe yield losses in cereal production. 50 million hectares of arable farm land under cultivation with cereals and legumes in Sub-Saharan Africa are infested with one or more *Striga* species. Variable statistics of *Striga* infestation of 40% of arable land in Sub-Saharan and 67% of the 73 million hectares in cereal zones are infested by *Striga*. Table 2 presents losses in the sub-Sahara Africa due to *Striga*.

In Africa, there are four species of agricultural importance: *Striga hermonthica*, which is the most troublesome species distributed in northern, eastern and southern Africa; *S. asiatica* is of economic importance only in eastern and southern Africa; *S. forbesii* is important only in Zimbabwe and *S. gesnerioid* is important primarily in West and East African cowpeas (e.g. Nigeria and Tanzania). They have spread widely, becoming a scourge in cereal production where there is low fertility and low rainfall.

The *Striga* issue has reached epidemic levels in many locations in Africa, as the condition is worse owing to several variables in the subsistence agriculture. Often reductions of yield due to harm caused by *Striga* ranges between 10% and 70% depending on the level of infestation, rainfall model and land degradation. On average the damages are projected at 40%[22]. Table 3 depicts the yield losses caused by Striga in Sub-Saharan Africa.

The United States and Australia are other nations impacted by Striga. Methods have been created in the last 50 years for the fight against *Striga* in these nations. The reasons why these methods are not used in Africa are because they include chemical inputs that are too expensive for African farmers. In Africa, the traditional agriculture systems include *Striga* resistant seeds and crop rotation[39].

Effects of Soil Condition and Fertilisers on Striga: The temperature and moisture of the soil affect the germination and development of *Striga*. Patil[62] noted that sometimes flooded soils were free from *Striga*, whereas intense infestation was seen in better drained soils. The temperature and moisture of the soil affect the germination and development of *Striga*. A study by Mohamed et al[49] discovered that the germination of *Striga* seeds in soils with less than 10 percent moisture at the beginning of conditioning exceeded 90 percent. Soil moisture levels exceeding 10 percent resulted in germination of 60 percent. High soil moisture is therefore usually not conducive to *Striga's* growth and development[26].

Table 2
Estimates of production losses due to Striga in sub-Sahara Africa[29]

	Sorghum and millets*	Maize	All crops
Area affected (million ha)	21.9	43	26.23
Estimated yield loss %	26	40	33
Estimated loss in production (million ton	8.6	2.07	10.67

* Includes cowpeas in West Africa

Table 3
Sub-Saharan Africa countries with the highest food production losses due to Striga[29]

Country	Estimated % yield loss	Yield loss ("000 tons)
Burkina Faso	35-40	710-820
Eritrea	20-60	30-90
Ghana	35	170
Kenya	35-40	50-60
Mali	40	580
Mozambique	35	40
Niger	40-50	930-1160
Nigeria	35	3750
Sudan	30	1230
Tanzania	up to 90	550
Togo	35	70
Total/Mean	39-45	8110-8520

On low fertility soils, *Striga* is more problematic[13,48]. High availability of soil nitrogen has been demonstrated to suppress the germination and attachment of Striga[13,63]. The use of organic and inorganic fertilisers decreased the amount of Striga[13,37]. Studies have shown that high nitrogen concentration leads to reduced germination stimulant production ammonium nitrogen and urea may exert direct toxic effects on the parasite.[56,57] The use of inorganic fertilisers especially those containing N and phosphorous has been reported to reduce *Striga* seed germination and growth[42,55,67,72,73]. Nitrogen reduces germination of *Striga* seeds through inhibition action.

Agroforestry species such as Leucaena and Calliandra have high N content of approximately 3% and this improves soil N and reduces *Striga* infestation[55]. The use of *Leucaena* biomass in sorghum plots has been reported to increase N content in the soil[14,52,61], improves soil water retention, reduce soil bulk density and increases cation exchange capacity and available phosphorous. This has been noted to have reduced *Striga* infestation in sorghum plots and improve yields. *Striga* infestation was reported to be high in soils with low N, moisture stress[30,77] and low soil fertility in general. The use of integrated soil fertility through mineral fertiliser, organic manure and /or application of legume tree biomass[51,55] improves soil fertility and reduce *Striga* problems.

These sentiments were supported by Dargo et al[14] who reported that *Striga* can be controlled by application of fertiliser and use of *Leucaena* biomass to improve soil fertility. Same information was also reported by Khan et al[40] who indicated that the use of legumes reduces *Striga* effects by producing chemicals that repel stembores and allelopathic compounds which suppresses *Striga*[38]. The use of legumes increases N through biological nitrogen fixation and conserves soil moisture, soil organic matter through fast decomposition and mineralisation, hence reduces *Striga* outbreak[16,17,38,42].

Legume trees such as *Sesbania sesban*, *Leucaena* species, *Acacia anguistissima*, *Calliadra calothyrsus* and *Cajanus cajan* practice deep capture[45,46] which brings back nutrients to the surface, increasing soil fertility and add more N to the soil. These have a potential of fighting against *Striga* due to improved soil fertility, soil moisture and reduced competition for nutrients with field crops.

Although some researches support that there is a relationship between soil fertility and *Striga*. Some authors have shown inconclusive results with a possibility that there might not be a relationship between *Striga* and soil fertility.

Effects of rate and time of Fertiliser application on *Striga*: For a positive effect on *Striga*, it is not the quantity but the rate of nitrogen application that is essential. Ayongwa[8] stated that the timing of application for inorganic nitrogen is more important than the amount applied. Early application of fertilizer even in tiny amounts of nitrogen could reduce *Striga* infestation. Potassium application promotes stimulant activity in the host and results in enhanced incidence of Striga while phosphorus does not affect the germination and infestation of *Striga* seeds[25,66,68,81]. Application of inorganic fertiliser in proper time can be a solution to improve soil fertility and suppress *Striga* infestation but the use of fertiliser has been hindered by low fertiliser application by smallholder farmers who are resource poor[51,52,54,55]. Hence there is need for smallholder farmers to adopt the use of crop residues, organic fertilisers and legume tree biomass to improve soil N and suppress *Striga*[55].

Effect of soil fertility on *Striga* threat level to crop production: Various characteristics can be given to high soil fertility. The soil should be rich in plant nutrients and trace components that are also accessible to the plant. If the soil has a pH between 6.0 and 6.8, this is obtained. Soil with elevated soil fertility also has elevated soil organic matter (SOC) content that helps enhanced soil structure and water retention ability.

The Striga seed bank was considerably linked to pH, complete quantity of C and N in soil when regression analysis was performed according to Larsson.[42] The soil's clay and silt content were also important for *Striga's* seed bank through the single regression analysis except pH. The amount of *Striga* plants in the soil was negatively related to nitrogen. The ideal pH is approximately 6.0 to 6.8 for excellent soil fertility[24]. PH range of 6.2-6.3 had the highest quantity of Striga seeds[42]. This could mean that *Striga* prefers the same pH as it is deemed optimal for good soil fertility. In reality, the findings could indicate a correlation between Striga infestation and soil fertility status.

The significance and correlation between soil organic matter and *Striga* infestation was proved by studies of both Ayongwa[8] and Gebreslasie[28]. Increased soil organic matter decreased *Striga* seed germination. In addition, organic matter is a soil fertility measure[24,69] indicating that Striga infestations are associated with soil fertility decrease. Soils of high quality organic matter have a low C: N ratio and are also more likely to reduce *Striga* seed survival. However, in a study by Ayongwa[8], it was shown that the biomass of Striga decreased when the same amount of inorganic N was applied rather than organic matter.

The first objective was that soil fertility has an impact on crop threat from Striga, so study by Erikson et al[24] shows that plant nutrient availability is essential to good soil fertility. Fields with a greater total quantity of N indicating good soil fertility have a reduced *Striga* seed bank[13] which would reduce the danger to farm crops.

Influence of tropical soils on *Striga spp* population and its damage to the crop: The results of studies agree with the findings of Cechin et al[12] and Dargo et al[14] who reported that higher concentrations of nitrogen reduced the number of *Striga* per sorghum plants.

This finding also confirms the results reported by Gebreslasie et al[28] who stated that decrease in *Striga* plant height was observed with increased nitrogen level application. Nitrogen fertilisers are known to increase plant height and promote vegetative growth. These reports also coincide with report by Nyambati et al[55] who reported that the use of Calliandra, crop residues, inorganic fertilisers and organic manure increases N content in the soil and suppress *Striga* infestation.

Nitrogen inhibits germination of *Striga* seeds which in a way adversely affects reproduction of the weed[14,42]. There is a significant increase in yield as a result of application of nitrogenous fertilisers and farmyard manure rich in nitrogen. For fields that have been used for crop production, the results show that there is a high rate of *Striga* reproduction in soil with very low levels of manure or fertility[55,77]. For most communal farmers who solely rely on farm manure, *Striga* reproduction was prevalent in fields where farmers could not apply farm manure. This scenario is a common feature in the Savannah areas since poverty puts inorganic straight fertilisers beyond the reach of most, if not all, small holder farmers. The result used in terms of effects of farm manure, nitrogen and phosphorus on *Striga* was derived basing on farm manure.

Thus the level of *Striga* reproduction especially in cereal crop fields where farm manure was applied was significantly reduced[13]. These findings can be supported by Kamara et al[35] who has noted that in Nigeria cereal productivity was high in fields where animal manure had been applied which also reduces *Striga* infestation. The rate of *Striga* reproduction is low when farmers use best agronomic practices that increase crop productivity like crop rotation, green manuring or even adding organic and inorganic manure. These findings are also supported by Dugje et al[19] who state that application of fertilisers suppress *Striga* reproduction. The application of nitrogen to crops has a positive effect on the increase in productivity. The findings are supported by Gebremariam and Assefa[27] as shown in table 4.

Table indicates that nitrogen application at different rates significantly increased grain yield. The grain yield improved with increased levels of nitrogen fertiliser application. The highest grain yield was obtained with 150 kg N ha^{-1} (2231.48 kg yield ha^{-1}) application. The enhance in grain yield with increase in N levels application might be due to the increase of yield attributing characters and nutrient uptake of the crop under these levels. This result is in line with the findings of Poornima et al[64] and Akdeniz et al[5] who reported higher grain yield with increased levels of nitrogen in sweet sorghum and grain sorghum respectively.

Effect of fertiliser application to soil fertility-*Striga* parasitism relation: A significant constraint for cereal production in Africa is soil fertility[67]. In addition to the direct negative effects on agricultural production and food security of low soil fertility, low soil fertility increases the susceptibility of the crop to biotic pests.

Showemimo et al[71] reported application of nitrogen fertilizer from 110-170 kg N ha^{-1} control *S. hermonthica* in sorghum. Similarly, Agbobli[3] recorded a reduction in the *S. asiatica* in maize plants after excess applications of 60 kg N ha^{-1}. Application of nitrogen fertilizers like ammonium nitrogen has been recorded by Cechin et al[12] and Chikwari et al[13] as affecting the development of *Striga* by decreasing the output of stimulating compounds (*Strigolactone*) or their specific leakage from host roots.

Strigolactone production is significantly reduced if nitrogen is present in the soil which represses the germination of *Striga* seeds. This subsequently reduces the infestation of Striga therefore increasing crop yield[19]. Crop species and nitrogen levels significantly affect *Striga* emergence[13,33]. The studies have shown that high nitrogen concentration leads to reduced germination stimulant production. Timko et al[75] found that ammonium nitrogen and urea may exert direct toxic effects on the parasite.

Aflapui et al[1] investigated the effects of time of applying nitrogen fertiliser on *S. hermonthica* population in maize at tasselling and harvest when nitrogen was applied to maize at 6 WAP (weeks after planting) than 4 WAP, the difference was not significant. The *S. hermonthica* population for both times was the same at 10 days after harvest. *Strig*a population declined in response to increased rate of nitrogen fertiliser.

Table 4
Effect of N levels on grain yield, Stover yield and harvest index[27]

Nitrogen levels	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index
0	1629.63^{b}	3787.04^{b}	0.30^{b}
50	1722.22^{b}	4027.78^{b}	0.30^{b}
100	2083.33^{a}	4129.63^{b}	0.34^{a}
150	2231.48^{a}	4851.85^{a}	0.32^{ab}
SEM (±)	51.38	123.25	0.007
Prop>F	<0.0001	0.0006	0.02
CV%	18.7	20.33	16.67

*Levels not connected by same letter within the same column are significantly different.

From the results, it can be shown that high levels of nitrogen in the soil reduce *Striga* population. In contrast, field studies[3,9,25] reported that increasing the rate of nitrogen fertiliser reduced the infestation of *Striga* and increased crop yield.

Conclusion

Results from the review showed that nitrogen is negatively related to strigolactone production. Adding nitrogenous fertilizers is one of the popular *Striga* control strategies. Fertilizer applications improves grain yield and farm manure also significantly improve grain yield. For a positive effect on *Striga*, it is not the quantity but the rate and timing of nitrogen application that is essential. The review study found that *Striga* emergence was greatly influenced by the level of soil fertility. Application of nitrogeneous fetiliser or manure reduces *Striga* growth by reducing production of stimulatory compounds (*Strigolactone*) from the host plant. When nitrogen is applied to the crop, *Striga* infestation is reduced and the crop yield increases.

Total soil nitrogen content has shown to be negatively correlated with Striga seed density in the soil.[58] As studies have shown that high nitrogen concentration leads to reduced germination stimulant production the rate and timing of fertiliser application also play an important role in dwindling *Striga* population. From the literature analysis, the review concludes that there is a strong negative relationship between *Striga* infestation and soil fertility status.

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