Interaction Effect of Common Bean Intercropping with NPS Blended Fertilizer on Striga hermontica severity reduction and Productivity of Sourghum at Fedis, Eastern Ethiopia

Lemma Degebasa
Haramaya University
Taye Tessema
Ethiopian Institute of Agricultural Research, Post Office
Zelalem Bekeko
zelalembekeko@yahoo.com

Haramaya University
Ketema Belete
Haramaya University

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Abstract

In Ethiopia, sorghum is the main crop grown for food and feed. But in the majority of eastern Ethiopia's sorghum-growing regions, *Striga hermonthica* is the main obstacle. In Fedis District, an experiment was carried out to assess the interaction effect of blended NPS fertilizer and common bean planting density for Striga management over the two main cropping seasons of 2019 and 2020. The treatment combination consisted of four NPS blended fertilizer levels (0, 50, 100, and 150 kg ha-1 NPS) in a factorial arrangement in a randomized complete block design with three replications, susceptible sorghum variety (Teshale) and common bean variety (Dursitu), planting densities of (25%, 50%, and 75%). The analysis of variance results indicated that treatment interactions on Striga infestation caused highly significant ($p < 0.001$) changes. The combination of 50% common bean planted density and 100 kg ha-1 NPS blended fertilizer application gave the lowest Striga count (2 Striga shoots) per plot, whereas the single planted susceptible sorghum variety (Teshale) produced the highest Striga count (8 Striga shoots) per plot. The main findings of this study consequently indicate that the host crop (sorghum) was supported by a 60% reduction in *Striga hermonthica* infestation when NPS fertilizer and common bean planted density were combined. The combination of 50% common bean planted density and 100 kg NPS ha-1 blended fertilizer application produced the maximum (2.54 t ha-1) grain yield of sorghum, while the control plot produced the lowest (0.98 t ha-1) grain yield. Hence, farmers in the study area could manage Striga and improve sorghum productivity through the combination of common bean with NPS blended fertilizer under natural Striga infestation.

1. Introduction

Sorghum [*Sorghum bicolor* (L.)] is one of the top five cereal crops and the major source of energy and protein for millions of people living in the arid and semiarid regions of the world. Its ability to adapt to adverse environmental conditions has made sorghum a popular crop worldwide. The crop also plays a significant role in millions of poor Ethiopians and grows in a wide range of agro-climatic zones, especially in eastern Ethiopia. It is used to make bread, beverage, fodder and as fencing materials in the dry season [1, 2]. The livelihoods of subsistence farmers in Ethiopia depend on sorghum production. However, its productivity is low at approximately 2 t ha^{-1} [3]. This is attributed to a number of biotic and biotic stresses. Yield reducing factors include Striga infestation, low soil fertility, drought, plant diseases, insect pests, like stem borers and sorghum shoot flies [4]. Although these constraints cause a significant loss of grain, the level of losses varies from region to region.

Striga (witchweed) is a severe problem in sorghum production in eastern Ethiopia [5]. This parasitic weed, mainly *Striga hermonthica*, also attacks other crops, including rice, millet, and maize [6]. In the cereal growing regions of Ethiopia, yield losses of 65–100% due to Striga are common in heavily infested fields [7, 5]. If Striga plants are allowed to flower and seed, a large number of seeds will be returned to the soil, increasing the soil seed bank. The severity of Striga depends upon the degree of infestation, seed viability, ecotypes, virulence, host crop susceptibility, climatic/edaphic factors, and cultural practices employed by the farmers [8].

There are numerous ideas suggested for the management of Striga. But, only a few seem to be technically feasible and cost effective for small-scale holdings. The long list of management measures includes the use of hand weeding, crop resistant varieties, land preparation, hoeing, herbicide, nitrogen fertilizer, trap crops, the use of biological control and Striga seed germination stimulants. Combined Striga management is a strategy comprising a combination of two control techniques, where the techniques are used at the same time to control Striga [9].

The severity of Striga infestation is reported to correlate negatively with soil fertility, and the critical element among the nutrients is widely believed to be nitrogen. The advantageous effects of fertilizers include increasing soil nitrogen and other nutrients, replacing the soil organic matter and increasing the soil moisture holding capacity [10]. The suppressive effects of nitrogen on Striga infestation are attributed to delayed seed germination, reduced stimulant production and reduced seed response to stimulants [11]. Suitable fertilization with respect to type, time, amount and fertilizer application method can enhance the advantage of intercropping [12].

Intercropping can provide a yield advantage compared to cropping alone (monocropping system) when planted at optimum density [13, 14]. The forms of these advantages are yield stability, low input, higher and better use of growth resources and better management of the parasitic weeds (Striga) than monocropping system. Intercropping legumes with sorghum also improves soil fertility through fixation of atmospheric nitrogen [15]. Hand pulling and crop rotation, which are practiced by farmers in the area, could not bring significant changes in reducing Striga infestation. Here, it is commonly intercropped with legumes and even '*Khat*' (*Catha edulis)*. Accordingly, the current research conducted in the Fedis district in East Hararghe Zone in Oromia Region, which represents one of Ethiopia's sorghum-growing belts, indicated that Striga spp. are one of the major constraints on sorghum production, followed by low soil fertility and drought. Thus, raising production levels and reducing vulnerability to Striga infestation is essential for improving the food security of sorghum farmers to help ensure adequate food availability and to increase household incomes. Combined application of fertilizers and use of trap crops, reduce the severity of Striga and enhance sorghum productivity.

Therefore, to reduce this constraint, research on mineral NPS blended fertilizer rates and common bean (*Phaseolus vulgaris* L.) intercropping at optimum density should be undertaken. From this point of view, the objective of this research was to evaluate the combined effect of mineral NPS blended fertilizers and common bean intercropping on Striga infestation and the yield and yield-components of sorghum.

2. Materials and Methods

2.1. Description of Study Area

A field experiment was conducted on farmers' fields in Edobaso village at Fedis during the 2019 and 2020 main rainy cropping seasons. Fedis is one of the districts in the semiarid belt of the eastern lowlands of East Hararghe Zone in the Oromian Regional State. The site is suited at 9°22' N latitude and 42°09' E longitude with an altitude of 1704 meters above sea level (m.a.s.l.). The mean annual maximum and mean minimum temperatures were 28.37 and 12.31°C, respectively, while the annual rainfall was 1178.61 mm in both growing seasons on monthly bases (Fig. 1). Fedis is characterized by bimodal rainy seasons; the first season (short rainy season) is between March and May, while the second main long rainy season is from July to October. According to the national Ethiopian agro-ecological classifications, Fedis is classified as 'Bada-dare (*Mid-highland)*' or 'Gammojji (*Lowland)*' 15% and 85%, respectively, of the total area of the district.

2.2. Treatments and Experimental Design

The treatments consisted of two factors, namely four levels of NPS blended fertilizer application rates (0, 50, 100 and 150 kg ha^{-1}) and three planting densities of common bean (25%, 50% and 75%) intercropped with the susceptible sorghum variety (Tashale). There were fifteen treatment combinations, which were assigned to each plot randomly. The treatment combination comprised:

1) 25% common bean + 0 kg/ha NPS blended fertilizers (25% CB + 0 kg/ha NPS),

2) 25% common bean + 50 kg/ha NPS blended fertilizers (25% CB + 50 kg/ha NPS),

3) 25% common bean + 100 kg/ha NPS blended fertilizers (25% CB + 100 kg/ha NPS),

4) 25% common bean + 150 kg/ha NPS blended fertilizers (25% CB + 150 kg/ha NPS),

5) 50% common bean + 0 kg/ha NPS blended fertilizers (50% CB + 0 kg/ha NPS),

6) 50% common bean + 50 kg/ha NPS blended fertilizers (50% CB + 50 kg/ha NPS),

7) 50% common bean + 100 kg/ha NPS blended fertilizers (50% CB + 100 kg/ha NPS),

8) 50% common bean + 150 kg/ha NPS blended fertilizers (50% CB + 150 kg/ha NPS),

9) 75% common bean + 0 kg/ha NPS blended fertilizers (75% CB + 0 kg/ha NPS),

10) 75% common bean + 50 kg/ha NPS blended fertilizers (75% CB + 50 kg/ha NPS),

11) 75% common bean + 100 kg/ha NPS blended fertilizers (75% CB + 100 kg/ha NPS),

12) 75% common bean + 150 kg/ha NPS blended fertilizers (25% CB + 150 kg/ha NPS),

13) Sole susceptible sorghum variety-Teshale (control-1),

14) Sole resistant sorghum variety-Gobiye (control-2), and

15) Sole common bean (control-3).

The experimental plot accommodating five rows of sorghum planted at a spacing of 75 cm between rows and 20 cm between plants in both sole and intercropped sorghum plots. A path width of 1 m between plots and 2 m between blocks. The treatments were randomly arranged in a randomized complete block design (RCBD) in a factorial arrangement with three replications.

2.3. Experimental Procedures

The experimental field was plowed using a tractor, and plots were leveled manually. Sowing was conducted on 25 June 2019 and 2020 cropping seasons. Sorghum was planted at the required intra-row spacing of 75 x 20 cm in both cropping seasons. Common bean (*Phaseolus vulgaris* L.) was planted with intra-row spacing of 6 cm, 12 cm and 24 cm based on the treatments, which represented 75%, 50% and 25%, respectively, of the recommended common bean planting density. The seeds were sown by hand in the rows as uniformly as possible and covered with soil manually. Nitrogen-phosphorus-sulphur (NPS) blended fertilizer was used as a source of mineral nutrients; and the NPS blended fertilizer was applied in two doses, i.e., half of the quantity was applied as band application at planting, and the remaining half was top-dressed at knee height growth stages of sorghum. It was applied 5 cm away from the plants for sorghum rows only. Thinning of seedlings was conducted two weeks after emergence at spacing of 20 cm for sorghum and 6 cm, 12 cm and 24 cm intra-row spacing of common bean. Three and two seeds per hill were planted for sorghum and common bean, respectively. Then, after emergence, it was thinned to one seedling per hill for each crop. All agronomic practices, such as weeding and chemical spray, were carried out equally starting from the planting date to the harvesting date for all experimental units as recommended and adopted for the location.

2.4. Soil Sampling and Analysis

Before planting, the physical and chemical properties of the soil were determined. Representative soil samples were collected at a depth of 0–30 cm randomly in a zigzag pattern using an auger from the experimental field before planting. The soil samples were composited, and a one kilogram sample was taken as a working sample. Crumbs of soil were broken into pieces and sieved. The collected composite samples were air-dried on paper trays, ground, and sieved to pass through a 2 mm sieve for chemical analysis. The soil analysis included textural analysis (sand, silt and clay), soil pH analysis, determination of total nitrogen, available phosphorus, cation exchangeable capacity and organic matter. Soil texture analysis was performed by the Bouyoucous hydrometer method. Total nitrogen was determined using the Kjeldahl method. The pH of the soil was measured in water at a soil to water ratio of 1:2.5 potentiometric pH meters with a glass electrode, and the cation exchange capacity (CEC) was determined using the 1 N ammonium acetate (NH_4-AOC) method. The available phosphorus content of the soil was determined by the Bray II method [16].

2.5. Data Collection

2.5.1. Crop Phenology

Data on days to 50% flowering and 95% physiological maturity of sorghum were recorded by counting the number of days from planting to the time when 50% and 95% of the plots reached each phenological stage, respectively. Growth parameters: Ten random plants/plot from the net plot area were taken to measure leaf area/plant cm^2. Three leaves/plants were considered to have performed physiologically well. It was determined at 50% heading described as follows: leaf area = leaf length of the leaves x maximum width of leaf x 0.75. Where 0.75 = correction factor for sorghum. The leaf area index (LAI) was measured from ten random plants/plot and was calculated as the ratio of unit leaf area per unit ground from the net plot, where unit leaf area = leaf area x number of leaves/plant. Ten random plants from each net plot were also taken to measure panicle length (cm) when the plants reached 95% physiological maturity. Similarly, plant height (cm) was measured from ten randomly taken plants of each net plot at 95%

physiological maturity from ground level to the base of the panicle. The ten randomly selected plants from the net plot area were tagged to take data on all these growth parameters.

2.5.2. Yield Related Traits and Yield

Panicle lengths of ten sorghum plants were recorded using centimeters (cm). Grain yield (kg) was obtained from all plants in the net plot area. It was determined using a sensitive balance after the grain had been dried, threshed, cleaned and adjusted to a 12% moisture level. Then, it is converted to ton/ha basis. The aboveground biomass (kg) was measured after the plants from the net plot area were harvested and sun dried until a constant dry weight was attained. The harvest index was also computed as the ratio of grain dry weight to aboveground dry biomass expressed as a percentage. Similarly, the number of pods/plant and seeds/pod of common bean at physiological maturity were determined from 50 pods taken from the ten sampled plants of the net plot. Similarly, a common bean grain yield sample was taken from a net plot area adjusted at a 12% moisture level using a digital grain moisture meter, and the hundred seed weight (g) was measured using a sensitive balance.

2.5.3. Striga parameters

The number of striga shoots that emerged per net plot area was counted at the **12th and 14th** weekly intervals from the time of emergence of striga seedlings and at harvest. Other parameters were as follows: Striga height (cm): Distance from the soil surface to the tip of the striga in cm was measured. The reduction in the Striga infestation level (RIL) was calculated as follows: **RIL** = Striga count in sole sorghum - Striga count in intercrop x100/Striga count in sole sorghum.

2.6. Land Equivalent Ratio (LER)

The land equivalent ratio was calculated from the economic yield of common bean and sorghum components. The sum of the ratio of intercropped yield to sole yield of sorghum and common bean components gave LER. The land equivalent ratio for common bean was calculated as the yield of common bean in intercropping divided by the sole yield, whereas the LER of sorghum was calculated as the yield of sorghum in intercropping divided by the yield of sole.

$$LER=\frac{Yield\ of\ crop\ 'A'\ in\ mixture}{Yield\ of\ crop\ 'A'\ in\ sole}+\frac{Yield\ of\ crop\ 'B'\ in\ mixture}{Yield\ of\ crop\ 'B'\ in\ sole},$$

Where A=Sorghum, B= Common bean

2.7. Economic analysis

Cost–benefit analysis was performed following CIMMYT methodology [17]. The analysis of data was made using the predominant inputs at planting and for outputs at the time the crop was harvested. Seed (ETB/ha), field management costs (ETB/day), market prices of NPS (ETB/ha), and fertilizer application cost (ETB/ha) in both the June 2019 and 2020 cropping seasons were recorded. The costs and benefits were calculated on a hectare basis in Ethiopian Birr (ETB/ha). The economic analysis was based on the formula developed by [17] and was shown as follows: average grain yield was the average yield (kg/ha) of each treatment. Gross field benefit (GFB) was the product of the field price (ETB/ha) of sorghum and the average grain yield for each treatment. Total variable cost (TVC) was the sum of the field cost (ETB/ha) of fertilizer and the cost of fertilizer application. Net benefit (NB) was calculated by subtracting the total costs from the gross field benefit for each treatment. NB = GFB – TVC. The marginal rate of return (MRR %) between any pair of treatments denotes the return per unit of investment in fertilizer expressed as a percentage. The marginal rate of return (MRR%) was calculated by dividing the change in benefit by the change in cost.1241

2.8. Data Analysis

The collected data were subjected to analysis of variance (ANOVA) using the R-Software computer package version Rx64 4.1.0. Mean separation was carried out using the least significant difference (LSD) test at the 5% probability level.

3. Results and Discussion

3.1. Soil Physical and Chemical Properties

The soil analysis results of the experimental soil showed that the soil textural class of Edobaso at the Fedis district study site was sandy loam in texture with a high proportion of (68%) sand, followed by (19%) clay and (13%) silt (Table 1).

The experimental site consisted of soil nutrients such as OM (1.478%) and total N (0.112%), which were considered to be in the low category, whereas CEC (34 meq/100 g) and available phosphorus P (12.74 ppm) were considered to be in the high category with a soil pH of 8.08 (Table 1). The experimental site was moderately alkaline in nature with soil pH 8.08, which is in agreement with classification of soil pH as very strongly alkaline (> 9.0), strongly alkaline (8.5-9.0), moderately alkaline (7.9–8.4), mildly alkaline (7.4–7.8), neutral (6.6–7.3), slightly acidic (6.1–6.5), moderately acidic (5.6-6.0), strongly acidic (5.1–5.5) and very strongly acidic (4.5-5.0) [18].

Table 1
Soil physical and chemical properties of the experimental site before planting at Fedis in the main cropping season.

Soil properties	Unit	Result	Score rate	Category
Chemical properties				
Soil PH	PH meter	8.08	7.9–8.4	moderately alkaline
Organic Matter (OM)	%	1.478	1–2%	low
Total Nitrogen (N)	%	0.112	0.1–0.15	low
Available Phosphorus (P)	ppm	12.74	> 11	high
Cation Exchange Capacity (CEC)	meq/100 g	34	> 20	high
Physical properties				
Sand	%	68		
Clay	%	19		
Silt	%	13		
Textural Class		Sandy loam		

The soil organic matter of the experimental site was 1.478%, which categorized the organic matter content of soil as very low (< 1%), low (1 to 2%), medium (2.1 to 4.2%), high (4.3 to 6%), and very high (> 6%) [19]. The low organic matter might be due to the concentrated cultivation and continuous removal of crop residue. Therefore, the experimental site needs the addition of NPS blended fertilizer, which increases the organic matter in the soil. The soil analysis further indicated that the experimental site had low total nitrogen (0.112%) compared with the rated total N (%) as very low (< 0.1), low (0.1–0.15), medium (0.15–0.25) and high (> 0.25) [20]. The low nitrogen content could be accompanied by the low soil organic matter content in the soil, which is a limiting factor for optimum crop growth. Thus, soils need improvement with organic fertilizers. The available phosphorus content of the experimental site was within the high range, with a result of 12.74 ppm, as presented in Table 1. In line with this result, [16] rating, P (mg/kg) content is: (< 3) very low, (4–7) low, (8–11) medium, (> 11) high and cation exchange capacity (CEC) of the study site was 34meq/100 g which is high according to [21] classification (10–20 cmol (+)/kg) is medium and > 20 cmol (+)/kg is high. This showed the high capacity of the soil to retain cations in exchangeable form for the plant.

3.2. Influence of intercropping and NPS fertilizer on sorghum growth parameters

The reaction of sorghum to different rates of NPS blended fertilizer and planting density of common bean intercropping was significantly different ($P < 0.001$) at 50% days flowering and 95% days to physiological maturity between the treatments (Table 2).

In general, the recommended rate of NPS blended fertilizer (100 kg NPS/ha) marginally increased the days to 50% flowering in sorghum (5%). The maximum days to 50% flowering were observed at 50% common bean planted and 100 kg NPS/ha with mean days to 50% flowering of 76 days. Minimum days to 50% flowering were recorded (63 days) in one control plot (Table 2). This might be due to soil fertility improvement. Similarly, increasing the nitrogen rate significantly prolonged the days to 50% flowering of reported in linseed [22]. In contrast non-significant interaction effects of N and sulfur on days to flowering of common bean reported [23].

An early 95% physiological maturity date was recorded from the control treatments (sole sorghum) because common bean most likely activates many species of living organisms for nitrogen fixation and NPS blended fertilizer may stimulate the plant growth and absorption of nutrients (Table 2). This result is in line with the findings that the soil nutrients used for increased cell division [24]. Also nitrogen promoted vegetative growth and delaying plant maturity in onion [25]. This result further agrees with the delayed physiological maturity due to nitrogen fertilization in common bean [26].

Table 2
Combined effect of common bean planting density and NPS blended fertilizer rate on sorghum growth parameters at Fedis experimental site in February in the 2019 and 2020 main cropping seasons.

	Days of flowering		**Physiological maturity**		**Plant height**		**Leaf area index**	
Treatments’	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2
25%CB + 0 kg/ha NPS	66^{cdef}	69^{cd}	96^{bcdef}	92.6^{fg}	140^{gh}	143.8^{g}	2.7^{cd}	2.92^{bc}
25%CB + 50 kg/ha NPS	69^{cde}	69^{cde}	97^{bcde}	95.4^{de}	154^{de}	153.4^{e}	3^{abc}	2.92^{bc}
25%CB + 100 kg/ha NPS	70^{bcd}	71^{bc}	98^{bc}	97.2^{bcd}	156^{cde}	158^{cd}	2^{efg}	2.57^{cd}
25%CB + 150 kg/ha NPS	72^{abc}	70^{cd}	99^{b}	99.2^{bc}	153^{e}	156^{cde}	2.4^{de}	2.42^{d}
50%CB + 0 kg/ha NPS	70^{a}	72^{ab}	88^{hij}	89.2^{h}	142^{gh}	146.4^{f}	1.8^{gh}	1.93^{fgh}
50%CB + 50 kg/ha NPS	75^{ab}	67^{cde}	90^{h}	93.6^{efg}	151^{e}	155.2^{de}	2.1^{efg}	2.12^{ef}
50%CB + 100 kg/ha NPS	75^{ab}	76^{a}	91^{gh}	101.4^{a}	160^{bc}	165.4^{a}	3.2^{a}	3.4^{a}
50%CB + 150 kg/ha NPS	74^{bcd}	75^{ab}	99^{bc}	102^{a}	155^{de}	161^{b}	2.4^{de}	2.64^{cd}
50%CB + 150 kg/ha NPS	74^{bcd}	75^{ab}	99^{bc}	102^{a}	155^{de}	161^{b}	2.4^{de}	2.64^{cd}
75%CB + 0 kg/ha NPS	70^{ab}	66^{def}	89^{hi}	90.4^{h}	139^{h}	142.6^{gh}	1.8^{gh}	1.75^{gh}
75%CB + 50 kg/ha NPS	72^{abc}	71^{bc}	98^{bcd}	96^{cdef}	152^{e}	155^{de}	2.6^{cd}	2.74^{c}
75%CB + 100 kg/ha NPS	74^{a}	74^{a}	100^{ab}	101.6^{a}	158^{bcd}	161.6^{b}	3^{abc}	3.14^{bc}
75%CB + 150 kg/ha NPS	72^{ab}	73^{ab}	104^{a}	102^{a}	154^{de}	156.4^{cd}	2.4^{de}	2.64^{cd}
Control 1	61^{f}	64^{f}	82^{k}	85.4^{jk}	130^{i}	130^{i}	1.9^{fgh}	1.89^{fgh}
Control 2	62^{f}	65^{ef}	84^{jk}	86.2^{ij}	120^{j}	120.4^{j}	1.83^{gh}	1.95^{efgh}
Control 3	38^{g}	40^{g}	41^{l}	39^{l}	40^{k}	40^{k}	1.7^{gh}	1.56^{h}
CV	3.24		1.69		1.29		8.20	
LSD (0.05)	1.62		0.85		0.65		0.039	

Means with the same letters in the column are not statistically significant at the alpha 0.05 probability levels. Sn1 and Sn2 represent season one and season two, respectively.

In both seasons, there were significant ($P < 0.001$) differences in plant height and leaf area index. At Fedis (Edobaso), 50% common bean planted density and application of 100 kg NPS/ha blended fertilizer gave the tallest plants with a mean of 162.7 cm and maximum LAI (3.3). The minimum plant height (130 cm) was recorded from unfertilized plot/control 1, and the minimum LAI (1.87) was observed at 75% common bean planted density without NPS/ha fertilizer (1.78), followed by the sole susceptible sorghum variety Teshale (Table 2). This increase in plant height could be due to nitrogen increasing the vegetative growth of plants. This result is in agreement with Abebe *et al.* (2013), who reported a significant difference in the plant height on maize–soybean intercropping was due to integrated nitrogen fertilizer application. This result is also in line with [27] the report on increasing the N level increased the plant height of common bean at both Hirna and Haramaya. In contrast with this result, [28] the report on common bean planting densities and the cropping system had no significant effect on the sorghum plant height. Increasing the leaf area index indicates the efficient use of nitrogen by sorghum. Similar findings took place [29] on the leaf area index of sweet sorghum increased with an increasing in N fertilizer application.

3.3. Effect of intercropping and NPS fertilizer on sorghum yield and yield-related traits

The analysis of variance showed that common bean planted density and NPS fertilizer rates ($P < 0.001$) influenced panicle length, above ground biomass, yield and harvest index (Table 3). The longest panicle length (21.2 cm) and the highest aboveground biomass (1561.4 kg/ha) were recorded from common bean planted density and application of 100 kg NPS/ha blended fertilizer rate, while the shortest panicle length (10.3 cm) and the lowest aboveground biomass (456.5 kg/ha) were recorded from susceptible sorghum variety/control 1 (Table 3). This might be due to improved soil fertility. This result agrees with [30] an increasing rate of nitrogen resulted in a significant difference in intercropped sorghum panicle length. Likewise, [31] the application of N fertilizer improved panicle length compared to nil fertilizer. The highest aboveground biomass might be due to the highest sorghum leaf area index. This is because of the special activity of common bean for nitrogen fixation and NPS enhancing metabolic activity of sorghum. This finding is in agreement with [32] the significant effect of N fertilizer on the yield of maize under maize-mung bean intercropping. Similarly, the collective mean biological yield of maize varied due to integrated nitrogen fertilizer on soybean–maize intercropping [33].

Table 3
Combined effect of common bean planting density and NPS blended fertilizer rate at Fedis experimental site on sorghum yield and yield components in February in the 2019 and 2020 main cropping seasons.

	Panicle length (cm)		Above ground biomass (kg)		Yield (t ha^{-1})		Harvest index (%)	
Treatments’	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2
25%CB + 0 kg/ha NPS	16.5^{de}	17.3^{d}	949.5^{ghi}	990.7^{ghi}	1.06^{ij}	1.1^{hij}	30^{i}	28.8^{j}
25%CB + 50 kg/ha NPS	17^{d}	19.01^{bc}	990.8^{ghi}	995.3^{ghi}	1.1^{hij}	1.13^{hi}	32^{fgh}	30.4^{i}
25%CB + 100 kg/ha NPS	20.5^{ab}	20.18^{b}	1299.5^{cd}	1465.5^{b}	1.14^{hi}	1.15^{hi}	32.5^{fg}	31.4^{h}
25%CB + 150 kg/ha NPS	14^{ef}	16.4^{de}	1036^{fgh}	1122.6^{ef}	1.17^{ghi}	1.3^{fg}	34^{e}	32.7^{f}
50%CB + 0 kg/ha NPS	$15d^{ef}$	17.76^{cd}	968^{ghi}	780.8^{j}	1.24^{gh}	1.4^{ef}	31^{hi}	31.6^{gh}
50%CB + 50 kg/ha NPS	17^{d}	18.8^{bc}	1000^{fghi}	1123.6^{ef}	1.5^{e}	1.5^{e}	40^{d}	39.7^{d}
50%CB + 100 kg/ha NPS	20.6^{ab}	21.8^{a}	1479^{b}	1643.8^{a}	2.3^{d}	2.78^{b}	44^{a}	42.4^{b}
50%CB + 150 kg/ha NPS	19.75^{bc}	19.68^{bc}	$1175d^{ef}$	1181.4^{de}	2.3^{d}	2.6^{ab}	43^{ab}	41.2^{c}
75%CB + 0 kg/ha NPS	13^{fg}	14.6^{ef}	820^{ij}	628.8^{k}	2.18^{d}	2.17^{d}	33^{ef}	32.2^{fg}
75%CB + 50 kg/ha NPS	15^{def}	16.8^{d}	990^{ghi}	919.6^{hi}	2.24^{d}	2.45^{c}	42^{bc}	41.1^{c}
75%CB + 100 kg/ha NPS	21^{ab}	20.04^{b}	1234^{cde}	1324^{c}	2.22^{d}	2.66^{a}	42^{ab}	41.4^{b}
75%CB + 150 kg/ha NPS	18^{bcd}	17.06^{d}	1100^{efg}	1102^{ef}	2.20^{d}	2.55^{ab}	43^{bc}	42.4^{c}
Control 1	10.5^{h}	10.1^{h}	498^{kl}	415^{l}	0.99^{ij}	0.96^{j}	26^{kl}	25.6^{l}
Control 2	10.5^{gh}	10.5^{h}	380^{lm}	486.4^{l}	0.98^{ij}	1.03^{ij}	27^{k}	26.5^{k}
Control 3	8^{h}	9.38^{h}	296^{m}	305.2^{m}	1.12^{k}	1.15^{k}	22^{m}	20.8^{n}
CV	6.57		6.69		4.28		1.31	
LSD(0.05)	1.17		3.25		1.69		0.20	

Means followed by the same letters are not significantly different following LSD at the alpha 5% probability level.

The highest harvest index (43.2%) was recorded with application of 100 kg NPS/ha blended fertilizer rate and 50% common bean planted density followed by 150 kg NPS/ha and 75% common bean with sorghum harvest index (42.7%). Conversely, the lowest harvest index (25.8%) was recorded with the control treatment (Table 3). The control plot produced the lowest harvest index of sorghum due to the absence of sufficient nutrient levels required for sorghum productivity. In line with this finding, a positive effect of nitrogen fertilizer application on the harvest index of grain sorghum reported [34]. Similarly, the harvest index of maize was increased when the application of nitrogen increased from 0 to 60 kg/ha [35].

The interaction effect of common bean and NPS blended fertilizer showed highly significant differences between treatments ($P < 0.001$) on the yield of sorghum (Table 3). The maximum mean yield (2.54 ton/ha) was recorded with the 50% common bean planted density and 100 kg NPS/ha blended fertilizer application treatments (Table 3), whereas the lowest mean yield (0.98 ton/ha) was recorded from the control plot (sole planted sorghum ~ Teshale). The sorghum yield was increased with the combination of common bean planted density and NPS blended fertilizer application compared to sole sorghum planted. This strong point may be due to the efficient use of nitrogen fertilizer by sorghum crops as well as the reduced number of striga infestations due to the greater nutrient composition and capacity to increase the availability of native soil nutrients through higher biological nitrogen fixation. The result of this study is confirmed that higher grain yield with increased levels of nitrogen from zero to 150 kg/ha in sorghum [36]. Low soil fertility, particularly low N status, is conducive to striga infestation, as reported [37]. This result clearly indicated that common bean had a more profound effect on striga reduction through more suicidal release than the control plot. These results are in agreement with the report on stimulant concentration resulted in the case of cowpea as a trap crop [38]. Cowpea cultivars reduced Striga emergence by 40%, as reported [39] and cowpea induced striga seed germination but did not support its successive growth in the absence of a suitable host. Striga seedlings died within four days of germination, as observed [40].

3.4. Effect of common bean intercropping and NPS fertilizer on striga management

There were significant differences ($P < 0.001$) in the combined influence of common bean planted density and NPS bent fertilizer rate on striga shoot count per sorghum plant and per plot, height of *Striga hermonthica* and reduction of striga infestation (Table 4).

The lowest striga count per sorghum plant (1 striga/plant) and per plot (2 striga/plot) was recorded from the 50% common bean planted density and 100 kg NPS/ha blended fertilizer application treatments (Table 4). The highest striga shoot count per plant and per plot was recorded from the sole planted sorghum (5 striga/plant) and per plot (8 striga/plot). The combined application of common bean and NPS fertilizer reduced striga infestation per sorghum plant over the sole planted sorghum (control) compared to other treatment combinations at 14 weeks after sowing (Table 4). The lowest striga shoot count per plant and per plot confirmed that the combined use of common bean and NPS fertilizer improved soil fertility or enhanced soil nitrogen and reduced the number of Striga hermonthica infestations. Similarly, the application of nitrogen significantly reduced the number of striga per sorghum plant by 22.58% over the control [41]. Higher concentrations of nitrogen also reduced the number of striga per sorghum plant [42]. This result is also in agreement with an increase in soil organic matter was associated with a reduction in the germination of Striga seeds [43]. There was no striga infestation in the solely planted resistant sorghum variety (Gobiye) compared to the solely planted susceptible sorghum variety (Teshale), as shown in Table 4. The significant interaction between sorghum varieties and nitrogen rates indicates that the susceptible variety (Teshale) requires higher rates of nitrogen to ameliorate the effect of striga compared with the resistant variety (Gobiye). Similar results were reported [44] on the incidence of Striga hermonthica in upland rice with high variations in striga shoot counts/m2.

The heights of Striga hermonthica were significantly different due to NPS rates and common bean planted density (Table 4). The height was significantly reduced due to all the combined NPS and common bean treatments compared with the sole planted susceptible sorghum variety Teshale/control 1 (Table 4). This could be due to sufficient soil nutrients available for intercropped sorghum and its shading effect on the striga. This result agrees with the finding on host plant shading can restrict striga growth when generous soil fertilizer is applied [45]. This result also confirms that the application of nitrogen significantly reduced the height of Striga hermonthica [41].

Table 4

Effect treatments on Striga shoot emergence, Striga shoot count per stand and per plot 12 and 14 weeks after planting in Fedis experimental site both in the 2019 and 2020 main cropping seasons.

	Striga count per plot 12 WAS		**Striga count per plot 14 WAS**		**Striga count per plant**		**Striga plant height(cm)**		**Reduction of striga infestation (%)**	
Treatments’	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2
25%CB + 0 kg/ha NPS	3^{b}	2.3^{bcd}	5^{c}	3^{ghi}	3^{cd}	2.7^{cde}	22^{b}	20.7^{bc}	48.7^{P}	65.7^{jkl}
25%CB + 50 kg/ha NPS	2.7^{bc}	1.7^{def}	4.3^{cde}	2.67^{hij}	2.7^{cde}	2^{ef}	20.3^{bcd}	19.3^{bcde}	52^{p}	68.3^{hijk}
25%CB + 100 kg/ha NPS	2^{cde}	1.7^{def}	4^{def}	2^{jk}	2.7^{cde}	1.7^{fg}	19^{cde}	18^{cdef}	58^{o}	68.3^{hijk}
25%CB + 150 kg/ha NPS	1.7^{def}	1.3^{efg}	4.67^{cd}	1.67^{kl}	3^{cd}	2.7^{cde}	18^{bcdef}	17^{cdefg}	61.7^{lmno}	67.7^{ijk}
50%CB + 0 kg/ha NPS	4^{a}	2.3^{bcd}	6^{b}	4^{def}	4^{b}	4^{b}	17.7^{cdefg}	16.7^{defgh}	52.3^{p}	62.7^{lmn}
50%CB + 50 kg/ha NPS	2.3^{bcd}	2.3^{bcd}	4.67^{cd}	2.3^{ijk}	3^{cd}	2.3^{def}	16.7^{defgh}	15.7^{efghi}	60.7^{mno}	67.3^{ijk}
50%CB + 100 kg/ha NPS	1^{ghi}	1^{ghi}	3.3^{fgh}	1^{m}	1.7^{fg}	1^{gh}	12^{ij}	11.7^{j}	75^{f}	88.6^{bc}
50%CB + 150 kg/ha NPS	1.7^{def}	1.3^{efg}	5^{c}	1.67^{kl}	2.7^{cde}	2.3^{def}	14^{ghij}	13^{hij}	65^{klm}	71.6^{fghi}
75%CB + 0 kg/ha NPS	2.67^{bc}	2.3^{bcd}	6^{b}	2.7^{hij}	3.3^{bc}	3^{cd}	17.7^{cdefg}	14.7^{fghij}	60^{no}	69.3^{hijk}
75%CB + 50 kg/ha NPS	2^{cde}	1.3^{efg}	4.3^{cde}	2^{jk}	2^{ef}	2^{ef}	13^{hij}	12^{ij}	69^{hijk}	74^{fg}
75%CB + 100 kg/ha NPS	1.7^{def}	1^{fgh}	3.7^{efg}	1.7^{kl}	2^{ef}	2^{ef}	12^{ij}	11^{j}	72.7^{fgh}	84.7^{cd}
75%CB + 150 kg/ha NPS	2.3^{bcd}	1.7^{def}	5^{c}	2.3^{ijk}	2.7^{cde}	1.7^{fg}	12.7^{ij}	11.7^{j}	70^{ghij}	79.7^{e}
Control 1	4^{a}	4^{a}	10.7^{a}	4^{def}	5.7^{a}	5^{a}	30^{a}	28^{a}	17.66^{r}	28^{q}
Control 2	0.3^{hi}	0.3^{hi}	1^{lm}	0.33^{m}	0.67^{h}	0.3^{h}	7.3^{m}	2.7^{n}	91.7^{ab}	95^{a}
Control 3	0.3^{hi}	0^{i}	0.33^{m}	0.33^{m}	0.3^{h}	0.3^{h}	4.7^{mn}	2.3^{n}	83.3^{de}	87.7^{bcd}
CV	25		16.4		21.6		11.6		4.13	
LSD (0.05)	0.76		0.89		0.86		2.86		4.54	

Means sharing similar letter(s) within each column are not significantly different at the (0.05) level of probability according to LSD. Note: CB and NPS represent common bean and NPS blended fertilizer, respectively.

The combination of 50% common bean planted density and 100 kg NPS/ha blended fertilizer application rate was also an effective integrated treatment that reduced striga infestation by 60% over the control (Table 4). The reduction in *striga* infestation was probably due to the higher quantity of nitrogen supplied by the fertilizer and common bean to inhibit the production of stimulants. This result is also confirms that nitrogen reduces strigolactone production from host plants and inhibits the germination of *Striga hermonthica* seeds [46]. Nitrogen also increases vegetative growth of the host plant, which strengthens it and protects the plant from *Striga* parasitism. In general, this study showed that common bean and NPS blended fertilizer were effective for *Striga hermonthica* control (Fig. 2).

Striga infestation was high (77%) or less reduced (23%) in sole planted susceptible sorghum variety (Teshale) as compared to the percentage reduction of striga (45–90%) in common bean intercropped and NPS blended fertilizer applied plot as well as reduced striga (93%) in sole planted striga resistant sorghum variety -Gobiye (Fig. 2). Striga infestation was also reduced (55%) in season two compared to (45%) in season one (Fig. 2).

3.5. Effect of intercropping on the yield and yield components of common bean

Common bean yield and yield components were affected by the NPS blended fertilizer rate and its planted density (Table 5). The sole common bean had obtained a higher number of pods per plant (19 pods/plant), seed per pod (11 seed per pod), hundred seed weight (17.5) and yield (1031.7 kg) followed by 50% common bean planted density and 100 kg & 150 kg NPS/ha blended fertilizer application rate as compared to other treatments (Table 5); this may be due to growth resource competition and the shading effect of sorghum that hinders nitrogen-fixation. This result agrees with the competitive effect of sorghum on the yield of cowpea under a mixed cropping system could lead to a low yield of cowpea seeds [47]. Similarly, maize soybean intercropping could be due to the shading effects of maize that significantly reduced the light interception potential of the associated soybean and reduced the photosynthetic assimilate [33]. Likewise, shading by taller plants in a mixture could reduce the photosynthetic rate of lower growing plants and thereby reduce their yields [48].

Table 5
Effect of intercropping on number of pods per plant, seed per pod, hundred seed weight and yield of common bean at Fedis during 2019 and 2020.

	CPP		**CSP**		**CHSW**		**CY**	
Treatments	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2	Sn1	Sn2
25%CB + 0 kg/ha NPS	12^{j}	14^{h}	5^{m}	6^{kl}	9^{k}	11.7^{hij}	523.3^{o}	550^{no}
25%CB + 50 kg/ha NPS	13^{i}	15^{g}	5^{l}	6.7^{ij}	10^{jk}	11.3^{hij}	555^{n}	583.3^{lm}
25%CB + 100 kg/ha NPS	14^{h}	17^{e}	6.3^{jk}	7^{hi}	12^{hi}	13^{gh}	610^{kl}	643.3^{j}
25%CB + 150 kg/ha NPS	15^{g}	17^{e}	7^{hi}	8^{f}	14^{fg}	15^{def}	643.3^{j}	673.3^{i}
50%CB + 0 kg/ha NPS	13^{i}	15^{g}	6.7^{ij}	7.7^{fh}	10^{jk}	11.3^{hij}	540^{no}	563.3^{mn}
50%CB + 50 kg/ha NPS	15^{g}	17^{d}	8^{f}	9^{e}	11.7^{hij}	15^{def}	680^{i}	710^{h}
50%CB + 100 kg/ha NPS	16^{d}	19^{a}	10.7^{c}	12^{a}	18^{b}	21^{a}	970^{cd}	1033.3^{a}
50%CB + 150 kg/ha NPS	15^{g}	18^{d}	9^{e}	10^{d}	14^{fg}	16^{cde}	875^{f}	1018.3^{ab}
75%CB + 0 kg/ha NPS	13.7^{hi}	16^{f}	6^{kl}	7^{hi}	10.3^{ijk}	11.7^{hij}	606.7^{kl}	626.7^{jk}
75%CB + 50 kg/ha NPS	15^{g}	17^{d}	6.3^{jk}	7.3^{gh}	11.7^{hij}	14^{fg}	726.7^{h}	786.7^{g}
75%CB + 100 kg/ha NPS	15^{f}	17^{c}	10^{d}	11^{bc}	15^{def}	17^{bc}	965^{d}	995^{bc}
75%CB + 150 kg/ha NPS	14^{g}	18^{d}	9^{e}	10^{d}	14.7^{efg}	16.7^{bcd}	861.7^{f}	906.7^{e}
Control 3	18^{e}	20^{b}	11^{bc}	11.3^{b}	17^{bc}	18^{b}	1023.3^{a}	1040^{a}
CV	2.86		4.14		8.11		2.23	
LSD (0.05	0.75		0.56		1.83		27.69	

Means followed by similar letter(s) within each column are not significantly different at the (0.05) level of probability according to LSD. Note: CPP, CSP, CHSW and CY represent common bean pods per plant, common bean seed per pod, common bean hundred seed weight and common bean yield (kg/ha), respectively.

3.6. Land Equivalent Ratio (LER)

Sorghum intercropping with common bean resulted in a significantly greater unit (Table 6). The highest LER (3.6) was achieved when 100 kg NPS/ha was applied to 50% s common bean plant density intercropped with sorghum, while the lowest LER (1.6) was recorded in plots having 25% common bean plant density intercropped with sorghum without NPS fertilizer (Table 6). This indicates that intercropping sorghum with common bean gave a higher yield than sole sorghum planting. An LER greater than one is considered to be a more efficient system from a land use point of view than a mono crop [49]. Similarly, environmental resources such as water and nutrients can be utilized more efficiently in intercropping systems than in cropping systems alone [50].

Table 6
LER of common bean intercropped with sorghum and NPS fertilizer rate.

Treatments (Cropping system and NPS fertilizer)	Yield of sorghum (ton/ha)	Yield of common bean (ton/ha)	LER
25%CB + 0 kg/ha NPS	1.08	0.59	1.6
25%CB + 50 kg/ha NPS	1.1	0.63	1.7
25%CB + 100 kg/ha NPS	1.15	0.69	1.8
25%CB + 150 kg/ha NPS	1.24	0.72	1.9
50%CB + 0 kg/ha NPS	1.32	0.61	1.9
50%CB + 50 kg/ha NPS	1.5	0.75	2.2
50%CB + 100 kg/ha NPS	2.54	1.10	3.6
50%CB + 150 kg/ha NPS	2.45	1.04	3.4
75%CB + 0 kg/ha NPS	2.18	0.68	2.8
75%CB + 50 kg/ha NPS	2.35	0.83	3.1
75%CB + 100 kg/ha NPS	2.44	1.08	3.4
75%CB + 150 kg/ha NPS	2.38	0.97	3.3
Control 1	0.98		
Control 2	1.01		
Control 3		1.14	

3.7. Economic analysis

Economic analysis was performed to assess the economic feasibility of the treatments using partial budget and marginal analyses. Starting from the lowest level of NPS blended fertilizer application and common planting techniques; the change in yield was multiplied by the sorghum price to develop marginal revenue (Table 7).

Based on economic analysis for NPS fertilizer levels presented in Table 7, 97.7% gain from 0 to 50 kg NPS/ha fertilizer and 25% and 50% common bean planted density, 576% gain from 50 to 100 kg NPS/ha fertilizer and 50% common bean planted density and 170% gain from 100 to 150 kg NPS/ha fertilizer and 75% common bean planted density level were obtained. The highest positive gross margin was shown when applying 100 kg NPS/ha with a 50% level common bean planting density, which was 27525 ETB/ha. The practices of this treatment as methods for Striga control would give an additional gain of 576% from every Birr invested in Striga control. The combination of 100 kg NPS/ha fertilizer with 50% common planting density was considered a profitable treatment and gave the best control mechanisms of Striga hermonthica as well as increased sorghum yield. It has the highest returns to the money invested in its production; it maximized profit (output) and minimized input costs (Table 7). In general, all NPS blended fertilizer rates and common bean planting methods were economically viable and had positive marginal rates of return. Similarly, the cultivation of sorghum in combination with other integrated striga control packages gave higher gross margins [51]. Thus, the combination of NPS blended fertilizer application and optimum common planting density reduced the number of striga infestations and enhanced the yield of sorghum.

Table 7
Partial budget analysis of NPS fertilizer application and planting techniques for sorghum production at Fedis experimental site during the 2019 and 2020 main cropping seasons.

Variables	NPS rate/ha + Common bean Planted Density (25%, 50%, 75%)			
	0	50	100	150
Seed (ETB/kg)	200	200	200	200
Field management costs (ETB/ha)	10200	10200	10200	10200
NPS Fertilizer cost (ETB/ha)	0	450	1200	1300
Fertilizer application cost (ETB/ha)	400	800	800	800
Total variable costs (ETB/ha)	10800	11650	12400	12500
Average grain yield (kg/ha)	1385	1497	1835	18353
Grain price (ETB/kg	15	15	15	15
Gross benefit (ETB/ha)	20775	22455	27525	27795
Net benefit (ETB/ha)	9975	10805	15125	15295
Marginal rate of return (%)		97.7{+}	576{+}	170{+}
Note: Labor cost to different agronomic practices= (200 birr per day); Retail price of sorghum grain = 15 birr per kg.				

4. Conclusions

The results of the present study showed that the interactions between common bean and NPS blended fertilizer were highly significant for Striga management and enhance sorghum productivity. The highest grain yield (2.54 t ha^{-1}) were obtained from the application of 100 kg NPS ha^{-1} in combination with 50% common bean planted density, whereas the lowest grain yield (0.98 t ha^{-1}) were obtained from the control plot (solely planted sorghum ~ Teshale). Therefore, farmers in the study area could sustainably manage Striga and increase sorghum productivity through the combined use of 50% common bean planting density and 100 kg NPS ha^{-1} blended fertilizer application under natural Striga infestation.

Declarations

Data availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Lemma Degebasa collected, analyzed, and interpreted the data. Taye Tessema and Zelalem Bekeko drafted and edited the manuscript. All authors read and approved the final manuscript.

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Figures

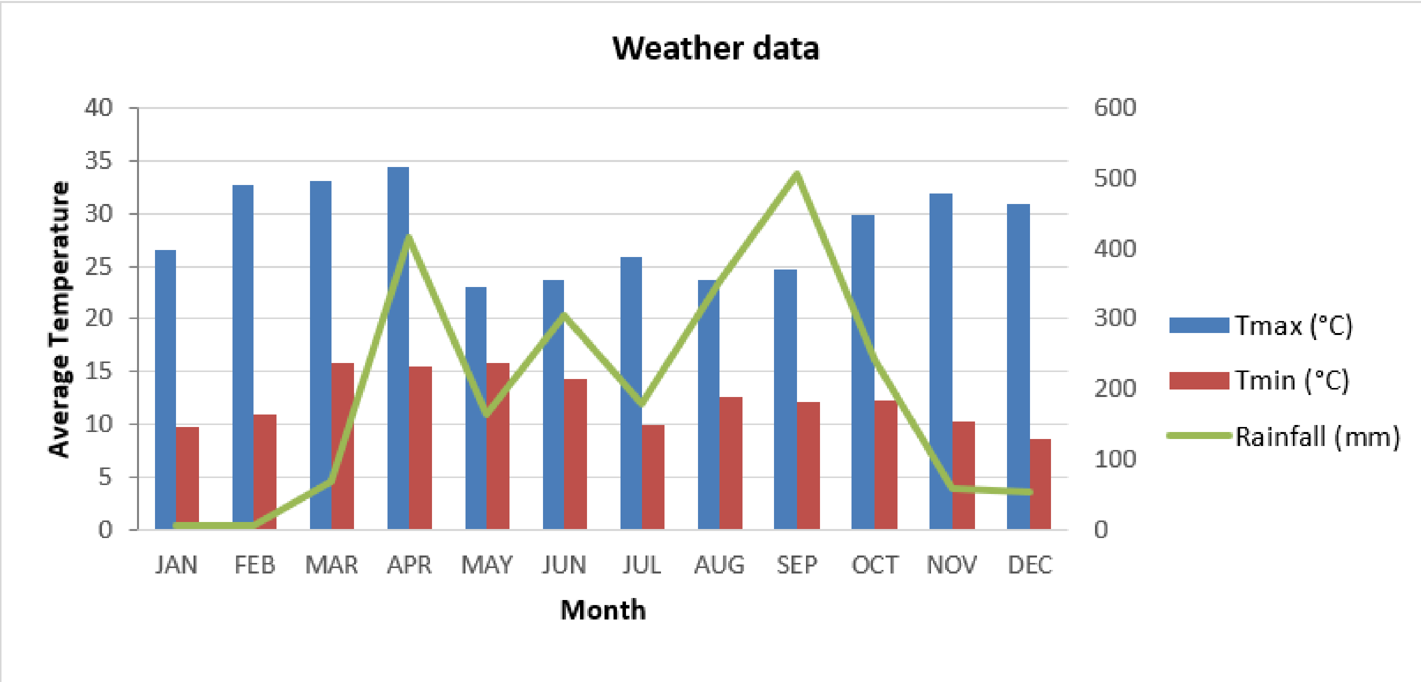

Figure 1

Weather data on monthly bases at Fedis experimental site both in 2019 and 2020 main cropping seasons.

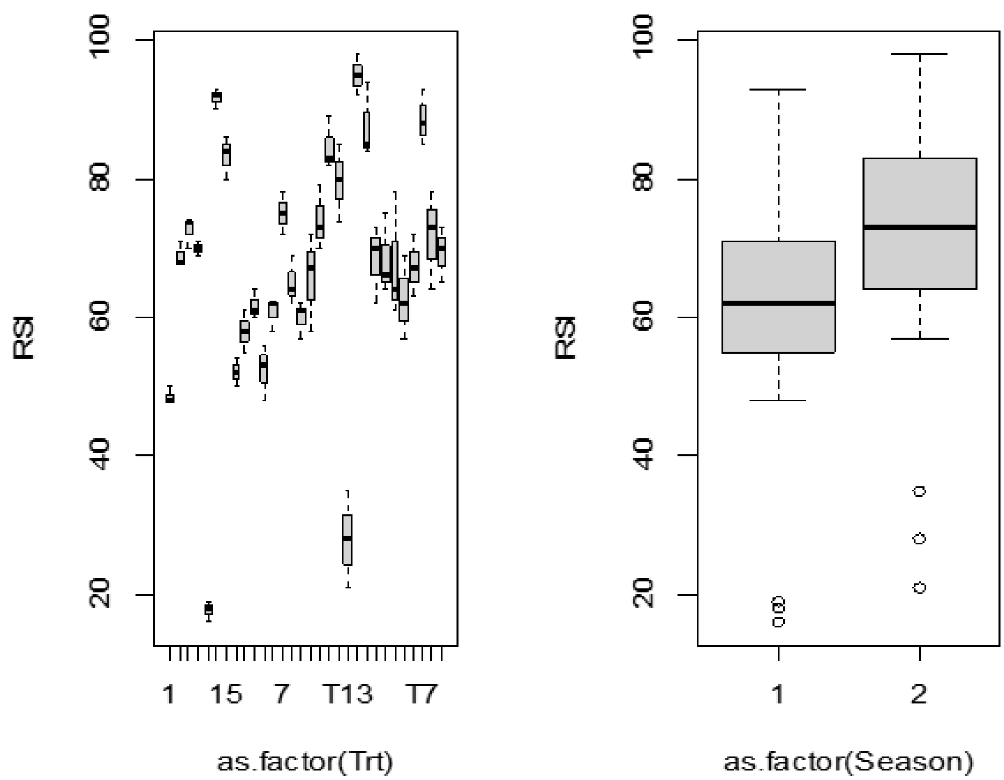

Figure 2

Percentage of *Striga hermonthica* reduction level in a treated and untreated sorghum plot at Fedis experimental site in the two 2019 and 2020 main cropping seasons.