SOIL & CROP SCIENCES | RESEARCH ARTICLE

Different planting dates of soybean intercropping for *Striga* (*Striga hermonthica* Del Benth) control and sorghum productivity, Northwest Ethiopia

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**Abstract**: *Striga hermonthica* is a major biotic threat to worldwide food security, especially in sub-Saharan Africa. Sorghum production in North Gondar is challenged by the parasitic weed causing low crop yields. One of the options widely practiced is intercropping with legumes and variation in sowing dates of the intercropped crop species. A field experiment was conducted at two locations; Metema and Sanja at Gondar Agricultural Research Centers in the 2017/18 cropping season. Three sowing dates of soybean (2 weeks and 1 week before sowing and at a sorghum plantation) to control *Striga*. The study laid in a randomized complete block design with three replications in a factorial combination, two sorghum varieties; improved (Berhan) and a local variety commonly grown in the area and soybean “Afgat” varieties were used. A highly significant difference between *Striga* count (SC) and dry matter, grain yield (GY), above-ground biomass, and thousand seed weight (TSW) were the main effects and their interactions. SC, GY, and TSW were significant at Metema and combined over locations, but only GY at Sanja. Highest grain yield, biomass, thousand seed weight and lowest *Striga* counts was obtained in sensitive variety at 2 weeks soybean sown before sorghum and, highest *Striga* was recorded in susceptible variety where soybean was sown at the same date with sorghum. Economic analysis results showed the highest and lowest net returns of 32,048.50 and 8,660.

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**PUBLIC INTEREST STATEMENT**

Sorghum has been becoming the potential food security crop for a hundred thousand people in North western Ethiopia. Infestation by the parasitic plant *Striga hermonthica* is a severe threat to food security in sub-Saharan Africa. Trap crops and various legume intercropping can be used to control the root parasite. We have done a field experiment under natural conditions in *Striga*-infested rain-fed fields. Three sowing dates of soybean and two sorghum varieties were tested. Soybean sowing 2 weeks before *Striga* resistant sorghum has significant control over the weed and gives high grain yield. Application of our method promises to alleviate the problem posed by this pernicious weed. The experiment resulted in between 38.44% and 43.35% reduction in *Striga* count per plot in Sorghum fields. Researchers conclude that suicidal germination is an effective method for reducing the *Striga* seed bank, and can be recommended for the area.
ETB per hectare from 2 weeks before with resistant sorghum and the same date with susceptible sorghum, respectively. Therefore, in the study area, the “Berhan” variety at 2 weeks before sorghum sowing is recommended for profitable sorghum production and Striga management.

**Subjects:** Agriculture & Environmental Sciences; Botany; Plant & Animal Ecology

**Keywords:** Productivity; sorghum; soybean; sowing date; Striga infestation

### 1. Background

Grain sorghum is Ethiopia’s leading traditional food crop, ranking third in area coverage after teff and maize, and second in total production after maize. Sorghum for its injera (national fermented flat pancake) making quality is next to teff. Sorghum was grown on 1.89 million hectares with a total production of 3.95 million tons in 2015/16, comprising about 22.3% of the total cereal production in the country CSA (Authority, 2016). Although there is a significant land area allocated for sorghum in Ethiopia, there is a high demand for food and other multiple uses, and it is a suitable crop for drought-prone areas. The average national yield is less than 2 tons per acre (Authority, 2016), but the potential yield under rainfed cultivation ranges from 3 to 6 tons per acre (Geremu et al., 2020). The productivity of the crop is poor due to the low yield potential of existing cultivars and the biotic and abiotic constraints, ICRISAT (Rao et al., 2009). Parasitic weeds and soil fertility are among the major factors attributed to the low yield in farmers’ fields.

The parasitic weed *S. hermonthisca* is the most important biotic constraint for sorghum and maize. In several tropical and subtropical regions, including Ethiopia, it is the production limiting factor for sorghum production. The losses due to *Striga* can reach 65% and 100% of the sorghum yield in Ethiopia and Sudan (Ejeta et al., 2002). Continuous cereal cultivation, which hosts the *Striga* parasite, and declining soil fertility will make the host plant more vulnerable to *Striga* attack. *Striga* is considered an indicator of poor soil fertility (Kanampiu & Friesen, 2004). *Striga*-affected areas have accumulated very high-level *Striga* seeds in the soil, which are long-lived in mono-cropping practices. The seeds stimulated by crop exudates need some breaking dormancy each season. Farmers cannot get rid of this pest easily once the field is infected with *Striga*, and a single plant can produce 10,000–200,000 minute seeds under optimal conditions (Hearne, 2009).

A combined means to tackle the challenges of *Striga* control approaches was practiced individually or in combined ways. The seed problem of the weed was not effectively addressed, even though they have checked the impact of this notorious weed (Oswald et al., 2002). If the seed bank of *Striga* is not controlled adequately, the widespread seed bank of *Striga* in infested fields remains an obstacle (Parker, 2012). Poor soil fertility and drought are worsening *Striga* infection. Soil fertility could affect plant signaling during *Striga*’s interaction with the host; about 20 different types of strigolactones (SLs) that may or may not be specific to the host have been identified, ICRISAT (Rao et al., 2009).

The roots of several legumes are known to induce *Striga* seeds to suicidal germination, and this feature has become incorporated into *Striga* suppression strategies involving cereal-legume intercropping or rotation (Waruru, 2013). Selection of legume cultivars that encourage fatal growth of *Striga* can effectively manage the problem (Dashiell et al., 2000). Legume crops which their root release exudates, like Desodium, cowpea, and soybeans will initiate *Striga* germination without being parasitized by the weed (Aliyu & Emechebe, 2006). As a result, as a component of cropping systems, various trap crops have a significant reduction impact on soil *Striga* seed bank. The *Striga* infestation in sorghum fields of North Gonder Zone in northwest Ethiopia is so severe. Sub-Saharan Africa cereal production is suffering from *Striga* (Oswald et al., 2002). *Striga* infestation in the study area is aggravated with fertility declining as a result of increased cereal monocropping (Rodenburg et al., 2005). *Striga*’s rapid spread has been aided
by declining plant diversity, which is common among poor farmers (Kudi & Abdul-salam, 2008). This soil fertility depletion problem is also common in Metema and Sanja, which are potential sorghum producing areas of North Gondar. “Sorghum farmers in the study area suffered seriously with low sorghum productivity that is mainly caused by the aforementioned reasons.” North Gondar takes the highest share, 38.18% of the regional sorghum area coverage, CSA (Authority, 2016).

Sustainable food production with affordable technologies for farmers can be achieved if there is a solution to the Striga problem. As Dugie (Dugie et al., 2008), Striga control in sorghum is more challenging than in other cereal crops. A more desirable option is the inclusion of leguminous non-host crops, which stimulate Striga germination but do not support its growth. These non-hosts can significantly deplete the seed bank (Berner et al., 1996). Soybean, one of the most important lowland legumes, has recently received a lot of attention in Metema and Sanja. They are helpful for their soil amendment and nutritional diet for human consumption (Chianu et al., 2006; Misiko, 2007). Soybean varieties are known to encourage Striga germination but are not parasitized themselves (Carsky et al., 2000; Songinga et al., 2001). S. hermonthica seeds have differences in relative germination to varieties of soybean as a result of the levels of crop stimulants.

Significant interactions of cultivars and sowing dates on maize grain yield were observed (Norwood, 2001; Darby & Lauer, 2002). Current information on the sowing date of soybean with sorghum cultivars about yield and Striga infestation is very limited in the study area. A better understanding is needed on sowing date of soybean intercropped with sorghum varieties, on yield and Striga infestation. Neither do farmers use appropriate soybean sowing dates to control Striga infestation and increase their sorghum productivity nor do research and extension interventions have well addressed this critical constraint for limiting sorghum productivity and production in the study area. Therefore, the principal objective of this study is to evaluate the usefulness of different sowing dates of soybean intercropping with Striga resistant and susceptible sorghum varieties for S. hermonthica management for increasing sorghum productivity in North west Ethiopia.

2. Materials and methods

2.1. Description of the study sites

A study to assess the usefulness of different sowing dates of soybean intercropping with Striga resistant and susceptible local sorghum varieties for S. hermonthica management and increasing sorghum productivity in Northwest Ethiopia was conducted in the 2017/18 main cropping season at Metema and Sanja. The study was conducted on land under fallow, which was naturally infested with Striga hermonthica, at the Experimental Station of the Gondar Agricultural Research Center sites.

Metema site is located at 12° 58’ Nlatitude and 36° 12’ Elongitude with an altitude range of 550–1608m above sea level. Whereas Sanja site is located at 13° 19.6” Nlatitude and 36° 44.6’ Elongitude with an altitude of 550–1550m above sea level. The climate of Metema and Sanja experimental sites is warm sub-humid with amean annual rainfall of 898.77mm and 850mm, respectively. The average maximum and minimum temperatures of the Metema site are 32.6°C and 20.1°C, while the Sanja site is 35°C and 19°C, respectively. At both experimental sites, the daily temperature is high during March to May. The topography of both experimental sites is almost flat with a 2–5% slope.

2.2. Experimental treatments, design, and procedures

Factorial combinations in randomized complete block design (RCBD) of three soybean dates of sowing (2 weeks, 1 week before and same with sorghum) and two sorghum varieties: Striga resistant (Berhan), susceptible (“Deber” local), and “Afget” soybean variety with three replications. There are nine treatment combinations. Seeds of sorghum (“Berhan”) and soybean “Afget” were
obtained from the Gondar Agricultural Research Center and the local variety ("Deber") from the local market.

After plowing twice with a traditional oxen plow, the selected plots were subdivided into blocks and plots manually as per the treatments, design, and replications. The gross plot size was 3.5 × 3.0 m (10.5 m²) with the net plot area of 2 × 2.4 m (4.8 m²). The adjacent plots and blocks were separated by 1.0 m and 1.5 m wide paths, respectively. Except for Striga, the experimental plots were kept free from other weeds manually. Beyond the treatments, all other agronomic practices were as per their respective recommendations used for sorghum and soybean in the study area.

2.3. Striga and crop data collection

Striga count and dry matter per plot in the net plot area was noted at sorghum maturity for about 150 days. Data on phenological, vegetative growth, and yield-related sorghum parameters were collected on time. Phenological parameters (days to 50% flowering and days to 90% physiological maturity), stand counts, biomass, and grain yields were taken from the net plot area. Plant height and panicle height of sorghum and soybean were taken as averages of 10 and 5 randomly selected plants, respectively, at physiological maturity in the net plot area. Plant and panicle height with a linear meter from randomly selected plants. When the grains reached the black layer stage, sorghum plants in the net plot area were harvested and spread to dry with the sun. Aboveground dry yield was estimated by weighing harvested plants of treatments with a balance. After threshing the heads of well-dried sorghum plants, grain yield was also estimated by weighing clean grains of each net plot area with a balance and adjusted to 12.5 moisture level and then converted to a hectare basis. A thousand grains were randomly taken from clean grains recovered in each net plot area and weighed with a sensitive balance to determine a thousand kernels’ weight. HI was calculated as grain to biomass yield ratio and converted to percentile. Grain yield was adjusted to 10% moisture level based on soybean pods per plant, number of seeds per pod, and hundred seed weight.

2.4. Land Equivalent Ratio (LER), Area Time Equivalent Ratio (ATER), Competitive Ratio (CR), Gross Monetary Value (GMV) and Monetary Advantage Index (MAI)

The relative land area in pure stands required to produce the yields of all products from the mixture is land equivalent ratio (Vandermeer, 1992). LER is employed to calculate intercropping efficiency.

\[
LER = \frac{AI \times BI}{AS \times BS}
\]

Where \(AI\) and \(BI\) are the intercropping yields, and \(AS\) and \(BS\) are the sole yields of each crop in a monoculture system. If LER is greater than one, intercropping would be better than monoculture (Mazaheri, 1993).

**Competition Ratio:** Competition between component crops was measured by the CR (Zhang et al., 2011). The CR of the intercrops was calculated by the formula:

\[
\text{CRSR} = \frac{\text{PLERSR} \times \text{ZSBSR}}{\text{PLERSB} \times \text{ZRSR}}
\]

\[
\text{CRSB} = \frac{\text{PLERSB} \times \text{ZSBSB}}{\text{PLERSR} \times \text{ZRSR}}
\]

where CRSR and CRSB are sorghum and soybean CRs, respectively; PLERSR and PLERSB are sorghum and soybean partial land equivalent ratios, respectively; and ZSRSB and ZSRSR are sorghum intercropped with soybean seed proportions and soybean intercropped with sorghum seed proportions, respectively. YSRIC and YSBIC are yields of sorghum and soybean in an
intercropping, respectively, and YSRSC and YSBSC are the yields of sorghum and soybean in sole cropping, respectively.

If CRSR is greater than one, it indicated that sorghum was a competitor, while CRSR less than one implied that the soybean crop suppressed sorghum production.

\[ MAI = \frac{(\text{value of combined intercrops}) \times (\text{LER} - 1)}{\text{LER}} \]

(Layek [23])

Sorghum and soybean yields in sole and intercropping are considered to measure the profitability of the system as Gross Monetary Value (GMV) and MAI. For GMV calculation, the market prices of sorghum and soybean were 13 and 25 ETB per kg, respectively, and labor was 80 ETB per man-day.

2.5. Data analysis
All collected Striga, crop, and land productivity data were further subjected to analysis of variance using SAS software version 9.2 (Institute, 2015). Since the homogeneity test of the two locations for all parameters was not significant, the combined analysis of variance was also done for each parameter over locations. Whenever the result showed a significant difference among treatments for a parameter in question, mean separation was performed using the least significant difference (LSD) test, while the coefficient of variations for considered parameters was lower than 10.

3. Results

3.1. Striga weed components
The analysis of variance for Striga count per plot shows that there was a highly significant (P ≤ 0.01) difference due to the main effects of soybean dates of sowing, whereas sorghum varieties were significant at Metema and combined over locations but non-significant at Sanja (Table 1). Striga counts per plot ranged from 113.18 in sole sorghum plots to 70.19 in soybean intercropped plots 2 weeks before sorghum plots. Susceptible sorghum was high (105.7) and resistant (90.91) Striga counts. The interaction effect was highly significant (P ≤ 0.01) with 140.2 susceptible in SD and at least 66.45 in resistant 2 weeks before (Table 2).

Striga dry matter differed statistically significantly (P < 0.01) for sowing date and sorghum varieties, with the highest being 83.38 g in sole sorghum same date (SD) and the lowest being 31.22 g at two weeks. Susceptible and resistant varieties were 43 and 39.08 g, respectively. Interaction effects highly significantly gave 68.67 and 21.67 g in susceptible sole SD and resistant variety at 2 weeks, respectively (Tables 1 and 2).

3.2. Sorghum yield components

3.2.1. Grain yield (tonne ha⁻¹)
There was a highly significant difference (P < 0.01) due to soybean different dates of sowing, 4.84 and 2.29 t ha⁻¹ at 2 weeks and SD, respectively, but varieties were non-significant (Table 3). Interaction effects highly significantly affected grain yield. The highest was 5.02, and at least 2.26 t ha⁻¹ resistant at 2 weeks and susceptible sorghum at SD (Table 4).

3.2.2. Aboveground dry biomass yield (tonne ha⁻¹)
In a similar trend, aboveground dry biomass of sorghum also showed highly significant variation (P < 0.01) for dates of sowing 13.88 at 2 weeks and 7.2 t ha⁻¹ at the same date, but variety was non-significant (Table 3). Interaction effects were highly significant, 14.02 and 6.64 t ha⁻¹ for 2 weeks of the resistant variety and the same date in susceptible sorghum varieties, respectively (Table 4).
Table 1. Main effects of Soybean Dates of Sowing and Sorghum Varieties on Striga Count (SC) and Striga Dry matter (SDM) at Harvesting Stage in Metema (M) and Sanja (S) and Combined over Locations (COL), North Gondar

| Main Effect                  | SC          | SDM         |
|------------------------------|-------------|-------------|
| Date Sowing                  | M           | S           | COL | M       | S       | COL |
| Same Date with Sorghum       | 138.8a      | 124.43a     | 131.62a | 41.67b | 42b | 41.83b |
| 2 Wks Before Sorghum         | 70.19d      | 82.89 c     | 76.54d | 25c | 22.17d | 23.58c |
| 1 Wk Before Sorghum          | 90.91 c     | 101.03b     | 95.97c | 40.17b | 37.17c | 38.67b |
| Sole Same Date with Sorghum  | 113.18b     | 106.84b     | 110.01b | 57.67a | 57.67a | 57.67a |
| P value **                    | ns          | **          |         | **     | **     | **     |
| LSD                          | 4.706       | 6.013       | 3.423  | 4.356  | 3.852  | 2.598  |
| S.E (±)                      | 1.581       | 2.02        | 1.245  | 1.463  | 1.294  | 0.945  |
| Sorghum Varieties            |             |             |         |         |         |         |
| SRS                          | 100.84b     | 102.7a      | 107.7b | 39.25b | 39.08a | 39.17a |
| SSS                          | 105.7a      | 104.9a      | 105.3a | 43a   | 40.42a | 41.71a |
| P value **                    | ns          | **          |         | **     | ns     | ns     |
| LSD                          | 3.328       | 4.252       | 2.24   | 3.08   | 2.724  | 1.837  |
| S.E (±)                      | 1.118       | 1.428       | 0.88   | 1.035  | 0.915  | 0.668  |
| CV (%)                       | 4.28        | 5.84        | 4.96   | 2.65   | 3.37   | 2.94   |

Means within a column followed by the same letter (s) are not significantly different; * * = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over Locations; Same D = Soybean Sown with sorghum on the same date; 2 Wks. B = Soybean Sown 2 weeks before sorghum; 1 Wks. B = Soybean Sown 1 week before sorghum; Sole SD = Sole Sorghum Sown on the same date; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum; SC = Striga Count/plot; SDM = Striga Dry Matter (gm/plot); SE = standard error; CV = coefficient of variation.

3.2.3. Thousand seed weight
The thousand seed weight differs significantly in the main effect of sowing dates; 31.99 and 21.93 in 2 weeks and SD, respectively. Sorghum varieties are highly significant at (P < 0.01) affected varieties, 26.01 resistant and 23.37 g in susceptible variety (Table 3). Highly significant interaction effects in TSW show sole and SD resistant 33.63 and 20.07 g, respectively (Table 4).

3.2.4. Productivity of intercropping
As induces, partial and total LERs were used to assess intercropping productivity. The partial LER of sorghum varied significantly in terms of soybean dates of sowing with sorghum. A significant increase in partial LER (0.69 to 1.41) of soybeans was calculated due to a proportional increase in the sowing dates of soybeans (Tables 5 and 6).

The GMV, MAI, SEY, and CR were statistically highly significant both in the main effects and interaction of soybean dates of sowing with sorghum varieties (Tables 7 and 8). The parameters were increased with the increase in the planting of soybeans 2 weeks before in intercropped sorghum/soybean. This might be because of higher seed yield values and the higher price per kg of soybean which contributed more to gross monetary value than soybean as reflected by the monetary value of soybean in intercrops. Thus, the highest GMV of ETB 83,943.00 per ha (LER = 1.78) and lowest GMV of ETB 48,664.00 per ha (LER = 1.17) were obtained when sorghum
intercropped with soybean at sowing dates of 2 weeks before sorghum and the same dates with sorghum, respectively (Tables 7 and 8).

3.3. Economic analysis
The economic (partial budget) analysis of the study parameters/treatments was carried out by taking mean grain yield and prices of input (sorghum and soybean seed and operation costs) for the nearby Metema and Sanja markets. The highest MRR was recorded 2 weeks before soybean intercropping with Striga resistant, followed by 201.14 in susceptible sorghum (Table 9). Adoption of this treatment as a method for Striga control would give an additional gain of 251.49% from every Birr invested in Striga control.

4. Discussions
The sole plots had a higher Striga count than the intercrop plots, which agrees with Zeyaur’s (Khan et al., 2007) finding that intercrop plots support lower Striga populations. Oswald (Oswald, 2005) assessed different legumes for their ability to control the parasite and no observable population reduction was seen. The findings of Gurney (Gurney et al., 1999) agree with the present result. Striga infestation has more negative effects at early stage than at late stage. In his research, Xie (Xie et al., 2008) got strigolactones that induce suicidal effects from soybean root exudates that contained orobanchyl acetate.

Striga dry matter and the emerged Striga were significantly reduced when sorghum was intercropped with soybean in both locations. However, more benefit was derived when sorghum was intercropped with soybean 2 weeks before sorghum. Another study on intercropping indicates that weed population and weed density may be highly limited when intercropping strategies are used (Alemán, 2000). Cowpea and soybeans released exudates that induced Striga germination, but they were not parasitized and served as trap crops, according to Aliyu and Emechebe (Aliyu &
Table 3. Main effects of Soybean Dates of Sowing and Sorghum Varieties on Grain Yield (GY), Aboveground Dry Biomass (AGBM) and Thousand Seed Weight (TSW) of Sorghum in Metema (M) and Sanja (S) and Combined over Locations (COL), North Gondar

| Main Effect | GY | AGBM | TSW |
|-------------|----|------|-----|
| Date Sowing |  |     |     |
| Same Date   | M  | S  | COL | M  | S  | COL | M  | S  | COL |
| 2 Wks Before| 4.84c| 4.43a| 4.64a| 13.88a| 12.44a| 13.16a| 29.84a| 31.99a| 30.91a |
| 1 Wk Before | 3.38b| 3.64b| 3.70b| 11.32b| 10.68b| 11.0b| 24.67b| 24.53b| 24.6b |
| sole SD     | 2.44c| 2.29c| 2.36c| 9.09c| 10.10b| 9.6c| 22.32b| 22.61b| 22.46b |
| P value     | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| LSD         | .627| .51 | .385| .916| 1.009| .612| 3.15| 2.13| 1.78 |
| S.E (±)     | .215| .175| .14 | .314| .345| .223| 1.06| .71 | .65 |

Sorghum Varieties

|      | GY |     |     |     |
|------|----|-----|-----|-----|
|      | M  | S  | COL | M  | S  | COL |
| SRS  | 3.49| 3.39| 3.44| 10.57| 10.49| 10.53| 26.01| 25.97| 25.99 |
| SSS  | 3.22| 3.15| 3.19| 10.08| 10.27| 10.18| 23.37| 25.05| 24.21 |
| P value | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| LSD   | 0.443| 0.361| 0.272| 0.648| 0.713| 0.433| 2.22| 1.5| 1.26 |
| S.E (±) | 0.152| 0.124| 0.099| 0.222| 0.244| 0.157| 0.75| 0.51| 0.46 |
| CV (%) | 4.6 | 7.74 | 6.41 | 5.43 | 4.54 | 5.12 | 7.41 | 4.85 | 6.31 |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over Locations; Same D = Soybean Sown with sorghum on the same date; 2 Wks = Soybean Sown 2 weeks before sorghum; 1 Wk B = Soybean Sown 1 week before sorghum; sole SD = sole Sorghum Sown on the same; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum; GY = grain yield (ton ha⁻¹); AGBM = Above ground biomass yield (ton ha⁻¹); TSW = thousand seed weight (g); SE = standard error; CV = coefficient of variation.

Emechebe, 2006). This research result is similar to the findings of Kureh (Kureh et al., 2006) who explained that the emerged Striga density was reduced in maize/cowpea intercropping.

The pronounced response of yield to intercropping with soybean 2 weeks before planting might be by the trap crop suicidal germination of the Striga seeds, which otherwise attacked and reduced the productivity of sorghum. The results were consistent with the findings of Kouchaki (Kuchinda et al., 2003). Aliyu and Emechebe, (Aliyu & Emechebe, 2006) showed higher grain yield with reduced Striga seed bank. Khan (Khan et al., 2011) discovered that soybean planting time had a significant impact on maize grain yield, with delayed soybean planting increasing yield in the maize/soybean cropping system. The interaction effect of legume and their planting time that planting of soybean before sorghum resulted in a significant increase in sorghum yield over other interactions (Addo-Quaye et al., 2011).

Variation in aboveground dry biomass may be due to lower number of plant leaves and stunted growth of sorghum as the negative impact of Striga on sole sorghum. In conformity with this result, plant height, biomass, and grain yield were largely reduced as a result of Striga infestation (Gurney et al., 1999). The extent of infestation will determine the level of yield losses as the observation of Oswald and Ransom (Oswald et al., 2002). Striga establishes the host plant vascular system to drain resources from the host and brings leaf area and leaf photosynthetic rates that are directly associated with plant dry matter production since light absorption by the leaves and changing it to assimilate are the other factors affecting the plant growth and production; the increase of leaf area in the farm increases the absorption of light, which ultimately increases the biomass yield (Malhi et al., 2001).
Table 4. Interaction effects of Soybean Dates of Sowing and Sorghum Varieties on Grain Yield (GY), Aboveground Dry Biomass (AGBM) and Thousand Seed Weight (TSW) of Sorghum in Metema (M), Sanja (S) and Combined over Locations (COL), North Gondar

| Interaction Effects | GY | AGBM | TSW |
|---------------------|----|------|-----|
|                     |    |      |     |    |      |      |
|                     | M  | S    | COL | M  | S    | COL | M  | S    | COL |
| Same D              |    |      |     |    |      |     |    |      |     |
| SRS                 | 2.45 c | 2.83 c | 2.64 c | 7.39 cd | 8.17 c | 7.78e | 22.12b | 23.49b | 20.07 |
| SSS                 | 2.28 c | 2.63de c | 2.47 c | 6.64d | 8.405 c | 7.53e | 21.75b | 22.36b | 28.46 |
| 2 Wks B             |    |      |     |    |      |     |    |      |     |
| SRS                 | 5.02 a | 4.66a | 4.84a | 14.02a | 12.579a | 13.3a | 32.41a | 32.7a | 28.34 |
| SSS                 | 4.67a | 4.2ab | 4.43a | 13.74a | 12.32a | 13.03a | 27.28ab | 31.7a | 29.33 |
| 1 Wk B              |    |      |     |    |      |     |    |      |     |
| SRS                 | 4.0 b | 3.77abc | 3.88b | 11.43b | 10.95ab | 11.19b | 26.05ab | 24.42b | 26.36 |
| SSS                 | 3.55b | 3.5bcd | 3.63b | 11.2b | 10.42b | 10.81bc | 23.28b | 24.63b | 26.72 |
| Sole SD             |    |      |     |    |      |     |    |      |     |
| SRS                 | 2.49 c | 2.31e | 2.40 c | 8.72 cd | 10.27b | 9.51d | 23.47b | 23.72b | 33.63 |
| SSS                 | 2.39 c | 2.26e | 2.33 c | 9.44bc | 9.94bc | 9.69 cd | 21.17b | 21.49b | 30.13 |
| p                   |    |      |     |    |      |     |    |      |     |
| LSD                 | .886 | .722 | 3.37 | 1.296 | 1.427 | 8.42 | 1.94 | 3.19 | 1.99 |
| S.E (±)             | .303 | .247 | 1.23 | .444 | .448 | .306 | .149 | 1.01 | 1.63 |
| CV (%)              | 4.6 | 7.74 | 6.41 | 5.43 | 4.54 | 5.12 | 7.41 | 4.85 | 6.31 |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over Locations; Same D = Soybean Sown with sorghum on the same date; 2 Wks. = Soybean Sown 2 weeks before sorghum; 1 Wk. B = Soybean Sown 1 week before sorghum; Sole SD = Sole Sorghum Sown on the same; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum GYt = grain yield (ton ha⁻¹); AGBM = Above ground biomass yield (ton ha⁻¹); TGW = thousand seed weight (g); SE = standard error; CV = coefficient of variation.
Table 5. Main effects of Soybean Dates of Sowing and Sorghum Varieties on Land Equivalent Ratio and Area Time Equivalent Ratio of Sorghum, Soybean and Total in Metema (M) and Sanja (S) and Combined over Locations (COL), North Gondar

| Main Effect | Land Equivalent Ratio | Area Time Equivalent Ratio |
|-------------|-----------------------|----------------------------|
|             | Sorghum | Soybean | Total | Sorghum | Soybean | Total |
| DS          |         |         |       |         |         |       |
| SD          | M | S | COL | M | S | COL | M | S | COL |
| 2 W         | 1.41a | 1.39a | 1.4a | .67a | .69a | .68a | 2.08a | 2.09a | 2.08a |
| 1 W         | 1.13a | 1.13ab | 1.13b | .55b | .57b | .56b | 1.69a | 1.7b | 1.69b |
| P           |      | **     |      | **     | **     |      | **     | **     | **     |
| LSD         | .37 | .31 | .20 | .03 | .03 | .02 | .37 | .32 | .21 |
| SE (t)      | .12 | .1 | .07 | .01 | .08 | .01 | .12 | .1 | .07 |
| Var         | SRS | 1.09a | 1.14a | 1.11a | .6a | .62a | .61a | 1.69a | 1.77a | 1.73a |
|             | SSS | 1.07a | 1.1a | 1.08a | .56b | .57b | .57a | 1.63a | 1.68b | 1.65a |
|             | P  |      |      | ns | ns | ** | ns | ns | ns |
| LSD         | .03 | .25a | .167 | .021 | .021 | .012 | .303 | .259 | .17 |
| S.E (t)     | .059 | .09 | .059 | .007 | .007 | .004 | .096 | .082 | .06 |
| CV(%)       | 18.81 | 15.1 | 16.21 | 2.37 | 2.36 | 2.27 | 12.38 | 9.95 | 10.66 |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over Locations; SD = Soybean Sown with sorghum on the same date; 2 W = Soybean Sown 2 weeks before sorghum; 1 W = Soybean Sown 1 week before sorghum; Sole Same D = Sole Sorghum Sown on the same; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum; LSD = Least Significant Difference; SE = standard error; CV = coefficient of variation.
Table 6. Interaction effects of Soybean Dates of Sowing and Sorghum Varieties on Land Equivalent Ratio and Area Time Equivalent Ratio of Sorghum, Soybean, Total in Metema (M) and Sanja (S) and Combined over Locations (COL), North Gondar

| IE | Land Equivalent Ratio | Area Time Equivalent Ratio |
|----|-----------------------|---------------------------|
|    | Sorghum | Soybean | Total | Sorghum | Soybean | Total |
| DS | Var   | M | S | COL | M | S | COL | M | S | COL | M | S | COL |
| SD | SPS   | 6.8b | 8.7b | 7.8b | 4.7c | 4.9c | 4.8d | 1.17b | 1.35c | 1.26c | 1.17b | 1.35c | 1.26c | 1.17b | 1.35c | 1.26c | 1.17b | 1.35c | 1.26c |
|    | SSS   | 6.8a | 8.2b | 7.5b | 5.8b | 5.7b | 5.6c | 2.12a | 1.4c  | 1.32c | 2.12a | 1.4c  | 1.32c | 2.12a | 1.4c  | 1.32c | 2.12a | 1.4c  | 1.32c |
|    | 2 W   | 3.43a| 1.41a| 1.420b| 0.9a | 7.3a | 7.0a | 1.76ab| 2.12a | 2.12a | 1.76ab| 2.12a | 2.12a | 1.76ab| 2.12a | 2.12a | 1.76ab| 2.12a | 2.12a |
|    | SSS   | 3.38a| 3.37a| 3.38a| 6.6a | 6.8a | 6.7b | 1.24b | 2.05ab| 2.05a | 1.24b | 2.05ab| 2.05a | 1.24b | 2.05ab| 2.05a | 1.24b | 2.05ab| 2.05a |
|    | 1 W   | 3.41a| 1.5a | 1.34a| 6.3a | 6.7a | 6.6a | 2.05a | 1.820bc| 1.86b | 2.05a | 1.820bc| 1.86b | 2.05a | 1.820bc| 1.86b | 2.05a | 1.820bc| 1.86b |
|    | SSS   | 3.33a| 3.11a| 3.120b| 4.6c | 4.7c | 4.6d | 1.59ab| 1.580bc| 1.58bc| 1.59ab| 1.580bc| 1.58bc| 1.59ab| 1.580bc| 1.58bc| 1.59ab| 1.580bc| 1.58bc |
| p  | **    | **  | **  | **  | **  | **  | **  | **   | **   | **   | **   | **   | **   | **   | **   | **   | **   | **   | **   |
| LSD| 5.2   | 4.4 | 2.89 | 0.4  | 0.4  | 0.2  | 0.3  | 0.49 | 0.29 | 0.29 | 0.525| 0.449| 0.293| 0.525| 0.449| 0.293| 0.525| 0.449| 0.293|
| SE | 1.6   | 1.4 | 1.02 | 0.1  | 0.1  | 0.1  | 0.1  | 1.62 | 1.04 | 1.04 | 1.66 | 1.42 | 1.04 | 1.66 | 1.42 | 1.04 | 1.66 | 1.42 | 1.04 |
| CV | 18.81 | 18.8 | 15.1 | 16.21 | 2.4  | 2.4  | 2.27 | 12.4 | 9.95 | 10.66 | 12.38 | 9.95 | 10.66 | 12.38 | 9.95 | 10.66 | 12.38 | 9.95 | 10.66 |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at $P < 0.01$; * = significant at $P < 0.05$; ns = non-significant at $P \geq 0.05$; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over Locations; SD = Soybean Sown with sorghum on the same date; 2 W = Soybean Sown 2 weeks before sorghum; 1 W = Soybean Sown 1 week before sorghum; Sole Same D = Sole Sorghum Sown on the same; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum; LSD = Least Significant Difference; SE = standard error; CV = coefficient of variation.
Table 7. Main effects of Soybean Dates of Sowing and Sorghum Varieties on Sorghum Equivalent Yield, Gross Monetary Value and Monitory Advantage Index in Metema (M) and Sanja (S) and Combined over Locations (COL), North Gondar

| Main Effects | SEY | Sorghum CR | Soybean CR | GMV | MAI |
|--------------|-----|------------|------------|-----|-----|
| DS           |     |            |            |     |     |
| SD           |     |            |            |     |     |
| 2 W          |     |            |            |     |     |
| 1 W          |     |            |            |     |     |
| P            |     |            |            |     |     |
| LSD          |     |            |            |     |     |
| SE (±)       |     |            |            |     |     |
| SorV         |     |            |            |     |     |
| SRS          |     |            |            |     |     |
| SSS          |     |            |            |     |     |
| P            |     |            |            |     |     |
| LSD          |     |            |            |     |     |
| SE (±)       |     |            |            |     |     |
| CV(%)        |     |            |            |     |     |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over Locations; SD = Soybean Sown with sorghum on the same date; 2 W = Soybean Sown 2 weeks before sorghum; 1 W = Soybean Sown 1 week before sorghum; Sole Same D = Sole Sorghum Sown on the same; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum; SEY = Sorghum equivalent yield; CR = Competition ratio; GMV = Gross Monetary Value; MAI = Monitory Advantage Index; LSD = Least Significant Difference; SE = standard error; CV = coefficient of variation.
Table 8. Interaction effects of Soybean Dates of Sowing and Sorghum Varieties on Sorghum Equivalent Yield, Gross Monetary Value and Monitory Advantage Index in Metema (M) and Sanja (S) and Combined over Locations (COL), North Gondar

| Interaction Effects | SEY | Sorghum CR | Soybean CR | GMV | MAI |
|---------------------|-----|------------|------------|-----|-----|
|                     | S   | M          | S          | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   | M   | S   |
| SD                  | SRS | 3.74d      | 3.91c      | 3.83c | 1.47b | 1.76a | 1.62bc | 6.8ab | 5.7a  | 6.1ab | 4866d | 50.845c | 49.754c | 694.1b | 16108b | 11.524c |
|                     | SSS | 6.46a      | 6.06a      | 6.26a | 3.0ka | 2.0a  | 2.05ab | 4.9ab | 5.0a  | 5.0bc | 51.845 | 52.196bc | 52.521c | 977.9b | 16541b | 13.160c |
| 2 W                 | SRS | 5.6abc     | 5.2ab      | 5.4bc | 1.76b | 1.71a | 1.74abc | 5.8ab | 5.9a  | 5.8abc | 8394a  | 78837a  | 81390a  | 44071a | 40628a  | 42350a  |
|                     | SSS | 3.99cd     | 4.09bc     | 4.04c | 1.22b | 1.44b | 1.33c  | 8.4a  | 6.9a  | 7.6a  | 794.77a | 74350a  | 76913ab | 404.2a  | 32337ab | 36382ab |
| 1 W                 | SRS | 6.1abc     | 5.72a      | 5.92ab | 2.08a | 2.02a | 2.05ab | 4.8ab | 5.1a  | 5.0bc | 72754bc | 68577ab | 70665b  | 31958ab | 28575ab | 30266ab |
|                     | SSS | 4.59bcd    | 4.3bc      | 4.45c | 2.47a | 2.35a | 2.41a  | 4.3b  | 4.3b  | 4.3a  | 59.669cd | 55.912bc | 57.791c | 21500ab | 29522ab | 25511bc |
| p                   |     | **         | **         | **    | **   | **   | **    | **   | **   | **   | **       | **       | **      | **       | **       | **      |
| LSD                 |     | .534       | .414       | .102  | .568 | .11   | .076  | .168 | .11   | .076 | 13.938   | 10.943   | 74.18   | 17.409   | 14.129   | 10.336   |
| SE                  |     | .169       | .331       | .287  | .053 | .035  | .027  | .053 | .04   | .027 | 4.398    | 3.453    | 26.65   | 59.3     | 44.58    | 3.740    |
| CV                  |     | 18.83      | 8.16       | 6.62  | 7.12 | 8.74  | 11.11 | 9.56 | 10.8  | 11.4 | 16.21   | 15.1     | 16.21   | 2.37     | 2.36     | 2.27     |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; Var = Crop Variety; M = Metema; S = Sanja; COL = combined over locations; SD = Soybean Sown with sorghum on the same date; 2 W = Soybean Sown 2 weeks before sorghum; 1 W = Soybean Sown 1 week before sorghum; Sole Same D = Sole Sorghum Sown on the same; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum; SEY = Sorghum equivalent yield; CR = Competition ratio; GMV = Gross Monetary Value; MAI = Monitory Advantage Index; LSD = Least Significant Difference; SE = standard error; CV = coefficient of variation.
Table 9. Partial Budget Analysis

|         | GYR      | TCV      | NB       |
|---------|----------|----------|----------|
| SD SRS  | 34,326.5 | 30,865   | 3461.5   |
| SD SSSS | 31,921.5 | 30,665   | 1256.5   |
| 2 W SRS | 62,913.5 | 30,865   | 32,048.5 |
| 2 W SSS | 57,629   | 30,665   | 26,964   |
| 1 W SRS | 50,466   | 30,865   | 19,601   |
| 1 W SSS | 45,851   | 30,665   | 15,186   |
| Sole SRS| 31,213   | 21,765   | 9448     |
| Sole SSS| 30,225   | 21,565   | 8660     |

AGY = adjusted Grain Yield; ASY = Adjusted Straw Yield; GYR = Grain; SYR = Straw Yield Revenue; GB = Gross Benefit; TVC = Total Variable Cost; NB = Net Benefit and MRR = Marginal Rate of Return; M = Metema; S = Sanja; COL = combined over Locations; SD = Soybean Sown with sorghum on the same date; 2 W = Soybean Sown 2 weeks before sorghum; 1 W = Soybean Sown 1 week before sorghum; Sole Same D = Sole Sorghum Sown on the same date; SRS = Striga Resistant Sorghum; SSS = Striga Susceptible Sorghum

The thousand seed weight of sorghum significantly differs due to variation in sowing dates of soybean. This result might be due to more release of exudates that do not support its growth but stimulate germination of Striga and depleting the seed bank. Soybean, in turn, reduces the number of Striga that compete for available nutrients, lowering the weight of the kernel. In agreement with this, an increase in kernel weight per head in response to the use of trap crops due to the low number of Striga that might have led to high kernel weight per head through facilitating leaf growth and photosynthetic activities, thereby increasing partitioning of assimilates to the storage organ (Gurney et al., 1999).

LER was superior in resource use efficiency, the intercropping was better than their respective sole cropping. The intercropped sorghum yielded the equivalent of 47% to 67% of its sole crop yield as a result of soybean planting dates. The LER total is greater than one in all cases. This indicates that intercropping soybeans at different dates with sorghum gives beneficial effect in all instances rather than sole planting of sorghum. Ullah (Ullah et al., 2007) reported a higher LER in maize/soybean cropping than in sole cropping. The yield advantage could be due to the efficient utilization of growth resources by the intercropped crops or the intercropping advantages of nitrogen fixation and increased light use efficiency (Reddy et al., 2012).

The GMV of intercrops (ETB 51,573.00 h⁻¹) was higher than that of sole cropped sorghum (ETB 32,370.00 h⁻¹) or greater by 61.04%. However, the GMV (ETB 57,417.00 h⁻¹) of sole cropped soybean was by far superior to the GMV of intercrops (ETB 32,000.00 h⁻¹), which confirms that the GMV of sole cropped soybean was greater than that of intercrops by 25,417.00 ETB h⁻¹ or 44.26% (Table 9). This might be because of a higher contribution of soybean seed yield from sole cropping (2.29 t h⁻¹) compared to intercrop (1.28 t h⁻¹) as the higher price per kg of soybean. The current economic benefits of intercropping were justified in different studies by Wondim (Wolde-Hanna & Fessehae, 1992; Thole, 2012; Tesfaye, 2007).

5. Summary and conclusions
Research conducted at Metema and Sanja Agricultural Research Center during 2017/18, three sowing dates of soybean and Striga resistant and susceptible sorghum varieties aimed at S. hermonthica infestation control and intercropping merits on system productivity.
The main effects of soybean dates of sowing and sorghum varieties significantly affected *Striga* count and dry matter per plot. The lowest *Striga* infestation was in soybean sown 2 weeks before sorghum. Sole sorghum showed higher *Striga* infestation than all other dates of planting in intercropping systems. Grain yield and attributes were affected by the main effects of dates of soybean sowing and sorghum varieties and their interaction highly significantly. Positive correlations were observed in *Striga* control with sorghum yield attributes.

The partial and total LER of sorghum was highest in intercropped soybeans with various dates and sorghum varieties. On the other hand, the interaction of dates of soybean sowing and sorghum varieties was highly significant for GMV, MAI, CR, and SEY. This shows the effectiveness of different dates of sowing of soybean with sorghum in controlling *Striga* and depleting the soil seed bank.

In conclusion, the results clearly depicted the role of legumes in reducing *Striga* infestation significantly. Therefore, soybean intercropping 2 weeks before sorghum will be advisable for effective *Striga* control and improve the production of sorghum.

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