

BIOLOGICAL AND ECONOMIC ESTIMATION OF BENEFITS OF INTER-CROPPING VETCH IN SORGHUM FOR INTENSIFYING EXISTING PRODUCTION SYSTEMS IN GUMARA-MAKSEGNIT WATERSHED, NORTH GONDAR, ETHIOPIA

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Abstract

*Intercropping legume forages in cereal crops is a widely proposed strategy to improve land use efficiency, and maximize the economic value of the farming system, especially in developing countries with restricted resources. The current study was carried out during the successive rainy seasons of 2019 and 2020 in the Gumara-Maksegnit watershed, Gondar Zuria district, Ethiopia to evaluate the feasibility of forage legume inter-cropping in a food sorghum-based inter-cropping system. The experiment was laid down in a randomized complete block design with 3 replications. Local sorghum variety 'Kucho' and the vetch *Vicia villosa* were used for the experiment. Sole sorghum at 75 cm row spacing (T1); sorghum at 75 cm row spacing plus vetch with simultaneous planting (T2); sorghum at 75 cm row spacing plus vetch planted 2 weeks after sorghum (T3); sorghum at 75 cm row spacing plus vetch planted 3 weeks after sorghum (T4); sorghum at 150 cm row spacing plus vetch with simultaneous planting (T5); sorghum at 150 cm row spacing plus vetch planted 2 weeks after sorghum (T6); and sorghum at 150 cm row spacing plus vetch planted 3 weeks after sorghum (T7) were applied as study treatments, on plant height (cm), grain yield ($t\ ha^{-1}$), Stover yield ($t\ ha^{-1}$) and thousand seed weight(g) of sorghum, plant height (cm) and dry biomass yield ($t\ ha^{-1}$) of Vetch. In addition, an economic analysis was made for the feasibility of under-sowing vetch in sorghum crops. At 75 cm row spacing sorghum was planted at 1 seed per hill and at 150 cm row spacing at 2 seeds per hill to maintain a constant population across treatments. Results revealed that the highest grain and Stover yields of sorghum were obtained from T1, T3, T4 and T7. Sorghum planted at 75 cm row spacing plus vetch with simultaneous planting (T2) produced the highest vetch dry matter yield during both years. Earlier vetch planting significantly depressed both grain and Stover yields of sorghum relative to a pure stand of sorghum. On the other hand, the earlier the vetch was planted the greater the dry matter yields of vetch produced. The economic assessment revealed that sowing sorghum at 75 cm row spacing and under-sowing of vetch at the same time was more profitable than pure sorghum with 15,550.00 ETB ha^{-1} gross margins. With the ultimate acceptance of the technology sorghum in 75 cm row spacing plus Vetch with simultaneous planting (T2) was found economically profitable. Based on the results of this study it is suggested that to get higher economic return from a given area of land, nutritious and high-quality fodder and soil improvement through nitrogen fixation, farmers should adopt the practice of intercropping sorghum with forage legumes, preferably sorghum in 75 cm row spacing plus Vetch with simultaneous planting. The testing of this system on a field scale would either confirm or reject the hypothesis that it is more profitable than the conventional pure sorghum planting system. Soil analyses to determine possible increased soil N levels could demonstrate additional benefits. Feeding studies to show the benefits of feeding vetch hay to livestock in comparison with sorghum stover would confirm other potential benefits.*

Key words: intercropping, legume-crop integration, tropical forage, profitability.

INTRODUCTION

Growth patterns of crops when food and forage crops are inter-cropped may be different from those in mono-crops. Intercropping, as a means of agricultural intensification, has proved to be a vital practice in increasing land use efficiency and, thus, uplifting the yield gain and increasing the economic value of the agricultural system (Xia et al., 2019). Cereal-legume intercropping is a widely proposed strategy to develop a sustainable food and forage production system

to replenish the food and feed gaps, especially in developing countries with restricted agricultural inputs (Yang et al., 2018). The integration of both cereals and legumes in the same cropping system gives many advantages to the farming practice, such as reducing the damage caused by pests, diseases and weeds, securing better financial stability for the farmers and improving soil fertility (Dahmardeh et al., 2010). In addition, the morphological and physiological differences between the component crops allow for their complementarity in using the

environmental resources resulting in a better yield and land use efficiency (Bacchi et al., 2021). In general, beneficial effects of intercropping legumes with cereals like sorghum have been observed under conditions of low fertility (Ibrar et al., 2002), as legumes can fix atmospheric nitrogen, thereby increasing the available soil N for the cereal.

In Ethiopia, cereals are the major food crops both in terms of the area they are planted and the volume of production obtained. According to the Central Statistical Agency (2020) data from the total cereal grain crop area 81.19% (10,538,341.91 ha), sorghum cover 15.93% (1,679,277.06 ha) and total production 15.70% (451,735.02 t). This indicates that the share of cereal crops is high both in terms of area coverage and production. Sorghum as food crop it is highly grown and cultivated in most mid land areas of the country and in the study area as well. Sorghum in its high share production it is the main staple food for a large portion of the population, especially for the mid and lowland residences who are most vulnerable to famine during drought years. As a legume forage crop, Vetch is an annual forage legume widely adapted to the high and midland areas of Ethiopia (IAR, 1986). It grows well on the reddish brown clay soil and the black soil as well. It has been grown successfully in areas of acid soil with pH of 5.5-6. Forage legumes like vetch are rich sources of N for livestock with cheaper prices compared to concentrates especially in developing countries. Vetch has a higher crude protein content compared to many other tropical herbaceous legumes (Getnet & Ledin, 2001). Specifically, common and hairy vetches have been reported to fix between 50 and 350 kg N ha⁻¹ and 25 and 190 kg N ha⁻¹, respectively. In addition, due to its cover nature, it is highly effective in reducing soil erosion and conserving the soil moisture content (Clark et al., 1995).

Although sorghum in its area coverage and production capacity it is an important food crop in Ethiopia particularly in the study area. To maximize its production potential row planting and other agronomic practices becoming prominent that makes sorghum field more convenient for forage legume integration. Vetch forages in its multiple benefits it has a potential to be integrated with cereal crops especially with

sorghum crop. On the other hand even though legume forages are the cheapest and quality form of feed for animals, as land is a very limited resource forage production is not as expected in Ethiopia particularly in the study area. To use the existing potential and to alleviate the problem associated with land shortage for forage production, integration of forage legumes into the cereal-based cropping system is vital in optimizing the productivity of a given land use. In the intercropping practice, each of the component crops needs enough surrounding space to adjust to the competition between the plants, keep this to the minimum and guarantee a reasonable amount of yield from each crop (Kim et al., 2018). In the sorghum–Vetch legume intercropping system, sorghum has a reported advantage due to its rapid initial growth, taller stems and larger root system, which results in its exposure to more limited competition than the companion legume crop (Kitonyo et al., 2013). In this regard Dahmardeh et al. (2010) suggested appropriate spatial arrangements to be among the most important factors enhancing sorghum - legume intercropping over sorghum sole cropping. Hence, the intercropping pattern should impact the growth and performance of Vetch because it determines the optimum space available for it to fulfill its needs from the different growth inputs. Even though there is an intercropping effort the issue of intercropping pattern does not take in to account by participating farmers in the study area. This study was therefore, conducted to explore the feasibility and profitability of intercropping sorghum with vetch under different planting patterns.

MATERIALS AND METHODS

Description of the study area

The A two-year field trial was conducted at Gumara- Maksegnit watershed of Gondar Zuria district, 45 km southeast of the Zonal capital, Gondar (12° 25' 14.8'' N, 037° 36' 18.5'' E; 2,061 masl). The area has a moist tropical climate with monthly maximum temperature ranging from 25.3 to 32.6°C (mean 29.0°C) and monthly minimum temperature from 11.1 to 16.9°C (mean 14.4°C). Based on 20 year's (2001-2020) data, annual rainfall is strongly seasonal, variable and unreliable with a mean of

1,225 mm (range 1,026 to 1,499 mm) (Figure 1). The soil types are predominantly Cambisols and Leptosols, which are found in the upper and central part of the watershed, whereas Vertisols

are found in the lower catchment (Addis et al., 2015). The topography of the area ranges from gentle slopes to very steep slopes (Yonas et al., 2010).

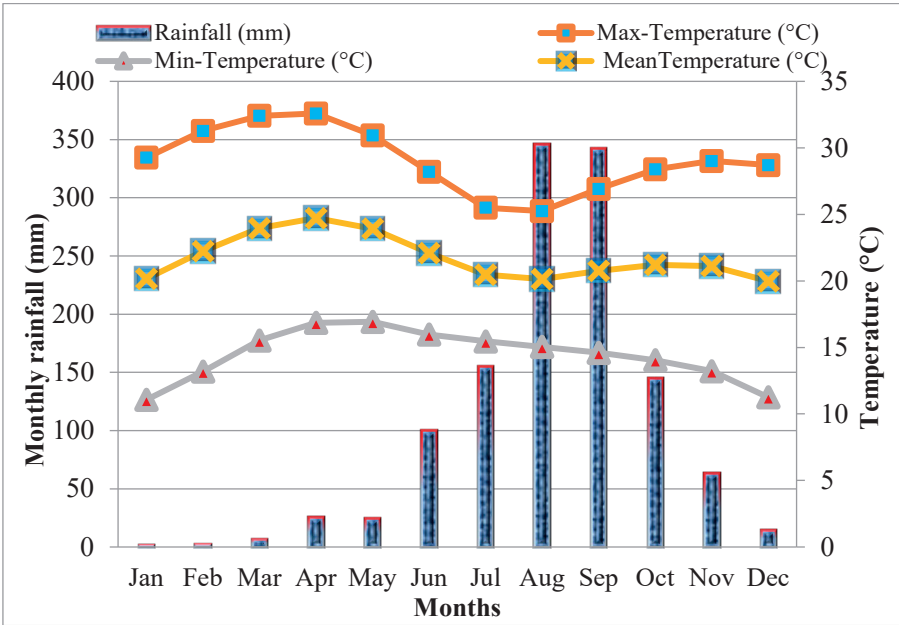


Figure 1. Monthly rainfall and mean monthly temperature data over 20 years (2001-2020) representing the medium-term average for the study area

Average monthly temperature and rainfall during both experimental seasons are illustrated in Figure 2. Monthly rainfall for 2019 and 2020 indicate annual registrations of 1,375 and 1,058 mm, respectively, while the recorded average

monthly temperatures were 22.5 and 20.0°C, respectively. Weather data presented in Figure 2 revealed variability in average monthly temperature and rainfall between the two growing seasons.

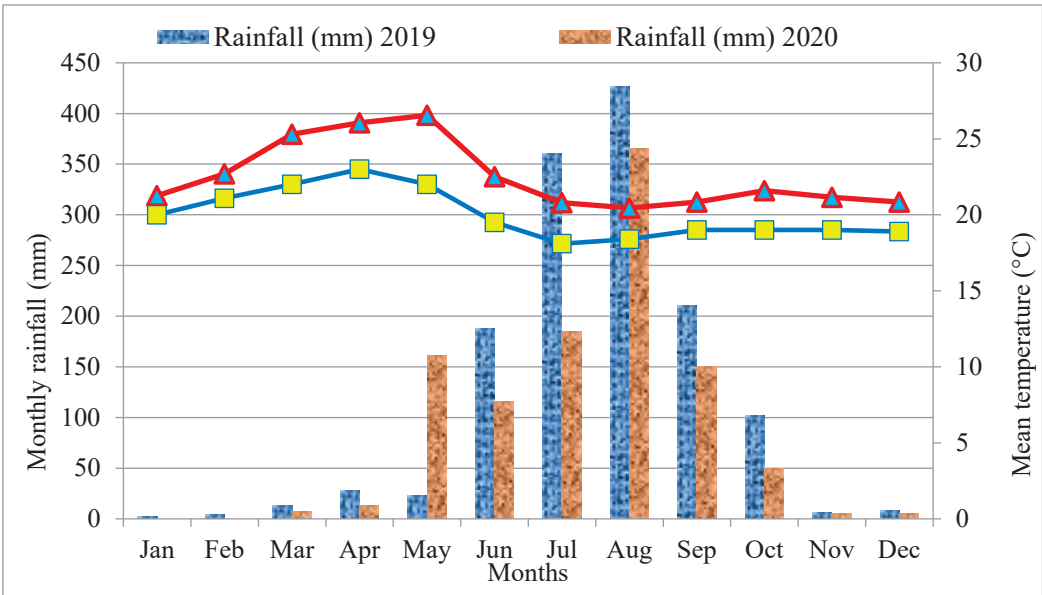


Figure 2. Monthly rainfall and mean monthly temperature data for 2019 and 2020 growing season in the study area

Even there is a slight variability in weather data obtained in experimental seasons, it was ideal for sorghum and intercropped vetch forage

production. Pérez et al. (2010) reported the ideal average temperature and annual rainfall for sorghum to germinate and grow properly is

expected above 18°C and from 500 to 1400 mm, respectively. A temperature of 10 to 35°C and an annual rainfall from 700 to 1400 mm are weather elements required for vetch optimum growth and development (Gezahegn, 2018).

Experimental design, treatments and crop management

The project design was a randomized complete block with 3 replications and the study continued for 2 consecutive years (2019 and 2020) at Gondar Zuria district of Gumara-Maksegnit watershed.

Treatment arrangements are as described in Table 1.

Table 1. Treatment arrangement for under-sowing vetch in a sorghum crop

Treatment	Row spacing (cm) for sorghum	Vetch planting date after sorghum planted
T1	75	No vetch planted
T2	75	simultaneously
T3	75	2 weeks after
T4	75	3 weeks after
T5	150	simultaneously
T6	150	2 weeks after
T7	150	3 weeks after

In Treatments 1-4, sorghum was planted at 1 plant per hill, while in Treatments 5-7 sorghum was planted at 2 plants per hill in a well-prepared seed bed in both years (2019 and 2020). Vetch was planted at 30 cm plant spacing midway between sorghum rows at a seeding rate of 12 kg ha⁻¹. The local sorghum variety Kucho and the vetch *Vicia villosa* were used. The vetch seed was purchased from the International Livestock Research Institute (ILRI) forage seed unit at Debre Zeit. The plot size was 4.5 m wide and 5 m long with 3 and 6 rows of sorghum in the 150 and 75 cm spacing, respectively. Spacing between blocks and plots was 1.5 m and 1 m, respectively. Fertilizer was applied at the rate of 41 kg N (as urea) and 46 kg P (as diammonium phosphate, DAP) ha⁻¹. All of the phosphorus was applied at planting, while 18 kg N was applied at planting and the remaining 23 kg N was applied 40 days after sorghum planting, when sorghum was knee high. Planting was done during the second week of June in both the 2016 and 2017 growing seasons.

Sampling of sorghum was performed on a single row for the wider spacing and on 4 rows for the narrow spacing by excluding guard rows, while vetch sampling was performed from 2 rows for the wider spacing and 5 rows for the narrower spacing, again discarding guard rows. Sorghum performance was evaluated via plant height at harvest from 10 random plants per plot, grain yield from complete rows, Stover yield from complete rows and thousand-seed weight at

harvest, when grain was fully mature. Performance of vetch was evaluated via plant height from 10 randomly selected plants from the ground to the tip of the plant and forage biomass yield when the legume reached 50% blooming stage for the different treatments at different times in their order of planting. Immediately after sampling of vetch the fresh samples were weighed using a Salter balance with a sensitivity of 0.05 kg for green biomass yield estimation. Individual samples (minimum of 500 g) of vetch forage were taken and oven-dried at 65°C for 72 hours until constant weight to determine dry matter (DM) yield.

Economic analysis

Economic analysis was performed following the CIMMYT partial budget analysis methodology (CIMMYT, 1988). Average prices in Ethiopian birr (ETB) for sorghum grain, sorghum Stover, vetch forage, vetch seed, fertilizer and labor for the cultivation of sorghum and vetch were considered for the analysis taking the prevailing price into account. The mean cost of production for sorghum and inter-cropped vetch is illustrated in Table 2. Total variable costs (TVC) and gross margins were calculated. Total variable costs were calculated as the sum of costs of sorghum seed, vetch seed and labor costs for planting, harvesting, drying and transporting of sorghum and vetch hay. Gross return was the value of the 3 products, i.e. grain, Stover and vetch hay for the various treatments

estimated at the prevailing price. Gross margin was calculated as the difference between gross return and the TVC for each treatment. Sorghum grain and Stover yields and vetch biomass yield were adjusted downwards by 10%, assuming

that farmers would obtain yields 10% lower than those obtained in this plot study (CIMMYT, 1988). Treatments with positive gross margins were considered economically profitable.

Table 2. Mean cost of inputs, labour and outputs as estimated at the prevailing price 2019 and 2020 as reference years

Treatment	Costs incurred (ETB) for sorghum and inter-cropped vetch cultivation							Reference years
	sorghum grain kg ⁻¹	sorghum Stover kg ⁻¹	vetch seed kg ⁻¹	vetch hay kg ⁻¹	labor for sorghum management and harvest ha ⁻¹	labor for vetch management and harvest ha ⁻¹	Fertilizer and application ha ⁻¹	
T1	6.11	0.12	0.00	0.00	750.00	0.00	1,400.00	2019 and 2020 average
T2	6.11	0.12	30.00	2.87	574.30	1,560.00	1,400.00	
T3	6.11	0.12	30.00	2.87	757.85	1,595.00	1,400.00	
T4	6.11	0.12	30.00	2.87	811.85	1,490.00	1,400.00	
T5	6.11	0.12	30.00	2.87	655.50	1,481.00	1,400.00	
T6	6.11	0.12	30.00	2.87	552.30	1,350.00	1,400.00	
T7	6.11	0.12	30.00	2.87	701.80	1,390.00	1,400.00	

TB = Ethiopian birr; T1 = sole sorghum at 75 cm row spacing; T2 = sorghum at 75 cm row spacing plus vetch with simultaneous planting; T3 = sorghum at 75 cm row spacing plus vetch planted 2 weeks later; T4 = sorghum at 75 cm row spacing plus vetch planted 3 weeks later; T5 = sorghum at 150 cm row spacing plus vetch with simultaneous planting; T6 = sorghum at 150 cm row spacing plus vetch planted 2 weeks later; T7 = sorghum at 150 cm row spacing plus vetch planted 3 weeks later.

Data analysis

The data collected were subjected to analysis of variance by using the general linear model (GLM) procedure of Statistical Analysis (SAS) (2003) version 9.1 and mean separation were done using Least Significant Difference (LSD) at 5% probability level.

RESULTS AND DISCUSSIONS

Plant height, grain and Stover yields of sorghum

Mean height of sorghum was 165 cm with no significant effect of row spacing, introduction of vetch or time of planting vetch ($P>0.05$; Table 3). However, planting patterns had significant effects on grain yield of sorghum ($P<0.05$) in both years, with reduced grain yield when vetch was planted at the same time as sorghum at both row spacings as well as by planting vetch 2 weeks after sorghum at the wider row spacing. This study has provided some interesting data on the possible benefits of under-sowing a sorghum grain crops with vetch. Including vetch sowing in the crop production process had quite variable outcomes depending on the time of sowing of the vetch relative to when sorghum was sown, with significant reduction in grain yield if sorghum and vetch were sown together but

generally no effect on sorghum grain yield if planting of vetch was delayed for at least 2 weeks after sorghum was sown. This variation in yields might be due to the fact that competition for nutrients, light and water in the sole sorghum crop was only between sorghum plants, while in treatments including vetch there was additional competition with vetch plants. The degree of competition with vetch would vary depending on when vetch was sown; with level of competition declining as planting of vetch was delayed. Singh & Jadhav (2003) also reported that planting pigeon pea, groundnut and soybean simultaneously with sorghum reduced grain yield of sorghum. On the contrary, Krishna et al. (1998) and Ayisi et al. (2001) have reported increased grain yields of sorghum planted on sandy loam soil at 75 cm row spacing when grown with cowpea from simultaneous planting. The variation in responses could be a function of amounts of N derived from biological fixation (BNF) between different legume species, variations in the fertility of the experimental fields as BNF was higher in fertile than infertile fields Romanyà and Casals (2020) and addition of organic and inorganic fertilizer. Generally, sorghum grain yields produced from all treatments in 2016 were relatively higher than those in 2017. Higher sorghum grain yield

in 2016 may be attributed to warmer temperature in 2016, resulting in better growth and development of sorghum in that year. Pérez et al. (2010) reported the warmer the temperature greater than 20°C the higher the sorghum grain will obtained.

Planting vetch at the same time as sorghum also reduced Stover yields of sorghum but the difference was significant only at the wider row spacing ($P<0.05$; Table 3).

Table 3. Mean (2019 and 2020) heights and yields of sorghum and under-sown vetch as affected by row spacing and time of planting of vetch

Treatment	Sorghum				Vetch	
	Plant height (cm)	Grain yield (t ha ⁻¹)	Stover yield (t ha ⁻¹)	Thousand-seed weight (g)	Plant height (cm)	Dry biomass yield (t ha ⁻¹)
T1	163.00	1.99 ^a	9.43 ^{ab}	30.80 ^a	-	-
T2	161.00	1.43 ^b	7.65 ^{bc}	30.30 ^{ab}	125.00 ^a	3.49 ^a
T3	168.00	1.87 ^a	10.19 ^a	30.20 ^{ab}	93.60 ^c	0.76 ^d
T4	161.00	2.15 ^a	10.22 ^a	30.00 ^{ab}	65.50 ^c	0.25 ^e
T5	170.00	1.32 ^b	7.35 ^c	29.70 ^b	125.00 ^a	3.06 ^b
T6	166.00	1.37 ^b	8.20 ^{bc}	29.90 ^{ab}	108.00 ^b	1.02 ^c
T7	167.00	1.99 ^a	8.83 ^{ab}	29.80 ^{ab}	81.00 ^d	0.47 ^{ed}
Mean	165.00	1.73	8.82	30.00	99.70	1.51
LSD (5%)	ns	0.33	1.47	2.03	8.93	0.41
CV (%)	3.62	10.70	14.10	2.82	4.92	14.8

Means within columns having different superscript letters are significantly different at * = $P<0.05$; ns = non-significant at ($P>0.05$) by LSD test.

T1 = sorghum row spacing 75 cm; T2 = sorghum row spacing 75 cm and vetch planted on same day as sorghum; T3 = 75 cm row spacing and vetch planted 2 weeks later; T4 = 75 cm row spacing and vetch planted 3 weeks later; T5 = 150 cm row spacing and vetch planted on same day; T6 = 150 cm row spacing and vetch planted 2 weeks later; and T7 = 150 cm row spacing and vetch planted 3 weeks later; CV = coefficient of variation; LSD = least significant difference.

The differences in Stover yield of sorghum between the treatment groups would also be a function of variation in level of competition for resources between the various treatments. Despite the ability of the legume to fix atmospheric nitrogen, if it was planted at the same time as the sorghum, regardless of row spacing, the increased competition from the legume suppressed growth of sorghum and reduced both grain and Stover yields. If sowing of vetch was delayed, especially by 3 weeks, there was no negative impact on yields of grain and Stover of sorghum and good quality vetch hay was produced, though in small amounts. Even though farmers' primary targets are often the grain crop, with Stover as a secondary issue, it seems they could practice cereal-legume inter-cropping without compromising grain yield, provided that sowing of the legume was delayed under the current circumstances. Thousand-seed weight of

sorghum was generally unaffected by planting times and configuration ($P>0.05$).

Mean plant height and biomass yield of under-sown vetch

The mean combined analysis results of plant height and biomass yield of vetch under-sown with sorghum are presented in Table 3. Plant height of vetch at harvest decreased progressively as time of planting of vetch was delayed ($P<0.05$) and was greater at the wider than the narrower row spacing ($P<0.05$), except when sorghum and vetch were planted at the same time. The increased vetch height achieved at early planting could be attributed to the better opportunity to compete with sorghum at the seedling stage rather than when sorghum was better established as with later plantings. Tuna and Okra (2002) reported heights of common vetch as a pure stand of 56.5 cm and 23.9 cm in the first and second year, respectively, which is much lower than the heights we obtained, while

Basbag et al. (1999) reported a 123 cm plant height, which is similar to the current result, when vetch was planted as a pure crop. Biomass yield of vetch also declined progressively ($P < 0.05$) as time of planting of vetch was delayed, while there was no consistent effect of row spacing on biomass yield. The highest vetch biomass yield was obtained when planted at the same time as the sorghum at 75 cm row spacing. This reflects the better opportunity to compete for moisture, nutrients and light with the sorghum in the early stages of growth plus possibly better conditions for growth and longer growth period. Vetch hay would also be of better quality and a better feed for livestock than sorghum Stover on a unit basis, which must be taken into account when assessing the benefits of the various systems.

Economic analysis

The results of partial budget analysis are shown in Table 4. Financial profitability is the ultimate measure to recommend a technology. While technology can be agronomically feasible and beneficial for soil improvement, it would not be attractive to farmers unless it is financially profitable. The partial budget analysis showed that sorghum planted at a 75 cm row spacing with vetch in the inter-rows planted at the same

time is most profitable as it returned the highest gross margin.

Results of the economic analysis suggest that the financial outcomes are not in agreement with the agronomic outcomes. Agronomic data would suggest that treatments T3 and T4, i.e. when vetch was planted after sorghum and yields of both sorghum grain and Stover were at least equal to those of pure sorghum, might be the most profitable. However, despite the depression of yields of sorghum grain and stover when vetch was planted at the same time as sorghum, the increased value of the vetch hay produced more than offset the reduced production from the sorghum plus the additional variable costs. It must be remembered that the economic outcomes are heavily dependent on the relative values placed on sorghum grain, sorghum stover and vetch hay. Based on values we used, the current study suggests that, by planting sorghum at 75 cm row spacing with vetch sown simultaneously in the inter-row space (T2); farmers in the watershed could achieve 15,550.00 ETB ha⁻¹ gross margins, compared with 11,179.00 ETB ha⁻¹ for pure sorghum, a very good return on investment. This financial benefit is in addition to the expected benefits in terms of soil fertility improvement through nitrogen fixation, which we could not quantify in terms of monetary value.

Table 4. Economic analysis for under-sowing vetch in a sorghum crop in Gumara-Maksegnit watershed

Treatment	Adjusted grain yield of sorghum (t ha ⁻¹)	Adjusted stover yield of sorghum (t ha ⁻¹)	Adjusted vetch dry matter yield (t ha ⁻¹)	Total gross benefit from sorghum grain, stover and vetch hay (ETB ha ⁻¹)	Total variable cost (ETB ha ⁻¹)	Gross margin (ETB ha ⁻¹)
T1	1.79	8.48	0.00	11,929.00	750.00	11,179.00
T2	1.29	6.88	3.14	17,684.00	2,134.00	15,550.00
T3	1.68	9.17	0.68	13,260.00	2,353.00	10,907.00
T4	1.93	9.20	0.23	13,315.00	2,302.00	11,013.00
T5	1.19	6.62	2.75	15,917.00	2,137.00	13,781.00
T6	1.24	7.38	0.92	11,134.00	1,902.00	9,232.00
T7	1.79	7.95	0.42	12,576.00	2,092.00	10,484.00

Yields from the study were reduced by 10% assuming that farmers would achieve lesser yields than in a small plot experiment.

ETB = Ethiopian birr; T1 = sole sorghum at 75 cm row spacing; T2 = sorghum at 75 cm row spacing plus vetch with simultaneous planting; T3 = sorghum at 75 cm row spacing plus vetch planted 2 weeks later; T4 = sorghum at 75 cm row spacing plus vetch planted 3 weeks later; T5 = sorghum at 150 cm row spacing plus vetch with simultaneous planting; T6 = sorghum at 150 cm row spacing plus vetch planted 2 weeks later; T7 = sorghum at 150 cm row spacing plus vetch planted 3 weeks later.

CONCLUSIONS

Agronomic yield is not the ultimate measure to recommend a technology, unless it is supported

by financial profitability. Based on the results of this study we conclude that, though sorghum planted at 75 cm row spacing plus vetch with simultaneous planting (T2) produced relatively

lower grain and stover yields, the value of vetch biomass (3.49 t DM ha⁻¹) produced, which could be used as animal feed, more than offset the reduced value of sorghum grain and stover plus the additional costs of inputs. This system seems a viable technology to combat feed shortage, soil degradation and overall productivity in the watershed and other similar areas. Testing the system on a field scale would confirm or reject this hypothesis that it is more profitable than the conventional pure sorghum planting system. An added benefit would be the possible improvement in soil N levels, which should be measured in further studies. Other potential benefits of feeding vetch hay to livestock in comparison with sorghum stover and their mixtures should be further studied.

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