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Evaluations of Grass Pea Relay Inter-Cropping with Wheat on Vertisol in Eastern Amhara Region, Ethiopia

Tilahun Taye*, Wudu Abiye, Muluken Lebay

Sirinka Agricultural Research Center, P. O. Box 74, Woldia, Ethiopia.

*Corresponding author; email: sarctilahun3@gmail.com

Abstract

Grass peas have been cultivated in Ethiopia for a long time; they are drought-tolerant and unaffected by excessive rainfall. This study evaluated the effectiveness of grass pea relay intercropping with wheat for better production and its effect on soil moisture and fertility improvement in the Jama district, northeastern Amhara, Ethiopia. The location is mainly dominated by vertisol, a black-to-gray clay with high swelling and shrinking character. The treatments were evaluated by arranging the randomized block design. At the tillering stage of wheat, planting grass peas on furrows and between rows with 30cm spacing effectively contributes to soil fertility status and soil moisture. Grass pea is a legume crop that incorporates nitrogen and is also used as a cover crop that retains soil moisture. This type of planting technique is also efficient in the case of land utilization; a 1.9 ha sole cropping area would be required to produce the same yields as 1 ha of the intercropped system. Planting grass peas during the tillering stage of the wheat crop is recommended.

Keywords: crop production, grass pea, land equivalent ratio, wheat planting, vertisol

Introduction

Lathyrus sativus L., or grass pea ('guaya' in Ethiopia), is a legume cultivated in South Asia and Ethiopia for over 2500 years and used as food and feed. The origin of grass pea cultivation is around 6000 Before Christ (De Ron, 2015). Its tolerance to drought, not affected by excessive rainfall, and can be grown on land subject to flooding, including very poor soils and heavy clays (Jiang et al., 2013). The world's population is increasing rapidly, and to feed it, one of the most attractive strategies is to increase productivity per unit area of available land or to increase the land area under production, which seems to be shrinking day by day (Sun et al., 2018). Therefore, to maximize land use and production, the goal of agriculture, namely yield, intercropping is an advanced agronomic technique that allows two or more crops to yield from the same land area. Better utilization of resources and reduced weed competition minimize the risk of food shortages by enhancing yield stability (Aziz et al., 2015)and in order to feed it, one of the most attractive strategies is to increase productivity per unit area of available land or to increase the land area under production, which seems shrinking day by day. Therefore, to maximize land use and production, the ultimate goal of agriculture, namely yield, intercropping is an advanced agronomic technique that allows two or more crops to yield from the same area of land. Better utilization of resources and reduced weed competition minimize the risk of food shortages by enhancing yield stability. Several factors can affect intercropping: plant density, sowing time, the maturity of a crop, the selection of crop that is compatible with another as well as farmers' and the region's socioeconomic conditions. In intercropping, the land equivalent ratio (LER).

In Ethiopia, vertisol covers about 12.6 million ha of land or about 10% of the total area of the country (Elias and Biratu, 2022). These soils have great potential for crop production since they have relatively good inherent fertility and are located mainly in the highlands where rainfall is sufficient. Since ancient times, grass peas have been an important crop for human consumption and animal feed or fodder.

Due to population growth, food shortages are common in many parts of the world, particularly in Asia and Africa. One possible solution to this dilemma is to boost productivity per unit area of available land by maximizing the use of limited agricultural land through multiple cropping (Praharaj et al., 2021; Sarkar et al., 2020). Intercropping is a crop management strategy that involves cultivating two or more dissimilar crop species or kinds in separate row combinations on the same piece of land simultaneously (Maitra et al., 2021; Glaze-Corcoran et al., 2019). Intercropping has been demonstrated in numerous studies to be more productive than monoculture, yet it can also result

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in resource rivalry (Jiao et al., 2024; Kushwaha and Mehta, 2023). One of the many competing resources in crop production systems is light, and soil moisture is another one that could be a competitor (Liu et al., 2020).

Grass pea is commonly grown in arid and semi-arid regions and known for being extremely drought-tolerant (Nadeem et al., 2019). They have high protein contents and remarkable resistance to extreme environmental conditions, such as flooding, drought, salinity, and low soil fertility, as well as significant resistance to biotic stress agents (Jiang et al., 2013). Grass pea is Ethiopia's third most crucial pulse crop after faba bean and chickpea. It is primarily planted in September / October on residual moisture in the cambisol and vertisol. It can withstand heavy rains in the early growth stages and prolonged drought during grain filling (Hillocks and Maruthi, 2012; Girma and Korbu, 2012). Before the first crop is harvested, growing one crop and planting another one in the same field extends the usage of the field (Stomph et al., 2020; Khanal et al., 2021).

This study experimented using a relay inter-cropping system for wheat and grass pea crops. Wheat yields and grain protein content are lower and more variable in organic conditions than in conventional agriculture, mainly due to nitrogen (N) deficiency and weed competition. The undersowing of legume cover crops in growing winter wheat, also known as relay intercropping, is assumed to be a proficient way of enriching the soil-crop system with nitrogen and improving weed control (Kocira et al., 2020).

Relay intercropping systems have the advantages of being affordable and simple to grow without requiring much work. Grass pea offers a variety of distinctive qualities that appeal to both growers and customers. Despite adverse environmental circumstances, including drought or high moisture, grass peas can be grown with little input, enhancing food security in harsh environments. They are low-input livestock feed and a cover crop for soil conservation. In relay intercropping, late-season crops are planted in rows while early-season crops are still growing (Gao et al., 2014). Therefore, the objectives of this study are to evaluate the effectiveness of grass pea relay intercropping with wheat for better productivity and to evaluate its effect on improving soil moisture and soil fertility.

Materials and Methods

Experimental Site Description

The study was conducted during the primary cropping season in 2019 and 2020 in the Jama district, which lies at 10^{o} 23’to10^{o}27’N latitudes and 39^{o} 07’ to 39^{o} 24’E longitudes. The dominant soil type of the study districts is Vertisol, the area is characterized by poor drainage or waterlogging, difficulty to work (Belete et al., 2013). The area receives an average annual rainfall of 1012.0 mm, of which 74.6% is received during the primary rain season (June to September), and the highland plateau of Jamaica has a very cold temperature, which ranges from 0 to 20^{o}C. The nature of its soil type is gray clay with high swelling and shrinking character. It is poorly drained when wet and cracking when dry. The land use is mainly cultivated field crops: wheat (*Triticum aestivum*), tef (*Eragrostis tef*), and faba bean (*Vicia faba*) in rotation, while the marginal lands along the roadsides and communal pasture land purposely left for feed sources are the major grazing grounds (Lebay et al., 2021).

Experimental Design

Nine field experiments were conducted: two grass pea planting times integrated with two wheat spacing and two planting techniques (Table 1). Each treatment was set up with a randomized complete block design in three replications. The plot size was adjusted to 4.8 m x 3 m, and the spacing between plots and replications were 1 m and 1.5 m, respectively.

Data Analysis

The data was analyzed using SAS version 9.0 and Microsoft Office Excel 2010. To determine whether the data was statistically significant, analysis of variance (ANOVA) was used. The LSD test was used to compare mean values at $P < 0.05$.

Soil Sampling Technique and Analysis Methods

Soil moisture content was taken after the last grass pea planting time (in the dry season), 15 days after the rainfall. For soil moisture and bulk density, the samples were collected from the soil surface up to 20 cm depth during wheat harvesting time (Funakawa et al., 2012). The soil moisture content was analyzed by the gravimetric method (Blake et al., 1965). Soil organic matter and pH were measured using volumetric, wet digestion, and water and potassium chloride suspension methods, respectively. Total nitrogen and available phosphorous were analyzed by Kjeldahl and Olsen procedure, respectively (Walkley, 1934).

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Table 1. Experimental treatments

Treatment	Grass pea planting time	Grass pea planting practice	Wheat planting spacing (cm)
1	The tillering stage of wheat	Grass pea planting practice	20
2	The tillering stage of wheat	Planting on furrows only	
3	The tillering stage of wheat	Planting on furrow and between rows	30
4	Conventional planting time of grass pea	Planting on furrows only	30
5	Conventional planting time of grass pea	Planting on furrow and between rows	20
6	Conventional planting time of grass pea	Planting between rows	30
7	Sole cropping of wheat (20 cm)		
8	Sole cropping of wheat (30 cm)		
9	Sole cropping of grass pea		

The land equivalent ratio is calculated based on the following formula for both sole and intercropping area coverage with the proportional yield productions (Yilmaz et al., 2008)500 plant ha^{-1}.

$$LER = \frac{\text{YG in mixed stand}}{\text{YG in pure stand}} + \frac{\text{YW in mixed stand}}{\text{YW in pure stand}}$$

LER= Land equivalent ratio (FAO, 1976)
YG= Yield of grass pea
YW = Yield of wheat

Result and Discussion

Effect of Intercrops on Crop Yield and Biomass Production

Relay intercropping did not impact wheat grain production, independent of the chance to grow a grass pea crop. Wheat biomass and yield did not significantly differ in terms of production potential. However, grass pea production potential varied according to the treatments (Table 2, Table 3, and Table 4). While it does contribute to maximizing the efficiencies of the cultivated field, this sort of cropping system has little impact on the output potential (Kocira et al., 2020). When the main crop and intercrop have separate growing seasons such that their principal resource demands are met at different times, the yield advantage is at its highest (Deng et al., 2022). The component crops in intercropping are concurrent throughout a sizable amount of their production cycle or growing period, even though they may not be planted or harvested at precisely the same time (Srivastava et al., 2008).

The second-year results 2020 are consistent with the previous yield and biomass of wheat and grass pea production. Planting grass peas with 30 cm of wheat at the tillering stage is more productive than the other treatments (Table 3).

Intercropping for Effective Utilization of Land Resource

The yield increase in intercropping is likely due to the effective utilization of environmental resources, particularly when combining cereals and legumes. The land equivalent ratio (LER) illustrates how successfully intercrops exploit plant growth sources compared to sole crops (Figure 1).

Utilizing plant growth factors effectively is essential for assessing the benefits of intercropping in sustainable agriculture to fulfill the growing demand for food caused by population growth. That is if LER >1 is used to indicate that intercropping is superior to solo crops in terms of light, water, and nitrogen use (Semahegn, 2022; Liu et al., 2018) very few studies have explored the reason of its high LER, and the relationships between light distribution and the variations in radiation use efficiency (RUE). Hauggaard-Nielsen et al., 2006 assessed using the relative efficiency index (REIc the intercrops' land equivalent ratios (LER) values ranged from 1.08 to 1.21 at both harvest stages. According to some studies, different intercrops use plant growth elements up to 50% more effectively than a single crop (Raza et al., 2021) but little information is available on its application to irrigated land. Therefore, a three-year field trial was conducted to compare two maize-soybean strip-intercropping planting patterns (two-rows of maize intercropped with two-rows of soybean [2M2S] or -three rows of soybean [2M3S]. Under conditions of low nitrogen fertilization, pea, and barley intercropping also utilized environmental resources for plant growth more effectively than a single crop

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Table 2.Grass pea and wheat yield and biomass (2019 study)

Treatments	Wheat grain yield (kg.ha^{-1})	Biomass (kg.ha^{-1})	Grass pea grain yield (kg.ha^{-1})	Grass pea bio-mass (kg.ha^{-1})
The tillering stage of wheat				
On planting on furrows (20 cm)	2432 a	6632 a	602 c	1818 b
Furrow and b/n row (30 cm)	2501 a	6458 a	1436 bc	4747 a
B/n rows (30 cm)	2218 a	6250 a	1331 bc	3939 ab
Conventional planting time of grass pea				
On furrows only (20 cm)	2254 a	6562 a	872 bc	2449 b
On furrow and b/n row (30 cm)	2491 a	6181 a	1637 b	5101 a
B/n rows (30 cm)	2501 a	6944 a	922 bc	2424 b
Sole cropping of wheat (20 cm)	3224 a	7917 a	-	-
Sole cropping of wheat (30 cm)	2266 a	6181 a	-	-
Sole cropping of grass pea	-	-	2625 a	6086 a
CV	21.1	17.3	36.90	31.45
Significance	ns	ns	*	*

Notes: *= significant; ns= non-significant according to the least significant differences (LSD) at α=0.05. CV = coefficient of variation

Table 3. Yield and biomass of grass pea and wheat in 2020

Treatments	Wheat grain yield (kg.ha^{-1})	Biomass (kg.ha^{-1})	Grass pea grain yield (kg.ha^{-1})	Grass pea bio-mass (kg.ha^{-1})
Tillering stage of wheat				
Planting on furrows (20 cm spacing)	1667	5595	976.9 ab	2803 a
Furrow and b/n row (30 cm spacing)	1906	6823	1508.5 a	3535 a
B/n rows (30 cm spacing)	1752	7083	1064.2 ab	2210 ab
Conventional planting time of grass pea				
On furrows only (20 cm spacing)	1687	5387	369.1 b	1193 b
On furrow and b/n (30 cm spacing)	1805	6042	882.9 ab	2247 ab
B/n rows (30 cm)	2005	5469	271.4 b	1136 b
Sole cropping of wheat (20 cm)	2014	6518	-	-
Sole cropping of wheat (30 cm)	1545	5208	-	-
Sole cropping of grass pea	-	-	1524.8 a	3580 a
CV	24.5	20.3	43.3	34.6
Significance	ns	ns	*	*

Notes: values followed by different letters within the same column are significantly different according to the least significant differences (LSD) at α=0.05. CV = coefficient of variation.

(Cowden et al., 2020; Hu et al., 2018). Thus, crops are similar in most characteristics of wheat and grass pea.

Because intercropping uses light, water, and nutrients more effectively than a single crop, it generally yields higher (Maitra et al., 2021). Using the land equivalent ratio (LER) makes it possible to precisely evaluate the competitiveness of the intercropping system's component crops, effective land use, and total production (Maitra, 2019). In addition, the LER can be used to gauge the productivity of the land (Seran and Brintha, 2009). A land equivalent ratio >1 indicates that the land is used more effectively in an intercropping system. LER demonstrated the benefits of cereal-legume intercropping due to more effectively using resources in intercropping by increasing plant density (Osiru and Willey, 1972; Fisher, 1977). An interpretation of this result would be that a total of 1.9 ha of sole cropping area would be required to

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Figure 1. Grass pea planting on furrows and rows

Table 4. Wheat and grass pea yield and biomass (2019-2020)

Treatments	Wheat grain yield ($kg.ha^{-1}$)	Biomass ($kg.ha^{-1}$)	Grass pea grain yield ($kg.ha^{-1}$)	Grass pea bio-mass ($kg.ha^{-1}$)
Tillering stage of wheat				
Planting on furrows (20 cm spacing)	2049 ab	6114	790 bc	2311 cd
Planting on furrow and b/n row (30 cm spacing)	2204 ab	6641	1472 ab	4141ab
Planting on rows (30 cm spacing)	1985 ab	6667	1198 bc	3074 bcd
Conventional planting time of grass pea				
Planting on furrows only (20 cm)	1971 ab	5975	620 c	1821 d
Planting on furrow and b/n row (30 cm)	1805	6042	882.9 ab	2247 ab
Planting on rows (30 cm spacing)	2253 ab	6207	597 c	1780 d
Sole cropping of wheat (20 cm)	2619 a	7217	-	-
Sole cropping of wheat (30 cm)	1905 b	5694	-	-
Sole cropping of grass pea	-	-	2075 a	4833 a
	16.5	14.8	31.2	23.9
Significance	*	ns	*	*

Notes: *= significant; ns= non-significant according to the least significant differences (LSD) at α=0.05. CV = coefficient of variation

produce the same yields as 1 ha of the intercropped system. This result was recorded from the treatment of the tillering stage of wheat with planting on furrows and between row spacing of 30 cm (Table 5).

Impact of Intercropping on Soil Fertility and Conservation Status

The soil moisture content was obtained after the rainfall decreased in August since the first soil moisture sample was taken in September, the second in December, and the third in January, respectively. The findings revealed that while there was no significant variation between the first two samples, there was a difference during the final measuring period (Table 6). Regarding soil health status, soil productivity could be improved by improving soil moisture content and enhancing basic soil macronutrients (Tables 6, 7, and 8). The crop should cover the land and furrow was possible to sustain the surrounding moisture (El-Beltagi et al., 2022). The main crop raised on the bed was grown well with a substantial amount of yield

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Table 5. Land equivalent ratio (LER)

Wheat tillering stage	Land equivalent ratio (LER)
Planting on furrows only (20 cm)	1.2
Planting on furrows and b/n row (30 cm)	1.9
Planting on rows (30 cm spacing)	1.6
Conventional planting time of grass pea	
Planting on furrows only (20 cm)	1.1
Planting on furrow and b/n row (30 cm)	1.4
Planting on rows (30 cm spacing)	1.5
Sole cropping of wheat (20 cm)	1.0
Sole cropping of wheat (30 cm)	1.0

Table 6. Soil moisture content and bulk density in 2019 experiment

Treatment	Soil moisture content (%)			Bulk density ($g.cm^{-3}$)
	February 2, 2019	March 11, 2019	April 10, 2019	
Wheat tillering stage				
Planting on furrows only (20 cm)	26.8	15.2	6.5 ab	1.4 b
Furrow and b/n row (30 cm)	24.3	15.9	7.2 b	1.3 ab
Planting on rows (30 cm)	22.4	14.8	5.1 ab	1.29
Conventional planting time of grass pea				
Planting on furrows only (20 cm)	28.0	16.2	6.8 b	1.6 a
Furrow and b/n row (30 cm)	25.0	17.8	3.5 ab	1.28 c
Planting on rows (30 cm)	22.3	14.5	4.2 ab	1.4 b
Sole cropping of wheat (20 cm)	23.7	19.4	2.5 c	1.5 a
Sole cropping of wheat (30 cm)	26.2	18.1	2.9 c	1.4 b
Sole cropping of grass pea	23.0	16.0	14.7a	1.3 ab
CV	15.5	15.5	14.2	9.77
Significance	ns	ns	*	*

Notes: *= significant; ns= non-significant according to the least significant differences (LSD) at α=0.05. CV = coefficient of variation

could be harvested on the furrows without affecting the main crop on the bed (Kathuli and Itabari, 2015).

In Italy, cultivation of grass peas almost stopped, but there is renewed interest in the crop to provide an efficient alternative to wheat on land degraded by excessive cereal cultivation (Grandgirard et al., 2002). Due to their very strong and deep-reaching root system, grass peas is tolerant to different soil pH, and are capable of growing and developing on various soil types, which makes them unique among legumes (Saikia et al., 2020; Lazali and Drevon, 2021).

The bulk density or soil compaction indicators showed that the treatments differed significantly (Table 6). The principal crops spaced 30 cm apart from the row and furrow planted with grass peas resulted in reduced bulk density (Table 6).

Conclusions

Planting grass peas alongside wheat did not substantially affect wheat production potential. Still, it contributed to additional output on specific land. Since grass pea planting during the wheat tillering stage is more effective, wheat should be spaced 30 cm apart. The covering of grass pea has impacted the soil moisture and fertility status of the land. As some qualities did not indicate a significant difference, most soil chemical and physical parameters show a more remarkable differential improvement in covering the land's bed and furrow. To increase output potential and soil fertility, farmers should employ release intercropping on vertisol with grass pea planting at the tillering stage of wheat. The cropping technique should be prepared for the broad bed and furrow based on its recommendation, as well as sowing

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wheat at 30 cm spacing. The grass peas should be sowed within the wheat row and throughout the furrow. Cropping techniques should include preparing the broad bed and furrow and sowing wheat at 30 cm spacing. The grass peas should be sown in the wheat row and throughout the furrow.

Table 7. Soil moisture content and bulk density in 2020 experiment

Treatment	Soil moisture content (%)			Bulk density ($g.cm^{-3}$)
	Jan 5, 2020	April 10, 2020	May 20, 2020	
Wheat tillering stage				
Planting on furrows only (20 cm)	26.8	9.5	8.5	1.2 ab
Furrow and b/n row (30cm)	26.2	10.4	8.7	1.1 a
Planting on rows (30 cm)	25.5	9.8	7.6	1.1 a
Conventional planting time of grass pea				
Planting on furrows only (20 cm)	29.1	9.4	9.2	1.1 a
Furrow and b/n row (30 cm)	26.6	10.2	7.6	1.3 ab
Planting on rows (30 cm)	27.3	8.9	8.1	1.3 ab
Sole cropping of wheat (20 cm)	27.7	10.5	7.3	1.4 b
Sole cropping of wheat (30 cm)	24.5	5.2	7.8	1.4 ab
Sole cropping of grass pea	31.7	11.3	9.4	1.2 ab
CV	9.5	20.6	17.0	8.8
LSD	ns	ns	ns	*

Notes: *= significant; ns= non-significant according to the least significant differences (LSD) at α=0.05. CV = coefficient of variation

Table 8. Organic matter content, total N and P, and pH of the study area in 2020 experiment

Treatment	Organic matter (%)	Total N (%)	Average P (ppm)	pH
Wheat tillering stage				
Planting on furrows only (20 cm)	1.36 ab	0.187	7.4 ab	6.5
Furrow and b/n row (30cm)	1.43 ab	0.163	9.0 a	6.4
Planting on rows (30 cm)	1.30 ab	0.150	7.2 ab	6.4
Conventional planting time of grass pea				
Planting on furrows only (20 cm)	1.41 ab	0.187	6.7 ab	6.4
Furrow and b/n row (30 cm)	1.34 ab	0.160	5.3 b	6.2
Planting on rows (30 cm)	1.58 a	0.150	7.1 ab	6.5
Sole cropping of wheat (20 cm)	1.10 b	0.173	6.6 ab	6.4
Sole cropping of wheat (30 cm)	1.26 ab	0.187	7.8 ab	6.4
Sole cropping of grass pea	1.29 ab	0.150	6.7 ab	6.3
CV	19.26	14.02	15.05	1.77
Significance	*	ns	*	ns

Notes: *= significant; ns= non-significant according to the least significant differences (LSD) at α=0.05. CV = coefficient of variation

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