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# Effect of Nitrogen and Phosphorus on Yield Components, Yield and Sugarcane Juice Quality parameters of Soybean-Sugarcane Intercropping at Tendaho Sugar Factory

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## Abstract

A field experiment was conducted at Tendaho Sugar Factory in Ethiopia to determine economic rate of nitrogen and phosphorus for soybean-sugarcane intercropping. The experiment was laid out in randomized complete block design with three replications. Germination percentage, plant population and yield were collected for soybean. Stalk number and weight data were collected for sugarcane at the age of 8 and 14 months, respectively. Cane yield, estimated recoverable sucrose (ERS), sugar yield, and juice quality parameters such as brix (%), pol (%), and purity (%) were also determined. The soil analysis result indicated that soil of the study site was clay in texture with high pH values at the surface and subsurface layers. Moreover, the soil was low in organic carbon, total nitrogen and available phosphorous. Analysis of the variance revealed that germination percentage, plant population and yield of soybean were highly significant ($p<0.01$). Stalk number and weight, cane yield, ERS, and sugar yield were not significant. Juice quality parameters were also not significant. Land Equivalent Ratio (LER) was the highest, 3.52, when the intercrop fertilized with 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$ at planting and 74 kg N $ha^{-1}$at 2.5 months of cane age. However, net return (NR) and net benefit cost ratio (NBCR) were found to be the 1st and 2nd highest, respectively, when the intercrop fertilized with 18 kg N $ha^{-1}$ and 46 kg $P_2O_5ha^{-1}$ at planting (T4). Due to this treatment (T4), net return increased by 14.45% over the control (sole sugarcane without fertilizer, T8) and also cost of fertilizer reduced by 50%. It is therefore, T4, fertilizing the intercrop at rate of 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$at planting could be the promising treatment to be recommended to Tendaho Sugar Factory.

**Keywords:** Soybean; Sugarcane; Intercropping; Cane yield; Sugar yield; Land equivalent ratio

## Introduction

Many countries where cane is produced by small scale producers have investigated intercropping as a means to improve home food security, with the largest output of scientific research papers originating from India, where almost 100 different crops have been tested for their suitability as cane intercrops [1]. Monoculture is common practice in sugarcane production throughout the world and leads to decline in yields and soil fertility and buildup of pests and diseases. Legumes have been shown as potential crops that break the monoculture cycles in several crops. Sugarcane offers a unique potential for intercropping [2]. Sugarcane intercropping with soybean offers opportunity for profitable utilization of available land, water, light and other natural resources, and it played an important role in development and commercialization of sugarcane crop in China in terms of economic and social benefit per unit land area and effectively solve the contradiction of land competition between sugarcane and other crops [3]. To ensure the optimum productivity in an intercropping system, one must ensure that the peak periods of growth of the two crops do not coincide, so that one quick-maturing crop completes its life cycle before the main period of growth of the other crop starts. Cane is planted in wide rows, and takes several months before canopy formation, during which time, the soil, solar energy and much of the rainfall between the rows goes to waste. Any interrow crop must therefore mature and be harvested within 90-120 days before the cane forms canopies.

Soybean can be grown on almost all well-drained soils; however, the crop is more productive on fertile loam soils. Soybean is not sensitive to acidic soils as many other legumes. Soil with pH 6-7 is suitable for crop growth. In this pH range, adequate calcium and magnesium are normally available. For efficient production as a monocrop, soil must be managed properly to allow optimum uptake of water and nutrients. Fertilizer application is important in the soybean production and has great effect on yield. Soybean requires substantial amount of P fertilizer and a small amount of N in less fertile soil. Fertilizer dose may vary according to the soil fertility and status. A report indicated that application of 18 kg N $ha^{-1}$ and 46 kg $P_2O_5ha^{-1}$ will give better yield [4].

Soybean is one of the important intercrop suitable for sugarcane. This is mainly due to the fact that soybean has adapted well to the climatic conditions of the sugarcane producing areas and has the greatest potential to fix nitrogen. Nitrogen fixation in soybean is ranging from 32 to 161 18 kg N $ha^{-1}$ [3]. Thus, intercropping soybean with sugarcane can provide an equivalent benefit as application of recommended fertilizer rate in sugarcane crop. Since N fertilizer is a substantial cost component of sugarcane system, the use of soybean as intercropping plays a considerable role in optimizing the benefit to be obtained from the sugar sector.

Soybean could also be used as rotation or fallow crop. Yield increases in yield of 20-30% are reported when sugarcane monoculture is broken with soybean [5]. This is because of the use of soybean as a break crop has a potential for N recapitalization and improvement of organic matter. Research conducted in several countries showed the soybean break crop had the potential to reduce N fertilizer needed by

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100 kg ha$^{-1}$ when ploughed under. Sugarcane growers can reduce N fertilizer requirements to the subsequent sugarcane crop when soybean is used as a fallow crop. A study conducted in Zimbabwe showed that sugarcane growers can save N fertilizer by using soybean crop and the N saved was estimated to be 80 kg ha$^{-1}$ [2]. Adding N fertilizer to soybeans usually decreases nodulation and results in smaller amounts of N being symbiotically fixed. Therefore, Nitrogen is recommended only when adequate nodulation is not achieved. However, supplemental N should not be applied within 30 days of emergence but should be applied before flowering, which is usually early March to spring crop and late July to autumn crop depending on maturity group of a variety.

Sugarcane in Ethiopia is cultivated with row spacing of 1.45 m and the growth rate of sugarcane during its initial stages (90-100 days) is rather slow with leafy canopy providing sufficient uncovered area of intercropping. Hence, it is possible to exploit the three valuable natural resources (radiant energy, soil and space) by growing intercrops. Intercropping, in sugarcane with short duration crops, is agronomically advantageous and could provide additional revenue and employment. In commercial cane fields of Tendaho Sugar Factory, one of the difficulties of intercropping was since manual harvesting is slightly costly. This will reduce the benefit obtained in terms of N reduction from nutrient recycling. Even if the benefit from fertilizer reduction cannot be realized in commercial fields there is anticipation of obtaining additional benefit from soybean grain yield. With this respect to realize the possible benefits obtained from soybean-sugarcane intercropping, the experiment was initiated with the objective to determine economic rate of N and P for soybean-sugarcane intercropping.

## Materials and Methods

Tendaho Sugar Factory is located in Afar regional state of Ethiopia at about 600 km North East of the capital city, Addis Ababa. The area is characterized with acidic climatic condition with mean maximum temperature of 40 °C and minimum temperature varying from 15°C to 24.9°C [6]. Mean annual rainfall of the area is about 200 mm with major rainfall occurring during the months of July and August. Soils of the area are known to be developed from lacustrine old alluvium and colluvium deposits. The study was conducted on clay textured soil.

The experiment was initiated during the crop season 2011/12 and completed in 2013. The experiment was laid out in randomized complete block design (RCBD) with three replications. The experiment included nine treatments (Table 1). The experimental size was 87 m$^2$ (6 furrows each with 1.45 m width and 10 m length). The test varieties were Williams and B52-298 for soybean and sugarcane crop, respectively. Phosphorus fertilizer was applied at planting while nitrogen fertilizer was applied at 2.5 months of cane age.

Representative soil data were collected and analyzed for particle size distribution, pH (1:2.5), EC (1:2.5), total N, available P, organic carbon, and $CaCO_3$. Data on germination, plant population and yield were collected for soybean. Stalk number count was done at 8 months of sugarcane cane age. At harvest, at the cane age of 14 months, 12 millable stalks were sampled from the middle four furrows and the following parameters were measured: stalk length, stalk girth, stalk weight and estimated recoverable sucrose (ERS). Cane yield was calculated from stalk weight and stalk number while sugar yield were calculated from cane yield and ERS. Furthermore, juice quality parameters such as brix, pol, and purity were taken.

### The percent soluble solids (brix %)

It is the percentage by mass of dissolved solids in the solution determined by temperature corrected refractometer [7]. The brix of the mixed juice was determined according to ICUMSA method.

### Percent pol (pol %)

Itis the apparent sucrose content of sugarcane expressed as a percentage by mass and determined by a direct polarization method [7]. The pol of the mixed juice was determined according to ICUMSA method. Pol (%) = Saccharometer reading x Pol factor [8].

### Juice purity

It is the percentage ratio of pol to the total soluble solids (or brix) in a sugar product [7]. The purity of a juice sample was determined by the percentage ratio of pol in juice to brix in juice [9].

### Estimated Recoverable Sucrose (ERS)

Itrefers to the estimated total recoverable sucrose percent in the cane or the proportion of sucrose produced by weight of cane processed [7].

### The land equivalent ratio (LER)

The land equivalent ration (LER) is the sum of the fractions of the intercropped yields divided by the sole-crop yield. A LER value equal to 1 indicates no difference in yield between the intercrop and collection of monocultures, and any value greater than 1.0 indicates a yield advantage for the intercrop. The land equivalent ratio (LER) was estimated through the following relationship [6]:

$$LER = \frac{Yij}{Yii} + \frac{Yji}{Yii}$$

Where:

Yij = Yield of sugarcane under intercropping conditions

Yji = Yield of soybean under intercropping conditions

Yii = Yield of sugarcane under sole crop conditions

| Treatment | Soybean component | Sugarcane component |
|---|---|---|
| T1 | 0 | 0 |
| T2 | 18 kg N ha$^{-1}$ & 46 kg $P_2O_5$ ha$^{-1}$ at planting | 74 kg N ha$^{-1}$ at 2.5 months |
| T3 | 0 | 92 kg N ha$^{-1}$ at 2.5 months |
| T4 | 18 kg N ha$^{-1}$ & 46 kg $P_2O_5$ ha$^{-1}$ at planting | 0 |
| T5 | 18 kg N ha$^{-1}$ & 46 kg $P_2O_5$ ha$^{-1}$ at planting | 92 kg N ha$^{-1}$ at 2.5 months |
| T6 | Sole soybean without fertilizer | - |
| T7 | Sole soybean fertilized with 18 kg N ha$^{-1}$ & 46 kg $P_2O_5$ ha$^{-1}$ at planting | - |
| T8 (Control) | - | Sole sugarcane without fertilizer |
| T9 | - | Sole sugarcane fertilized with 92 kg N ha$^{-1}$ at 2.5 months |

**Table 1:** Treatment combinations for soybean-sugarcane intercropping.

Yjj = Yield of soybean under sole crop conditions

### Statistical analysis

Statistical analysis of the variance was performed for the collected data using SAS software [10]; mean separation for significant treatments was executed by Duncan Multiple Range Test using the same software.

### Partial budget analysis

A partial budget analysis was carried out by considering the following assumptions and cost components: experimental sugar yield was adjusted down by 15% to reflect actual sugar yield at commercial level. Price of Urea, \$600 USD ton$^{-1}$; price of DAP, \$700 USD ton$^{-1}$, haulage cost, \$12.5 USD ton$^{-1}$ of sugar;processing cost, \$58 USD ton$^{-1}$ of sugar; production cost of sugar, \$206.5 USD ton$^{-1}$; selling price of sugar, \$536 USD ton$^{-1}$. Partial budget analysis was used to compare treatments. For partial budget analysis, factors with significant effects were considered [11]. Finally, net benefit cost ratio (NBCR) was computed using the appropriate relationships [12].

| Physicochemical characteristics | 0-30cm | 30-60cm | Rating[1] |
|---|---|---|---|
| Sand (%) | 10 | 13 | - |
| Silt (%) | 33 | 34 | - |
| Clay (%) | 57 | 53 | - |
| Textural class | Clay | Clay | - |
| pH | 8.82 | 8.74 | Very high |
| ECe (dS/m)[2] | 1.72 | 2.97 | None saline |
| Total N (%) | 0.06 | 0.05 | Very low |
| Available P (ppm) | 2.95 | 1.68 | Very low |
| OM (%) | 1.04 | 0.74 | Very low |
| $CaCO_3$ (%) | 7.78 | 7.60 | Medium high |

[1] [15]; [2] EC at 1:2.5 soil to water ratio was changed to ECe [16]

**Table 2:** Major physicochemical characteristics of the study site.

| Treatments | Germination (%) | Plant population ( '000 ha$^{-1}$) | Soybean yield (qt ha$^{-1}$) |
|---|---|---|---|
| T1 | 62.89ab | 41.07a | 4.37ab |
| T2 | 72.17a | 44.75a | 5.78a |
| T3 | 66.39ab | 38.89a | 5.63a |
| T4 | 66.11ab | 41.95a | 5.12a |
| T5 | 56.83bc | 36.74a | 3.77ab |
| T6 | 46.50c | 24.29b | 2.27b |
| T7 | 48.67c | 24.17b | 3.30ab |
| Sig | ** | ** | ** |
| CV | 9.35 | 14.77 | 24.89 |

**Table 3:** Effect of N and P on germination, plant population, and soybean yield.

## Results and Discussion

### Soils of the study area

Analytical results of soil samples indicated that soil of the study site was clay in texture with high pH values at the surface and subsurface layers (Table 2). Moreover, the analytical results indicated that soil samples were low in organic carbon, total nitrogen and phosphorous contents indicating the need for application of N and P fertilizers.

### Germination percentage, plant population and soybean yield

Analysis of the variance indicated that germination percentage, plant population and yield of soybean were highly significant ($p<0.01$) among treatments. Germination percentage and soybean yield were the lowest when sole soybean fertilized with neither N nor P while it was the highest for the intercrop fertilized with 18 kg N ha$^{-1}$ and 46 kg $P_2O_5$ha$^{-1}$ at planting and 74 kg N ha$^{-1}$ at 2.5 months. Plant population was the lowest when sole soybean fertilized with 18 kg N ha$^{-1}$ and 46 kg $P_2O_5$ha$^{-1}$ at planting while it was the highest for the intercrop fertilized with 18 kg N ha$^{-1}$ and 46 kg $P_2O_5$ ha$^{-1}$ at planting and 74 kg N ha$^{-1}$ (Table 3). In this study, germination percentage and plant population had contributed remarkable differences for yield of soybean.

The response to the applied fertilizer was not consistent; this is in agreement with a study conducted in North Dakota in which soybean response to fertilizer had varied considerably to applied commercial fertilizer such as nitrogen and phosphorus; however, it is recommended to build phosphorus levels by adding 34 kg $P_2O_5$ ha$^{-1}$on soils prior to soybean planting. Fields those have no prior history may benefit from additional N fertilizer if the soil test shows less than 67.2 kg N ha$^{-1}$available in the top 60 cm at planting time. High nitrogen fertility circumvents the benefits of rhizobium bacteria as the bacteria will not convert atmospheric nitrogen when soil nitrogen is readily available to the plant. Soybean with ineffective nodules will respond to N like any other crop [13]. A report indicated that when soybean is planted it should be fertilized with 18 kg N ha$^{-1}$and 46 kg $P_2O_5$ha$^{-1}$[4]. The same report explained soybean requires substantial amount of P until it is matured and hence application of P is not a choice rather mandatory to apply at planting.

### Yield component, cane and sugar yield, ERS, and juice quality parameters of Sugarcane

Stalk number and weight, cane yield, ERS, and sugar yield were not significant. Juice quality parameters such as brix, pol, and purity were also not significant (Table 4). However, in absolute terms, stalk number was the lowest when the intercrop fertilized with only N at rate of 92 kg N ha$^{-1}$ while it was the highest when the intercrop fertilized only at rate of 18 kg N ha$^{-1}$ and 46 kg $P_2O_5$ha$^{-1}$. Stalk weight

| Treatment | Stalk number ('000 ha$^{-1}$) | Stalk Weight (kg stalk $^{-1}$) | Cane yield (t ha$^{-1}$ ) | ERS (%) | Sugar yield (t ha$^{-1}$ ) | Juice quality parameters | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Brix (%) | Pol (%) | Purity (%) |
| T1 | 63.38 | 1.13 | 71.78 | 9.21 | 6.21 | 18.74 | 14.94 | 79.64 |
| T2 | 64.94 | 1.42 | 92.00 | 9.17 | 8.32 | 18.23 | 14.70 | 80.53 |
| T3 | 51.90 | 1.85 | 95.89 | 7.57 | 7.30 | 19.01 | 13.35 | 74.24 |
| T4 | 84.57 | 1.34 | 113.05 | 7.83 | 8.85 | 17.77 | 13.46 | 75.83 |
| T5 | 73.51 | 1.44 | 105.88 | 6.98 | 7.39 | 18.13 | 12.94 | 71.41 |
| T8 | 81.03 | 1.25 | 101.05 | 8.38 | 8.52 | 18.76 | 14.29 | 76.43 |
| T9 | 73.28 | 1.27 | 93.06 | 7.65 | 7.57 | 18.74 | 13.71 | 73.09 |
| Sig | NS | NS | NS | NS | NS | NS | NS | NS |
| CV | 29.53 | 19.87 | 19.41 | 17.05 | 30.20 | 8.78 | 13.06 | 9.39 |

**Table 4:** Effect of N and P on yield components, cane and sugar yield, ERS and juice quality parameters of sugarcane.

| Treatment | Net Return, $USD | Gross Benefit Cost Ratio | Net Benefit Cost Ratio | Land Equivalent ratio |
|---|---|---|---|---|
| T1 | 1139.31 | 1.60 | 0.60 | 2.65 |
| T2 | 1865.57 | 1.84 | 0.84 | 3.52 |
| T3 | 1502.32 | 1.71 | 0.71 | 3.34 |
| T4 | 2144.69 | 2.00 | 1.00 | 3.29 |
| T5 | 740.79 | 1.36 | 0.36 | 2.53 |
| T6 | 93.18 | 5.59 | 4.59 | 1.00 |
| T7 | 65.47 | 1.66 | 0.66 | 1.45 |
| T8 | 1873.94 | 1.93 | 0.93 | 1.00 |
| T9 | 1378.04 | 1.67 | 0.67 | 0.89 |

**Table 5:** Partial budget analysis and land equivalent ratio (LER) for Soybean-Sugarcane Intercropping.

was the lowest when both crops were not fertilized, but the highest was found to be the intercrop fertilized with nitrogen at rate of 92 kg N $ha^{-1}$. Stalk number and weight contributed for cane yield differences even if these yield attributes were not statistically significant. Surprisingly, unfertilized plots gave highest estimated recoverable sucrose than others treatments. Nevertheless, it had the lowest cane weight consequently lowest cane and sugar yields. Sugar yield was highest when the intercrop fertilized with 18 kg N $ha^{-1}$ and 46 kg $P_2O_5$ $ha^{-1}$. Juice quality parameters including brix, pol, and purity were not significantly differed among treatments.

## Land Equivalent Ratio (LER)

The land equivalent ratio (LER) ranged from 0.89 to 3.52; similar study conducted in Guangzhou, China, [14] stated that LER of sugarcane-soybean intercropping at different N application levels ranged from 1.36 to 2.12 suggesting that sugarcane-soybean intercropping had higher LER than monoculture sugarcane. In this study, LER was the highest, 3.52, when the intercrop received 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$at planting and 74 kg N $ha^{-1}$at 2.5 months of cane age. However, the highest net return and net benefit cost ratio were found as the intercrop fertilized with 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$ at planting. The lowest LER, 0.89, was found for sole sugarcane fertilized with 92 kg N $ha^{-1}$ (Table 5).

## Partial budget analysis

Net benefit cost ratio (NBCR) under sugarcane-soybean intercropping ranged from 0.36 to 4.59. It was the highest when sole soybean fertilized neither N nor P; the lowest was obtained as the intercrop fertilized with 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$at planting and 92 kg N $ha^{-1}$at 2.5 months. Other reports stated at higher nitrogen application level, there had been the lowest economic benefit suggesting that the increase of the economic benefit under reduced nitrogen application [14]. Thus, the intercrop fertilized with only 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$at planting (T4) gave the 2nd highest net benefit ratio that was 1.00 (Table 5). For this rate, profit could be maximized by 14.45%over the control.

## Conclusion

Soil of the study site was clay in texture with high pH values at the surface and subsurface layers. Moreover, the analytical results indicated that soil was low in organic carbon, total nitrogen and available phosphorous. Such low levels of these essential nutrients, N and P, are indicating the need for application of N and P fertilizers. Analysis of variance for soybean showed that germination percentage, plant population and yield of soybean were highly significant ($p<0.01$) among treatments. Germination percentage and plant population had contributed remarkable differences for yield of soybean. Stalk number and weight, cane yield, ERS, and sugar yield were not significant. Juice quality parameters such as brix, pol, and purity were also not significant. Land Equivalent Ratio (LER) was the highest, 3.52, when the intercrop received 18 kg N $ha^{-1}$ and 46 kg $P_2O_5ha^{-1}$ at planting and 74 kg N $ha^{-1}$ at 2.5 months of cane age. However, the 1st highest net return and the 2nd highest net benefit cost ratio (NBCR) were found as the intercrop fertilized with 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$at planting (T4). In addition, due to adoption of intercropping practice, profit could be maximized by 14.45% over the control (T8) and about 50% of fertilizer cost can be reduced. Therefore, T4, fertilizing the intercrop at rate of 18 kg N $ha^{-1}$and 46 kg $P_2O_5ha^{-1}$at planting was found to be the promising treatment to be recommended to Tendaho Sugar Factory.

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