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Research Article

# Incorporation of Soybean Biomass that was treated by *Bradyrhizobium* and Phosphorus in Soil Improved Sugarcane Yield and Juice Attributes under Intercropping System

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## ABSTRACT

This study was initiated to investigate the effect of intercropped soybean biomass incorporation on sugar yield at Metahara Sugar Estate. The treatment consisted of combined application of four P rates and three levels of inoculation and was laid out in randomized complete block design and replicated three times. Results showed that incorporation soybean biomass treated with P and Bradyrhizobium increased the OM and available P. Sole sugarcane produced higher millable stalk when compared than sugarcane planted in intercropping. However, sole sugarcane produced inferior stalk diameter and juice purity. It was also found that significantly higher cane and sugar yields were recorded in plots amended with soybean biomass and sole sugarcane cultivation. Intercropping improved land equivalent ratio and net return compared with the sole cropping of soybean/sugarcane. Hence, these results recommend that soybean-sugarcane intercropping and the need of inoculation and P application to increase the profitability of the suggested cropping system.

**Keywords:** *Bradyrhizobium*; Metahara sugar estate; Soybean biomass; Sugarcane

## INTRODUCTION

Intercropping is practiced traditionally in many parts of the world particularly widely spread in sub-Saharan Africa [1,2]. Intercropping of legumes with industrial crop like sugarcane is getting big attention, since this cropping system maintain the soil N, protect the soil from erosion and enhance soil organic matter [3,4]. During cultivating sugarcane, a juvenile period of $100^{-1}10$ days can produce other food crops such as legume plants in the wider inter-row spaces ($120^{-1}45$ cm) for the better utilization of soil resources, solar energy and the moisture. Hence, short duration and high value crop cultivation in sugarcane based cropping systems may have great potential in increasing the land utilization, increase water utilization efficiency, reduction in cost of production, and making sugarcane production more sustainable. Soybean could be one of the important intercrops suitable for sugarcane [5].

In other countries such as China, sugarcane-soybean intercropping could increase the land productivity (LERs) advantage over sole cultivation of sugarcane [6]. Other report found that sugarcane yield increased when sugarcane intercropped with soybean [7]. In contrast to such promising results in soybean-sugarcane intercropping, sugarcane yield reduction was recorded in South Africa when intercropped with the same legume species [8]. In Ethiopia, one side ridge planting of sugarcane-soybean intercrop gave a higher net return compared to the sole sugarcane cropping [9]. Better net return from such intercropping system could be obtained when 18 kg N and 46 kg $P_2O_5$ $ha^{-1}$ has been applied in this cropping system [10].

Soybean has a great potential of $N_2$ fixation which can fix $N_2$ from atmosphere approximately 300 kg N $ha^{-1}$ when grown with sugarcane and can obtain up to 80% of its total N demand from BNF [11,12]. This fixed N may also improve the soil N and thus benefit associated cereal crops as well as subsequent crops during crop rotation [13,14]. Study in Ethiopia found that inoculation of *Bradyrhizobium* significantly increased the yield and nodulation of soybean in alkaline and soil devoid of rhizobia nodulating soybean [15]. However, the effect of *Bradyrhizobium* inoculation and P application in sugarcane-soybean intercropping and thereby incorporation of soybean biomass on sugarcane yield and juice qualities was not evaluated. We hypothesized that by well-

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nourished the intercropped soybean may reduce its antagonistic effect on the main crop, in this case sugarcane. Hence, this study was initiated to determine the effect of P application and *Bradyrhizobium* inoculations treated soybean residue incorporation on sugar yield and yield traits of sugarcane.

## MATERIALS AND METHODS

### Description of the study area

Metahara Sugar Factory is situated at 8°53' N latitude and 39°52' E longitude at an altitude of 950 meters above sea level. The area has a semi-arid climatic condition with long term annual mean rainfall of 551 mm with the long term mean annual maximum and minimum air temperatures of 33°C and 17.5°C, respectively. Most soils of the experimental site are comparatively of recent alluvial origin and are classified as Cambisols. The soils have high clay content and show shiny ped faces and thus are Hypovertic and Haplic Cambisols according to Booker Tate Limited.

### Experimental design and treatments procedure

The experiments consisted of sugarcane-soybean intercropping in which the soybean had been treated with four rates of P (0, 23, 46 and 69 kg $P_2O_5$ $ha^{-1}$) in the form of triple super phosphate (TSP) (0:46:0%; N: $P_2O_5$:$K_2O$) and three levels of *Bradyrhizobium* inoculation, viz. SB6B1 (local isolate), legume fix (UK isolate) and uninoculated control. Beside this, the experiment comprised the sole cultivation of soybean and sugarcane for land equivalent ratio (LER) calculation (detail description of the treatments are depicted in Table 1). Nitrogen fertilizer in the form of urea was applied as starter dose at the rate of 20 kg N $ha^{-1}$. The experiment was laid out in randomized complete block design with three replications. Soybean residue was added to their respective plots and plowed down at molding except for conventional intercropping practices where soybean was not treated with either *Bradyrhizobium* or P application and its respective soybean biomass was not incorporated but sugarcane received full recommended N dose.

Land preparation was done according to the estate practice and then divided into blocks and plots. Sugarcane was planted on November 21st 2015 and soybean was sown one day later. Sugarcane was planted in the furrow trench with end to end sett position and 145 cm row spacing. Soybean seed was also sown at one side of the ridge with the spacing of 10 cm between plants and similar row spacing as sugarcane having 6 rows and 5.0 m length with 43.5 m2 gross plot size, but data were collected from four central rows. There was a 1 m space between each plot and two furrow (2.90 m) path between blocks.

### Data collection

The major sugarcane yield and yield components were collected following the data collection standard procedure. The collected agronomic data comprise tiller number, number of millable cane, cane length, cane diameter, cane yield, estimated recoverable sucrose (ERS), sugar yield, and juice quality attributes such as, Pol%, °Brix and juice purity. Percent stalk recovery and/or tiller mortality was also computed. The productivity of sugarcane-soybean intercropping was assessed using land equivalent ratio (LER) which was calculated as:

$$LER = \left[\frac{\text{Sugar yield of sugarcane in intercrop}\left(\frac{kg}{ha}\right)}{\text{Sugaryield of sugarcane in sole}\left(\frac{kg}{ha}\right)}\right] + \left[\frac{\text{Grainyield of soybean in intercrop}\left(\frac{kg}{ha}\right)}{\text{Grainyield of soyabean in sote}\left(\frac{kg}{ha}\right)}\right]$$

### Cost benefit and statistical analysis

Cost benefit analysis was computed by considering the current price of mineral and bio-fertilizers, application cost of soybean biomass and other production costs from land preparation to sugar bagging. Therefore, the total costs for cane haulage and sugar processing was 95.9 USD $t^{1}$, cost of fertilizers was 433.8 USD $t^{1}$ for Urea, 506.1 $t^{1}$ for DAP, 5.8 USD $ha^{-1}$ for bio-fertilizer and 6.9 USD $ha^{-1}$ for fertilizer and residue application. The prevailing market price of sugar and soybean grain has been 650.7 USD $t^{1}$ and 304.1 USD $t^{1}$, respectively (Exchange rate (1 USD=27.663 ETB). The experimental sugar and soybean yield was adjusted down by 15% to reflect the commercial yield.

Data were subjected to analysis of variance using Gen Stat Software [16]. Comparison among treatment means with significant difference was done using Least Significant Difference (LSD) at 5% level of significance.

**Table 1:** Details of treatment combination.

| | Treatment Combination |
|---|---|
| $T_1$ | Full recommended N fertilizer |
| $T_2$ | Incorporated soybean biomass treated local isolate + 50% recommended N fertilizer |
| $T_3$ | Incorporated soybean biomass treated UK isolate + 50% recommended N fertilizer |
| $T_4$ | Incorporated soybean biomass treated 23 kg $P_2O_5$ $ha^{-1}$+ 50% recommended N fertilizer |
| $T_5$ | Incorporated soybean biomass treated 23 kg $P_2O_5$ $ha^{-1}$ & Local isolate + 50% recommended N fertilizer |
| $T_6$ | Incorporated soybean biomass treated 23 kg $P_2O_5$ $ha^{-1}$ & UK isolate + 50% recommended N fertilizer |
| $T_7$ | Incorporated soybean biomass treated 46 kg $P_2O_5$ $ha^{-1}$+ 50% recommended N fertilizer |
| $T_8$ | Incorporated soybean biomass treated 46 kg $P_2O_5$ $ha^{-1}$ & Local isolate + 50% recommended N fertilizer |
| $T_9$ | Incorporated soybean biomass treated 46 kg $P_2O_5$ $ha^{-1}$ & UK isolate + 50% recommended N fertilizer |
| $T_{10}$ | Incorporated soybean biomass treated 69 kg $P_2O_5$ $ha^{-1}$+ 50% recommended N fertilizer |
| $T_{11}$ | Incorporated soybean biomass treated 69 kg $P_2O_5$ $ha^{-1}$ & Local isolate + 50% recommended N fertilizer |
| $T_{12}$ | Incorporated soybean biomass treated 69 kg $P_2O_5$ $ha^{-1}$ & UK isolate + 50% N recommended fertilizer |
| $T_{13}$ | Sole Sugarcane + full recommended N fertilizer |
| $T_{14}$ | Sole Soybean + 46 kg $P_2O_5$ $ha^{-1}$ |

**Table 2:** Selected soil physicochemical properties of the experimental site at planting and harvesting.

| Treatment | pH | ECe | OC | Avail. P | TN | Exchangeable Bases | | | | CEC | Texture | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Na⁺ | K⁺ | $Ca^{2+}$ | $Mg^{2+}$ | | Sand | Clay | Silt |
| | (1:2.5) | ($dSm^{-1}$) | (%) | (ppm) | (%) | (Cmol (+) $kg^{-1}$) | | | | | (%) | | |
| | Composite soil sample at planting (soil depth 0-30 cm) | | | | | | | | | | | | |
| | 7.7 | 1.5 | 1.8 | 5.6 | 0.12 | 1.9 | 3.3 | 49 | 11 | 67 | 12 | 70 | 18 |
| $T_1$ | 7.5 | 1.5 | 1.8 | 6.2 | 0.09 | 1.3 | 3.1 | 49.3 | 6.7 | 62.3 | 21.2 | 60 | 18.8 |
| $T_2$ | 7.6 | 1.4 | 2.2 | 5.6 | 0.11 | 1.4 | 4.5 | 51.5 | 8.4 | 66.2 | 17.2 | 60 | 22.8 |
| $T_3$ | 7.6 | 1.3 | 2.2 | 5.8 | 0.12 | 2 | 4.6 | 48.7 | 7.3 | 64.2 | 23.2 | 56 | 20.8 |
| $T_4$ | 7.7 | 1.3 | 1.9 | 8.8 | 0.11 | 1.6 | 4.5 | 49.3 | 10.1 | 68.1 | 17.2 | 60 | 22.8 |
| $T_5$ | 7.7 | 1.5 | 1.9 | 7.5 | 0.11 | 1.6 | 4.6 | 48.7 | 10.4 | 66.2 | 26.6 | 54 | 19.4 |
| $T_6$ | 7.6 | 1.5 | 2 | 7.8 | 0.13 | 1.7 | 5 | 44.2 | 14 | 68.1 | 16.6 | 62 | 21.4 |
| $T_7$ | 7.6 | 1.4 | 2.1 | 8.5 | 0.12 | 1.5 | 4.3 | 50.4 | 5.6 | 62.3 | 18.6 | 60 | 21.4 |
| $T_8$ | 7.7 | 1.5 | 1.9 | 7.7 | 0.1 | 1.6 | 4.3 | 50.1 | 9 | 66.2 | 8.6 | 66 | 25.4 |
| $T_9$ | 7.7 | 1.4 | 1.9 | 7.5 | 0.11 | 1.3 | 4.8 | 49.6 | 9.8 | 68.1 | 14 | 62.8 | 23.2 |
| $T_{10}$ | 7.7 | 1.5 | 1.4 | 7.2 | 0.12 | 1.4 | 5.2 | 50.1 | 9.5 | 68.1 | 12 | 64.8 | 23.2 |
| $T_{11}$ | 7.7 | 1.4 | 1.9 | 6.1 | 0.11 | 1.4 | 4.6 | 46.2 | 9.5 | 62.3 | 16 | 64.8 | 19.2 |
| $T_{12}$ | 7.7 | 1.3 | 2 | 6.8 | 0.11 | 1.7 | 5.2 | 46.5 | 9.5 | 64.2 | 16 | 62.8 | 21.2 |
| $T_{13}$ | 7.7 | 1.3 | 1.9 | 6.4 | 0.11 | 1.3 | 6.4 | 47.9 | 9.2 | 66.2 | 6 | 68.8 | 25.2 |
| $T_{14}$ | 7.7 | 1.4 | 1.8 | 7.7 | 0.11 | 1.3 | 5.5 | 48.7 | 7.3 | 64.2 | 12 | 60.8 | 27.2 |

## RESULTS AND DISCUSSION

### Selected soil physicochemical properties before and after the experiment

Results in Table 2 show that the soil of the experimental site is moderately alkaline in reaction and non-saline non sodic and mainly dominated by clay texture. The soil organic carbon at planting and at sugarcane harvesting was found within the medium range whereas total N was rated as in the low except T6 in which it was moderate at sugarcane harvesting according to Tekalign [17]. At this time, soil organic carbon of the study site was improved by 2.2 to 21.6% for the plots that was amended with soybean biomass as compared to soil organic carbon at planting as well as conventional intercropping (soybean-sugarcane intercropping but the soybean biomass was not incorporated). However, incorporated the soybean biomass that had treated with 69 kg $P_2O_5$ $ha^{-1}$ and 50% of recommended N fertilizer decreased the soil organic carbon by 21%. Unlike SOC, soil total N was depleted regardless the intercropped soybean was treated when compared with total Nat planting. When compared with conventional intercropping, soil amended with soybean biomass that was treated with *Bradyrhizobium* inoculation and P improved soil N content from 11.1 to 44.4%. This might be attributed to the mineralization of N rich soybean biomass, including roots and nodules.

The soil analysis result further revealed that the soil had low available Pat both planting and at harvesting. However, the results found an increase in available P as a result of amending the soil with soybean biomass that had treated with *Bradyrhizobium* and P compared with the conventional intercropping. In this case, the soil available P increased by 3.6 to 55.2% at sugarcane harvesting over the soil available P at planting. The CEC of the soil was rated as very high according to Landon with the dominant cation in the exchange site was calcium followed by magnesium [18]. It was also found that soils amended with soybean biomass that had treated with *Bradyrhizobium* and P improved the soil fertility status such as CEC, exchangeable K and Mg by 3.1-9.3%, 38.7-106% and 8.9-109% over those determined from the conventional intercropping.

### Effect on cane yield and yield attributes of sugarcane

The analysis of variance showed that soybean biomass that had treated with *Bradyrhizobium* inoculation and P application rates did not significantly ($P<0.05$) affect sugarcane sprouting at 30 days after planting (DAP). However, it was significantly ($P<0.001$) influenced the tiller number of sugarcane when soybean was harvested (Table 3). The soil amendment did not improve the tiller number, rather the highest tiller number was found in sole sugarcane planting (309770) which was exceeded over the other treatments by 302-415%. This result coincides with the result of Tsado et al. who found a non-significant effect of P fertilizer up to 150 kg P $ha^{-1}$ on sugarcane sprouting [19]. This could be due to the fact that sugarcane sprouting is rarely affected by soil nutrients as it could use its stored nutrients in the setts, but it could be severely affected by soil moisture and temperature [20]. Reduction of tiller number in intercropping system in the present study could be related the negative influence of shading soybean on the intercropped sugarcane through reducing photosynthetic activity in sugarcane. Most growers consider profuse tillering as an assurance for the final cane yield, however, due to intra-competition, 50-80% of the tillers become lost in sole cultivation of sugarcane [21,22].

Results show that in plots that was amended with soybean biomass that had treated with *Bradyrhizobium* and P did not significantly ($P<0.05$) influence cane length and single cane weight but it was significantly ($P<0.01$) influenced cane diameter. In general, plots that were amended with soybean biomass produced significantly the highest cane diameter. This variation might be attributed to lower number of millable cane in the sugarcane when intercropped with soybean, which endowed less competition for resources among canes after soybean had harvested and thereby rendered better cane diameter.

The soil amended with soybean biomass that had treated with

**Table 3:** Effect of *Bradyrhizobium* inoculation and P rates treated soybean biomass incorporation on cane yield and yield attributes.

| Treatment | Sprouting (%) | Tiller number | Cane diameter (cm) | Cane length (m) | Single cane weight (kg) | Number of millable cane | Cane yield t $ha^{-1}$ |
|---|---|---|---|---|---|---|---|
| $T_1$ | 69.9 | 66209$^{b}$ | 3.0$^{ab}$ | 1.9 | 1.4 | 100115$^{c}$ | 137.451$^{ab}$ |
| $T_2$ | 70 | 61930$^{b}$ | 3.0$^{ab}$ | 1.8 | 1.3 | 102874$^{c}$ | 136.166$^{ab}$ |
| $T_3$ | 71.9 | 77013$^{b}$ | 2.9$^{bc}$ | 1.7 | 1.2 | 104138$^{c}$ | 131.996$^{ab}$ |
| $T_4$ | 73 | 72300$^{b}$ | 2.9$^{ab}$ | 2.1 | 1.3 | 105977$^{bc}$ | 143.130$^{a}$ |
| $T_5$ | 72.1 | 60195$^{b}$ | 3.1$^{ab}$ | 1.9 | 1.5 | 102414$^{c}$ | 148.090$^{a}$ |
| $T_6$ | 70.6 | 75287$^{b}$ | 3.0$^{ab}$ | 1.7 | 1.2 | 100879$^{c}$ | 120.750$^{b}$ |
| $T_7$ | 69.3 | 61593$^{b}$ | 3.0$^{ab}$ | 1.9 | 1.4 | 100394$^{c}$ | 135.061$^{ab}$ |
| $T_8$ | 70.8 | 68490$^{b}$ | 3.0$^{ab}$ | 1.7 | 1.2 | 101149$^{c}$ | 120.834$^{b}$ |
| $T_9$ | 68.7 | 68353$^{b}$ | 3.0$^{ab}$ | 1.9 | 1.4 | 104138$^{c}$ | 144.424$^{a}$ |
| $T_{10}$ | 69.5 | 68093$^{b}$ | 2.9$^{bc}$ | 1.8 | 1.3 | 100920$^{c}$ | 132.487$^{ab}$ |
| $T_{11}$ | 74.9 | 69543$^{b}$ | 3.0$^{ab}$ | 1.8 | 1.2 | 103563$^{c}$ | 141.503$^{a}$ |
| $T_{12}$ | 71.9 | 70807$^{b}$ | 2.9$^{ab}$ | 1.8 | 1.4 | 111954$^{b}$ | 147.375$^{a}$ |
| $T_{13}$ | 73.6 | 309770$^{a}$ | 2.7$^{d}$ | 1.9 | 1.2 | 127471$^{a}$ | 144.264$^{a}$ |
| LSD (5%) | ns | 26330.2 | 0.14 | ns | ns | 7131 | 17.5934 |
| CV (%) | 5.8 | 18 | 2.8 | 13.5 | 10.8 | 4 | 7.6 |
| P-Value | 0.812 | <.001 | <0.001 | 0.803 | 0.217 | <.001 | 0.046 |

[a,b,c,d] The super-scripted letters are statistically significant.

**Table 4:** Effect of *Bradyrhizobium* inoculation and P rates treated soybean residue incorporation on sugar yield and juice qualities.

| Treatment | Estimated recoverable sucrose (%) | Sugar yield (t $ha^{-1}$) | Pol % | °Brix | Juice purity (%) |
|---|---|---|---|---|---|
| $T_1$ | 11.41 | 15.693$^{a-e}$ | 16.66 | 19.01 | 87.60$^{abc}$ |
| $T_2$ | 11.73 | 16.480$^{abc}$ | 16.99 | 19.19 | 88.49$^{ab}$ |
| $T_3$ | 11.22 | 14.795$^{cde}$ | 16.39 | 18.72 | 87.52$^{abc}$ |
| $T_4$ | 11.41 | 17.678$^{ab}$ | 16.67 | 18.05 | 87.40$^{bc}$ |
| $T_5$ | 11.56 | 17.129$^{ab}$ | 16.66 | 18.72 | 89.04$^{ab}$ |
| $T_6$ | 11.36 | 13.740$^{e}$ | 16.62 | 19.05 | 87.25$^{bc}$ |
| $T_7$ | 12.49 | 16.869$^{abc}$ | 17.94 | 20.05 | 89.45$^{a}$ |
| $T_8$ | 11.85 | 14.305$^{de}$ | 17.09 | 19.21 | 88.96$^{ab}$ |
| $T_9$ | 11.3 | 15.775$^{a-e}$ | 16.45 | 19.05 | 87.86$^{ab}$ |
| $T_{10}$ | 11.82 | 15.638$^{b-e}$ | 17.08 | 19.26 | 88.70$^{ab}$ |
| $T_{11}$ | 11.97 | 17.752$^{a}$ | 17.3 | 19.49 | 88.72$^{ab}$ |
| $T_{12}$ | 11.35 | 16.747$^{abc}$ | 16.59 | 18.97 | 87.43$^{bc}$ |
| $T_{13}$ | 10.96 | 15.864$^{a-d}$ | 16.25 | 18.94 | 85.81$^{c}$ |
| LSD (5%) | 0.94 | 2.1061 | 1.17 | 1.172 | 1.939 |
| CV (%) | 4.8 | 7.8 | 4.1 | 3.6 | 1.3 |
| P-Value | 0.187 | 0.012 | 0.287 | 0.278 | 0.046 |

[a,b,c,d] The super-scripted letters are statistically significant.

*Bradyrhizobium* inoculation and inorganic P significantly ($P<0.001$) affected number of millable cane (NMC) of the intercropped sugarcane. Significantly the highest number of millable cane per hectare (127471) was found in plot that had sole sugarcane while the least value was found from plots with conventional intercropping. In contrast to the result of the present study, Khandagave reported higher number of millable cane per hectare (87830) due to sugarcane-soybean intercropping than sugarcane cultivated solely (85910) [23].

The result from correlation analysis showed that NMS was significantly and positively related with accompanied soybean biomass yield ($P<0.01$, $r=0.53$), soybean straw N uptake ($P<0.01$, $r=0.53$) and nodule number ($P<0.05$, $r=0.33$) (Table 5). This result showed that *Bradyrhizobium* inoculation and/or P application could improve soybean $N_2$ fixation and thus may release high soil N through decomposition of the incorporated soybean residues and eventually improve number of millable cane.

It was found that soil amendment with soybean biomass significantly ($P<0.05$) influenced cane yield (Table 3). The highest mean cane yield (148.090 t $ha^{-1}$) was noted in 23 $P_2O_5$ $ha^{-1}$ + SB6B1 while the least value was recorded in plots amended with soybean biomass that had treated with 23 kg $P_2O_5$ $ha^{-1}$ and legumefix and 46 kg $P_2O_5$ $ha^{-1}$ and SB6B1. The increase in cane yield could be attributed to the increase in soil N derived from soybean biomass [24,25] by which the symbiotic $N_2$ fixation by the legumes could be enhanced through *Bradyrhizobium* and P application. Hunsigi [26] pointed out that substantial cane yield improvement was also noted due to incorporation of intercropped soybean, French-beans, sun-hemp and green gram. Moreover, the presence of residual P could also improve ratoon cane yield by 64.6% over those obtained from no P residue in the soil [27].

It was found that number of millable cane in intercropping system drastically increased after soybean biomass has been incorporated in the soil (Figure 1). The percent stalk recovery ranged from 30.1 to 73% at stalk counting stage (10 month after planting), with the lowest and the highest stalk recovery noted in plots amended with soybean biomass that had treated with 23 kg $P_2O_5$ $ha^{-1}$ + legumefix and 23 kg $P_2O_5$ $ha^{-1}$ + SB6B1, respectively. On the contrary, number of millable cane in mono-cropping of sugarcane was dramatically reduced at the same age, with the tiller mortality rate of 57.3% (Figure 1). The result the present study also found that the intercropping system could improve the recovery of tiller of sugarcane at late stage, although sugarcane-soybean intercropping imposed suppressive effect on tillering ability of sugarcane at early stage. The increase in number of millable cane in soils where soybean biomass was incorporated was suggested by Fukai and Trenbath [28]. They also pointed out that nutrients from soybean residues could gradually release and thereby this could improve the synchrony of nutrients supply by the soil and demand of the nutrients by sugarcane.

**Table 5:** Correlation analysis of sugar yield and yield attributes and juice quality with respect to the major soybean parameters.

| | ERS | °Brix | CY | CD | CL | NMC | Pol% | Purity | SY |
|---|---|---|---|---|---|---|---|---|---|
| SBY | 0.092$^{ns}$ | 0.03$^{ns}$ | -0.10$^{ns}$ | -0.18$^{ns}$ | -0.34$^{*}$ | 0.53$^{**}$ | 0.10$^{ns}$ | 0.14$^{ns}$ | 0.02$^{ns}$ |
| SNU | 0.04$^{ns}$ | -0.18$^{ns}$ | -0.03$^{ns}$ | -0.16$^{ns}$ | -0.15$^{ns}$ | 0.53$^{**}$ | 0.01$^{**}$ | 0.34$^{*}$ | 0.13$^{ns}$ |
| NPP | 0.35$^{*}$ | 0.10$^{*}$ | -0.25$^{ns}$ | -0.07$^{ns}$ | -0.35$^{*}$ | 0.33$^{*}$ | 0.30$^{*}$ | 0.19$^{ns}$ | -0.03$^{ns}$ |
| NDW | 0.14$^{ns}$ | 0.11$^{ns}$ | -0.14$^{ns}$ | -0.32$^{*}$ | -0.22$^{ns}$ | 0.45$^{*}$ | 0.14$^{ns}$ | -0.06$^{ns}$ | -0.05$^{ns}$ |
| SPU | 0.01$^{ns}$ | -0.23$^{ns}$ | 0.05$^{ns}$ | -0.01$^{ns}$ | -0.02$^{ns}$ | 0.32$^{**}$ | -0.08$^{ns}$ | 0.10$^{ns}$ | 0.06$^{ns}$ |
| TNU | 0.18$^{ns}$ | 0.06$^{ns}$ | -0.08$^{ns}$ | 0.21$^{ns}$ | -0.23$^{ns}$ | 0.43$^{*}$ | 0.17$^{ns}$ | 0.07$^{ns}$ | 0.14$^{ns}$ |
| TPU | -0.10$^{ns}$ | -0.18$^{ns}$ | 0.07$^{ns}$ | -0.06$^{ns}$ | -0.17$^{ns}$ | 0.49$^{**}$ | -0.14$^{ns}$ | 0.11$^{ns}$ | 0.19$^{ns}$ |
| SGY | 0.28$^{ns}$ | 0.20$^{ns}$ | -0.16$^{ns}$ | 0.14$^{ns}$ | -0.29$^{ns}$ | 0.35$^{*}$ | 0.25$^{ns}$ | 0.28$^{ns}$ | 0.10$^{ns}$ |

$^{ns}$: Not Significant

**Table 6:** Land equivalent ratios and benefit cost ratios.

| Treatments | Total Cost (USD) | Benefit Cost Ratio (B:C) | Net Benefit Cost Ratio NB:C | Land equivalent ratio (LER) |
|---|---|---|---|---|
| $T_1$ | 3332.9 | 2.11 | 1.11 | 1.88 |
| $T_2$ | 3316.9 | 2.24 | 1.24 | 2.51 |
| $T_3$ | 3124.5 | 2.09 | 1.09 | 2.43 |
| $T_4$ | 3296.7 | 2.26 | 1.26 | 1.88 |
| $T_5$ | 3434.1 | 2.3 | 1.3 | 2.94 |
| $T_6$ | 3177 | 2 | 1 | 2.5 |
| $T_7$ | 3491.9 | 2.18 | 1.18 | 1.84 |
| $T_8$ | 3258.6 | 2.05 | 1.05 | 2.74 |
| $T_9$ | 3401.6 | 2.16 | 1.16 | 2.73 |
| $T_{10}$ | 3332.5 | 2.06 | 1.06 | 1.71 |
| $T_{11}$ | 3352.7 | 2.33 | 1.33 | 3.16 |
| $T_{12}$ | 3401.2 | 2.22 | 1.22 | 2.73 |
| $T_{13}$ | 3292.7 | 2.07 | 1.07 | 1 |
| $T_{14}$ | - | - | - | 1 |

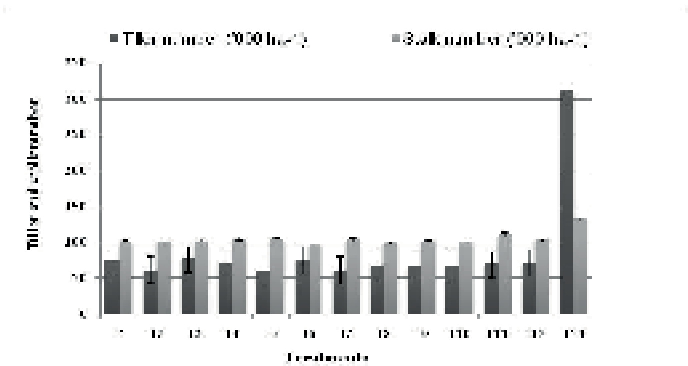

**Figure 1:** Effect of *Bradyrhizobium* and P treated soybean residue on sugarcane stalk recovery.

## Effect on sugar yield and juice qualities of sugarcane

Incorporation of soybean biomass that was amended with *Bradyrhizobium* and inorganic P had no significant (P<0.05) influence on estimated recoverable sucrose (ERS), pol % and °brix (Table 4). Albeit estimated recoverable sucrose was not significantly varied but the result found a substantial increase in ERS by incorporating of soybean biomass by the range from 3.1 to 14.0%.

On the other hand, the inferior mean value of sucrose recovery, pol% and juice purity was recorded in monoculture of sugarcane. Similar scenario was also observed in °Brix. This variation in sucrose recovery amongst the treatments could be explained by the positive influence of residual P supplied that was applied for soybean and NP from decomposition of soybean residues. This result evidently showed that incorporation of soybean biomass treated *Bradyrhizobium* inoculation and P fertilizer play a significant role in enhancing the sugarcane juice quality attributes.

In Table 5, sucrose recovery and pol% were significantly (P<0.05) correlated with nodules number that had been produced by intercropped soybean with r=0.35 and r=0.30, respectively. Pol% was also significantly but weakly correlated with intercropped soybean straw N uptake (P<0.01, r=0.01). Moreover, juice purity also significantly (P<0.05) correlated with effective nodules (r=0.43) and straw N uptake (r=0.34).

Incorporation of soybean biomass fertilized with *Bradyrhizobium* inoculation and P fertilizer significantly (P<0.05) affected sugar yield (Table 4). The highest sugar yield (17.752 t ha$^{-1}$) was recorded in plots where 69 kg $P_2O_5$ ha$^{-1}$ and SB6B1 inoculation treated soybean biomass incorporated but it was statistically at parity with the conventional intercropping and monoculture of sugarcane. The inferior sugar yield (13.740 t ha$^{-1}$) was recorded at plots that received soybean biomass fertilized with 23 kg $P_2O_5$ ha$^{-1}$ and UK isolate. The significant difference on sugar yield by incorporation of soybean biomass might be due to the various effect of incorporated soybean biomass on available P, soil organic carbon and total soil N content. In line with this fact, the positive effect of soybean biomass incorporation in soils could be due to the increase in soil N as a result of N contributed from legume residues after microbial mineralization [29]. Similar results was also noted that incorporation of soybean residue plus 30 kg N in the form of inorganic fertilizer produced higher sorghum grain yield (3.34 t ha$^{-1}$) than fallowing plus 60 kg N (3.105 t ha$^{-1}$) [30].

### Land equivalent and benefit cost ratio analysis

The land equivalent ratios (LERs) based on the monoculture of sugarcane and soybean yield provide a quantitative evaluation of the yield advantage due to intercropping. When LER> P2O51, it indicates that the intercrop is more productive than the respective sole cropping. In general, the LER that was obtained by the current experiment was varied from 1.71 to 3.16 (Table 6). These values could indicate a greater advantage in soybean based-intercropping. In general, it was found that the plots amended with soybean biomass that was produced with *Bradyrhizobium* inoculation resulted in more productive than those plots amended with uninoculated soybean biomass. Generally, plots treated with soybean biomass inoculated *Bradyrhizobium* produced higher LER by 32.7 to 72.7% over plots incorporated soybean biomass that had been uninoculated.

Based on the cost benefit analysis result, net benefit cost ratio (NB:C) was ranged between 1.0 and 1.33. The highest NB:C was obtained in plots amended with soybean biomass that was produced with SB6B1 inoculation while the lowest was found in plots amended with legume fix inoculated soybean biomass, sole sugarcane cropping and conventional intercropping. This shows current sugarcane-soybean intercropping is economically feasible as most of the treatments had the value of NB:C greater than a unit. Moreover, the plots amended with soybean biomass treated with 23 kg $P_2O_5$ $ha^{-1}$ + SB6B1 and 69 kg $P_2O_5$ $ha^{-1}$ + $SB_6B_1$ followed by 23 kg $P_2O_5$ $ha^{-1}$ + uninoculated recorded the highest net return.

## CONCLUSION

In general, sugarcane-soybean intercropping could improve the productivity of sugarcane (cane yield and sugar yield) through amending the soils with soybean biomass. Incorporation of soybean biomass that is produced with inoculation with appropriate rhizobia and fertilized with P could increase the beneficial effect of intercropped soybean to the accompanied sugarcane. On top of increasing the productivity of sugarcane, this novel cropping system could improve the juice quality attributes such as ERS and °brix. Based on the economic feasibility analysis of the different strategies we suggested that incorporation of soybean residues treated with P and *Bradyrhizobium* in the soil result in the highest net return and thus we recommend the *Bradyrhizobium* inoculation and P fertilizer application for soybean in soybean-sugarcane intercropping system in the study site.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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