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# The Effect of Plant Density, Zinc Added to Phosphorus Fertilizer Sources and Location on Selected Yield Parameters of Soybean

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## ABSTRACT

**Background:** Soybean [*Glycine max* (L.) Merrill] is an annual herbaceous leguminous grain crop which is cultivated mainly for its oil and protein. The objective of the study was to determine the effects of plant density and zinc added to phosphorus fertilizer sources on soybean yield performance under different environmental conditions.

**Methods:** A field trial was executed in two sites during the 2018/19 and 2019/20 summer planting seasons. The experimental design involved a 2 × 2 × 5 factorial fitted into a randomized complete block design (RCBD) with four replications. The experiment consisted of two plant densities, a lower plant density of 66 666 plants/ha and a higher plant density of 111 111 plants/ha. The five different types of fertilizer treatments were single superphosphate, monoammonium phosphate, zinc sulphate added to single superphosphate, zinc sulphate added to monoammonium phosphate and control.

**Result:** The results showed that plant density has a significant effect ($P<0.05$) on soybean number of pods per plant and the field biomass yield. Soybean planted under lower plant density conditions produced a significantly larger number of pods per plant during both planting seasons, whereas higher plant density conditions resulted in a higher soybean field biomass yield during the 2018/19 planting season. It was observed that soybean treated with monoammonium phosphate had higher seed mass.


**Key words:** Field biomass, Location, Phosphorus, Plant density, Zinc.

## INTRODUCTION

Soybean is one of the top-ranked grain crops produced in terms of area planted and production in South Africa (Engelbrecht *et al.* 2020). Soybean varieties are sensitive to a change in environmental conditions. High temperatures adversely affect the seed yield of soybean (Onat *et al.* 2017). Temperatures above 30°C result in a reduction in soybean yields (Tacarindua *et al.* 2013). A higher seed mass was noted in soybean grown under higher temperatures (Khalil *et al.* 2001). Variations in soybean yields are the result of an insufficient rainfall and irregular distribution of rainfall throughout the growing season (Mandic *et al.* 2017). Moisture stress that occurs between the start of seed swelling stage and in the middle of the full seed formation in pods results in losses in soybean yields (Staton, 2020). Higher yields of soybean are observed when there is a considerable increase in the rainfall (Magugu *et al.* 2016). Soil with a greater sand texture (66.20 and 71.80%) and a lower silt texture (7.20 and 9.30%) had slightly positive effects on the performance of cowpea number of pods produced per plant, the pod yield and the 1000 seed weight (Ndema *et al.* 2010). Soybean seed yields are better in sandy loam soils than in loamy sand soils (Arora *et al.* 2010).

Improved applications of phosphorus fertilizer are required to optimize crop yields and reduce the environmental impacts of phosphorus (Antonangelo *et al.* 2019). Phosphorus fertilizer sources have been shown to positively influence cowpea yields (Ayodele and Oso, 2014). Diammonium phosphate fertilizer source is known to significantly increase the number of pods per plant in the case of common beans, while the lowest number of pods per plant have been recorded in cases where there have been no applications of phosphorus fertilizer (Meseret and Amin, 2014). Triple superphosphate and rock phosphate phosphorus fertilizer sources produce higher grain yields in soybean (Kumah, 2016). Studies on the application of different phosphorus sources on cowpea yields have been found to have a positive effect. In terms of their order of importance, the associated fertilizers are triple superphosphate, followed by single superphosphate and lastly NPK (Ayodele and Oso, 2014). Diammonium phosphate and manure were found to be important inputs in that they produced 62 and 60% respectively of the soybean biomass yields (Abuli *et al.* 2012).

Applications of zinc fertilizer at successive rates were found to produce higher soybean yields, even though there was a reduction in yield with further applications (Aytac *et al.* 2007). In the study conducted by Shittu and Ogunwale (2012),

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the interaction of phosphorus and zinc showed an influence on the soybean pod and grain yield per plant. The highest grain yield of beans was obtained from combined applications of 40 kg phosphorus per hectare and 10 kg zinc per hectare (Bildirici and Oral, 2020). Aboyeji *et al.* (2020) reported that the interaction of zinc and phosphorus fertilizers on groundnut total biomass was significant. They further stated that the best combination was observed at eight kilograms (8 kg) zinc per hectare and 80 kg phosphorus per hectare.

When the inter-row spacing is narrow, the number of pods per plant decreases due to an increasing population and resource competition (Masa *et al.* 2017). Matsuo *et al.* (2018) reported that the production of pod mass per square metre is significantly higher at a high plant density than at a lower plant density. Frequently, there is an increase in yield with an increase in plant density, although yields tend to decline across the soybean varieties after the 200 000 plants per hectare mark has been reached (Madanzi *et al.* 2012). In terms of the cowpea, Ahmed *et al.* (2010) reported that reduced plant densities lead to increased cowpea 100 seed weight. The number of soybean plants per unit area and the distance between the rows affects the field biomass production of soybean (Luca and Hungria, 2014). Kamara *et al.* (2016) reported that cowpea fodder yield increases with an increase in plant density.

Lack of information on different phosphorus sources has led farmers to depend on and apply only single superphosphate rather other phosphorus sources in the production of soybean. Soils with low zinc accessibility show lower potential in terms of soybean yield (Sadeghzadeh, 2013). Soybean seed yields decrease as the plant density decreases (Gulluoglu *et al.* 2017). The objective of the study was to determine the effects of plant density and zinc added to phosphorus fertilizer sources on soybean yield performance under different environmental conditions.

## MATERIALS AND METHODS

### Description of experimental site

The experiment was conducted at two sites in South Africa, North-West province namely the North-West University's experimental farm at Mafikeng, situated at 25°48′S, 45°38′E; 1 012 metres above sea level and the Department of Agriculture's experimental station at Taung, situated at 27°30′S, 24°30′E; 1 111 metres above sea level, during the 2018/19 and 2019/20 summer planting seasons. The soil type at the Mafikeng experimental farm is classified as Hutton. It is red in colour and has a sandy loam texture (Kasirivu *et al.* 2011; Molope, 1987). The summer average temperature range is between 22°C and 34°C, while the summer mean rainfall is 571 mm.

The Taung experimental station, an initiative of the Department of Agriculture, has deep but fine sandy dominated red, freely drained and eutrophic soils, with their parent material having originated from aeolian deposits (Staff, 1999). According to the South Africa Soil Classification (Molope, 1987; Kasirivu *et al.* 2011), the soil belongs to the Hutton series. The Taung summer mean minimum temperature ranges between 7 and 11°C while the mean maximum temperature is 37°C. The Taung experimental station has a mean annual rainfall of 1 061 mm that usually begins in October. The weather data for Mafikeng and Taung for the course of the study are presented in Fig 1 and Fig 2.

### Experimental design

The experimental design involved a 2 × 2 × 5 factorial fitted into a randomized complete block design (RCBD) with four replications. The experiment was conducted at two locations, namely Mafikeng and Taung. The experiment consisted of two plant densities, a lower plant density of 66 666 plants/ha and a higher plant density of 111 111 plants/ha. The five different types of fertilizer treatments investigated were single superphosphate, monoammonium phosphate, zinc sulphate added to single superphosphate, zinc sulphate added to monoammonium phosphate and a control. The experiment consisted of 10 treatment combinations per replication, thus giving a total of 40 subplots per location.

### Data collection

At 91 days after planting, the number pods per plant were counted from randomly selected and tagged plants from the middle rows of the sampling area per plot; five from low density plantings and nine from high density plantings. At maturity, once the pods were brown, the respective components of the soybean yield were harvested from the plots, each with an area of 5.88 square metres. At the harvest stage, the pods were hand-picked from the harvest area of each plot. After the harvesting of the soybean pods, the plants were cut down to ground level using a shear and the plants from the harvesting area were weighed as biomass using a field weighing scale, in kilograms. Hundred seeds per plot were counted and then weighed in grams. The biomass data were converted from the harvested plot size area to hectares.

### Data analysis

The data collected were subjected to the analysis of variance (ANOVA) using the Genstat 11$^{th}$ Edition to compare the effects of treatment factors on the respective parameters of the soybean. The least significant difference (LSD) technique at a five percent (5%) probability level was used to separate the treatment means. A correlation analysis was conducted using Microsoft Excel Program Version 12.0.

## RESULTS AND DISCUSSION

### The effect of plant density, location and phosphorus fertilizer sources/zinc on number of pods per soybean plant

As indicated in Table 1, plant density had a highly significant effect ($P<0.001$) on the number of pods per soybean plant during the 2018/19 and 2019/20 planting seasons. Soybean planted at a lower plant density produced a significantly higher number of pods per plant of 109.01 and 70.38 during the 2018/19 and 2019/20 planting seasons respectively than soybean planted at a high plant density. The higher number of pods per soybean plant produced at a low plant density could be attributed to the higher number of branches produced per plant because there would then be less competition for nutrients at low plant densities. This observation correlates with the findings of Gulluoglu *et al.* (2016), who reported a higher number of pods per soybean plant at lower plant densities compared to higher densities.

Location had a significant effect (P<0.05) on the number of pods per soybean plant during the 2018/19 and 2019/20 planting seasons. Soybean planted at Taung produced a significantly higher number of pods per plant of 111.01 and 66.46 during the 2018/19 and 2019/20 planting seasons respectively as opposed to the soybean planted at Mafikeng. The higher number of pods per plant at Taung could be attributed to its soil fertility status and climatic conditions such as temperature (Fig 2), which lead to bushier and taller plants that produce a higher number of pods per plant. The higher number of pods per plant at Taung corroborates the findings by Islam and Sebetha (2020) who reported higher number of drybean pods per plant at Taung due to adequate rainfall received.

Phosphorus fertilizer sources/zinc had no significant effect (P>0.05) on the number of pods per soybean plant during the 2018/19 and 2019/20 planting seasons. The interaction of treatment factors on the number of pods per soybean plant had no significant effect (P>0.05) during the 2018/19 and 2019/20 planting seasons.

### The effect of plant density, location and phosphorus fertilizer sources/zinc on soybean 100 seed mass

As indicated in Table 1, plant density had no significant effect (P>0.05) on soybean 100 seed mass during the 2018/19 and 2019/20 planting seasons. Location had a highly significant effect (P<0.001) on soybean 100 seed mass during the 2018/19 and 2019/20 planting seasons. Soybean planted at Taung had a significantly higher 100 seed mass of 16.62 and 19.00 g/plot during the 2018/19 and 2019/20 planting seasons respectively than soybean planted at Mafikeng. The higher seed mass produced at Taung could be attributed to favourable environmental and climatic conditions such as moderate precipitation (Fig 1) and higher temperature (Fig 2). The results corroborate the findings of Lyimo *et al.* (2017), who reported that compared to other sites, the soybean 100 seed mass at Ilonga was significantly

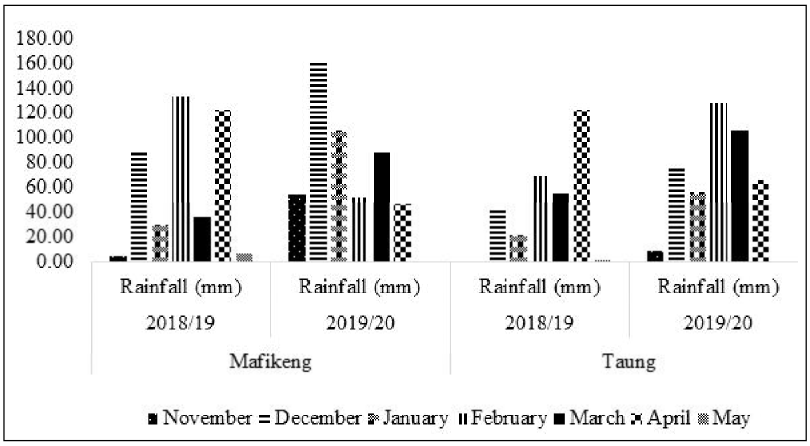


**Fig 1:** Mean rainfall (mm) at Mafikeng and Taung during the 2018/19 and 2019/20 planting seasons.

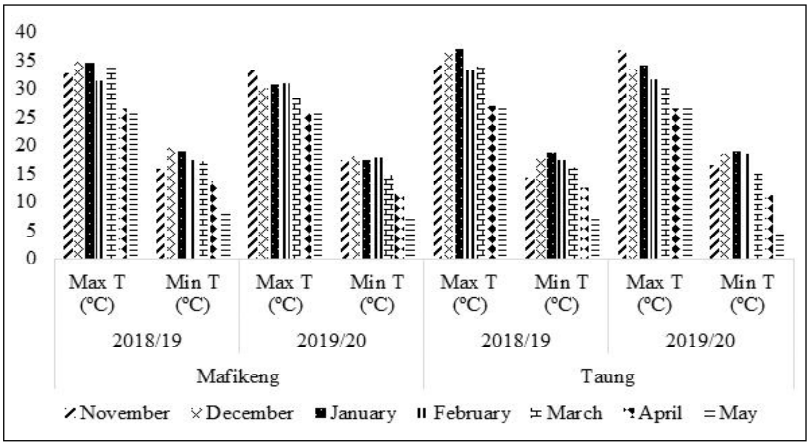


**Fig 2:** Mean maximum and minimum temperatures (°C) at Mafikeng and Taung during the 2018/19 and 2019/20 planting seasons.

higher, thus affirming that this could be attributed to the moderate rainfall during the growing stage, in the month of March. This observation confirms the findings of Angelotti *et al.* (2020), who reported that plants kept at temperatures of 29/23°C (day/night) and at 32/29°C have the higher seed mass compared to plants kept at 26/20°C.

Phosphorus fertilizer sources/zinc had no significant effect ($P>0.05$) on soybean 100 seed mass during the 2018/19 and 2019/20 planting seasons. Although no significant differences were observed amongst the phosphorus fertilizer sources and zinc, soybean plants treated with MAP had a higher seed mass of 17.10 g/plot during the 2019/20 planting season than other phosphorus fertilizer sources and zinc. The higher 100 seed mass of soybean plants treated with MAP compared to other phosphorus sources/zinc for both seasons could be attributed to the availability of the required elements (*e.g.* the proportions of nitrogen, calcium, magnesium and phosphorus) released into the soil by MAP fertilizer for plant use. This observation corroborates the findings of Rady *et al.* (2018), who reported that applications of MAP at two levels (10 and 20nM) significantly increase the 100 seed weight of common bean plants, compared to the control. The interaction of treatment factors on soybean 100 seed mass was not significant ($P>0.05$) during the 2018/19 and 2019/20 planting seasons.

**The effect of plant density, location and phosphorus fertilizer sources/zinc on field biomass yield of soybean**

As indicated in Table 1, plant density had no significant effect ($P>0.05$) on the field biomass yield of soybean during the 2019/20 planting season. However, plant density had a significant effect ($P<0.010$) on the field biomass yield of soybean during the 2018/19 planting season. Soybean planted at a higher plant density produced a significantly higher field biomass yield of 3132.30 kg/ha than soybean planted at a lower plant density. A higher field biomass yield for soybean under higher plant density conditions during the 2018/19 planting season could be attributed to a greater number of plants per harvested area as opposed to lower density plantings. This observation corroborates the findings of Rahman and Hossain, (2011), who reported that the highest stover yield was produced at a plant density of 80 plants per square metre, while the lowest stover yield was produced at a plant density of 20 plants per square metre.

Location had a highly significant effect ($P<0.001$) on the biomass yield of soybean during the 2018/19 and 2019/20 planting seasons. Soybean planted at Taung had a significantly higher field biomass yield of 3424.12 and 6113.81 kg/ha during the 2018/19 and 2019/20 planting seasons respectively. The higher field biomass yield at Taung could be attributed to the adaptability of soybean plants to

**Table 1:** The effect of plant density, location and phosphorus fertilizer sources/zinc on soybean number of pods per plant, 100 seed mass (g) and field biomass yield (kg/ha) during the 2018/19 and 2019/20 planting seasons.

| Treatment factors | 2018/19 | | | 2019/20 | | |
|---|---|---|---|---|---|---|
| | Pods/plant | 100 seeds mass | Biomass yield | Pods/plant | 100 seeds mass | Biomass yield |
| **Plant density** | | | | | | |
| 111 111 plants/ha | 76.71 | 14.93 | 3132.30 | 48.94 | 16.23 | 3613.81 |
| 66 666plants/ha | 109.01 | 15.20 | 2816.15 | 70.38 | 16.76 | 4158.23 |
| $LSD_{(0.05)}$ | 13.52 | 0.94 | 236.56 | 10.28 | 0.64 | 1047.72 |
| **Location** | | | | | | |
| Mafikeng | 74.11 | 13.51 | 2524.32 | 53.17 | 13.99 | 1658.56 |
| Taung | 111.01 | 16.62 | 3424.12 | 66.46 | 19.00 | 6113.81 |
| $LSD_{(0.05)}$ | 13.52 | 0.94 | 236.56 | 10.28 | 0.64 | 1047.72 |
| **Phosphorus sources/zinc** | | | | | | |
| MAP | 97.37 | 15.68 | 2954.77 | 59.99 | 17.10 | 4182.88 |
| MAP + Zn | 95.68 | 15.57 | 3161.48 | 65.66 | 16.28 | 4182.88 |
| SSP | 102.25 | 15.20 | 3161.48 | 60.70 | 16.39 | 4146.40 |
| SSP + Zn | 94.20 | 15.18 | 3185.80 | 64.36 | 16.76 | 3623.54 |
| Control | 74.80 | 13.70 | 2407.59 | 48.37 | 15.93 | 3295.23 |
| $LSD_{(0.05)}$ | 21.38 | 1.48 | 374.03 | 16.26 | 1.01 | 1656.58 |
| **Interactions** | | | | | | |
| D × L | ns | ns | ns | ns | ns | ns |
| D × PSo-Zn | ns | ns | ns | ns | ns | ns |
| L × PSo-Zn | ns | ns | ns | ns | ns | ns |
| D × L × PSo-Zn | ns | ns | ns | ns | ns | ns |

DAP= Days after planting, MAP= Monoammonium phosphate, SSP= single superphosphate, Zn= Zinc, PSo= Phosphorus source, ns= Not significant.

higher temperatures (Fig 2) and moderate precipitation (Fig 1), conditions that would lead to bushier soybean plants and thicker stems. The higher soybean biomass yield at Taung concurs with the findings by Sebetha and Modi (2016) who reported higher cowpea biomass yield at that location due to better environmental factors such as rainfall and temperature during growing season. It was also reported by Khalil *et al.* (2011), that soybean yield and yield components are significantly affected by temperature and relative humidity during the growing period.

Phosphorus fertilizer sources/zinc had no significant effect (P>0.05) on the field biomass yield of soybean during the 2019/20 planting season. However, phosphorus fertilizer sources/zinc had a highly significant effect (P<0.001) on the field biomass yield of soybean during the 2018/19 planting season. Soybean treated with SSP + Zn, SSP, MAP + Zn and MAP produced a significantly higher field biomass yield of 3185.80, 3161.48, 3161.48 and 2954.77 kg/ha respectively than the control. Soybean treated with SSP + Zn had a higher field biomass of 3185.80 amongst the phosphorus fertilizer sources and zinc during the 2018/19 planting season though no significant differences were observed. During the 2018/19 season, the higher field biomass yield of soybean treated with a combination of SSP + Zn could be attributed to the presence of zinc, thus enhancing the uptake and translocation of the required nutrients, mainly phosphorus. This observation supports the findings of Rahman *et al.* (2015), who observed significantly higher stover yields for mungbean with applications of phosphorus and zinc than would have been the case with no fertilizer applications at all. The interaction of treatment factors on the field biomass yield of soybean was not significant (P>0.05) during the 2018/19 and 2019/20 planting seasons.

**The correlation analysis for three soybean yield variables in Mafikeng and Taung during the 2018/19 planting season**

Table 2 and Table 3 presents a correlation analysis for the associations between the three selected yield variables of soybean in Mafikeng and Taung respectively during 2018/19 planting season. In Mafikeng during 2018/19 planting season presented in Table 2, pods per plant had a positive and significant correlation with field biomass ($R^2$= 0.04). The significant and positive relationship between pods per plant and biomass might be attributed to bushy plants producing more branches that are able to carry more pods number per plant. This observation corroborates the findings of Xu *et al.* (2021), who reported that pods number per plant increased with increased branch number. However, the association between pods per plant with 100 seeds weight ($R^2$= 0.148) and 100 seeds weight and field biomass ($R^2$= 0.437 was positive but not significant. In Taung, number of pods per plant had a positive and significant relationship with 100 seeds weight ($R^2$= 0.002). The positive and significant and relationship between pods per plant and 100 seed weight could be attributed to assimilation of nutrients throughout the plant. This observation confirms the findings of Kakiuchi and Kobata, (2006) who reported that a positive linear relationship existed between seeds weight and total pods number in all cultivars. However, number of pods per plant had positive but not significant relationship with field biomass ($R^2$= 0.94). Soybean 100 seeds weight had a positive but not significant relationship with field biomass ($R^2$= 0.783) presented in Table 3.

**The correlation analysis for three selected soybean yield variables in Mafikeng and Taung during the 2019/20 planting season**

Table 4 and Table 5 present a correlation analysis of the respective associations between the three yield variables for soybean in Mafikeng and Taung during 2019/20 planting season. Number of pods per plant had a positive but non-significant association with 100 seeds weight ($R^2$= 0.744). On the other hand, pods per plant had a positive and highly significant correlation with field biomass ($R^2$= 0.001). A positive but non-significant relationship between 100 seeds weight and field biomass ($R^2$= 0.114) was observed in Mafikeng presented in Table 4. In Taung during 2019/20 planting season presented in Table 5, pods per plant had a positive and significant correlation with 100 seeds weight ($R^2$= 0.043) and field biomass ($R^2$= 0). The significant and positive relationship between pods per plant and field

**Table 2:** Correlation analysis for respective soybean yield variables in Mafikeng during the 2018/19 planting season.

| | | PP | SW (g) | FB |
|---|---|---|---|---|
| PP | Pearson correlation | 1 | 0.233 | .335* |
| | Sig. (2-tailed) | | 0.148 | 0.034 |
| | N | 40 | 40 | 40 |
| SW (g) | Pearson correlation | 0.233 | 1 | 0.126 |
| | Sig. (2-tailed) | 0.148 | | 0.437 |
| | N | 40 | 40 | 40 |
| FB | Pearson correlation | .335* | 0.126 | 1 |
| | Sig. (2-tailed) | 0.034 | 0.437 | |
| | N | 40 | 40 | 40 |

PP= Pods per plant, SW= 100 seed weight, FB= Field biomass, * = Significant.

**Table 3:** Correlation analysis for respective soybean yield variables in Taung during the 2018/19 planting season.

| | | PP | SW (g) | FB |
|---|---|---|---|---|
| PP | Pearson correlation | 1 | .467** | -0.014 |
| | Sig. (2-tailed) | | 0.002 | 0.932 |
| | N | 40 | 40 | 40 |
| SW (g) | Pearson correlation | .467** | 1 | -0.045 |
| | Sig. (2-tailed) | 0.002 | | 0.783 |
| | N | 40 | 40 | 40 |
| FB | Pearson correlation | -0.014 | -0.045 | 1 |
| | Sig. (2-tailed) | 0.932 | 0.783 | |
| | N | 40 | 40 | 40 |

PP= Pods per plant, SW= 100 seed weight, FB= Field biomass, * = Significant.

**Table 4:** Correlation analysis for respective soybean yield variables in Mafikeng during the 2019/20 planting season.

| | | PP | SW (g) | FB |
|---|---|---|---|---|
| PP | Pearson correlation | 1 | 0.053 | .520** |
| | Sig. (2-tailed) | | 0.744 | 0.001 |
| | N | 40 | 40 | 40 |
| SW (g) | Pearson correlation | 0.053 | 1 | -0.254 |
| | Sig. (2-tailed) | 0.744 | | 0.114 |
| | N | 40 | 40 | 40 |
| FB | Pearson correlation | .520** | -0.254 | 1 |
| | Sig. (2-tailed) | 0.001 | 0.114 | |
| | N | 40 | 40 | 40 |

PP = Pods per plant, SW = 100 seed weight, FB = Field biomass, * = Significant.

**Table 5:** Correlation analysis for respective soybean yield variables in Taung during the 2019/20 planting season.

| | | PP | SW (g) | FB |
|---|---|---|---|---|
| PP | Pearson correlation | 1 | .321* | .572** |
| | Sig. (2-tailed) | | 0.043 | 0 |
| | N | 40 | 40 | 40 |
| SW (g) | Pearson correlation | .321* | 1 | .402* |
| | Sig. (2-tailed) | 0.043 | | 0.01 |
| | N | 40 | 40 | 40 |
| FB | Pearson correlation | .572** | .402* | 1 |
| | Sig. (2-tailed) | 0 | 0.01 | |
| | N | 40 | 40 | 40 |

PP = Pods per plant, SW = 100 seed weight, FB = Field biomass, * = Significant.

biomass might be attributed to more branches that are able to carry more pods number per plant. This observation confirms the findings of Agegnehu and Beyene (2009) who reported that the results indicated a highly significant positive response of total biomass and number of pods per plant to tillage frequency. The association between 100 seeds weight and field biomass ($R^2$ = 0.01) was positive and significant.

## CONCLUSION

In this study, yield parameters of soybean differ according to the plant density per area. A low plant density produced a greater number of pods per plant and a greater 100 seed mass due to less competition for nutrients by the plants for both planting seasons. Low plant density is recommended for farmers targeting a higher seeds mass. Higher plant densities are recommended for livestock feeds and soil improvements with biomass. In terms of location, Taung produced higher number of pods per plant,100 seed mass and field biomass yield. Climatic and environmental conditions, such as higher temperatures, moderate rainfall and sandy soils, were found to lead to higher soybean yields.

The soybean yield components were influenced by the phosphorus fertilizer source in addition to zinc. The application of monoammonium phosphate resulted in higher seed mass across the planting seasons. Field biomass was higher with the addition of zinc to single superphosphate during the 2018/19 planting season. The application of zinc with phosphorus fertilizer is recommended for farmers targeting higher soybean biomass yields.

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