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Full Length Research Paper

The result of phosphorus fertilizer application on growth and yield of three soybean (*Glycine max*) cultivars in Limpopo Province

Jovic T. Hadi, Tahid Munir and Soraya Damasey

Department of plant and crop science, Faculty of Agriculture, University of Melbourne, Parkville, Victoria, Australia.

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This study aimed at assessing the effects of phosphorus (P) rates on the growth and yield of three soybean cultivars in Vhembe district, Limpopo Province, South Africa. Field experiments were carried out at the University of Venda's experimental farm, Thohoyandou over two seasons (season I: February – May 2006; season II: November 2006 – March 2007). The experiments consisted of a factorial combination of P fertilizer rates (0, 30 and 60 kg P ha^{-1}) and soybean cultivars (Pan 520RR, Highveld Top, and LS 555) arranged in a randomized complete block design and replicated three times. Crop biomass (three stages: vegetative phase, 50% flowering and harvest maturity) and grain yield were determined. The (Agricultural Production Systems Simulator) APSIM model (version 5.3) was used to simulate crop biomass and grain yield and to assess the long-term risks associated with yield production of soybean crop. P did not affect crop biomass at harvest maturity but the effect of cultivar was significant (P = 0.01); LS 555 had lower grain yield (701 kg ha^{-1}) compared with Pan 520RR (1457 kg ha^{-1}) and Highveld Top (1241 kg ha^{-1}). There was a strong positive relationship (R^2 = 0.97) between observed and predicted grain yield data but the predicted yields were generally lower than the observed values. These preliminary findings show firstly, that the addition of P may not affect grain yield of soybean in this area, secondly, that Pan 520RR and Highveld Top may be suitable for cultivation in this area, and lastly, that APSIM model may be a useful tool in predicting soybean productivity in this area.

Key words: P application, cultivar, crop biomass, grain yield, APSIM simulation.

INTRODUCTION

Soybean (*Glycine max*) is one of the most important sources of oil and protein and is commonly used in both human and animal diets (Ariyo, 1995) . Moreover, soybean is increasingly becoming important as a source of oil for biodiesel production. This trend is likely to continue, at an even faster rate, considering the volatility in crude oil prices and/or the environmental concerns related to use of crude oil (Krawczyk, 1996). In South Africa, soybean has been grown for the past 20 years but only in the past five years has it become a major cash crop (Biowatch, 2004). In Limpopo Province, soybean is becoming a popular crop for biodiesel production. For example, Mapfura-Makhura Incubation (MMI) Company has been established to train small scale black farmers (incubatees) within Limpopo Province in business and managerial skills to optimize the yield of soybean that is required for biodiesel production.

There are several constraining factors that lead to low levels of soybean production; these include, but not limited to, biotic and abiotic factors such as drought and low soil fertility status (Singh et al., 2003). For example,

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*Corresponding author. Email: Jovic50@yahoo.com

Table 1. Soil (0 – 15 cm) physical and chemical properties at the experimental site during seasons I and II.

	pH	EC	Particle size (%)			%		mg kg^{-1}					
									Exchangeable cations				$cmol_c$ kg^{-1}
	(Water)	S M^{-1}	Sand	Silt	Clay	C org.	N Total	P	Na	K	Ca	Mg	CEC
I	5.73	0.02	12.76	25.24	62.00	1.72	0.081	2.98	140.0	67.0	798.0	265.0	25.3
II	5.83	0.004	12.76	25.24	62.00	1.82	0.051	3.25	22.8	58.9	1060	221.4	11.0

the low levels of crop production in Limpopo Province have been attributed partly to declining soil fertility (Ramaru et al., 2000) . One of the causes of declining soil fertility is continuous cropping without the use of either organic or inorganic fertilizers. Incorporation of soybeans into the existing cropping systems can help in reducing the rate of soil fertility decline in this region. This is because soybean crop is capable of fixing atmospheric nitrogen to meet its requirements and those of subsequent crops (Aulakh et al., 2003). Also, studies elsewhere show that low native soil phosphorus availability coupled with poor utilization efficiency of added P is a major constraint limiting the productivity of soybean. However, the use of fertilizer P is limited by its high cost, while organic inputs generally do not provide sufficient P for optimum crop growth due to their low P concentration (Aulakh et al., 2003).

Therefore, the optimal use of phosphorus fertilizers leading to increased P use efficiency should be encouraged. However, recommended appropriate phosphorus rates have not been developed for emerging small scale farmers in the Limpopo province, South Africa. Moreover, Odhiambo and Magandini (2008) showed that current fertilizer recommendations in the Limpopo Province are largely blanket, based on the Fertilizer Society of South Africa (FSSA) handbook.

Furthermore, as new varieties of soybean are continuously being developed to meet food demand and biodiesel production, it is important to evaluate these new varieties, in terms of best yielding cultivar(s) and appropriate fertilizer rates. The evaluations are largely done through field experiments which may, however, involve much time and space. Therefore the use of crop simulation models may be important to complement direct measurements from the field. This is because the use of models may enable the testing of several scenarios by changing simultaneously a number of parameters and hence reducing the number of field experiments required (Ogola et al., 2006).

The importance of crop models has been reported in a number of studies. For example, Whitbread and Ayisi (2004) and Whitbread and Clem (2006) reported that the Agricultural Production Systems Simulator (APSIM) maize model was able to simulate biomass production with high degree of precision and that APSIM is well suited to examining crop rotation systems in the semi- arid tropics. Ogola et al. (2007) reported that crop models can be important tools for predicting the production of maize in semi-arid Kenya. Earlier, Jagtap and Jones (2002) indicated that CROPGRO-soybean model simulated regional yield, but noted that further improvements were needed to account for other loss factors (disease, insects, weeds and flooding).

The objective of this study was to (i) evaluate the effect of different rates of phosphorus fertilizer on soybean growth and yield, and (ii) assess the performance of APSIM model in simulating soybean growth and yield at different phosphorus rates in Limpopo Province.

MATERIALS AND METHODS

Site description

Field studies were carried out between February 2006 and May 2006 (season I), and November 2006 and March 2007 (season II) at the University of Venda's Experimental Farm, Thohoyandou, Vhembe District Limpopo Province, South Africa. The site is situated at latitude of 22°35'14.0" S and longitude 30°15'50.3" E. respectively and the elevation of the site is 595 m above the sea level (Tadross et al., 2006).

The site is characterized by deep, well-drained clay soil (Soil Classification Workgroup, 1991). Some of the pre-sowing soil physical and chemical properties for the two seasons (collected from 0 – 15 cm depth) are presented in Table 1.

Design of experiments

The treatments in both seasons I and II consisted of a factorial combination of phosphorus fertilizer rates (0, 30 and 60 kg P ha^{-1}) and soybean cultivars (Pan 520RR, Highveld Top, and LS 555). Fertilizer P was applied at planting as superphosphate (10.5% P) using banding method. The treatments were laid out in a randomized complete block design and replicated three times. Each experimental unit measured 4.5 m x 3 m. Seeds were sown manually at a spacing of 0.9 m x 0.45 m. Irrigation was applied once at planting for good crop establishment. Nitrogen was applied uniformly at planting as limestone ammonium nitrate (LAN 28 %) fertilizer at 40 kg N ha^{-1}. Plots were kept weed-free throughout the growing seasons.

Measurement of soil water parameters

Measurements of drained upper limit (DUL), crop lower limit (CLL) and bulk density (BD) and the calculation of plant available water capacity (PAWC) at the site were undertaken using the methods described by Dalgliesh and Foale (1998). The soil water parameters are given in Table 2. These data together with biomass and grain yield from the field experiments were used to validate the APSIM model.

Table 2. Soil water parameters used in the short and long term simulations.

Depth mm	Air-dry mm/mm	LL mm/mm	DUL mm/mm	SAT mm/mm	SW mm/mm	BD g cm^{-3}
0 -150	0.06	0.12	0.26	0.49	0.26	1.10
150 - 300	0.08	0.13	0.29	0.49	0.29	1.20
300 - 450	0.13	0.13	0.29	0.49	0.29	1.20
450 - 600	0.13	0.13	0.32	0.49	0.32	1.20
600 - 750	0.13	0.13	0.32	0.49	0.32	1.20
750 - 900	0.13	0.13	0.32	0.49	0.32	1.20

LL = crop lower limit; DUL = drained upper limit; SAT = saturation; SW = soil water; BD = bulk density; SWCON = drainage coefficient.

Measurement of crop biomass and grain yield

Above ground biomass was determined at three different stages: Vegetative (14 days after emergence, DAE for seasons I and II); 50% flowering (30 and 40 DAE, in seasons I and II, respectively); and harvest maturity (82 and 110 DAE, in seasons I and II, respectively). At vegetative and 50% flowering stages, crop biomass was determined from a 0.9 m^2 quadrat of two inner rows. Biomass at harvest maturity was determined from an area of 1.8 m^2 of the two inner-most rows. The harvested plants were oven dried at 65°C for 48 h and weighed to obtain the biomass. Grain yield was determined from the same plants used for biomass at harvest maturity. Pods were separated from the plants, weighed and threshed to determine grain yield. Harvest index was calculated as the ratio of grain yield to aboveground biomass at maturity.

APSIM simulation

The APSIM model (version 5.3) was used to simulate crop biomass and grain yield and to assess the long-term risks associated with the yield production of soybean crop in one area of Vhembe District, Limpopo Province, South Africa. The cultivars Cpi26671 and Magoye available in the APSIM were found to best represent the growth of LS555, and Highveld Top and Pan520RR cultivars, respectively. The soybean cultivars used in the field experiment in the current study were not available in APSIM.

In running the simulations the following assumptions were made: simulated cropping seasons corresponded with seasons for the field experiments; planting density of 2.4 plants m^{-2} was observed; harvesting was done at physiological maturity; and P was not limiting (because the main effects of P were not significant in the field experiments).

The major inputs to the model included: weather data (temperature, rainfall and radiation) for the site and seasons of the field experiments; and number of days between planting and emergence, emergence and flowering, flowering and physiological maturity, and physiological maturity and harvest maturity. Simulations were run from the date of planting (26 February, 2006) until the assumed date of crop harvest maturity (13 May, 2006) in season I. The corresponding dates for season II were 15 November, 2006 and 1 March, 2007, respectively.

Long term simulation

APSIM was configured to simulate the response of cultivar (in terms of yield production) to long-term weather changes. Weather data for 25 years (daily records from 1982 - 2007) was used. Soybean was assumed to be planted as a sole crop and the yield production was simulated for each season. Each year, the soybean crop was assumed to be sown within the sowing window (from 1 August, 1982 - 26 June, 2007); each season had a sowing window of four months, when at least 30 mm of rain had been received over 3 consecutive days.

The APSIM-soybean model was linked with the soil water model (SOILWAT) and the soil model (SOIL) that was obtained from the experimental site. The initial surface residues were initialized as zero as residues were assumed to be absent at the start of the field experiment in 2006. Other inputs to the model included date of sowing, name of crop and cultivar, plant population, row spacing, sowing depth, and number of days between planting and emergence, emergence and flowering, flowering and physiological maturity, and physiological maturity and harvest maturity.

The major outputs included: emergence date, flowering date, biomass weight, maturity date and grain yield.

Statistical analysis

The Genstat 7th edition statistical package (Genstat, 2003) was used to analyze the data. Analysis of variance (ANOVA) was used to assess the effect of fertilizer P and cultivar on growth and yield of soybean. Significant differences among the treatment means were recorded at P 0.05; the treatment means were compared using the standard error of difference of the means (SED).

In order to assess the goodness of fit of crop biomass and grain yield, the Chi -square test (Equation 1) was used to determine whether a set of observed and predicted data showed significant differences.

$$\text{Chi-square} = [\ (O - P)^2] / P \qquad (1)$$

Where O and P are the paired observed and predicted data.

RESULTS

Crop biomass

The effects of P fertilizer rates and cultivars on aboveground biomass at vegetative stage were not significant in seasons I and II (Table 3). Similarly, the main effects of phosphorus rates and cultivars on crop biomass at 50% flowering were not significant in season I. However, the interaction between cultivars and P rates affected ($P < 0.05$) aboveground biomass at 50% flowering stage (Table 3). Application of 30 kg P ha^{-1} increased crop

Table 3. Effect of P rates on crop biomass of three soybean cultivars at different vegetative stages of growth for two seasons.

		14 DAE	30 DAE	40 DAE		82 DAE	110 DAE
Cultivar	**P rate**	**I**	**II**	**I**	**II**	**I**	**II**
		Soybeans biomass (kg ha^{-1})*					
C1	0	C1	C1	183.0a	58.0	222.0a	C1
	30	13.4	20.6	176.0a	71.0	212.0a	2982.0a
	60			55.0c	74.0	64.0c	
C2	0	C2	C2	110.0b	55.0	132.0b	C2
	30	10.8	25.6	137.0b	40.0	152.0b	2889.0a
	60			61.0c	70.0	87.0c	
C3	0	C3	C3	67.0c	59.0	88.0c	C3
	30	19.0	19.6	170.0a	62.0	231.0a	1682.0b
	60			170.0a	97.0	141.0b	
SED		3.52	4.44	42.70	27.07	43.80	250.60
	0	11.6	24.7				2383.0
	30	16.1	25.2				2491.0
	60	15.6	15.8				2679.0
SED		3.52	4.44				354.50
				P (F-ratio)			
Cultivar (C)		ns	ns	ns	ns	ns	<0.01
P rate (P)		ns	ns	ns	ns	ns	ns
C x P		ns	ns	<0.05	ns	<0.05	ns

Vegetative stage (14 days after emergence, DAE), 50% flowering (30 and 40 DAE), harvest maturity (82 and 110 DAE), season (I and II), P rate (0, 30 and 60 kg ha^{-1}) and cultivar of soybeans (C1 = Pan 520R, C2 = Highveld Top, C3 = LS 555). * SED = standard error or differences of the means; means of each column followed by the same letter are not significantly different according to SED at P < 0.05

biomass by 154% (103 kg ha^{-1}) for LS 555 cultivars, but had no effect on crop biomass for Highveld Top and Pan 520RR. In contrast, application of 60 kg P ha^{-1} increased crop biomass of LS 555 by 154% (103 kg ha^{-1}) but decreased biomass in Pan 520RR by 71% (128 kg ha^{-1}) and in Highveld Top by 45% (49 kg ha^{-1}) (Table 3). Crop biomass was lowest with application of 60 kg P ha^{-1}, except for LS 555 (Table 3). Cultivars and P fertilizer rates did not significantly affect crop biomass at 50% flowering in season II (Table 3).

The effect of the interaction between phosphorus fertilizer rates and cultivars on aboveground biomass at harvest maturity (82 DAE) was significant ($P < 0.05$) in season I (Table 3). Application of 30 kg P ha^{-1} increased crop biomass by 163% (from 88 to 231 kg ha^{-1}) in LS 555 but had no effect on crop biomass in Highveld Top and Pan 520RR (Table 3). In contrast, application of 60 kg P ha^{-1} increased crop biomass in LS 555 by 60% (from 88 to 141 kg ha^{-1}); but decreased crop biomass by 71% (from 222 to 64 kg ha^{-1}) in Pan 520RR and by 34% in Highveld Top (from 132 to 87 kg ha^{-1}) (Table 3). Crop biomass was lowest with application of 60 kg P ha^{-1}, except for LS 555 (Table 3).

Soybean cultivars significantly affected ($P < 0.01$) aboveground biomass at harvest maturity in season II, but neither the effect of P fertilizer rates nor the interaction between phosphorus rates and cultivars were significant (Table 3). LS 555 cultivar had lower crop biomass (1682 kg ha^{-1}) compared with Pan 520RR (2982 kg ha^{-1}) and Highveld Top (2889 kg ha^{-1}) (Table 3).

There were significant ($P < 0.01$) differences between the observed and simulated crop biomass at vegetative, 50% flowering and harvest maturity stages in seasons I and II. However, there was a moderate positive relationship ($R^2 = 0.49$) between observed and predicted crop biomass in season I (Figure 1). The model underestimated crop biomass at all stages of crop growth in season I but the magnitude of underestimation appeared to be greater at later stages of crop development (Figure 1). In contrast, the relationship between predicted and

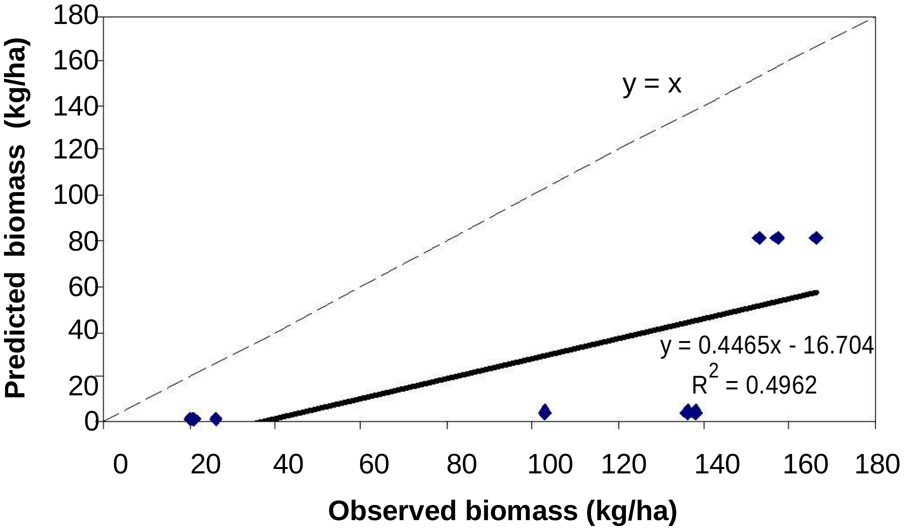

Figure 1. The relationship between observed and predicted crop biomass (kg ha^{-1}) at vegetative, 50% flowering and harvest maturity in season I.

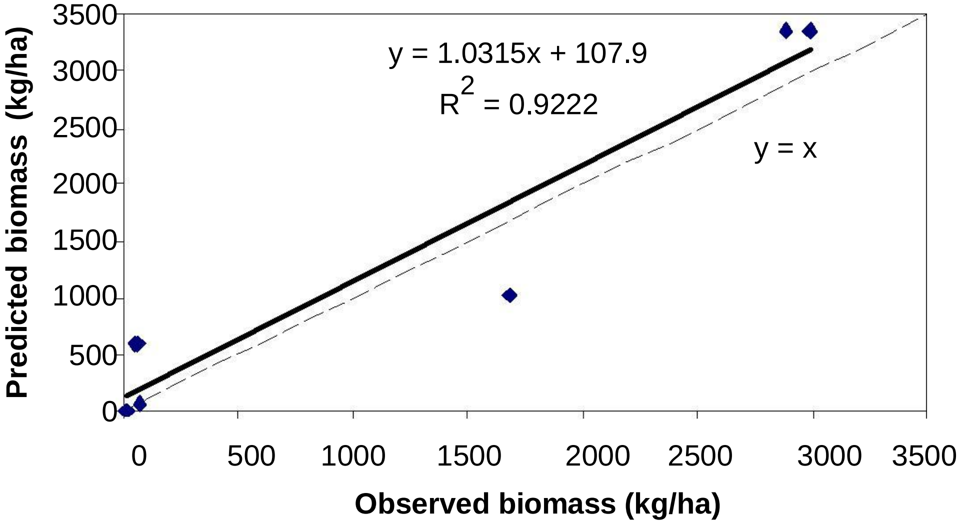

Figure 2. The relationship between observed and predicted crop biomass (kg ha^{-1}) at vegetative, 50% flowering and harvest maturity in season II.

observed crop biomass values was strong and positive (R^2 = 0.92) in season II (Figure 2).

Grain yield

The effect of P rates and cultivars on grain yield was not significant in season I (Table 4) . In contrast, cultivars affected ($P < 0.01$) grain yield but the effect of P and the interaction between cultivar and P were not significant in season II (Table 4). Pan 520RR and Highveld Top cultivars had greater grain yield (1457 and 1241 kg ha^{-1}, respectively) compared with LS 555 (701 kg ha^{-1}) . Grain yields were lower (by 163%) in season I (mean of 430 kg ha^{-1}) compared with season II (mean of 1133 kg ha^{-1}).

There were significant ($P < 0.01$) differences between the observed and simulated grain yield in seasons I and II. However, there was a strong positive relationship (R^2 = 0.97) between observed and predicted grain yield (Figure 3). The APSIM model underestimated grain yield in both seasons but the underestimation was greater at lower grain yields (realised in season I) compared with higher

Table 4. Effect of P rates on grain yield and harvest index of three soybean cultivars in two seasons.

Cultivar	P rate (kg ha^{-1})	Grain yield of soybeans(kg ha^{-1}) Season I	Grain yield of soybeans(kg ha^{-1}) Season II	Harvest index Season I	Harvest index Season II
Pan 520R		465.0	1457.0a	0.46	0.27
Highveld Top		358.0	1241.0a	0.47	0.25
LS 555		468.0	701.0b	0.41	0.26
SED		83.20	217.49	0.360	0.01
	0	399.0	1080.0	0.46	0.27
	30	459.0	1096.0	0.41	0.26
	60	433.0	1222.0	0.47	0.26
SED		83.2	217.49	0.360	0.01
			P (F-ratio)		
Cultivar (C)		ns	<0.01	ns	ns
P rate (P)		ns	ns	ns	ns
C x P		ns	ns	ns	ns

Phosphorus rate (P kg ha^{-1}) and cultivar effects on grain yield of soybeans and harvest index

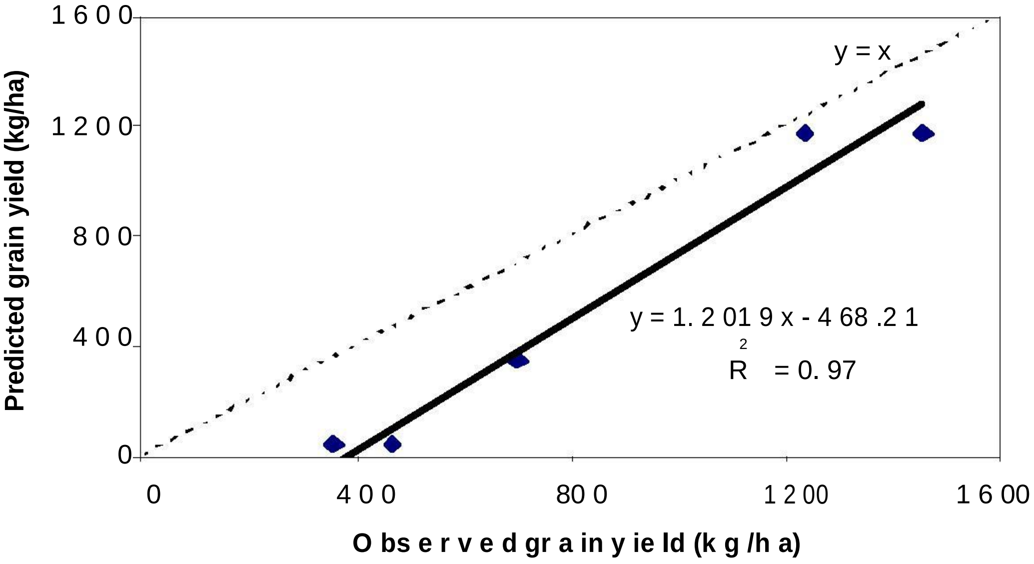

Figure 3. The relationship between observed and predicted grain yield (kg ha^{-1}) in season I and season II.

grain yields in season II (Figure 3).

Harvest index

Cultivars and P rates did not affect harvest index in both seasons I and II (Table 1). The harvest index was much lower in season II (0.26) compared with season I (0.45) (Table 4).

Long-term simulations

The results for long term simulations under dryland conditions at University of Venda's experimental farm, using the weather data for the period 1982 – 2007, are given in Figure 4. The grain yield for the three cultivars ranged between 177 and 1634 kg ha^{-1} (Figure 4). Cultivar LS 555 gave poor grain yield (<1000 kg ha^{-1}) in all

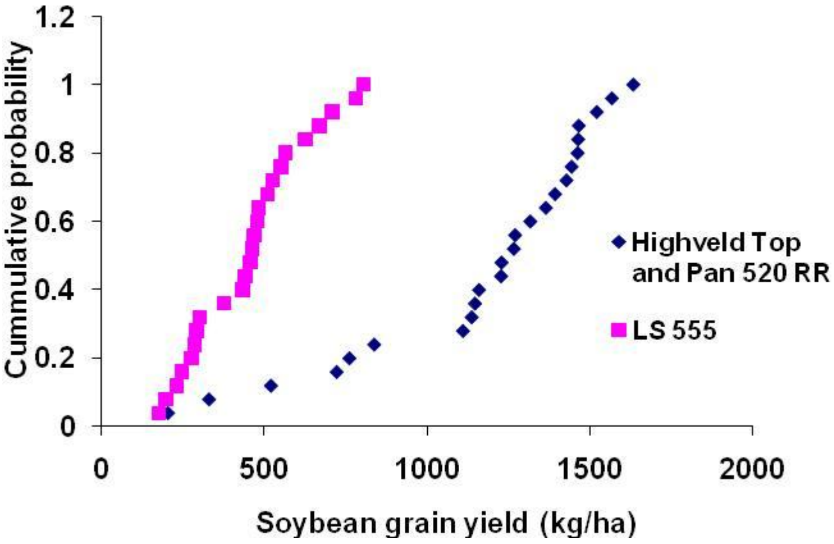

Figure 4. Cumulative probability of soybean grain yield for the period 1982 to 2007 at University of Venda's experimental farm.

seasons; with a minimum of 177 kg ha^{-1} and at least 50% of the seasons yielding less than 500 kg ha^{-1} (Figure 4). Highveld Top and Pan 520RR realized grain yield greater than 1000 kg ha^{-1} in more than 70% of the seasons (Figure 4).

DISCUSSION

Crop biomass at vegetative stage for Highveld Top and Pan 520RR was lower in season I compared with season II, but at harvest, maturity biomass was greater in season II compared with season I for all the cultivars. Lower crop biomass in season I could be attributed partly to late sowing (late February) and hence lower temperatures (21.1°C in season I and 25.1°C in season II) and shortening daylengths, particularly during the reproductive stage of growth. Similarly, Calvino et al. (2003) reported lower above-ground biomass of late-sown soybeans compared with early-sown ones.

Application of phosphorus fertilizer did not have any significant effect on crop biomass in season II probably because of the high soil P levels (Table 1). However, the significant effect of the interaction between cultivar and P at 50% flowering and harvest maturity in season I could be due to the high rainfall amount (183.8 mm) during flowering period; this could have resulted in greater uptake and utilization of P by the crop. There are other studies that do show that the interaction between temperature, nutrients and soil moisture affect P utilization by a soybean crop (Kamara et al., 2008).

The APSIM model gave better estimates of crop biomass in season II compared with season I where the model grossly underestimated crop biomass. It is likely that the underestimation of crop biomass in season I was due to low temperatures and shortening day lengths that coincided with a considerably long growth period of the crop. Moreover, the cultivars used in the field experiment were not available in the model and this could have compounded the effect of unfavourable temperatures and daylength.

Grain yield was 163% lower in season I compared with season II. Lower grain yield in season I could be due to late planting (late February) in season I. In Limpopo Province the recommended planting window for soybean is between mid November and mid December. In late sown crops, stresses such as low temperature during late vegetative and early reproductive stages could be detrimental to yield production. Moreover, in high latitude areas like the site of the current study, late planting results in a considerable growth period of the crop coinciding with shortening daylengths. Similar findings have been reported elsewhere. For example, Bello et al. (1996) found greater grain yields in soybean varieties planted earlier in the season, and Jones et al. (1991) reported that low night temperature during late repro-ductive growth of soybean could affect pod and grain set. More recently, a decline in average soybean yield with late sowing was observed; this decrease in grain yield was associated with a decrease in seed set (Calvino et al., 2003). Grain yield reported in the current study was 38% lower (Highveld Top), 58% lower (LS 555), and 16% greater (Pan 520RR) compared with results from an earlier study in the same region (ARC-Grain Crop Institute, 2006). Greater grain yield from the ARC study could partly be due to timely planting (and hence conducive temperature and daylength regimes).

The relationship between the observed and simulated grain yield was strong and positive but the model underestimated grain yield; the underestimation was greater in season I (where the yield levels were much lower) compared with season II. The greater underestimation of grain yield by the APSIM model in season I may suggest that time of planting is a critical factor affecting the productivity of soybean in this region and thus the importance of sowing within the recommended planting window.

Cultivar and P rates did not affect harvest index in the current study. However, other studies (e.g., Malik et al., 2006) have reported significant effect of phosphorus rates on harvest index of soybeans. The non-significant effect of cultivar and P could be attributed to a similar non-significant effect of cultivar and P rates on grain yield. Ogola et al. (2005) have also reported the link between treatment effects on grain yield and harvest index in maize.

The long-term simulation results are consistent with results from the field experiment (season II) and short term simulations that LS 555 generally gave lower grain yields compared with Pan 520RR and Highveld Top. These results may suggest that LS 555 is not suitable for the region where the current study was conducted. Therefore the use of APSIM model may help in speeding up the research process of evaluating the adaptation of cultivars to a particular region and thus help in saving valuable research funds and time. Moreover, the APSIM model could be useful, to researchers, in designing mitigation strategies against the effects of climate change on soybean productivity in this region.

Conclusion

The results from this study show that (i) early planting could lead to greater soybean productivity in this region, (ii) the APSIM may be capable of stimulating crop growth and grain yield of soybean in one area of Limpopo Province and (iii) Pan 520RR and Highveld Top cultivars may be suitable for this area. However, further studies involving more P rates, growing seasons, planting densities and multiple sites in Limpopo Province need to be undertaken before definite recommendations can be made.

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