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Growth and Yield Responses of Pigeonpea to Variable Phosphorus Application Rates When Intercropped With Maize under Dryland Conditions

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Abstract: An Agronomic field study was conducted at University of Limpopo Experimental farm, Syferkuil, over two summer growing seasons to determine the optimum phosphorus (P) rate and also assess the productivity of pigeonpea under intercrop with maize. Five P rates (0, 15, 30, 45, and 60 kg P ha-1) were evaluated under sole and intercropped pigeonpea. Treatments were laid out in a randomized complete block design with four replicates. Results revealed that variable P fertilizer rates exerted significant effect on pigeonpea grain yield in both seasons. Highest grain yields of 922 and 1141.7 kg ha-1 under sole and intercrop plots, respectively, were achieved at 45 kg P ha-1 during first and second seasons, respectively. However, the predicted optimum grain yield of 734 and 1034 kg ha-1 based on the response model was achieved at 52.67 kg P ha-1 and 42.84 kg P ha-1, in the respective seasons. Intercropping achieved a significantly higher pigeonpea grain yield (+37%) during second year than sole cropping following P addition; with over 21% mean grain yield advantage across the two planting seasons. Hence, depending on the inherent soil-P level, application of 42-53 kg P ha-1 under pigeonpea/maize intercrop represents the range at which P is optimum for maximum pigeonpea grain yield and better returns for farmers.

Keywords: Grain legume; Intercropping; Pigeonpea P rate; Sole; Season.

1. Introduction

Intercropping of legumes with cereals is an age-long practice, particularly among rural smallholder (SH) farmers. The practice is often employed for the purpose of economizing inorganic nitrogen (N) fertilizer use thereby increasing and sustaining productivity and profitability per unit area [1]. In South Africa, numerous cereal/legume intercrop trials have been reported by different authors. Such studies include maize (Zea mays) and pigeonpea (Cajanus cajan) intercropping systems in Mpumalanga [2], maize and cowpea intercrop [3], and maize and drybean intercrops [4, 5]. However, the successes of such intercrop studies have largely depended on the compatibility of the component crops to lessen the negative effects of shading and competition for resources. Moisture stress is one likely adverse effect of cereal/legume intercropping in dry land areas typical of Limpopo Province as most SH farmers that practice this system often operate on marginal lands in low rainfall areas. Plant available soil phosphorus (P) level in many soils is also low and constitutes major constraint to crop production, which is particularly worse with grain legumes [6].

In Eastern and Southern Africa, pigeonpea is becoming increasingly important in SH farming systems partly due to its ability to produce food grain under harsh conditions of moisture stress, high temperatures and infertile soils [7]. Its drought tolerant, deep rooted and slow-growing attributes [8] represent unique characteristics that could potentially increase the crop's adaptation and suitability for successful intercropping with maize in low rainfall areas typical of most parts of South Africa. Available literature suggests that there is abundant regional and international market for both whole grain and a range of processed pigeonpea products within Eastern and Southern Africa [9]. In addition, the reduction in incidences of insect pest attack on legumes intercropped with cereals [10] constitutes the impetus for promoting maize/pigeonpea intercropping among resource-poor SH farmers. However, highly limited agronomic research work has been reported in South Africa on the crop despite its adaptation to drought conditions, its high nutritional value and the evidence of its increased cultivation by resource-poor farmers [2]. Yet, pigeonpea is

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reported to have valuable medicinal properties [11] and its seeds have been used for the treatment of a wide range of ailments such as skin, liver, lungs, and kidney diseases [12].

The high P demand of most leguminous crops coupled with the complex chemistry of P in many soils due to the high P fixation, low cation exchange capacity and excessive leaching losses of basic cations and low organic carbon content, often result in P deficiency on most croplands. Moreover, the sensitivity of legumes to P-deficiencies in low P soils during biological nitrogen (N) fixation has been reported to significantly decrease plant biomass, plant P uptake, average leaf area and the photosynthetic activity of pigeonpea genotypes [13]. On the other hand, optimum fresh and dry shoot weights, plant water content, and shoot height have been reported when 0.1 g P/pot representing 39 kg P/ha was applied to pigeonpea under sole planting [14]. The objectives of the study were to determine the optimum P level and assess the productivity of pigeonpea under the dry land intercropping system.

2. Materials and Methods

2.1. Description of Experimental Site

A 2-year agronomic field trial was conducted at University of Limpopo Experimental farm, Syferkuil (23°51'S, 29°42'E, 1250 masl) during the 2009/2010 and 2010/2011 growing seasons. The soil at Syferkuil belongs to Hutton soil form according to South Africa soil classification system and to Rhodic Ferralsol as per the World Reference classification system [15]. Maize had been previously cultivated on the site. Details of physical and chemical properties of the surface (0-15 cm) and sub-surface (15-30 cm) soil samples collected from the trial site prior to planting are given in Table 1. Soil pH was determined in soil: water ratio of 1:2.5 as described by Eckert [16] while total N was determined by macro-Kjeldahl digestion method as described by Bremner [17]. Available P was extracted using Bray1 extractable P as described by Kuo [18] and read on Atomic absorption spectrophotometer (AAS). Percentage organic carbon was determined by Walkley-Black (WB) method as described by Jackson [19] while K, Mg and Ca was extracted using ammonium acetate (1N) as described by Chapman [20] and read on atomic absorption spectrophotometer. Soils at the trial site are generally low in soil carbon and available P content. Potassium level was considerably high on the trial site. Mean average summer day temperature at Syferkuil varies from 28 to 30°C while the area receives mean annual rainfall that ranges between 400 and 600 mm (Figures 1 and 2).

2.2. Experimental Design, Treatments and Layout

The experiment comprised of two treatment factors namely: i) Cropping system that consisted of sole pigeon pea (C1), Intercropping (C2), and ii) Inorganic P fertilizer rates applied at 0, 15, 30, 45 and 60 kg ha-1 and designated as P1, P2, P3, P4 and P5, respectively. Treatment factors were combined and laid out as a 2×5 factorial arrangement fitted into a randomised complete block design with 4 replications. Pigeonpea variety ICPL 87091 and Maize hybrid SNK 2147 seeds were used in the experiment. Inter and intra row spacing of 60 cm X 15 cm sole pigeonpea and 90 cm X 25 cm for sole maize. However, inter-row spacing of 90 cm for both crops was used under intercrop plots. Pigeonpea and maize seeds were sown manually and simultaneously during 2009/2010 and 2010/2011 summer growing seasons. Sole pigeonpea plot had 6 rows of 5 m length while intercrop plots of pigeonpea had 3 rows and each planted between 2 maize rows. All P fertilizer treatments were band placed at planting using single superphosphate (10.5% P). The gross plot size for both sole and intercropped pigeonpea was 18m2 while the net plot size that was used for the estimation of pigeonpea yields under sole and intercropped was 3.6 m2 and 2.7 m2, respectively. Thus the net plot represented 2 central rows x 3 m and the only central row x 3 m under sole and intercrop plots, respectively.

2.3. Cultural Practices

Experimental plots were kept nearly weed-free by hand hoeing while the trial was similarly fully protected from pest attack by spraying with 50% malathion. The plots received 4 mm irrigation immediately after seed sowing to facilitate good establishment and thereafter the plots received only natural precipitation.

2.4. Pigeonpea Growth and Yield Analysis

Plant density, number of branches per plant, plant height and were used to assess growth performance of pigeonpea at harvest maturity. Leaf chlorophyll content as part of growth performance parameter was assessed at flowering stage. Aboveground biomass, number of pods per plant, number of seeds per pod, pod length, 100-seed weight and grain yield were parameters used for yield analysis at harvesting maturity. In addition, harvest index (HI) was computed as the ratio of seed yield to total above-ground dry matter. Land equivalent ratio (LER) - the land equivalent ratio (LER) value, which measures the productivity of the intercrop system, was calculated using the equation:

LER=PLERM +PLERP

PLERM = YIM/YSM; PLERP=YIP/YSP

where, PLERM = partial LER for maize, YIM = grain yield per unit area of intercropped maize, YSM = grain yield per unit area of sole crop maize and PLERP=partial LER for pigeonpea, YIP= grain yield per unit area of intercropped pigeonpea, YSP= grain yield per unit area of sole crop pigeonpea [21].

2.5. Statistical Analysis

Growth and yield data generated were subjected to Analysis of Variance using Statistix 9.0 version [22]. The response of pigeonpea to variable P rates under both cropping systems was done through a quadratic model that was fitted into a grain yield data to determine the optimum P level for maximum pigeonpea production. The value of Y in the quadratic equation represents the grain yield data, 'a' is the intercept, b is the coefficient of the quadratic equation, and 'X' is the application rates. The value of X was optimized using the equation X = –b1/2b2 as cited by Masowa, *et al.* [23]. The fitting of the grain yield data to the quadratic model as well as the optimization of P fertilizer application rate were performed by means of an Excel program. Monetary value evaluation was performed to estimate the gross income on pigeonpea at each P fertilizer rate as described by Govindan [24] and also establish the economic advantage or profitability of pigeonpea/maize intercropping. Pigeonpea market grain price per ton of R 4625 and R 4989, respectively in 2009/10 and 2010/11 was used [24]. Thus, the economic advantage of each of the P fertilizer rate was determined using monetary advantage index. Monetary advantage index (MAI) was calculated according to Ghosh [25] as:

MAI = (monetary value of combined intercrops) x (LER- 1)/ LER

where LER implies Land equivalent ratio.

Higher MAI value denotes greater profitability of the cropping system [25].

3. Results and Discussion

3.1. Effect of P Rates and Cropping System on Measured Pigeonpea Growth Parameters

Plant density, plant height, branches per plant and chlorophyll content did not show any response to P application during both years of planting (Table 2). Nevertheless, variation in cropping systems exerted a significant effect on the plant density and plant height only during 2009/10 planting. Pigeonpea plant density was significantly higher under sole than under intercrop plots while significantly taller pigeonpea plants were observed under intercrop plots during the 2009/10 season (Table 2). The shorter plants observed in sole plots during 2009/10 season might be ascribed to intensification of intra plant competition for growth factors (light, water and soil nutrients). Results obtained in the present study contradict earlier findings by Tejpal and Mahendra [26] who reported that intercropping pigeonpea with maize significantly decreased the growth parameters of pigeonpea such as plant height and leaf area index.

Although the effect of increase in P application rates on plant height in 2009/10 was not significant in both sole and intercrop plots, the interaction between cropping system and P rates gave a significant effect (Table 3). Among the different P fertilizer rates, the 60 and 30 kg ha-1 produced the tallest pigeonpea plants under sole and intercropped plots, respectively. The mean number of branches produced per plant under sole pigeonpea plots was highest at 15 kg P ha-1 fertilizer rate but was least under intercropped plots (Table 3). The interaction between P rate and cropping system, as well as the increase in rates of P application, on the mean number of branches produced per plant under both sole and intercrop plots was not significant (Table 3). The trend of response of pigeonpea leaf chlorophyll content to P rate was neither consistent nor significant within the two cropping systems. However, statistically the cropping system × P rates interaction exhibited significant effect on the leaf chlorophyll content in both years of planting but with slightly lower leaf chlorophyll content under intercrop plots compared to sole plots (Table 3).

3.2. Effect of P Rates and Cropping System on Measured Pigeonpea Grain Yield and Yield Attributes

Pigeonpea grain yield increased with increased in P fertilizer rate up to 45 kg P ha-1 in both summer planting seasons with a generally higher increases under intercrop than in sole crop in both seasons (Table 4). Highest grain yields of 781 and 894 kg ha-1 were achieved at 45 kg P ha-1 in both seasons. This increase may be due to increase in N fixation as influenced by P application. Some study revealed that the amount of N2 fixed by soybean increased by 49.39 and 69.82 % when 22.5 and 45 kg P2O5 ha-1 was applied, respectively over the control Abdul-Aziz [27]. Stephen, *et al.* [28] also reported increase in nodulation and nutrient uptake by pigeon pea when P rates ranging from 25-75 kg ha-1 were applied. The application of 45 kg P ha-1 rate in the current study achieved approximately 166 % and 91% higher grain yield advantage than the control plot in 2009/10 and 2010/11, respectively. The application of P may have promoted more extensive and deeper root system thus serve as enabler for the crop to extract the water from deeper soil layers which may be out of reach of the unfertilized crop due to its shallower root growth. However, the sharp decrease in percent increase in yield during 2010/11 might be due to early planting that favoured the growth and the yield of both treated plots and control plots. Adu-Gyamfi, *et al.* [29] reported a significant increment in dinitrogen fixation in pigeonpea cultivars due to the increase in P application rate. Srinivasan and Ahlawat [30] also noticed increases in pigeonpea grain yield of 29.5, 45.1 and 47.9%, over the control following application of 30, 60 and 90 kg P ha-1, respectively. Similarly, Janboonme, *et al.* [31] reported grain yield increases in pigeonpea from 1.56 to 1.83 t ha-1 with 37, 56 and 75 kg P ha-1 application. The results obtained from the present study contradict the findings by Ansari, *et al.* [32] who reported lower pigeonpea yield (0.61 t/ha) under intercrop than sole (1.52 t/ha) plot. Moreover, Mathews, *et al.* [33] reported higher grain yield of 1379 kg ha-1 under sole plots compared to 891 kg ha-1 under intercrop plots with maize. The decline in the number of pods per plant, dry pod weight and grain yield of intercropped pigeonpea as compared to its sole crop might also have resulted from inter- and intra- specific competition for plant growth resources.

Grain yield obtained from the second year planting season as influenced by P rate application was 21.83% higher than the first year of planting. The huge variation in grain yield between the two planting seasons could be due to the late planting following delayed rainfall in the first year of planting and also limited, poor rainfall distribution during the growing season that resulted into flower abortion and poor pod filling. Earlier study conducted at Chitedze Agricultural Research Station, Malawi showed that two pigeonpea varieties gave extreme low grain yield (mean range of 3-227 kg/ ha) of pigeon pea due to late planting that resulted into flower abortion and poor pod filling [34]. In addition, maximum grain yield of 734 and 1034 kg ha-1 were achieved at optimum rates of 52.67 kg P ha-1 and 42.84 kg P ha-1 during 2009/10 and 2010/11 seasons, respectively (Table 5). The quality of data generated in this study, particularly in the first season, seems to have been compromised by late planting which was done around January and considerable gap filling as a result of bird damage. However, the second year planting of the trial was done much earlier and scaring of birds performed thus improving the uniformity of plant stands on the field. Mathews and Saxena [2] reported that late planting of the medium to long duration pigeonpea varieties after December in South Africa could result in smaller canopies and lower yields. Grain yield during 2010/11 followed the same trend with 2009/10 but it was higher probably due to better rainfall distribution and earlier planting. The decrease in yield parameters under low P in both cropping systems may be due to the negative effect of low soil P on the ability of nodules to fix N (Table 6). Tsvetkova and Georgiev [35] reported that P deficiency decreased the whole plant fresh and dry mass, nodule weight and number, and general functioning of a soybean plant.

In the present study, the highest pigeonpea grain yield of 922 kg ha-1 was achieved under sole plot at 45 P kg ha-1 in 2009/10 but the same 45 kg P ha-1 fertilizer rate gave the highest grain yield of 1141.7 kg ha-1 under intercrop in 2010/11 season (Figures 4 and 5). The highest number of pods per plant was obtained under sole plots at 60 kg P ha-1 application rate during 2009/10 (Table 6) while P increases up to 45 kg ha-1 similarly led to increase in the mean number of pods per plant under intercrop (Figure 3). Yakubu, *et al.* [36] observed 153, 288 and 378 % increment, respectively in the number of nodules, N content in the plant tissue and amount of N fixed in cowpea following application of 40 kg P ha-1 compared to the unfertilized control. Increased yield due to P application in the present study could thus have been achieved through increased nodulation.

The responses of the number of pods per plant and total aboveground biomass to incremental P application rates during the 2-year planting seasons were not consistent. Lingaraju, *et al.* [1] reported a reduction in pigeonpea dry matter production, number of pods per plant and grain weight per plant due to intercropping. The lower number of pods per plant in plots without P fertilizer application as observed during the first planting season in this study might be ascribed to low inherent soil P on the experimental site. Fujita, *et al.* [13] reported a reduction of photosynthetic rate under low soil P (10 kg P ha−1) condition among three pigeonpea cultivars that included one hybrid (ICPH 8) and two non-hybrid cultivars (ICPL 87 and UPAS 120).

Results revealed that reduction in whole plant weight under low soil P was least with ICPH 8 but largest with UPAS 120 suggesting tolerance to low P in the improved hybrid cultivar. However, the increase in P rate up to 60 kg ha-1 in the current study resulted in an increase in the mean number of pods per plant under sole plots while P increases up to 45 kg ha-1 similarly led to an increase in the number of pods per plant in the intercrop plots The highest number of pods per plant was observed with 60 kg P ha-1 under sole plots and 45 kg P ha-1 under intercropping during 2009/10 (Table 6).

Phosphorus enhances symbiotic N fixation process in legumes [37]. The yields of pigeonpea under intercrop were generally higher than in sole crop in both seasons (Table 4). The inconsistency in the grain yield of pigeonpea obtained in both sole and intercrop plots may be due to sporadic rainfall patterns. The results obtained from the present study contradict the findings by Ansari, *et al.* [32] who reported lower pigeonpea yield (0.61 t ha-1) under intercrop than sole (1.52 t ha-1) plot. Moreover, Mathews, *et al.* [38] reported higher grain yield of 1379 kg ha-1 under sole plots compared to 891 kg ha-1 under intercrop plots with maize. The decline in the number of pods per plant, dry pod weight and grain yield of intercropped pigeonpea as compared to its sole crop might also have resulted from inter- and intra- specific competition for plant growth resources. In the present study the maize plants were quite short in the first season and could thus have offered little competition to the pigeonpea.

3.3. Assessment of Productivity and Profitability of Pigeonpea Intercropping System

In the current study, application of 30 kg P ha-1 fertilizer rate produced the highest PLER for pigeonpea in the first year of planting while the 45 kg P ha-1 recorded the highest PLER during the second year of planting. The mean for LERT across the 2-year planting seasons was 2.37 (Table 7) indicating that intercropping had 137% yield advantage over sole cropping system. Thus, the yield advantage was obtained due to increase P rates application to pigeonpea. Exceptionally high LERT obtained in this study may be due to P applied to pigeonpea that benefitted maize crop in intercrop plots compared to unfertilized sole maize. In addition, the partial LER values that were greater than one for pigeonpea in the intercropped plots suggest positive interactions between pigeonpea and maize in the use of available resources. Marer [39] stated that large yield advantage in intercropping system is due to the component crops that differed in their use of natural resources and utilized them more efficiently resulting in higher yields per unit area than that produced by their sole crops. In addition Pigeonpea crop in terms of grain yield showed favourable response up to 52.67 and 42.84 kg P ha-1 during 2009/10 and 2010/11, respectively.

The calculated monetary value obtained from sole pigeonpea plot was higher than the value obtained from intercropped plots during the first year of planting while the intercropped pigeonpea had greater value during the second year. These first season results contradict an earlier study by Anonymous [40] who reported higher yield and net return of pigeonpea from pigeonpea/maize intercrop than sole pigeonpea. This may be attributed to maize replanting during the first year of planting (2009/2010) following bird damage, which resulted in the shading effect on pigeonpea with prolonged maize growth period and consequently reduced sunlight interception to the pigeonpea. MAI was significant different as influenced by P rate during both seasons. The highest MAI values during 2009/10 season (R2263.09) and 2010/11 season (R3248.04) were obtained at 60kg P ha-1 and 45 kg P ha-1, respectively under intercropped while the minimum value of R636.77 and R1153.46 during 2009/10 and 2010/11, respectively were obtained from unfertilized control plot (Table 8).

4. Conclusion

Based on the results obtained from the 2-years field study the following conclusions are drawn:

- The findings underpin the necessity of higher fertilizer P addition to pigeonpea for optimal yields, particularly in P deficient soils. The competition indices revealed a significant advantage from P rates treatment plots than control plots.
- Among the P rates evaluated, the 45 kg P ha-1 was more productive and profitable under both intercrop and sole pigeonpea.
- The calculated values of the monetary advantage index were positive suggesting grain yield advantage.

5. Future Line of Work

- It is recommended that other pigeonpea varieties, preferably with shorter growth duration, be tested to check their response to lower P application rates since the current study only used one medium pigeonpea variety.
- It may also be beneficial to intercrop pigeonpea with shorter duration maize so as to reduce competition for growth factors during grain filling in pigeonpea.
- There is also need to monitor the nodulation patterns in future P trials on pigeonpea so as to assess the response to biological nitrogen fixation.
- Early planting of short season varieties of pigeonpea is necessary under Syferkuil conditions.

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Appendix

Table-1. Soil physical and chemical properties at test sites in the 2009/10 and 2010/11 growing seasons

Planting season	Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	pH	TN (g/kg)	OC (%)	Bray P1 (mg/kg)	Exchangeable K (mg/kg)	Extractable Zn (mg/kg)	S-value (mg/kg)
2009/10	0-15	26.2	70.0	3.8	Sandy loam	6.67	4.26	0.24	2.8	220	2.64	6.182
	15-20	19.6	73.8	6.6	Sandy loam	6.61	3.43	0.98	3.1	103	2.48	5.774
2010/11	0-15	30.0	57.5	12.5	Sandy loam	6.63	3.89	0.26	3.0	155	2.76	6.490
	15-20	24.8	68.6	6.6	Sandy loam	6.67	4.21	1.27	3.4	115	2.84	7.369

TN-total nitrogen, OC- organic carbon, S-value represents the calculated CEC value

Table-2. Growth parameters of pigeonpea as influenced by cropping system and P application rates during the 2 years planting seasons

Treatments	Plant density (plants m^{-2})			Plant height (m)			No. of branches $plant^{-1}$			Leaf chlorophyll content (cci)		
	2009/10	2010/11	Mean	2009/10	2010/11	Mean	2009/10	2010/11	Mean	2009/10	2010/11	Mean
P rates												
0	8.1^{a}	9.7^{a}	8.9	0.96^{a}	0.91^{a}	0.94	11.5^{a}	10.1^{a}	10.8	107.4^{a}	102.4^{a}	104.9
15	8.5^{a}	9.4^{a}	9.0	0.94^{a}	0.90^{a}	0.92	10.8^{a}	10.1^{a}	10.5	93.8^{a}	97.0^{a}	95.4
30	9.5^{a}	9.8^{a}	9.7	0.99^{a}	0.89^{a}	0.94	10.9^{a}	10.3^{a}	10.6	89.3^{a}	97.9^{a}	93.6
45	9.7^{a}	9.4^{a}	9.6	0.98^{a}	0.91^{a}	0.95	10.9^{a}	10.0^{a}	10.5	90.6^{a}	94.7^{a}	92.7
60	9.7^{a}	9.6^{a}	9.7	1.01^{a}	0.89^{a}	0.95	10.8^{a}	9.9^{a}	10.4	94.2^{a}	97.1^{a}	95.7
p-value	ns	ns		ns	ns		ns	ns		ns	ns	
Cropping systems												
Sole	10.5^{a}	9.3^{a}	8.7	0.80^{b}	0.88^{a}	0.84	10.1^{a}	11.5^{a}	10.8	96.7^{a}	99.1^{a}	97.9
Intercrop	8.1^{b}	9.9^{a}	10.2	1.15^{a}	0.93^{a}	1.04	10.1^{a}	8.7^{b}	9.4	93.4^{a}	95.7^{a}	94.6
p-value	***	ns		*	ns		ns	*		ns	ns	

Means followed by different letter in a column are significantly at P≤ 0.05, ns=not significant, *, and *** indicate significance at 5 and 0.01% probability, respectively

Table-3. Cropping system × P application rate interaction effect on plant density, plant height, number of branches and leaf chlorophyll content

Cropping system	P rates (kg ha^{-1})	2009/10			2010/11	
		Plant density (m^{-2})	Plant height (m)	Chlorophyll content (cci)	No branches $plant^{-1}$	Chlorophyll content (cci)
Sole	0	8.1^{bc}	0.73^{c}	109.5^{a}	11.3^{abc}	106.6^{a}
	15	7.8^{c}	0.75^{bc}	97.9^{ab}	13.3^{a}	100.6^{ab}
	30	8.2^{abc}	0.80^{bc}	102.0^{ab}	10.8^{bcd}	101.7^{ab}
	45	7.1^{bc}	0.83^{bc}	86.8^{ab}	10.5^{bcd}	95.5^{ab}
	60	8.3^{abc}	0.90^{b}	87.1^{ab}	11.8^{ab}	95.6^{ab}
Intercropping	0	9.9^{abc}	1.20^{a}	105.2^{a}	9.0^{def}	98.2^{ab}
	15	9.2^{abc}	1.13^{a}	89.6^{ab}	7.0^{f}	93.5^{b}
	30	10.8^{abc}	1.18^{a}	76.6^{b}	9.8^{bcde}	94.1^{b}
	45	11.5^{a}	1.13^{a}	94.4^{ab}	9.5^{cde}	93.9^{b}
	60	11.1^{ab}	1.13^{a}	101.4^{ab}	8.5^{ef}	98.7^{ab}
P value		***	***	*	***	*

Means followed by different letter in a column are significantly at P≤ 0.05, ns=not significant, *, and *** indicate significance at 5 and 0.01% probability, respectively

Table-4. Yield and yield components of pigeonpea as influenced by cropping system and P application rates in 2009/10 2010/11 seasons

Treatments	Aboveground biomass (kg ha^{-1})			No. pods plant^{-1}			100-seed weight			Grain yield (kg ha^{-1})			Monetary value (R ha^{-1})			HI (%)		
	2009/10	2010/11	Mean	2009/10	2010/11	Mean	2009/10	2010/11	Mean	2009/10	2010/11	Mean	2009/10	2010/11	Mean	2009/10	2010/11	Mean
P rates																		
0	3493^{a}	1424^{b}	2459	19.1^{d}	35.5^{a}	27.3	9.64^{a}	9.81^{a}	9.73	294^{d}	467^{d}	381	1360^{d}	2328^{d}	1844	9.3^{b}	33.2^{ab}	21.3
15	3219^{a}	1906^{b}	2563	25.2^{c}	30.2^{a}	27.7	9.64^{a}	10.43^{a}	10.04	392^{c}	609^{c}	501	1814^{c}	3037^{c}	2426	12.7^{b}	32.4^{ab}	22.6
30	3491^{a}	2033^{b}	2762	32.6^{b}	30.5^{a}	31.55	10.53^{a}	10.63^{a}	10.58	502^{b}	768^{b}	635	2322^{b}	3831^{b}	3077	15.1^{ab}	37.9^{a}	26.5
45	3693^{a}	3348^{a}	3521	39.6^{a}	32.8^{a}	36.2	10.04^{a}	10.03^{a}	10.04	781^{a}	894^{a}	838	3613^{a}	4461^{a}	4037	23.0^{a}	28.2^{bc}	25.6
60	3900^{a}	3221^{a}	3561	40.1^{a}	31.9^{a}	36.0	10.56^{a}	10.00^{a}	10.28	733^{a}	721^{b}	727	3394^{a}	3597^{b}	3496	21.4^{a}	23.6^{c}	22.5
p-value	ns	***		***	ns		ns	ns		***	***		***	***		***	***	
Cropping systems																		
Sole	3351^{a}	1886^{b}	2618	31.5^{a}	30.6^{a}	31.1	10.30^{a}	9.20^{b}	10.3	543^{a}	534^{b}	539	2665^{b}	2665^{b}	2665	16.48^{a}	31.3^{a}	23.9
Intercrop	3769^{a}	2887^{a}	3328	31.4^{a}	33.8^{a}	32.6	9.90^{a}	11.16^{a}	9.9	538^{a}	849^{a}	694	4236^{a}	4236^{a}	4236	16.13^{a}	30.8^{a}	23.5
p-value	ns	***		ns	ns		ns	*		ns	***		***	***		ns	ns	

Means followed by different letter in a column are significantly at P≤ 0.05, ns=not significant, *, and *** indicate significant at 5 and 0.01% probability, respectively

Table -5. Quadratic equation of the grain yield parameter with the cropping system as independent variable and the corresponding R2 values of the equation

Cropping system	Season	Regression equation	X	Y-value	R^2 value	P
Sole	2009/10	$-0.1985x^2 + 20.909x + 183.83$	52.67	734.44	0.7543	0.0000
	2010/11	$-0.12x^2 + 10.04x + 395.4$	41.83	605.40	0.884	0.0000
Intercropping	2009/10	$0.1211x^2 + 0.6492x + 355.35$	-2.68	354.48	0.969	0.0000
	2010/11	$-0.3013x^2 + 25.815x + 481.42$	42.84	1034.37	0.8672	0.0000

Table-6. Interaction effects of P rate and cropping system on the yield and yield components of pigeonpea in 2009/10 and 2010/11 seasons

Cropping system	Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	No pods plant^{-1}	100 seed weight (g)	Grain yield (kg ha^{-1})		Monetary value (R ha^{-1})	
					2009/10	2010/11	2009/10	2010/11
Sole	0	3077^{a}	20.1^{e}	10.63^{a}	249^{f}	397^{e}	1156^{f}	1978^{f}
	15	2789^{a}	24.8^{d}	9.00^{a}	343^{e}	529^{d}	1587^{e}	2637^{e}
	30	3810^{a}	32.7^{c}	10.68^{a}	565^{c}	549^{d}	2615^{c}	2737^{e}
	45	3994^{a}	37.8^{b}	10.15^{a}	922^{a}	647^{cd}	4264^{a}	3226^{d}
	60	3083^{a}	42.4^{a}	11.10^{a}	635^{c}	551^{d}	2938^{c}	2751^{e}
Intercropping	0	3909^{a}	19.9^{e}	8.65^{a}	338^{e}	537.0^{d}	1565^{e}	2679.2^{e}
	15	3651^{a}	25.5^{d}	10.28^{a}	441^{d}	688.9^{c}	2041^{d}	3436.8^{d}
	30	3172^{a}	32.6^{c}	10.38^{a}	439^{d}	987.0^{b}	2030^{d}	4924.2^{b}
	45	3393^{a}	41.4^{a}	9.93^{a}	641^{c}	1141.7^{a}	2962^{c}	5695.7^{a}
	60	4718^{a}	37.8^{b}	10.03^{a}	832^{b}	890.7^{b}	3849^{b}	4443.8^{c}
P value		ns	*	ns	***	***	***	***

Means followed by different letter in a column are significantly at P≤ 0.05, ns=not significant, *, and *** indicate significance at 5 and 0.01% probability, respectively

Table-7. Partial and total LER for the component crops under intercrop as affected by the different phosphorus fertilizer rates

P rates (kg ha^{-1})	2009/10				2010/11		
	$PLER_M$	$PLER_{PP}$	LER_T		$PLER_M$	$PLER_{PP}$	LER_T
0	0.863	0.823	1.686		0.779	0.977	1.756
15	1.686	0.784	2.47		0.804	1.0247	1.8287
30	1.656	2.046	3.702		0.874	1.145	2.019
45	1.671	1.675	3.346		0.889	1.438	2.327
60	1.324	1.103	2.427		0.941	1.231	2.172
Mean	1.440^{a}	1.286^{a}	2.726^{a}		0.857^{b}	1.165^{a}	2.02^{b}
Seasons							
SEM	0.115	0.117	0.119				
Prob 0.05	0.004	ns	0.018				

P = phosphorus, $PLER_M$ = partial land equivalent ratio for maize, $PLER_{PP}$ = partial land equivalent ratio for pigeonpea, LER_T=total land equivalent ratio, SEM= standard error of mean

Table-8. Monetary value, total land equivalent ratio, monetary advantage index of pigeonpea-based intercropping system as influenced by P rate during 2009/10 and 2010/11 season

Phosphorus rates (kg ha^{-1})	Monetary value (R/ton)		Total land equivalent ratio		monetary advantage index	
	2009/10	2010/11	2009/10	2010/11	2009/10	2010/11
Sole						
0	1156^{f}	1978^{f}	-	-	-	-
15	1587^{e}	2637^{e}	-	-	-	-
30	2615^{c}	2737^{e}	-	-	-	-
45	4264^{a}	3226^{d}	-	-	-	-
60	2938^{c}	2751^{e}	-	-	-	-
Intercropping						
0	1565^{e}	2679.2^{e}	1.686	1.756	636.77^{d}	1153.46
15	2041^{d}	3436.8^{d}	2.470	1.829	1214.69^{bc}	1557.43
30	2030^{d}	4924.2^{b}	3.702	2.019	1481.65^{b}	2485.27
45	2962^{c}	5695.7^{a}	3.346	2.327	2076.76^{ab}	3248.04
60	3849^{b}	4443.8^{c}	2.427	2.172	2263.09^{a}	2397.85

Figure-1. Monthly rainfall and mean monthly minimum and maximum temperature during the 2009/10 growing season at Syferkuil.

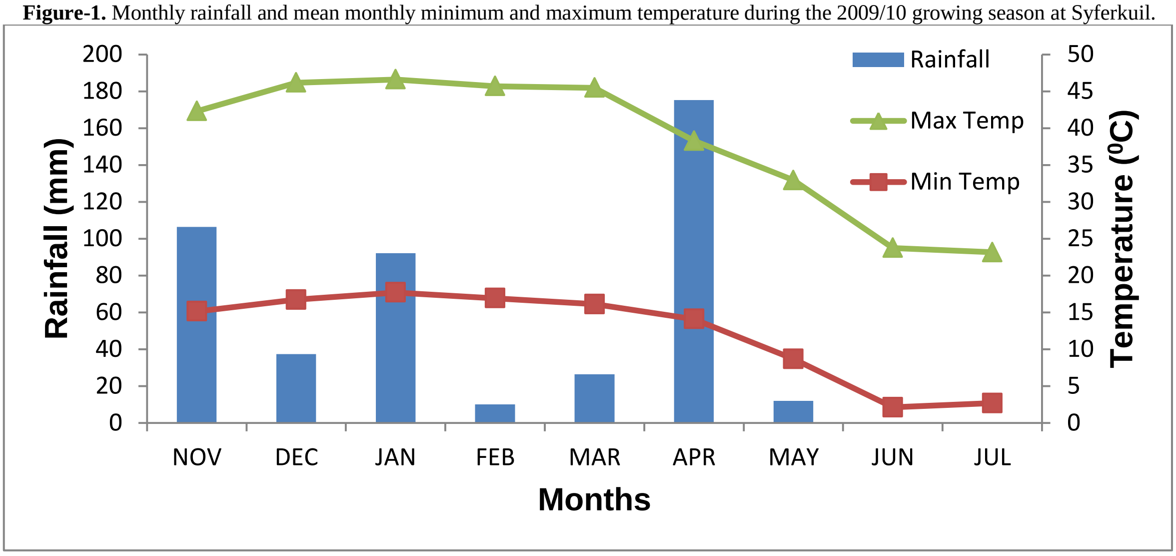

Figure-2. Monthly rainfall and mean monthly minimum and maximum temperature during the 2010/11 growing season at Syferkuil.

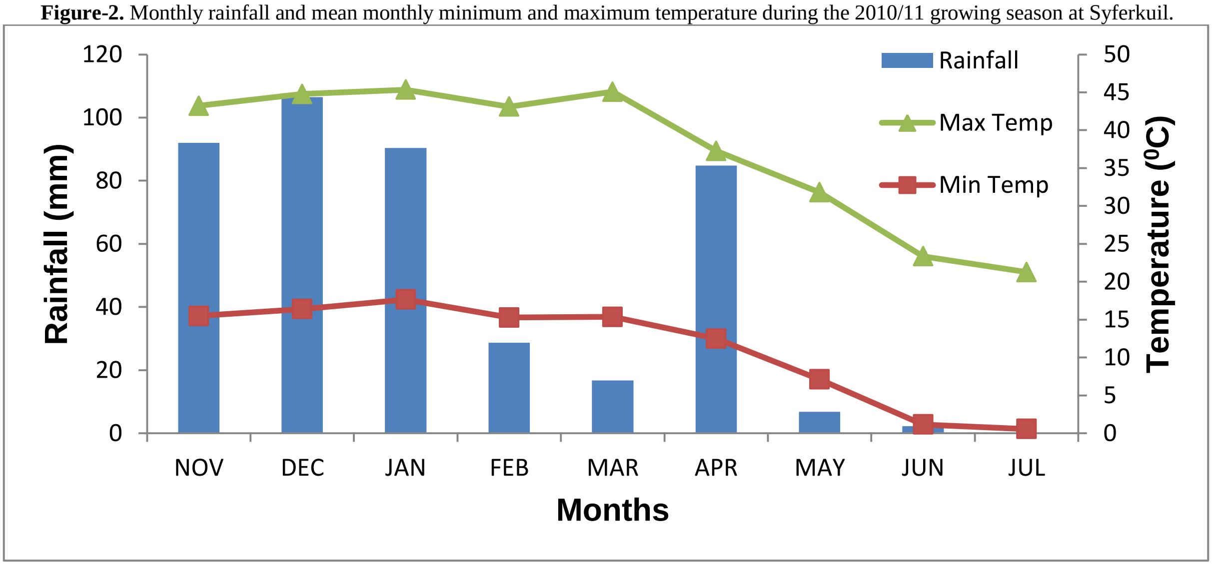

Figure-3. Number of pods per plant of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10 season

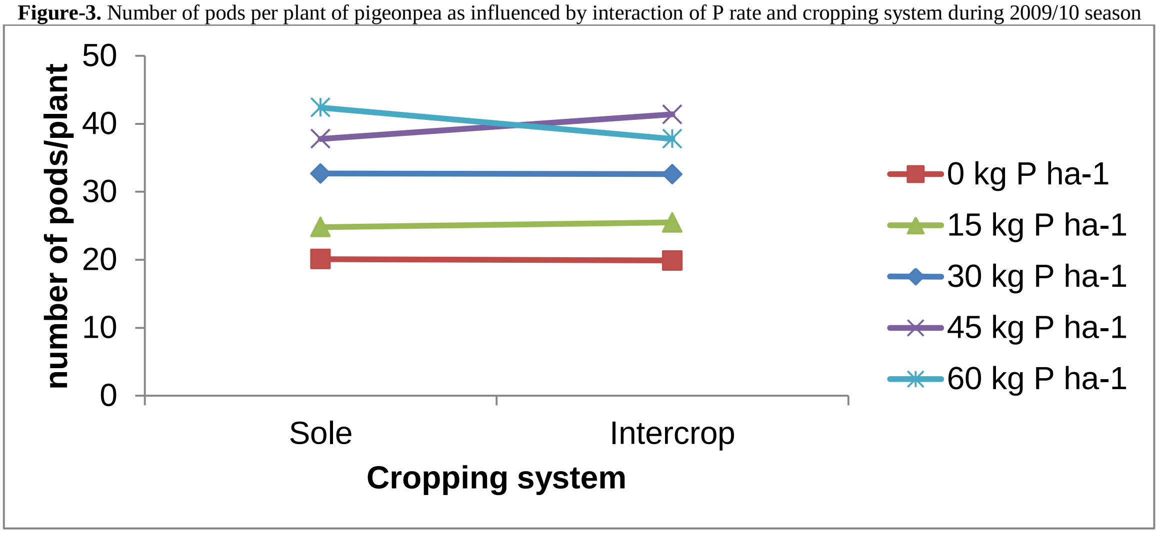

Figure-4. Grain yield of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10 season

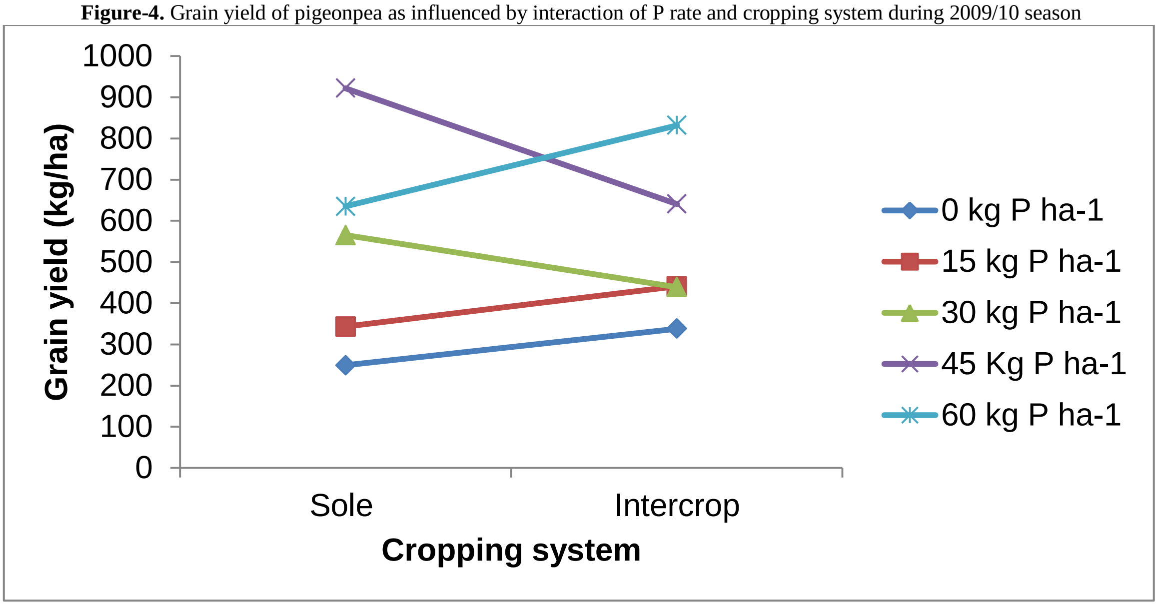

Figure-5. Grain yield of pigeonpea as influenced by interaction of P rate and cropping system during 2010/11season