Der Tropenlandwirt, Beiträge zur tropischen Landwirtschaft und Veterinärmedizin,
97. Jahrgang, April 1996, S. 17 - 28.

Chickpea and Lentil Varietal Response to Phosphorus Supply

T. Mamo* and C. Richter**

1 Introduction

Chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medic.) are important leguminous crops which are used for food, feed, and forage in the arid and semi arid environment. The productivity of both crops is influenced by biotic and abiotic stresses; among the latter, soil phosphorus fertility is one of the important yield limiting factors of both crops.

Under Ethiopian conditions, both crops are mainly grown on dark clay soils, commonly known as Vertisols. These soils are representative of the dark clay soils found in excess of 12m ha in the country (JUTZI et al., 1986). Farmers traditionally plant both crops towards the end of the rainy season since yield is often reduced as a result of waterlogging. Consequently, the crops suffer from moisture stress towards the end of the growing season and yield is compromised. One recently implemented recommendation to improve the productivity of both crops has been the practice of early planting and the use of an animal-drawn broad-bed maker (BBM) to enhance drainage of excess water through the furrows (JUTZI et al., 1986; MAMO et al., 1993).

In the past, P fertilisation studies conducted on some central highland Vertisols involving chickpea or lentil did not result in improved yield of the crops under drained or undrained seedbed conditions (MAMO et al., 1993). The lack of response to P application on these soils which make up a good portion of the 70% of the P deficient agricultural soils in the country (BEYENE, 1982; MAMO and HAQUE, 1991) has been the subject of recent studies, including the standardisation of available P calibration methods (MAMO et al., 1995), and attempts to investigate whether breeding and selection have altered the phosphate requirement of both crop varieties.

Although varietal differences in response to P application have been identified in many other crops, our knowledge about the P utilisation of chickpea and lentil varieties is very limited. To date, many chickpea and lentil varieties have been selected and recommended by breeders to Ethiopian farmers, but the existing fertiliser recommendations do not take into account varietal differences, if any. This paper therefore dis-

---

* Dr. Tekalign Mamo, Alemaya University of Agriculture, Agricultural Research Center, P.O.Box 32, Debre Zeit, Ethiopia.

** Prof. Dr. Christian Richter (Author for Correspondence) Institut für Nutzpflanzenkunde, Gesamthochschule Universität Kassel, Steinstraße 19, 37213 Witzenhausen, Germany

cusses the results of a sand culture study conducted on the responses of four varieties each of chickpea and lentil to P application under controlled growth conditions.

2 Materials and Methods

Seeds of chickpea and lentil varieties (four in each case) were obtained from Debre Zeit Agricultural Research Center in Ethiopia, where improvement programs on both crops are being carried out. The chickpea varieties used in the studies were DZ-Local, Mariye, DZ-10-9-2 and DZ-10-16-2. Similarly, the four lentil varieties were R-186, NEL-358, EL-142 and NEL-2704. The chickpea variety DZ-Local and lentil variety EL-142, are varieties recommended through selection from landrace populations. All the other varieties are, however, improved through hybridisation and released varieties. All of the varieties are under production by farmers. Both experiments were carried out separately in a glasshouse which was maintained at a day/night temperature of 20/20°C, 50-70% relative humidity and 15 000 lux illumination for 12hrs a day.

The experiments were conducted using conventional plastic pots (4.5kg capacity; top and bottom diameters 15 and 11cm, respectively). Phosphorus levels were 0, 0.05,0.5 and 5mg P per 100g sand applied as $Ca(H_2PO_4)_2.H_2O$ in a solution form. The corresponding P level calculated for each P treatment was dissolved in 5l nutrient solution using magnetic stirrer and the final pH adjusted to 5 using dilute HCl and NH_4OH. The composition of the nutrient solution was the same as that used by HOPPENSTEDT (1991): 25, 1.5 and 1.0 mM l^{-1} of KNO_3, $MgSO_4.7H_2O$, and $CaCl_2.2H_2O$, respectively; and 1.5, 0.7, 0.32, 0.1 and 2.2μMl^{-1} corresponding to $MnSO_4.H_2O$, $ZnSO_4.7H_20$, $CuSO_4.5H_20$, $(NH_4)_6Mo_7O_{24}.4H_20$, and H_3BO_3, respectively; and 25 mg l^{-1} Fe chelate (sequestrene, 6% Fe).The final solution was thoroughly mixed with a measured quantity of sand (5l nutrient solution with 60kg fine sand) using electrical mixer. Each pot was then filled with 4.5kg of the moist sand. On the same day, uniform, pre-soaked and germinated seeds (24hrs) of each crop variety were sown (15 per pot and about 7cm deep) in the corresponding pot, and each pot covered with a saucer to avoid evaporation loss until germination. The pots were arranged in a Randomised Complete Block Design, with three replications. The plants were irrigated with phosphate free nutrient solution twice a week with intermittent supply of clean tap water as often as necessary. Plants were grown for 7 and 4 weeks (in the case of chickpea and lentil, respectively); the difference in length of growth period was due to the higher sensitivity of lentil to P deficiency in which plants stopped growth before reaching maturity.

Before the crops were harvested, total plant height was taken as the average height of the majority of plants per treatment. Plants were then harvested at the specified dates by cutting at the surface level and rinsed in distilled water to remove any contaminants. Roots were, however, rinsed several times to remove adhering sand particles. The plant parts were then put in paper bags and oven-dried at 70°C for 48hrs. Chickpea seeds were then separated from the pods and weighed. Similarly, the shoots and roots were also weighed before all samples were ground using a tecator plant mill. For P determination, 0.2g of the material was dry ashed at 550°C for 5hrs, dissolved with 10ml conc.

HCl, and then diluted with distilled water to 50ml. The P concentration was then read on an Hitachi 2000 Spectrophotometer after colour development by the yellow vanadomolybdate method. Data were analysed for statistical significance on a computer using the SAS package.

3 Results and Discussion

3.1 Chickpea growth and yield

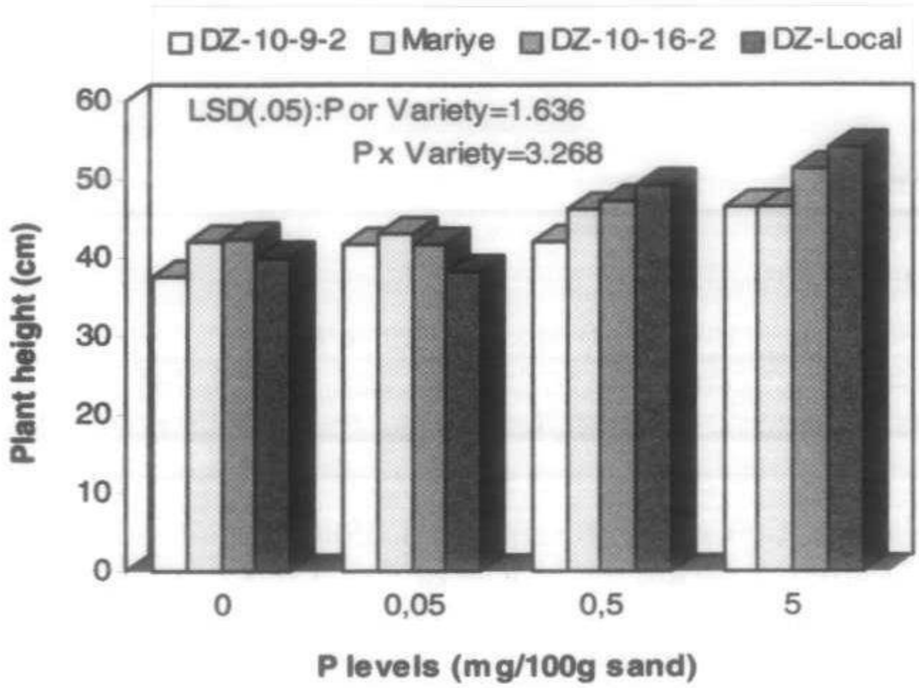
Plant height measurement taken at maturity was similar in three of the varieties except DZ-10-9-2, where it was significantly lower than the rest. Plant height increased as a function of P levels, but in general, height difference between the first two P levels was not significant (Fig. 1).

The variety by P level interaction was also significant ($P \leq 0.001$), thus showing differential responses of the varieties. In the traditional variety (DZ-Local) and the modern variety DZ-10-16-2, differences in plant heights between the control and the 0.05mg P application rates were not significant, while in variety Mariye, although plant height increased with increase in P levels, none of the differences were significant. In variety DZ-10-9-2, height measurements between the two middle P levels (0.05 and 0.5mg P/100g sand) were also similar.

Shoot and root dry weights were always higher in the three modern varieties than in the traditional one (Table 1). For both parameters, of the three modern varieties, variety Mariye produced the highest dry weight, while varieties DZ-10-9-2 and DZ-10-16-2 had similar weights. The effects of both treatment factors (P levels and varieties) on shoot and root dry weights were significant ($P \leq 0.001$); however, the interaction effects were only significant ($P \leq 0.01$) for shoot dry weight. On the other hand, unlike in the shoots where every increase in P level resulted in a significantly higher dry weight, in the roots, difference in dry weight between the last two higher P levels was not significant. In the shoots, in all varieties, dry weight increment between the control and the 0.05mg P treatments was also not significant.

Grain yield data (Table 1) also showed the significant ($P \leq 0.001$) effects of variety, P levels, and their interaction. Similar to the shoot and root dry weights, the highest grain yield was obtained from variety Mariye and the lowest from the traditional variety. The grain yield obtained from variety DZ-10-9-2 was not significantly different from that of the traditional variety. In varieties DZ-Local, Mariye, and DZ-10-16-2, grain yield differences between the control and the 0.05 mg P/100g application rates were not significant, while in variety DZ-10-9-2, yield obtained at every P level was significantly different from the other. In variety DZ-10-16-2, the yield difference between the last two higher P levels was also not significant.

Chickpea plant height



Lentil plant height

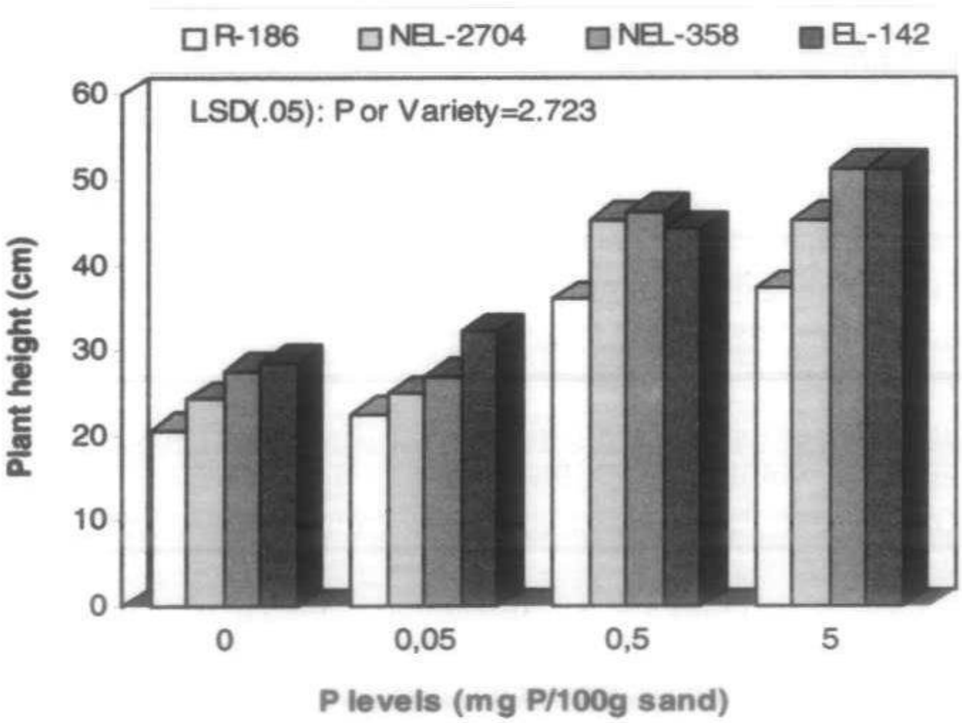


Fig. 1: Effect of P application levels on plant height of chickpea and lentil varieties

Table 1: Plant height (cm), shoot and root dry weight (g/15 plants) and grain yield (g/15 plants) of four chickpea varieties as influenced by P application (mg P/100 g sand).

	Shoot dry weight				**Root dry weight**				**Grain yield**			
Variety	0	0.05	0.5	5	0	0.05	0.5	5	0	0.05	0.5	5
DZ-Local	4.24	4.60	7.14	11.40	1.49	1.78	2.18	2.31	0.29	0.49	2.95	4.71
Mariye	8.34	9.05	10.50	13.41	2.65	2.90	3.12	2.92	2.08	2.40	3.21	3.75
DZ-10-9-2	6.58	7.72	11.03	13.82	2.35	2.60	2.90	2.80	0.80	1.32	2.81	4.09
DZ-10-16-2	6.90	7.54	10.09	14.36	2.38	2.50	2.90	2.84	1.42	1.74	3.46	3.49
LSD(.05) P or Variety	0.456				0.231				0.180			
P x Variety	3.269				NS				0.360			

The comparatively higher shoot and root dry weight and grain yield of variety Mariye over the others confirms earlier findings on the field. This variety is also the most popular among farmers, since it has bigger seeds, gives higher yields than the farmers` traditional varieties, and has wider adaptation; the word "Mariye" (meaning "my honey" in Amharic) is also a local name given to it by the local farmers, as a result of their appreciation of this variety. The two other varieties (DZ-10-9-2 and DZ-10-16-2) are recent releases; they also mature earlier than variety Mariye, but are not as wide spread as the other two.

In the past it has been reported (MAMO et al., 1993) that chickpea had poor response to P application on Vertisols low in available P content in central highlands of Ethiopia. The results of this study may partially answer the reason: the large seeded chickpea varieties contain some P that may help the plant in its initial establishment, and thereafter the plant utilises the available P in the soil through root exploration of large volume of soil, or excretion of exudates that solubilise the non-available P forms through the mechanisms explained by AE et al.(1990).

3.2 Chickpea P uptake

Shoot P uptake was comparatively higher in the three modern varieties and lower in the local variety, and increased with increase in P application (Table 2). The effects of variety, P level, and the interaction of both were all significant ($P \leq 0.001$). In all varieties, the difference in P uptake between the control and the 0.05mg P application rate was not significant. Shoot P uptake at all P levels of application was the lowest in the traditional variety, and this also corresponded with its lower shoot and root dry weights.

Root P uptake data (Table 2) showed that mean P uptake in the three modern varieties was similar, and at the same time was significantly higher than that in the local variety. Mean root P uptake generally increased with increase in P application, but the difference between the first two P levels was not significant; in addition, P in the roots was about one-fourth of that in the shoots. However, root P content as a function of P application changed with the variety (i.e. significant variety x P level interaction). In all varieties except Mariye, root P content at the first three P levels was similar; in the latter, however, only P content between the first two P levels remained significantly unchanged.

Table 2: Shoot, root and grain P uptake (mg/15 plants) of four chickpea varieties as influenced by P application (mg P/100g sand).

	Shoot P				Root P				Grain P			
Variety	0	0.05	0.5	5	0	0.05	0.5	5	0	0.05	0.5	5
DZ-Local	2.5	3.0	8.1	40.1	1.3	1.6	2.1	8.5	1.6	1.9	2.5	4.7
Mariye	5.5	5.8	12.4	44.3	2.5	3.0	3.9	10.9	2.0	2.7	3.3	4.7
DZ-10-9-2	3.7	4.3	10.5	48.8	2.1	2.2	3.1	14.0	1.8	2.0	2.9	4.2
DZ-10-16-2	4.1	4.4	9.8	57.8	2.1	2.2	2.8	13.6	1.9	1.9	2.5	4.7
LSD(.05) P or Variety	1.406				0.428				0.201			
P x Variety	2.809				0.856				0.402			

Mean grain P uptake (Table 2) was generally similar in all varieties except Mariye, where it was significantly ($P \leq 0.05$) higher than in the rest. It also increased with increase in P levels, but followed different trends based on the variety. Similar to the root P data, in varieties DZ-Local and DZ-10-16-2, it was not statistically different between the first two P levels, while in variety Mariye, no difference in grain P was found between the second and third P rates. In variety DZ-10-9-2, however, grain P at each P level was significantly different from the rest.

Not only was grain P content comparatively lower at all P levels in the traditional variety, but the initially planted seeds also showed the same trend. Although data not shown, the average seed dry weights of the four varieties (DZ-Local, Mariye, DZ-10-9-2, and DZ-10-16-2) were 0.163, 0.317, 0.286 and 0.339g per grain, respectively. The four varieties, in the same order, had initial mean P contents of 0.45, 0.86, 0.77, and 0.86mg P per seed grain, thus showing that the initial P contribution to the seedlings was also the lowest in the traditional variety. Similar findings were reported by BOLLAND and BAKER (1989) and by RILEY et al.(1993), where a higher P content of the seeds (per unit dry weight or per seed) could induce a better early growth and improved phosphorus uptake of the following plant.

3.3 Lentil growth and yield

Lentil shoot height measured 4 weeks after planting was significantly ($P \leq 0.001$) influenced by varieties and P levels, and their interaction. Data given in Fig. 1 showed that plant height was highest in varieties NEL-358 and EL-142 and lowest in variety R-186; the height difference between the first two was not significant. Similarly, varieties EL-142 and NEL-2704 were similar in their height data. In all varieties, plant height increased with increase in P levels, but the difference between the control treatment and the 0.05mg P application rate was not significant.

Shoot dry weight (Table 3) was significantly ($P \leq 0.001$) influenced by the two treatment factors and their interaction. Similar to the plant height data, it was low in variety R-186, while in the rest three varieties it was statistically similar; it also increased with increase in P levels. Shoot dry weight at the maximum P application rate was on the average about nine times that in the control treatment. In all varieties, the weight difference between the control and the second P rate (0.05mg P/100g) was not significant.

Table 3: Shoot and root dry weight (g/15 plants), and shoot P uptake (mg/15 plants) of four lentil varieties as influenced by P application (mg/100g sand).

	Shoot dry weight				Root dry weight				Shoot P			
Variety	0	0.05	0.5	5	0	0.05	0.5	5	0	0.05	0.5	5
R-186	0.33	0.33	1.74	3.07	0.38	0.43	0.79	1.06	0.17	0.22	1.71	13.28
NEL-358	0.49	0.56	2.52	4.02	0.36	0.39	0.96	1.16	0.21	0.39	2.16	12.73
EL-142	0.42	0.54	2.47	3.90	0.29	0.33	0.66	0.97	0.30	0.40	2.66	16.25
NEL-2704	0.35	0.37	2.55	3.85	0.24	0.30	0.71	0.93	0.29	0.32	2.44	15.36
LSD(.05) P or Variety	0.121				0.053				0.281			
P x Variety	0.242				NS				0.561			

Root dry weight (Table 3), on the other hand, was highest in variety NEL-358, and lowest in two of the varieties - EL-142 and NEL-2704 (the latter two were also not significantly different from each other in their root dry weight). Similar to the shoot dry weight, root dry weight also increased with increase in P levels, but the weight difference between the first two P levels was not significant.

It was evident from visual observation during the course of the experiment that growth of lentil was adversely affected by the first two P treatments, where plants showed stunted growth and chlorosis as a result of P deficiency. By the end of the third week, many of the plants from the two treatments had stopped growth, while those plants receiving the 0.5 and 5 mgP/100g treatments were healthy and showed vigorous growth; at the time of harvest, some of these plants had started flowering.

Interestingly, the standard check, EL-142, not only had comparable dry weight with the other recommended varieties, but it was also superior to variety R-186. This initial result may however, not necessarily indicate that the final yield obtained on the field will be the same since crop varieties may have differences in dry matter accumulation depending upon the stage of growth, and grain yield production at maturity. The reasons for the observed differences between the varieties in P efficiency may be due to differences in the development of the root system (SCHJORRING and NIELSEN, 1987). In soil grown plants additional factors such as the release of chemical substances such as H^+ (MOORBY et al., 1988), citrate (HORST and WASCHKIES, 1987) or phosphatases (TARAFDAR and MARSCHNER, 1994) by the roots and root-VA mycorrhizal association (SMITH et al., 1992) or differences in mycorrhizal dependency of genotypes (LAMBERT et al., 1980) may be responsible for differences in P uptake by plants.

3.4 Lentil P uptake

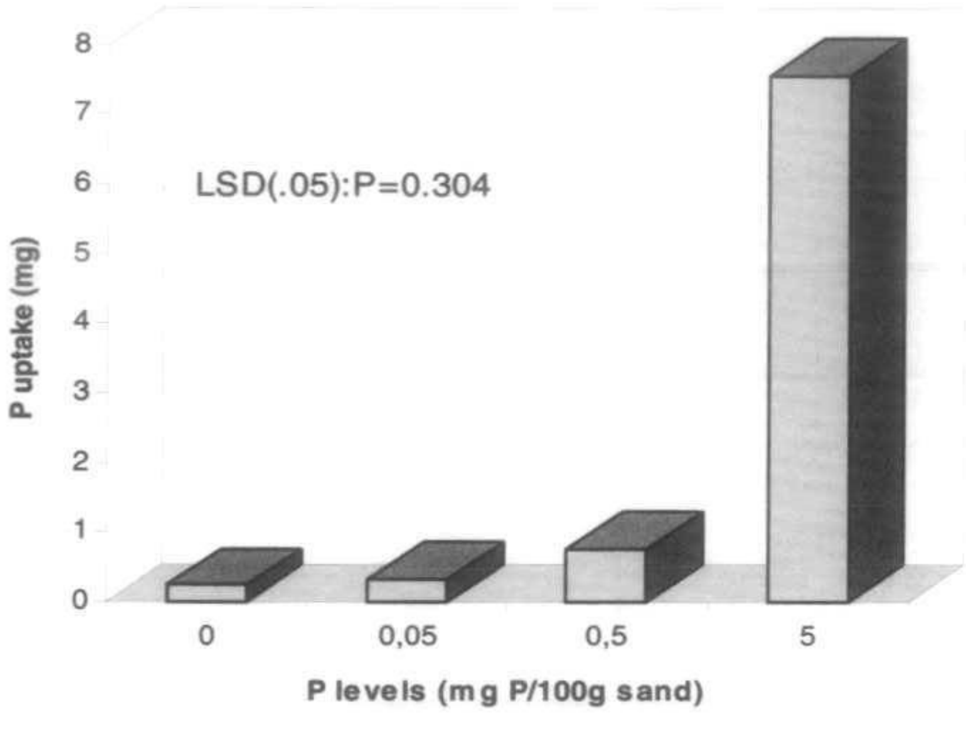


Fig. 2: Mean root P uptake (mg/15 plants) of four varieties of lentil as influenced by P application

Shoot P uptake increased as a function of P levels and reached the maximum at the highest P application rate (Table 3). It was the lowest, at the first two P levels, where the difference was not significant. The highest mean uptake was recorded from variety EL-142 and the lowest from varieties NEL-358 and R-186. Differences in shoot P uptake were also observed in different varieties of other legumes, e.g. white clover (CARADUS and SNAYDON, 1987; HART and COLVILLE, 1988) or in beans (YOUNGDAHL, 1990). Similar results were also found in durum wheat and tef varieties (MAMO et al., in press). In all varieties of our study, shoot P uptake between the control and the second P application rate was not significantly different.

Root P uptake, on the other hand, was not significantly different among the varieties (Fig. 2). Similar to the shoot P uptake data, it was highest at the maximum P application and lowest in the first two application levels (where the difference between the two was also not significant). At the maximum P rate, root P uptake was about half of that in the shoots.

4 Conclusion

Plant species and varieties are classified according to their P efficiency - which is their capacity to give a higher yield at a certain level of nutrient supply (LONERAGAN and ASHER, 1967), and the uptake efficiency, which is the capacity of roots to take up a large quantity of nutrient and transport it to the shoot (CLAASSEN and JUNGK, 1984).

Results of this study indicated that P application increased plant yield parameters and P uptake of both crop species. The modern chickpea varieties had higher yield components than the traditional variety. In lentil, however, although the experiment was only conducted for 4 weeks, it was found that the standard check also performed as good as the modern varieties.

The foregoing results also show the contrasting performances of chickpea and lentil crops at no or very low level of P application. Chickpea plants could withstand P deficiency to some degree, grow up to maturity and produce some seeds, while lentil plants were adversely affected by P deficiency and could not reach physiological maturity. One of the reasons may be the difference in the initial content of P in lentil seeds (on the average 0.065mg P/ lentil seed versus 0.735mg P/chickpea seed), thus enabling chickpea plants to survive under P deficiency. This finding will also have implications on which of the two crops to choose for growing under low soil available P conditions.

For both crops, the difference in mean shoot dry weight between the 0.5 and 5mg P/100g application rates was not as large as that between mean dry weight at the highest P rate and the other two lowest P levels, indicating that there was substantial growth improvement, even by the application of 0.5mg P/100g. Vertisols of the central highlands in Ethiopia, where chickpea and lentil are commonly grown have a mean soil available P content of generally greater than 0.5mg P/100g (MAMO et al., 1995); this may indirectly indicate that the legumes do not normally suffer from P deficiency when grown on these soils. Recent reports (MAMO et al., 1993) about the lack of response of chickpea and lentil to P application when grown on some Ethiopian Vertisols also support this conclusion.

Further examination of the shoot dry weight and P uptake data indicated that (data not shown) P utilisation efficiency (shoot dry matter produced per unit amount (mg) of P in shoots) of both crops decreased with increase in P levels (from 1.03 at the 0.5mg P/100g application level to 0.25 at the maximum P application level of 5mg/100g in lentil). Similarly, the corresponding mean values for chickpea were 0.97 and 0.27 for the 0.5 and 5mg P/100g application rates, respectively. These results indicate that P uptake at the highest P application rate was related more to luxury consumption than inducing higher rate of dry matter production.

5 Summary

Studies were undertaken to investigate the responses of four varieties each of chickpea (DZ-Local, Mariye, DZ-10-9-2 and DZ-10-16-2) and lentil (R-186, NEL-358, EL-142 and NEL-2704) to P application. Two of these varieties (DZ-Local and EL-142) are traditional or local varieties selected from the land race population where as all the rest were recommendations based on genetic improvement. The P levels used in the studies were 0, 0.05, 0.5 and 5mg P/100g sand applied in a nutrient solution.

Results showed that whereas chickpea varieties could survive P deficiency and grow up to maturity, lentil varieties were adversely affected by P deficiency and the experiment had to be terminated after 4 weeks of growth. The better performance of chickpea as compared to lentil under P deficiency conditions was attributed, besides other factors, to the initially higher P content of the seeds. In chickpea, data for plant parameters and P uptake showed that the modern varieties were superior to the local or traditional variety. In lentil, however, the traditional variety EL-142 was as good as the rest and even better than variety R-186.

In general, the maximum growth improvement was induced by the application of 0.5mg P/100g, and yield improvement with further application of P was lower. The 0.5mg P/100g application rate is roughly lower than the quantity of soil available P found in central highland Vertisols, where the majority of chickpea and lentil are grown in Ethiopia. It is therefore concluded that lack of response to P application on these soils seems to be due to the adequacy of the soil available P to satisfy the growth potentials of both crops, not mentioning that the crops have also other mechanisms to further exploit sparingly soluble soil P.

Einfluß der Phosphorernährung auf das Wachstum verschiedener Sorten von Kichererbsen (Cicer arietinum L.) und Linsen (Lens culinaris Medic.)

Zusammenfassung

Bei vier verschiedenen Sorten von Kichererbsen (DZ-Local, Mariye, DZ-10-9-2 und DZ-10-16-2) und Linsen (R-186, NEL-358, EL-142 und NEL-2704) wurde der Einfluß von unterschiedlich hoher P-Versorgung auf den Ertrag und die P-Aufnahme geprüft. Zwei dieser Sorten (DZ-Local und EL-142) sind traditionell angebaute, lokale Sorten aus Äthiopien, die aus alten Landsorten selektiert wurden. All die anderen Sorten werden den Landwirten wegen ihrer züchterischen Verbesserung empfohlen. Die P-Versorgung in den hier beschriebenen Sandkultur-Versuchen war 0; 0,05; 0,5 und 5mg P in der applizierten Nährlösung je 100g Boden.

Die Ergebnisse ergaben, daß die Kichererbsen trotz wenig vorhandenem Phosphor im

Boden gut bis zur Reife wachsen konnten, die Linsen hingegen sehr unter dem P-Mangel litten und ihr Wachstum nach 4 Wochen wegen P-Mangel einstellten. Diese bessere Entwicklung von Kichererbsen als von Linsen unter Phosphormangelbedingungen liegt neben anderen Faktoren an dem höheren P-Gehlt je Korn der Kichererbsensamen. Während bei den Kichererbsen der Ertrag und die P-Aufnahme von den neuen Sorten besser als von der traditionellen Sorte war, erwies sich bei den Linsen die traditionelle, lokal übliche Sorte EL-142 genauso gut wie die anderen, ja sogar besser als die neue Sorte R-186.

Meist wurde das beste Wachstum bei Zufuhr von 0,5mg P/100g Boden erreicht, dagegen war noch mehr Zufuhr von P nicht erforderlich. 0,5mg P /100g Boden sind weniger als die Menge pflanzenverfügbaren Phosphors der Vertisol-Böden im zentralen Hochland von Äthiopien, wo Kichererbsen und Linsen sehr viel angebaut werden. Daher liegt die häufig beobachtete ausbleibende Ertragswirkung einer Phosphordüngung auf diesen Böden sicherlich daran, daß trotz dieser auffallend geringen P-Menge im Boden ausreichend pflanzenverfügbares Phosphat vorhanden ist, um das Ertragspotential beider Pflanzenarten sicherzustellen. Außerdem haben diese Leguminosenarten sicherlich weitere Mechanismen, um schwer lösliches Bodenphosphat zu nutzen.

6 Acknowledgements

We are grateful to Burkhard Heiligtag, Abdallah Diop and Martina Pletsch-Betancourt for their assistance in the conduct of the study. The advice given by Dr. Hans-Peter Piepho on statistical analyses and computation procedures is highly appreciated.

7 References

1. AE, N., ARIHARA, J., OKADA, K., YOSHIHARA, T. and C. JOHANSEN, 1990. Phosphorus uptake by pigeon pea and its role in cropping systems of the Indian subcontinent. Science, 248: 477-480.

2. BOLLAND, M. D. A. and M. J. BAKER, 1989. High phosphorus concentration in *Trifolium balansae* and *Medicago polymorpha* seeds increases herbage and seed yields in the field. Aust. J. Exp. Agric. 29: 791-795.

3. BEYENE, D., 1982. Diagnosis of phosphorus deficiency in Ethiopian soils. Soil Sci. Bull. No. 3, Inst. Agr. Research, Addis Ababa, Ethiopia.

4. CARADUS, J. R., and R. W. SNAYDON, 1987. Aspects of the phosphorus nutrition of white clover populations. I. Inorganic phosphorus content of leaf tissue. J. Plant Nutr.10: 273-285.

5. CLAASSEN, N., and A. JUNGK, 1984. Bedeutung von Kaliumaufnahmerate, Wurzelwachstum und Wurzelhaaren für das Kaliumaneignungsvermögen verschiedener Pflanzenarten. Z.Pflanzenernähr. Bodenkunde 147: 276-289.

6. HART, A.L. and C. COLVILLE, 1988. Differences among attributes of white clover genotypes at various levels of phosphorus supply. J. Plant Nutr. 11: 189-207.

7. HOPPENSTEDT, A., 1991. Untersuchungen zur morphogenetischen Wirkung von "Stickstoff" auf das Wurzelsystem unter Berücksichtigung des Stickstoff- und Kohlenhydratmetabolismus bei unterschiedlicher Energiezufuhr (Lichtintensität) über die Photosynthese an Maiskeimpflanzen (*Zea mays* L.). Ph.D Dissertation, University of Kiel, Germany, 133pp.

8. HORST, W.J., and C. WASCHKIES, 1987. Phosphatversorgung von Sommerweizen (*Triticum aestivum* L.) in Mischkultur mit Weißer Lupine (*Lupinus albus* L.).Z.Pflanzenernähr.Bodenkunde 150: 1-8.

9. JUTZI, S. C., ANDERSON, F.M. and A. ASTATKE, 1986. Low cost modification of traditional Ethiopian tine plough for land shaping and surface drainage of heavy soils: preliminary results from on-farm verification. ILCA Bull. 27: 28-31.

10. LAMBERT, D. H., COLE, Jr, H., and D. E. BAKER, 1980. Variation in the response of alfalfa clones and cultivars to mycorrhizae and phosphorus. Crop Sci. 20: 615-618.

11. .LONERAGAN, J. F., and C. J. ASHER, 1967. Response of plants to phosphate concentration in solution culture: II. Rate of phosphate absorption and its relation to growth. Soil Sci. 103: 311-318.

12. MAMO,T. and I. HAQUE,1991. Phosphorus status of some Ethiopian soils, II. Forms and distribution of inorganic phosphates and their relation to available phosphorus. Trop. Agric. (Trinidad), 68: 2-8.

13. MAMO, T., ASTATKE, A., SRIVASTAVA, K.L. and A. DIBABE, 1993. Improved management of Vertisols for sustainable crop-livestock production in the Ethiopian highlands: Synthesis report 1986-1992, Technical Committee of the Joint Vertisol Project, Addis Ababa, Ethiopia, 200pp.

14. MAMO, T., RICHTER, C. and B. HEILIGTAG, 1995. Phosphorus availability studies on ten Ethiopian Vertisols. Tropical Agriculture (Trinidad), (submitted).

15. MAMO, T., RICHTER, C. and HOPPENSTEDT, A., 1996. Phosphorus response studies on some varieties of durum wheat (*Triticum durum* Desf.) and tef (*Eragrostis tef* (Zucc.) Trotter) grown in sand culture. J. Agron. Crop Sci. (in press).

16. MOORBY, H., WHITE, R. E., and P.H. NYE, 1988: The influence of phosphate nutrition on H-ion efflux from the roots of young rape plants. Plant and Soil 105, 247-256.

17. RILEY, M. M., ADCOCK, K. G., and M. D. A. BOLLAND, 1993. A small increase in the concentration of phosohorus in the sown seed increased the early growth of wheat. J. Plant Nutr. 16: 851-864.

18. SCHJORRING, J. K., and N. E. NIELSEN, 1987. Root length and phosphorus uptake by four barley cultivars grown under moderate deficiency of phosphorus in field experiments. J. Plant Nutr. 10: 1289-1295.

19. TARAFDAR, J. C. and H. MARSCHNER, 1994: Phosphatase activity in the rhizosphere of of VA-mycorrhizal wheat supplied with inorganic and organic phosphorus. Soil Biol. Biochem. 26: 387-395.

20. YOUNGDAHL, L. J., 1990. Differences in phosphorus efficiency in bean genotypes. J. Plant Nutr. 13: 1381-1392.