DETERMINING MODEL BASED PHOSPHOROUS FERTILIZER REQUIREMENT FOR CANOLA CROP

Ahmad Bilal*, A.M. Ranjha**, Rahmatullah** and M. Rashid***

*Directorate General Agriculture (Water Management), Punjab, Lahore.
**Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad.
***Directorate of Small Ruminants, L&DD, Punjab, Multan

A field experiment was conducted on the Lyallpur soil series (Haplargids) to determine P requirement of canola for obtaining 95 % relative yield. Phosphorus sorption isotherm was constructed by equilibrating 2.5 g soil with 0, 5, 10, 15, 20, 25, 30, 35, 40 and 50 mg P L^{-1} for 24 hours at 20°C using KH_2PO_4 in 25 ml 0.01 M $CaCl_2$ solution. The data obtained was fitted to the modified Freundlich equation to compute P sorption parameters and derive the equations to attain theoretical solution P levels of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30 and 0.35 mg L^{-1} with native solution P level as control. The fertilizer doses were computed against these solution levels by using Freundlich model and applied to canola crop. Maximum canola grain and oil yield of 2.94 and 1.17 Mg ha^{-1}, respectively was recorded at solution P level of 0.25 mg P L^{-1} which was obtained by adding P_2O_5 at 116 kg ha^{-1}. Maximum P concentration in canola grain (0.61 %) was obtained at solution P level of 0.25 mg P L^{-1}, while in straw (0.14 %) it was at 0.30 mg P L^{-1}. External solution P requirement was 0.215 mg P L^{-1} and internal P requirement found was 0.51 % for obtaining 95 % relative yield of canola.

Key words: Phosphorus, canola, yield, oil content.

INTRODUCTION

Balanced use of nutrients is essential for successful harvesting of crops on sustainable basis. The use of fertilizers have been mainly confined to the application of nitrogen while the use of phosphorous (P) is far below the needs of crops and soils in Pakistan. Almost all soils are deficient in N and about 95 % low to medium in P. Phosphate availability in Pakistani soils is reduced due to alkaline soil conditions, high calcium contents and a large amount of calcium saturated clay. To maintain a given level of available phosphorus, it is necessary to apply adequate quantities of phosphatic fertilizers into the soil (NFDC, 2003). High P sorption is considered as a constraint to economic utilization of P as more than 80 % of fertilizer applied P will immediately become unavailable for plant uptake either due to adsorption, precipitation or both in soil (White, 1982). Soil solution P is an immediate source of P for plant uptake (Holford, 1989). Soils vary greatly in the amount of P required to provide an adequate supply of available P for plant and plants also vary in their P requirement for optimal growth (Vanderzaag et al., 1979). The literature suggests that optimum solution P concentration (0.2 mg L^{-1}) provides P adequately for many crops if it is continuously maintained in the medium (Beckwith, 1965). The Freundlich equation is often considered to be purely empirical in nature but has been used extensively to describe the adsorption of phosphate by soils (Aslam et al., 2000; Arshed et al., 2000; Javid and Rowell, 2002; Chaudhry et al., 2003). Using P sorption approach, P requirement of several crops has been determined under a variety of soil and climatic conditions (Fox, 1981; Vanderzaag et al., 1979; Memon et al., 1992 Hassan et al., 1993 & 1994). This approach has an advantage over conventional method of soil testing since it integrates P intensity, capacity and buffering capacity aspects of the soil which play important role in controlling the P flux to most of the growing plants. Moreover, fertilizer requirement can be estimated directly from P sorption curves. According to the scale given by Juo and Fox (1977), the data from P sorption studies indicated that the soils of Pakistan had a low P sorption capacity. The addition of 50-100 kg P_2O_5 ha^{-1} in many cases increased the level of solution P to the desired level for optimal production.

Keeping all this in view, a field study was planned to estimate the P requirement of canola, a very important oilseed crop of Pakistan, by using adsorption isotherm technique.

MATERIALS AND METHODS

The study was conducted at Post Graduate Agricultural Research Station, Faisalabad. Representative composite soil samples were collected from 0-20 cm depth and analysed for soil physical and chemical properties by using standard analytical methods.

P sorption isotherm

Phosphorus sorption isotherms were constructed by following the methods as described by Rowell (1994). Soil samples (2.5 g) were shaken on end over end

shaker for 24 h with 25 ml 0.01M $CaCl_2$ containing P concentrations of 0, 5, 10, 15, 20, 25, 30, 35, 40 and 50 mg L^{-1} as KH_2PO_4. The samples were filtered through a Whatman No. 42 filter paper. The P concentration in the final solution was determined by the method of Murphy and Riley (1962). The difference between amount of P in solution before and after equilibrium was taken as the amount of P sorbed (Nair et al., 1994). The sorption isotherms were examined by Freundlich equations proposed by Le Mare (1982) as given below:

P = a C ^{b}

Where,

P = Amount of P adsorbed per unit of soil (μg g^{-1})

C = Equilibrium P concentration in soil solution (μg ml^{-1})

a and **b** are constants which represent the intercept and slope of the sorption isotherms.

Phosphatic fertilizers doses to develop theoretical P levels in soil solutions (0.05, 0.10, 0.15, 0.20, 0.25, 0.30 and 0.35) with native solution P level as control under field conditions were calculated from this equation (Table 1).

Table 1. Computed P doses applied in the field

Tr. No.	Soil solution P levels (mg L^{-1})	P (mg kg^{-1} soil)	P_2O_5 (kg ha^{-1})
1	Control	0.0	0
2	0.05	7.6	35
3	0.10	12.8	58
4	0.15	17.3	78
5	0.20	21.5	98
6	0.25	25.4	116
7	0.30	29.1	133
8	0.35	32.7	150

Field Trial

The experiment was conducted at under farmers' field conditions using Randomized Complete Block Design (RCBD). Canola (Brassica compestris L.) cv. Hyola-443 was sown by using 5 kg seed ha^{-1}. Half of the recommended nitrogen (60 kg ha^{-1}) and full dose of potassium (K_2O) at 70 kg ha^{-1} along with phosphorus (P_2O_5) (as mentioned in Table 1) were applied at sowing time in the form of urea, potassium sulphate and diammonium phosphate (DAP), respectively. Second half of nitrogen was applied at first irrigation. The crop was harvested at ground level at maturity. Grain and straw yield data were recorded by harvesting the whole plot. Grain and straw samples were analyzed for P concentration. The yield representing each phosphorus level was expressed as percentage of maximum yield of the experiment. The

percentage yield, also termed as relative yield, was expressed as the yield with test nutrient added as percentage of maximum yield. The relative yield is a measure of the yield response to a single nutrient when other nutrients are supplied adequately but not in excessive amount. It is calculated as

$$\text{Relative yield} = \frac{\text{Threshold yield for x}}{\text{Plateau yield for x}} \times 100$$

Where,

Threshold yield = Yield at zero level of x

Plateau yield = Point of maximum response to x

x = Rate of nutrient (P) applied.

Relative yield (%) was plotted against soil solution P level and P concentration (%) in grain to determine the external and internal P requirement of canola from the regression equation. The seed oil contents were measured by using Nuclear Magnetic Resonance (NMR) test (Robertson and Morison, 1979). The data obtained were statistically analyzed using method as described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

The soil used was non-saline, alkaline in reaction, calcareous ($CaCO_3$ = 8.2 %) and sandy clay loam in texture. The soil was deficient in organic matter and available P but medium in extractable K (Table 2).

Table 2. Physical and chemical characteristics of the soil used

Determinant	Units	Values
Sand	%	58
Silt	%	20
Clay	%	22
Textural Class	-	Sandy Clay Loam
Group	-	Haplargids
Series	-	Layalpur
Electrical Conductivity	dS m^{-1}	1.4
pH	-	7.9
$CaCO_3$	%	8.2
O.M (%)	%	0.7
Olsen-Extractable P	mg kg^{-1}	7.8
NaH_4 OAc-Extractable K	mg kg^{-1}	148

Freundlich plot of sorption data

After constructing the P adsorption isotherm (Fig. 1), the data was subjected to examine the fitness to the modified Freundlich equation. The linear plot of the modified Freundlich equation is presented in Fig. 2. The buffer capacities (**b**) of the soil was 54 mL g^{-1} and the amount of P adsorbed (**a**) was 71.9 μg g^{-1}. The goodness of the fit of the model was ascertained by

Fig. 1. Phosphorus sorption curve
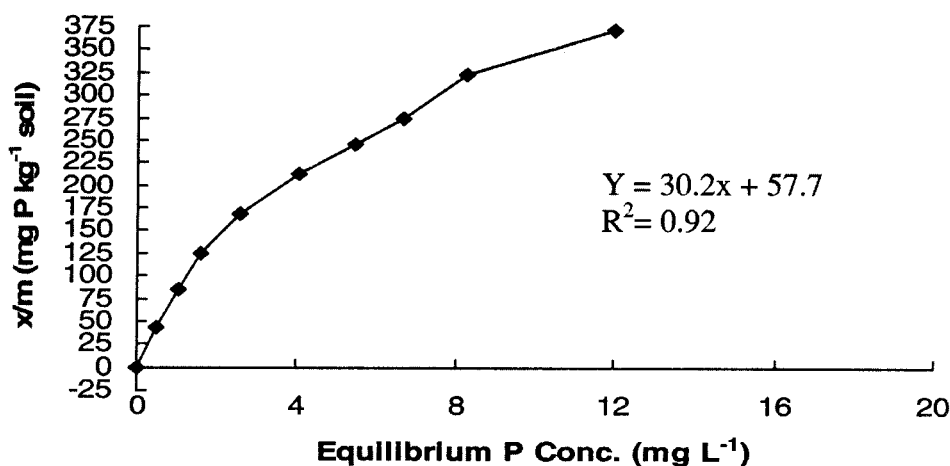
Y = 30.2x + 57.7
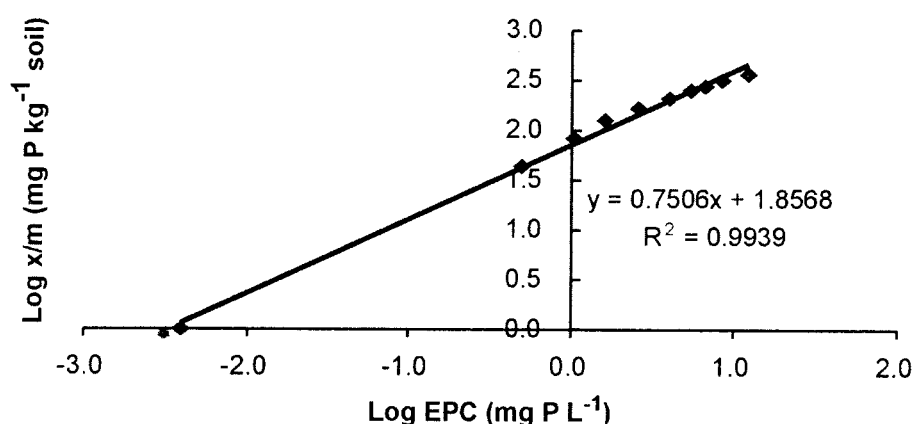R^2= 0.92

y = 0.7506x + 1.8568
R^2 = 0.9939

Fig. 2. Fitted Freundlich equation on P sorption data

looking at the r^2 value (0.99) which indicates high conformity of the adsorption data with the modified Freundlich model. The value of the exponent was found < 1 (Table 3) which relates to the characteristics of the adsorbent (soil or $CaCO_3$). The findings are in agreement with those of Fitter and Sutton (1975), Rathowsky (1986), Zhou and Li (2001), Chaudhry *et al.* (2003) and Hussain *et al.* (2006) who reported that exponent of the Freundlich equation was independent of the time and temperature and the values depended on solution P concentration.

Table 3. Freundlich model

Soil	Freundlich Equation	
	Model Form	Linear Form
	P = a C $^{b/a}$	Y = 0.75 x + 1.86
Haplargids	P = 71.9 C $^{0.75}$	

Grain and straw yield of canola crop

Results regarding canola grain and straw yield are depicted in table 4. The data revealed that maximum canola grain yield (2.94 Mg ha^{-1}) was obtained at solution P level of 0.25 mg P L^{-1} which was developed by adding 116 kg P_2O_5 ha^{-1}. Further increase in the level of P fertilizer could not improve grain yield of canola. This means that canola responded differently to the solution P but response to the higher doses (> 0.30 mg P L^{-1}) was not observed. Similar results were reported by other authors (Hocking *et al.* 1997, Kumar *et al.* 1997). Gammellvind *et al.* (1996), working in Copenhagen, reported a higher seed yield, varying from 2.8 to 4.8 t ha^{-1}, in winter oilseed rape. An adequate application of fertilizer, enables the crop to produce rapid leaf growth to intercept more solar radiation and thus to produce and fill many pods. Both Potter *et al.* (1995) and Hocking *et al.* (1997) have

Table 4. Effect of different solution P levels on different yield components of canola

Solution P (mg L^{-1})	Yield (Mg ha^{-1})		Oil Content (%)	Oil Yield (Mg ha^{-1})	P (%) in	
	Grain	Straw			Grain	Straw
0.00	2.13 e	3.61 c	38.7 e	0.83 f	0.08 h	0.05 g
0.05	2.36 d	4.92 b	38.7 e	0.91 e	0.19 g	0.07 f
0.10	2.37 d	4.95 b	39.8 d	0.94 d	0.29 f	0.09 e
0.15	2.55 c	5.22 b	40.2 c	1.02 c	0.38 e	0.11 d
0.20	2.75 b	5.59 a	41.3 b	1.13 b	0.49 d	0.13 c
0.25	2.94 a	5.80 a	42.0 a	1.23 a	0.61 a	0.14 b
0.30	2.94 a	5.79 a	41.9 a	1.23 a	0.59 c	0.15 a
0.35	2.93 a	5.80 a	41.9 a	1.23 a	0.60 b	0.14 b

Means sharing same letters are statistically at par at 5 % level of probability.

suggested breeding varieties of canola with reduced plant height and better pod production/retention characteristics.

Similarly straw yield also increased at the same soil solution P levels and the trend was almost same as was seen in the case of grain yield. Maximum straw yield of 5.8 Mg ha^{-1} was noted at soil solution P level of 0.25 (116 kg P$_2$O$_5$ ha^{-1}), but it was statistically at par with the straw yield obtained at solution P level of 0.20, 0.30 and 0.35 mg L^{-1}. Minimum straw yield was recorded in the control plots where no fertilizer was added. The reason for this might be poor tillering in control plots which increased significantly with the application of P fertilizer and building solution P levels. Linear increase in grain and straw yield with increasing rates of P was also observed by Malik et al. 2002; Cheema et al. 2001; Baily and Grant (1990); and Allen and Morgan (1975).

Oil contents and oil yield

Oil content is typically characteristic of species, varieties and their genetic makeup. The application of P significantly influenced the oil content of canola. The maximum oil content of 42 % was found in grains with solution P level of 0.25 mg P L^{-1} which was however, statistically at par with the oil contents obtained at 0.3 and 0.35 mg P L^{-1}. It seems that application of 116 kg P$_2$O$_5$ ha^{-1} is an optimum level for canola in terms of oil content. According to Holmes (1980) both deficiency and higher levels of P decrease oil content in rapeseed. However, Trivedi et al., (1995) reported that increase in P levels improve oil content of canola.

The oil yield of a crop is the combined expression of seed oil content and seed yield of a variety. Increasing the rate of fertilizer application significantly enhanced oil yield only up to the solution P level of 0.25 mg P L^{-1} which was developed by adding 116 kg P$_2$O$_5$ ha^{-1}. Thereafter, further increase in the level of P fertilizer

could not improve oil yield of canola. The lowest oil yield was produced in the control treatment. The higher oil yield with increasing rate of fertilizer application (solution P level) was probably due to increasing effects on seed yield. The oil yields (825–1233 kg ha^{-1}) found in this study are in line with the results reported by others (Asare and Scarisbrick 1995, Hocking et al. 1997, Cheema et al. 2001, Govahi and Saffri 2006).

Phosphorus concentration (%) in canola grain and straw

Data regarding P concentration of canola grain depicted in Table 4 reveal that maximum P concentration (0.61 %) was observed when solution P level of 0.25 mg L^{-1} was developed by adding 27.7 mg P kg^{-1} soil. Minimum P concentration of 0.08 % was determined in control plots. Wysocki et al. (2005) reported P concentration in canola grain between 0.88–0.96 %. The data also revealed that maximum P concentration in canola straw of 0.15 % was recorded at solution P level of 0.30 mg L^{-1} which was obtained by adding 29.1 mg P kg^{-1} soil. However, minimum P concentration 0.05 % was observed in plots receiving no fertilizer. It is an established fact that low P concentration in straw than grain is due to more P translocation to the grain in the reproductive stage. Wysocki et al. (2005) reported P concentration in canola straw between 0.09 - 0.18 %.

Phosphorus requirement of canola

The P requirement of canola crop was determined on the basis of 95 % of the maximum yield. The fertilizer requirements are crop specific and site specific and can be estimated as external and internal P requirements. Fox (1981) reported that P requirement, both external and internal, of most crops were greater during early stages of growth than for crops approaching to maturity.

External (solution) P requirement of canola

The solution levels developed for growing canola crop were plotted against 95 % relative yield of canola for the determination of P requirement by the Boundary Line Technique (Webb, 1972) as shown in the Fig. 3. The graph revealed that solution P requirement of 0.215 mg L^{-1} was found in Layalpur soil series for near maximum yield of canola (95 %). This value elucidated

1976). Similarly, Beckwith (1965) suggested a standard concentration of 0.2 µg P mL^{-1} as adequate for most plant species. Samadi (2003) reported solution P level of 0.4 mg L^{-1} for attaining maximum wheat yield. Similar results were found by Nisar (1988) and Hassan *et al.* (1993 & 1994) under soil conditions in Pakistan.
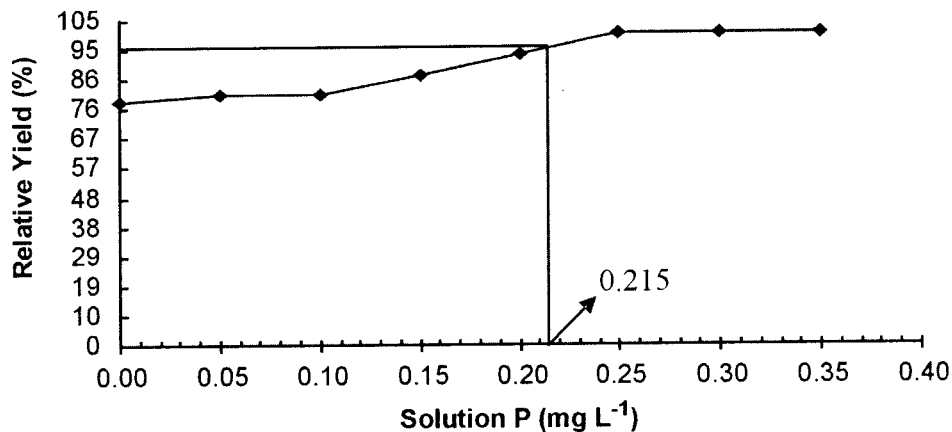
Fig. 3. External phosphorous requirement of canola

that near maximum yield of canola (95 %) was obtained at medium solution P level. This means that P requirement is medium in coarse textured soil with respect to yield and the reason might be that coarse textured soil has a low P fixation capacity. Memon *et al.* (1991) found that 18-29 kg P ha^{-1} is required to develop a solution level of 0.032 mg P L^{-1} in calcareous soils. Values of 0.2 and 0.3 mg L^{-1} in soil solution have been proposed as required equilibrium P concentration at which most plants attain near maximum growth (Borrero *et al.* 1988; Elrashidi *et al.*

Internal P requirement of canola

Internal P requirement of canola was determined at crop maturity i.e. in grain by making a graph of P concentration in grain and maximum attainable 95 % relative yield as shown in Fig. 4. The value obtained for internal P requirement of canola was 0.51 % (Fig. 4). This means that as the crop passed through reproductive phase, the P was translocated to the seed and this transfer of P was very rapid and highest in this coarse textured soil.
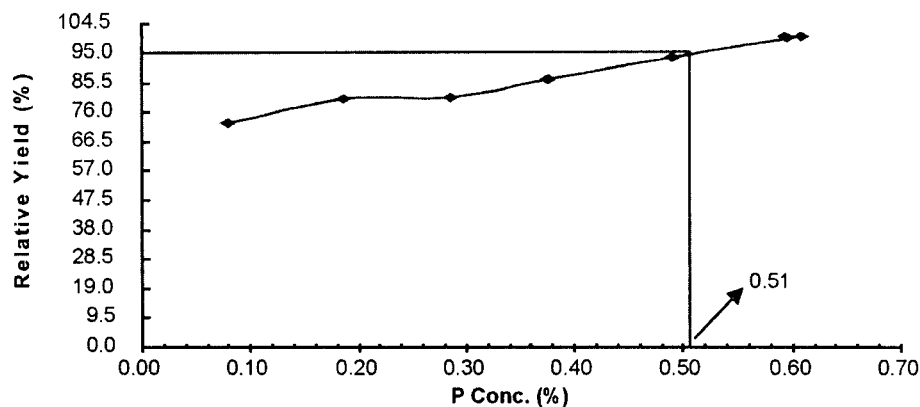
Fig. 4. Internal phosphorous requirement of canola

CONCLUSIONS

It can be concluded from this study that Freundlich adsorption isotherm was quite effective in determining the phosphorus requirement of canola. Maximum grain and oil yields of 2.94 and 1.23 Mg ha^{-1} was recorded at solution P level of 0.25 mg P L^{-1}, respectively. Phosphorus concentration in grain and straw was 0.61 and 0.15 % which was found at solution P level of 0.25 and 0.30 mg P L^{-1}, respectively. External solution P requirement was 0.215 mg P L^{-1} and internal P requirement was found 0.51 % for obtaining 95 % relative yield of canola.

REFERENCES

Allen, E.J. and D.G. Morgan. 1972. A quantitative analysis of the effects of nitrogen on the growth, development and yield of oilseed rape. *J. Agric. Sci.* 78,315-324.

Allen, E.J. and D.G. Morgan. 1975. A quantitative comparison of the growth, development and yield of different varieties of oilseed rape. *J. Agric. Sci.* 85,159-174.

Arshed, M., Rahmatullah, M. Salim and M. Yousaf. 2000. Soil properties related to phosphorus sorption as described by modified Freundlich equation in some soils. Int. J. Agri. Biol. 2: 290-292.

Asare, E. and D.H. Scarisbrick. 1995. Rate of nitrogen and sulfur fertilizers on yield, yield components and seed quality of oilseed rape (*Brassica napes*). *Field Crops Res.* 44, 41-46.

Aslam, M., M.S. Zia, Rahmatullah and M. Yasin. 2000. Application of Freundlich adsorption isotherm to determine phosphorus requirement of several rice soils. Int. J. Agri. Biol. 2: 286-288.

Beckwith, R.S. 1965. Sorbed phosphate at standard supernatant concentration as an estimate of the phosphate needs of soils. Aust. J. Exp. Agri. and Anl. Hus. 5: 52-58.

Borrero, C., F. Pena and J. Torrent. 1988. Phosphate sorption by calcium carbonate in some soils of Mediterranean part of Spain. Geoderma. 42: 261-269.

Chaudhry, E.H., A.M. Ranjha, M.A. Gill and S.M. Mehdi. 2003. Phosphorus requirement of maize in relation to soil characteristics. Int. J. Agric. Bio. 5(4): 625-629.

Cheema, M.A., M.A. Malik, A. Hussain, S.H. Shah and S.M.A. Basra. 2001. Effects of time and rate of N and P application on the growth, seed yield and oil yield of canola. J. Agro. and Crop Sci. 185: 1-8.

Elrashidi, M.A., A.E. Damaty and H. Hamdi. 1976. Adsorption of phosphorous in highly calcareous soils. Egypt. Soil Sci. 16: 191-202.

Fitter, A.H. and C.D. Sutton. 1975. The use of the Freundlich isotherm for soil P sorption data. J. Soil Sci. 26: 241-246.

Fox, R.L. 1981. External Phosphorus requirement of crops. In M. Shelly *et al.* (Ed). Chemistry in the soil environment. Am. Soc. of Agron. Madison, WI, USA. p. 223-239.

Gammellvind, L.H., J.K. Schjoerring, V.O. Mogensen, C.R. Jensen and J.G.H. Bock. 1996: Photosynthesis in leaves and siliques of winter oilseed rape (*Brassica napes* L.). *Plant Soil*. 186,227-236.

Gohavi, M. and M. Saffari. 2006. Effect of Potassium and Sulphur Fertilizers on yield, yield components and seed quality of spring canola (*Brassica napus* L.) seed. J. Agron. 5 (4): 577-582.

Hassan, M.M., A. Rashid and M.S. Akhtar. 1993. Phosphorus requirement of corn and sunflower grown oncalcareous soils of Pakistan. Commun. Soil Sci. Plant Anal. 24: 1529-1541.

Hassan, M.M., A. Rashid and M.S. Akhtar. 1994. Phosphorus requirement of maize and sunflower on selected bench mark soils of Pakistan. In Proc. 4th Nat. Cong. Soil Sci. May 24-26, 1992 at NARC, Islamabad. p. 327-332

Hocking, P.J., P.J. Randall, D. Demarco and I. Bamforth. 1997. Assessment of the nitrogen status of field grown canola (*Brassica napes* L.) by plant analysis. *Aust. J. Exp. Agric.* 37, 83-92.

Holford, I. 1989. Phosphorous behavior in soils. Agri. Sci.12: 15-20.

Holmes, M.R.J. 1980. Nitrogen, phosphorous and potassium in nutrition of the oilseed rape crop. Applied Science Publisher Inc., England. Pp 21-100.

Hussain, A., A. Ghafoor and G. Murtaza. 2006. Use of models for phosphorus adsorption on some sodic soils of Punjab. Int.J.Agri.Biol.8:242-248.

Javid, S. and D.L. Rowell. 2003. Effect of soil properties on Phosphate adsorption in calcareous soils of Pakistan. Pak. J. Soil Sci. 21(4): 47-55.

Juo, A.S.R. and R.L. Fox. 1977. Phosphate sorption capacity of some benchmark soils in West Africa. Soil Sci. 143: 370-376.

Kumar, S., J. Sing and K.K. Dhingra. 1997. Leaf area index relationship with solar-radiation interception and yield of Indian mustard (*Brassica juncea*) as influenced by plant population and nitrogen. *Indian J. Agron.* 42,348-351.

Kuo, S. and E.G. Lotse. 1974. Kinetics of phosphate adsorption and desorption by lake sediments. Soil Sci. Soc. Am. Proc. 38: 50-54.

Le Mare, P.H. 1982. Sorption of isotopically exchangeable and non-exchangeable phosphate by some soils of Colombia and Brazil, and comparisons with soils of southern Nigeria. J. Soil Sci. 33: 691-707.

Malik, M.A., M.A. Cheema and M.F. Saleem. 2002. Production efficiency of canola (*Brassica Napus* L.) as affected by different NPK levels. Pak. J. Agri. Sci., 39(4): 278-280.

Memon, K.S., A. Rashid and H.K. Puno. 1992. Phosphorus deficiency diagnosis and P soil test calibration in Pakistan. Tropical Soil Bulletin No. 92-02, Phosphorus Decision Support System Workshop, March 11-12, 1992. College Station, Texas, University of Hawaii, Honolulu, USA.

Memon, K.S., H.K. Puno and R.L. Fox. 1991. Phosphate sorption approach for determining phosphorus requirements of wheat in calcareous soils. Fert. Res. 28(1): 67-72.

Moodie, C.D., H.W. Smith and R.A. Mcreery. 1959. Laboratory manual for soil fertility. State college of Washington, Mimeograph, Pullman Washington, D.C. USA. p. 31-39.

Murphy, J. and H.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27: 31-36.

Nair, P.S., T.J. Logan, A.N. Sharpley, L.E. Somers, M.A. Tabatabai and T.L. Yuan. 1994. Inter laboratory Comparison of a Standardized Phosphorus Adsorption Procedure. J. Environ. Qual. 13(4): 591-595.

NFDC. 2003. Fertilizers and their use in Pakistan. 3rd edition An extension guide. National Fertilizer Development Center, Islamabad. p.76.

Nisar, A. 1988. Phosphorus use efficiency and soil test crop response correlation. Ph.D. Thesis. Dept. Soil Sci., Uni. Agri., Faisalabad, Pakistan.

Potter, T.D., P.A. Salisbury, D.J. Ballinger, N. Wratten and R.J. Mailer. 1995. Comparison of historical varieties of rapeseed and canola in Australia. In: Proceedings of the 9th International Rapeseed Congress, Cambridge, UK, pp. 365-367.

Rathowsky, D.S. 1986. A statistical study of seven curves for describing the sorption of phosphate by soil. J. Soil Sci. 37: 183-189.

Robertson, J.A. and W.H. Morrison. 1979. Analysis of oil content of sunflower seed by NMR. *J. Am. Oil Chem. Soc.* 56,961-964.

Rowell, D.L. 1994. Soil Science. Methods and Applications. Longman Scientific and Technical, Harlow, Essex, UK.

Samadi. A. 2003. Predicting phosphate fertilizer requirement using sorption isotherms in selected calcareous soils of Western Azarbaijan province, Iran. Comm. Soil Sci. & Plant Analysis. 34: (19 & 20) pp. 2885-2899.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. 2nd Ed. Mc Graw-Hill Book Corp. Inc., NY, USA.

Trivedi, S.K., V. Singh, C.P. Shinde and V. Singh. 1995. Effect of various levels of nitrogen, phosphorous and sulphur on the yield and quality mustard in blackgram-mustard cropping sequence. Crop Res. Hisar., 10: 265-270.

U.S. Salinity Lab. Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Washington, DC, USA.

Vanderzaag, P., R. Fox, R.S. Delapena, W.M. Laughlin, A. Ryskamp, S. Villa-gracia and D.T. Westermann. 1979. The utility of phosphate sorption curves for transferring soil management information. Trop. Agri. 56: 153-160.

Watanabe, F.S. and S.R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. proc. 29: 677-678.

Webb, R.A. 1972. Use of boundary line technique in the analysis of biology data. J. Hort. Sci. 47: 309-319.

White, R.E. 1982. Retention and release of phosphate by soil and soil constituents. In: Soils in Agriculture, Critical reports on applied Chemistry. Vol. 2. Soc. Chem. Tinker, P. E. (ed). p. 71-114. Industry, Blackwell Scientific Publications, Oxford, UK.

Wysocki, D., N. Sirovatka and S. Ott. 2005. Growth and Nutrient uptake of Winter Canola at Pendleton, Oregon. Dryland Agricultural Research. Oregon State University. Special Report 1061.

Zhou, M. and Y. Li. 2001. Phosphorus sorption characteristics of calcareous soils and limestone from the southern everglades and adjacent farmlands. Soil Sci. Soc. Am. J. 65:1404-1412.