

PHOSPHORUS USE EFFICIENCY
AND
SOIL TEST-CROP RESPONSE CORRELATION

BY

NISAR AHMAD

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE

FACULTY OF AGRICULTURE

UNIVERSITY OF AGRICULTURE, FAISALABAD

(PAKISTAN)

1988

Amuda/116/24/3
DEAD
Faculty of Agriculture
University of Agriculture
Faisalabad.

Mohammad Aslam
CHAIRMAN.
Department of Soil Sciences,
University of Agriculture,
FAISALABAD.

To

The Controller of Examinations
University of Agriculture
Faisalabad, PAKISTAN.

The members of the Committee find the thesis submitted by
Mr. Nisar Ahmad, satisfactory and recommend that it be processed for
evaluation by external examiner (s) for the award of degree.



Chairman *Mohammad Aslam*

(Dr. Mohammad Aslam Mian)

Member *Riaz Hussain*

(Dr. Riaz Hussain Qureshi)

Member *Mohammad Shafi Nazir*

(Dr. Mohammad Shafi Nazir)

Member *Sardar Ahmad*

(Dr. Sardar Ahmad Qureshi)

ACKNOWLEDGEMENTS

The author expresses his profound gratitude to Dr. M. Aslam Mian, his Advisor, Professor and Chairman Department of Soil Science, for the inspiring guidance and helpful suggestions in the conduct of this work and particularly in reviewing the manuscript. Appreciation is extended also to the other members of the Advisory Committee, Dr. Riaz Hussain Qureshi, Professor, Department of Soil Science, Dr. Shafi Nazir, Professor and Chairman, Department of Agronomy and Dr. Sardar Ahmad Qureshi, Professor Emeritus, Ayub Agricultural Research Institute, Faisalabad for their valuable advice and helpful comments.

The author deeply appreciates the inspiration, encouragement, and concern given by my dear friend Dr. Mohammad Rashid, Agricultural Chemist (Soils) Ayub Agricultural Research Institute, Faisalabad, about his pursuit for higher studies and the assistance provided in the laboratory and field work. Thanks are also expressed to Ch. Hayat Mohammad Bhatti, then Agricultural Chemist (Soils), Mr. Dost Mohammad Malik, Director Soil Fertility and Soil Testing Institute, and to Mr. M. Alim Mian, Director Soil Survey of Pakistan for the necessary support and assistance they provided during the conduct of the studies and to Dr. Kazi Suleman Memon, Associate Professor, University of Agriculture Sind, Tando Jam for his valuable help in the laboratory work done at the University of Hawaii.

The author gratefully acknowledges the cooperation and moral support of Dr. J. G. Davide, FAO Agronomist, particularly for critically reviewing the manuscript. Thanks are due to Mr. C.A.de Bie, FAO data processing specialist for his help in statistical analysis of the data. Sincere thanks too, to Dr. H. Nabhan and Mr. M. Tahir Saleem, Project Manager and Project Director, NFDC, respectively for their support and words of encouragement from time to time.

The author wishes to record his sense of admiration for all colleagues in the NFDC and in Ayub Agricultural Research Institute, Faisalabad for their cooperation. Thanks are due to Mr. Mohammad Ashraf for his cooperation and patience in typing this manuscript using word processing software on IBM personal computer.

Finally, the author would like to recognize the support, patience and understanding of his family during the period of this study.

TABLE OF CONTENTS

LIST OF TABLES.....	VIII
LIST OF FIGURES.....	IX
INTRODUCTION.....	1
REVIEW OF LITERATURE.....	5
PHOSPHORUS STATUS OF PAKISTAN SOILS.....	5
CROP RESPONSE TO PHOSPHORUS IN PAKISTAN SOILS	6
FACTORS AFFECTING PHOSPHORUS AVAILABILITY.....	9
PHOSPHORUS USE EFFICIENCY.....	12
TIME AND METHOD OF PHOSPHORUS APPLICATION	14
PHOSPHORUS UPTAKE BY PLANTS.....	19
ADSORPTION ISOTHERMS AND ASSESSMENT OF PHOSPHORUS REQUIREMENTS.....	22
FACTORS AFFECTING PHOSPHORUS ADSORPTION.....	24
PHOSPHORUS SOIL TEST-CROP RESPONSE CORRELATION	27
COMPARISON OF SOIL TESTING METHODS FOR AVAILABLE PHOSPHORUS	28
CRITICAL VALUES FOR SOIL TEST PHOSPHORUS.....	32
MATERIALS AND METHODS	37
PHOSPHORUS USE EFFICIENCY.....	37
EXPERIMENT I: INFLUENCE OF TIME, METHOD AND RATE OF PHOSPHORUS APPLICATION	38
EXPERIMENT II: METHODS OF PHOSPHORUS PLACEMENT.....	41
DATA ANALYSIS.....	42
ASSESSING PHOSPHORUS REQUIREMENTS OF WHEAT USING P ADSORPTION ISOTHERMS	44
FIELD EXPERIMENTS IN FARMERS' FIELDS.....	44
CALCULATION OF RELATIVE YIELDS	46
PHOSPHORUS SORPTION DETERMINATION	47

SOIL TEST-CROP RESPONSE CORRELATION STUDIES.....	49
SOILS USED IN THE STUDY.....	49
GREENHOUSE EXPERIMENT.....	54
DETERMINATION OF AVAILABLE P BY DIFFERENT EXTRACTANTS.....	55
NaHCO ₃ EXTRACTABLE-P.....	55
NH ₄ HCO ₃ - DTPA EXTRACTABLE-P.....	56
WATER EXTRACTABLE-P.....	56
DOUBLE ACID-MEHLICH-III-P.....	56
DATA ANALYSIS TO COMPARE METHODS.....	57
RESPONSE OF CORN TO APPLIED PHOSPHORUS	57
METHODS FOR CORRELATION OF SOIL TEST WITH PLANT RESPONSE.....	57
GRAPHICAL METHOD.....	57
ANALYSIS OF VARIANCE METHOD.....	58
RESULTS AND DISCUSSION.....	61
PHOSPHORUS USE EFFICIENCY.....	61
EXPERIMENT-I: INFLUENCE OF TIME, METHOD AND RATE OF PHOSPHORUS APPLICATION.....	61
RESULTS	61
Tillering stage.....	61
Dry matter yield.....	61
P concentration and uptake.....	63
Boot stage	65
Dry matter yield.....	65
P concentration and uptake.....	68
Harvest stage.....	70
Grain yield.....	70
Straw yield.....	72
P concentration in grain	72
P concentration in straw.....	72
Total phosphorus (P ₂ O ₅) uptake.....	77
Quantification of phosphorus use efficiency	77

DISCUSSION.....	80
Yield as influenced by time and method of P application	80
Pattern of phosphorus uptake.....	83
Phosphorus use efficiency	85
Phosphorus efficiency and economics of fertilizer use.....	90
 EXPERIMENT-II:METHODS OF PHOSPHORUS PLACEMENT.....	 91
RESULTS	91
DISCUSSION.....	95
 ASSESSING PHOSPHORUS REQUIREMENTS OF WHEAT.....	 96
RESULTS	96
Phosphorus adsorption characteristics of soils.....	96
Phosphorus requirement of wheat.....	98
DISCUSSION.....	104
Phosphorus adsorption characteristics of soils.....	104
Phosphorus requirement of wheat.....	107
 SOIL TEST-CROP RESPONSE CORRELATION STUDIES.....	 109
RESULTS	109
Crop response to applied P in pot experiment.....	109
Relative yield, P content in plant and soil test P values	110
Comparison of soil tests for Phosphorus.....	118
Correlation with P content in plant.....	118
Correlation with response (additional yield).....	122
Critical values of extractable P through correlation of soil test with plant response data.....	128
DISCUSSION.....	134
Response of maize crop to applied phosphorus	134
Comparison of soil test methods for available P.....	137
Correlation with P content in plant.....	137

Correlation with crop response (additional yield).....	138
Critical values of soil test P (partitioning of soil test crop response probability).....	140
GENERAL DISCUSSION	143
SUMMARY AND CONCLUSIONS.....	149
LITERATURE CITED	156
ANNEXURES	173

LIST OF TABLES

Table.....	Page
1. Properties of the four soil series used for wheat trials.....	45
2. Location and classification of soil series sampled.....	50
3. Selected soil characteristics of soil series.....	52
4. Mineralogy of the soils used in the study.....	53
5. Dry matter yield of wheat at tillering stage as influenced by time, methods and rates of phosphorus application.....	62
6. P concentration (%) in plant at tillering stage as influenced by time, methods and rates of phosphorus application.....	64
7. Dry matter yield of wheat at boot stage as influenced by time, methods and rates of phosphorus application.....	67
8. P concentration (%) in plant at boot stage as influenced by time, methods and rates of phosphorus application.....	69
9. Grain yield of wheat as influenced by time, methods and rates of phosphorus application.....	71
10. Straw yield of wheat as influenced by time, methods and rates of phosphorus application.....	74
11. P concentration (%) in wheat grain as influenced by time, methods and rates of phosphorus application.....	75
12. P concentration (%) in wheat straw as influenced by time, methods and rates of phosphorus application.....	76
13. Uptake of phosphorus by wheat crop at harvest as influenced by time, methods and rates of phosphorus application.....	78
14. Phosphorus use efficiency in wheat as influenced by time, methods and rates of phosphorus application.....	79
15. Economics of applying phosphorus by different methods.....	92
16. Grain yield of wheat as influenced by methods of phosphorus placement.....	92
17. Wheat yield as influenced by P application at four locations.....	100
18. Fertilizer P required to maintain P concentration in solution for 95% of maximum yield.....	101
19. Regression equations for dry matter yield with P rates.....	116
20. Relative yield, P in plant, and extractable soil P	117
21. Regression equations for P uptake (% P Conc.) with soil test values.....	121
22. Correlation between available phosphorus extracted by different methods and P uptake (% Conc.) in plant (maize).....	121
23. Correlation between the soil testing methods used for P extraction.....	127
24. Correlation of crop response (additional yield) with soil test values.....	127

LIST OF FIGURES

FIGURE.....	PAGE
1. Method used to estimate the concentration of P in solution corresponding to rates of P fertilizer applied in the field. Values for P in solution corresponding to P fertilizer rates (0 to 180 P ₂ O ₅ kg ha ⁻¹) were 0.015, 0.026, 0.047, 0.081 and 0.15 ug ml ⁻¹ (Gujranwala soil series).....	48
2. Format of clear plastic overlay used for finding critical soil test values.....	59
3. Response of wheat to phosphorus at tillering.....	66
4. Response of wheat to phosphorus at booting.....	66
5. Response of wheat (grain) to phosphorus at harvest.....	73
6. Response of wheat (straw) to phosphorus at harvest.....	73
7. Phosphorus use efficiency as indicated by yield increase per kg P ₂ O ₅ and recovery (%) of applied P ₂ O ₅ as influenced by time method and rate of application.....	87
8. Wheat yield as influenced by methods of P placement.....	94
9. Phosphorus adsorption isotherms of soils from four experimental sites used in the study.....	97
10. Grain yield of wheat as a function of P concentration in solution.....	99
11. The yield response curves of wheat as a function of P concentration in solution in Sultanpur and Hafizabad soil series.....	102
12. The yield response curves of wheat as a function of P concentration in solution in Lyallpur and Gujranwala soil series.....	103
13. The composite yield response curve of wheat grain at four locations as a function of P concentration in solution.....	105
14. Phosphorus response curves for maize (Rasulpur, Rajar, Pindorian, Balkassar soils).	111
15. Phosphorus response curves for maize (Sultanpur, Miranpur, Hafizabad, Bhalwal soils).	112
16. Phosphorus response curves for maize (Gujranwala, Missa, Lyallpur, Guliana soils).	113
17. Phosphorus response curves for Maize (Peshawar, Warsak, Kotli, Pacca soils).	114
18. Phosphorus response curve for maize (Murree soil).	115
19. Scatter diagram of P in plant (%) vs P soil test values by NaHCO ₃ and water extractants.	119
20. Scatter diagram of P in plant (%) vs P soil test values by NH ₄ HCO ₃ -DTPA and double acid (Mehlich-III) extractants.	120
21. Relationship between soil test values (P-Olsen) and response at 50 and 100 mg kg ⁻¹ of applied P.....	123

22.	Relationship between soil test values (P-Water) and response at 50 and 100 mg kg ⁻¹ of applied P.....	124
23.	Relationship between soil test values (P-Mehlich-III) and response at 50 and 100 mg kg ⁻¹ of applied P.....	125
24.	Relationship between soil test values (P-NH ₄ HCO ₃ -DTPA) and response at 50 and 100 mg kg ⁻¹ of applied P.....	126
25.	Scatter diagram of relative yield in relation to soil test values for 0.5 M NaHCO ₃ method	130
26.	Scatter diagram of relative yield in relation to soil test values for NH ₄ HCO ₃ -DTPA method.....	131
27.	Scatter diagram of relative yield in relation to soil test values for Mehlich-III method	132
28.	Scatter diagram of relative yield in relation to soil test values for water extractable method.....	133

INTRODUCTION

Phosphorus is an important element essential for nutrition and growth of plants. It plays a vital role in plant metabolism, energy transfer, stimulation of seedling growth and reproduction of plants.

Phosphorus, after nitrogen, is reported to be the most deficient plant nutrient in almost all soils in Pakistan. The use of phosphatic fertilizer in Pakistan started in 1960 with 100 tonnes P_2O_5 and reached a level of 350 thousand tonnes by the year 1986. However, as compared to nitrogen the level of phosphorus use per hectare is still low. Based on the national consumption figures in 1985-86, the ratio of nitrogen to phosphorus use is 3.2:1 (NFDC, 1986a). According to the Sixth Five Year Plan (1983-88) the ratio has been envisaged to narrow down to 2.9:1 by 1987-88 (Planning Commission, 1983). The low usage of phosphorus in relation to nitrogen is considered as one of the constraints holding back crop yields and thus affecting the efficiency and economics of applied nitrogen.

Phosphatic fertilizers, when applied to soils low in available phosphorus, promote plant growth. However, the low plant utilization of applied P fertilizer is still a major problem. The efficiency of phosphatic fertilizer use by plant roots is largely influenced by the rate of movement of phosphorus through the soil to the root. Phosphorus diffuses to the root and can diffuse only in short distances; consequently, for many

crops only 5 to 15% of the applied phosphatic fertilizer is used by the first crop (Barber, 1977). The recovery of applied phosphorus is reported to be low in alkaline, calcareous soils of Pakistan and this has been attributed to the rapid rates of fixation converting the applied available P into difficultly available forms (Chaudhry, 1982).

With rising cost of crop production inputs the cost of producing crops is becoming more expensive. It is, therefore, imperative for farmers to maximize their yield outputs through an efficient use of fertilizers. The amount of fertilizer phosphorus required to provide an adequate supply of available phosphorus to growing plants varies with the type and fertility status of soils. Several agronomic practices such as the method, time and rate of application of phosphate fertilizer influence the utilization of phosphorus by plants; hence, its efficiency in producing profitable economic returns in crop production. However, more information is needed under the various crop production conditions in Pakistan to further refine practices which could promote a more efficient utilization of applied fertilizer phosphorus.

There is an abundant evidence available to show that the immediate source of P for plants growing in soil is the soil solution P (Fox and Searle, 1978). Further, it has also been shown that a close relationship exists between P in solution and the P in sorbed state. Fox and Kamprath (1970) used this information to plot P required to maintain given level of P in solution. The P sorption curves obtained have been