SOIL FERTILITY ATLAS OF PAKISTAN

The Punjab Province

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Note for the Readers

The objective of this Atlas is to present information regarding fertilizers, farmers' common practices, crop yields under different nutrient use scenarios and cropping practices in the Punjab province. Thus, the overall trends and inferences drawn are valid (and justified) primarily for a particular crop grown under the respective zone suitable for that crop. However, variations from the normal trends may be noticed for a crop's yield viz-a-viz fertilizer use when grown on a small area in an ecological zone not specific for that crop. Therefore, the stated patterns and conclusions may be viewed in the perspective of the available data sets, assumptions for interpretations and the methodology adopted rather than making comparisons with a given site-specific situation. All possible care has been taken in data analysis and presentation; suggestions for improvements are welcome.

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The Punjab Province

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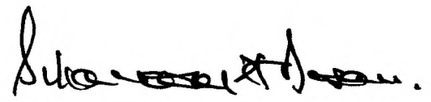
FOREWORD

Agriculture has a critical role in supporting economic growth in Pakistan. More than 67% of the country's rural population is directly or indirectly dependent on agriculture. The sector accounts for 22% of Pakistan's GDP and 45% of direct employment. The prosperity of a large portion of the population revolves around good growth in agriculture which requires timely and adequate use of inputs like certified seeds, balanced use of fertilizers along with mechanization and provision of agricultural credits. Imbalanced fertilizer use and high fertilizer prices are the major constraints to achieve sustainable crop production. 4R nutrient stewardship can help decrease the cost of production and enhance nutrient use efficiency. The Soil Fertility Atlas is a part of the project 'Soil Fertility Management for Sustainable Intensification in Pakistan: Baseline Input Atlas and Promotion of Soil Fertility with Private Sector'. The ultimate objective is to promote the use of appropriately balanced inputs and Right fertilizer/nutrient at the Right rate at the Right time in the Right place (4Rs) in partnership with the public and private sectors.

Globally, today's challenge is to produce more and healthier food in a sustainable manner. The promotion of sustainable soil management is essential if humanity's overarching need for food is to be met. Moreover, one of the major causes of the depletion of the soil fertility is the mining of essential plant nutrients from the soils due to intensive cultivation and unsustainable soil management practices. The loss of soil fertility in many developing countries poses an immediate threat to food security. Appropriate use of fertilizers on soils of low natural fertility makes it possible to grow more and promote crop diversification. Fertilizers constitute the most important scientific breakthrough in feeding the growing population of Pakistan and elsewhere. FAO, NFDC, PARC and other Research Institutes have reported up to 50% enhanced crop productivity with the use of fertilizer application. However, imbalanced use of fertilizers (Nitrogenous, Phosphatic, Potassic and Micronutrients) and low fertilizer(s) efficiency are the major constraints in enhancing crop productivity in the country. The use of fertilizers in Pakistan is imbalanced; proper ratio of fertilizers is being ignored, resulting in low income of farmers. Consequently, agricultural production has been stagnant in some of the cropping zones. On the other hand, population is increasing at an alarming rate and sustainable agriculture intensification is essential. Organic manure, which can help restore nutrient status, has great potential, but cannot meet the sizeable crop(s) nutrient requirements alone. This is especially true for soils that have been depleted of their nutrients for decades by intensive cropping.

The Soil Fertility Atlas for the Punjab Province provides a comprehensive account of the soil types and their current fertility status, native best management practices, fertilizer use trends at the farm-gate level, and management strategies for normal and constrained soils for resource based improvement. I am confident that this document will help define the soil fertility management changes required for sustainable intensification in the Punjab province initially, which would also be applicable to similar agro-ecological scenarios across the country. Hopefully, an array of stakeholders will be benefitted from this Atlas including the farmers, extension workers, soil/agriculture/environment professionals, economists and policy makers in the public as well as private sectors. Specifically, the farmers are deemed to benefit the most; they need to get involved for applying the 4R strategy for ensuring sustainable agriculture as there is a close association between soil fertility management and soil health. Additionally, the soil fertility database would provide a basis for the development of an improved capacity for monitoring and management of fertilizer use in Pakistan. This will pave the way to upscale the activities concerning 4R nutrient stewardship.

At the end let me express my deep appreciation of those involved in this undertaking of monumental national importance. I have no doubt that this document will go down as vade mecum for scientists, researchers and policy makers. This will also help develop an assertive vision for progress and prognosis in soil fertility protocol in Punjab and beyond.



Sikandar Hayat Khan Bosan
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The preparation of the Punjab Soil Fertility Atlas for final publication has been led by Dr. Waqar Ahmad (Soil/NRM Expert - Project Manager, FAO). The Atlas benefited from the kind support of Dr. Nisar Ahmad, Ex-Chief of the National Fertilizer Development Center (NFDC), Planning Commission of Pakistan, Mr. Abdul Jalil Marwat (Chief NFDC), Dr. Ahmad Ali Khan (Assistant Chief NFDC) and Dr. Muhammad Islam (Assistant Chief NFDC) for sharing disaggregated data on fertilizer offtake and postulation of different hypotheses.

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The editorial comments on the final product were provided by Dr. Muhammad Anjum Ali, Dr. Shahzada Munawar Mehdi, Dr. Munir H. Zia (FFCL), Dr. Muhammad Salim (PARC), Dr. Khalid Mahmood (Ex-Deputy Chief Scientist, Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad), Dr. Arshad Ashraf (NARC) and Dr. Masood A. Shakir (Ayub Agricultural Research Institute, Faisalabad). The development of this Atlas would have been difficult, if not impossible, without the leadership and oversight of Mr. Nasar Hayat (Assistant Representative - Head Programme, FAO) and Dr. Yuji Niino (Technical Officer, FAO Rome).

INTRODUCTION

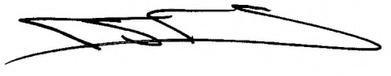
The promotion of sustainable soil and crop management practices is crucial to ensure sustainable agricultural development in Pakistan. Agriculture faces the major challenge of combining intensive production with sustainability. Producing in a more sustainable way means using natural resources efficiently, recycling them as much as possible for further use, and avoiding negative impacts on the soil and environment. With respect to fertilizers/ nutrients, the objective is to minimize losses that occur, for example, through volatilization, soil fixation (due to alkaline calcareous nature, salt buildup, poor organic matter status, etc.), soil erosion and leaching, and to replenish nutrients that have been removed from the soil through plant uptake or any other process causing nutrient loss. Food and Agriculture Organization of the United Nations (FAO) in partnership with the Ministry of National Food Security & Research, Pakistan Agricultural Research Council (PARC) and US Department of Agriculture (USDA) with funding from USAID is implementing a project entitled 'Soil Fertility Management for Sustainable Intensification in Pakistan: Baseline Input Atlas and Promotion of Soil Fertility with Private Sector - GCP/PAK/130/USA'. For this, FAO is collaborating closely with both the public and private sector partners to:

- Assess district-wise soil fertility status;
- Conduct rapid fertilizer use assessment/survey;
- Identify best soil health and fertility management practices;
- Disaggregate commodity-wise fertilizer offtake/use;
- Collect soil survey and classification related information;
- Promote balanced use of inputs and 4R nutrient stewardship (commonly known as Right nutrient/fertilizer at the Right rate at the Right time in the Right place) through organizing symposia, commodity-based workshops, seminars and holding policy dialogues;
- Strengthen the provincial and national capacity to undertake sustainable soil fertility management, and visualization of data;
- Prepare the baseline atlas of current soil fertility and soil health management practices; and
- Use the outputs of these activities to support informed decision making at various scales, for example, setting provincial frameworks for Agriculture and Natural Resources Management in achieving Sustainable Development Goals (SDGs).

In order to achieve the objective, the use of appropriate balanced fertilizer inputs and 4R Nutrient Stewardship is being promoted through a series of events (workshops, seminars, dialogues) in the main centers of the country. Some of the key recommendations coming out of these events are:

- Development of a nutrient stewardship framework and manual on 4R nutrient stewardship for the farming community of Pakistan;
- Use of public-private partnership as a mechanism for sustainable agriculture intensification in the country;
- Include farmers' experience in devising soil and fertilizer management strategies for sustainable crop production; and
- Collaborative efforts are required to address such issues in the best interest of the farming community.

This Soil Fertility Atlas for the Punjab Province has four sections: 1) General Maps, 2) Rapid Fertilizer Use Assessment, 3) Mapping NFDC Fertilizer Offtake Data, and 4) Soil Fertility Status Mapping. Besides, several annexures offer details of the important parameters of the fertilizers data used. The Atlas provides use of different fertilizers/nutrients for major commodities/crops grown in the Punjab province. Yield of different commodities under different nutrient use scenarios is often not consistent, as is evident from the variable overall crop productivity viz-a-viz region-wise application of inputs/fertilizers. This clearly indicates the impact of factors, other than the material fertilizer inputs, such as soil constraints and inappropriate crop management practices. Identification of hot spots with regard to inadequate nutrient applications (over or less) coupled with low use efficiency factors would help to explain required soil fertility management changes for sustainable agriculture intensification.



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FAORepresentative
Pakistan

METHODOLOGY

The Atlas is based on the agricultural statistics, field-based assessment and source data collected from provincial and federal departments and agencies. Series of workshops/ consultations were conducted at various locations across the Punjab province for gathering information and document experience from the national and provincial stakeholders including growers of major crops like wheat, rice, cotton, maize, and sugarcane. These consultations were aimed to highlight the significance of 4R nutrient stewardship, differentiate this relatively new concept from the balanced fertilization, identify soil and crop management constraints, and best soil health management practices for sustainable agricultural intensification in the province. Major steps involved in Atlas preparation are as follows.

Rapid Fertilizer Use Assessment

The assessment was based on the assumption that Fertilizer Offtake data (a term used by NFDC to describe fertilizer consumption based on the marketing of products) does not necessarily reflect the application of fertilizers at the farm-gate level. This community-based assessment was conducted with the involvement of the Punjab Agriculture Extension Department. A questionnaire was developed after consultation with different stakeholders and district-wise farmers' interviews were conducted. The selection of farmers was presumably skewed towards medium level progressive farmers with whom agriculture extension workers frequently interact. The sample population (farmers interviewed) was 33 per district. Overall this sample size was found representative when aggregated at crop production region and provincial scales. Further, the data so collected was deemed representative for a group of farmers, as rural communities often follow similar practices as elders decide after consultation in the family. The collected information through this assessment pertains to the use of various fertilizers, yield of major crops, major soil constraints hampering productivity, and percentage of the farmers availing soil and water testing facility in each district across Punjab. The validation of such trends in each district was based on field surveys, follow-up interviews and discussions with public and private sector stakeholders.

The crop data was disaggregated by districts according to the following crop production regions:

- **Cotton-Wheat**
  Bahawalnagar, Bahawalpur, Dera Ghazi Khan, Khanewal, Lodhran, Multan, Muzaffargarh, Rajanpur, Rahim Yar Khan, and Vehari
- **Rice-Wheat**
  Gujranwala, Gujrat, Hafizabad, Mandi Bahauddin, Narowal, Nankana Sahib, Sheikhupura, and Sialkot
- **Mixed Cropping**
  Chiniot, Faisalabad, Jhang, Kasur, Lahore, Okara, Pakpattan, Sahiwal, Sargodha, and Toba Tek Singh
- **Pulses-Wheat (Thal Area)**
  Bhakkar, Khushab, Layyah, and Mianwali
- **Maize-Wheat-Oilseeds (Rainfed Area)**
  Attock, Chakwal, Jhelum, and Rawalpindi

Regarding the application of different nutrient sources, all progressive, medium- and small-holder farmers were assumed to apply fertilizers/nutrients in eight different combinations: N only; NP; NPK; NP + MN; NP + FYM; NP + MN + FYM; NPK + MN; NPK + MN + FYM, where, N = Nitrogen; P = Phosphorus; K = Potassium; FYM = Farm Yard Manure; MN = Micronutrients. Moreover, keeping the other factors of production constant, addition of each nutrient to individual nutrient use scenario will presumably increase the commodity/crop yield.

NFDC Offtake Data

The crop-wise disaggregation of total offtake data was based on the relative use and area sown for each crop and was assumed to be equal to what farmers are using at the farm-gate level. Despite minor fluctuations in annual fertilizer offtake, the overall trends of total and product-wise offtake of fertilizers remained comparable across past several years. These patterns of such trends also coincided with those derived from the information regarding fertilizer use gathered directly from the farmers. Therefore, the used data-sets suffice for the objective and scope of the Atlas, i.e. development of overall fertilizer/nutrient use scenarios in the perspective of sustainable crop intensification and better soil health. Weights to specific crop(s) sown were assigned to segregate product-wise offtake data (tons per district) in kg/ acre for each crop in a district. Later, for regional scenarios the amounts of fertilizers for each crop were aggregated to represent cumulative use of fertilizers for five crops in each

crop production region.

The fertilizer offtake data acquired from NFDC was incorporated district-wise in tabular form. The agricultural statistics data and addresses of soil and water testing facilities in the province have been documented which would provide a fundamental baseline for future management and planning of nutrient(s) use in the province.

Spatial Data Mapping and Analysis

Preliminary, a base map of the province containing the district boundaries was prepared in ArcGIS software to aid geo-spatial mapping and analysis. The results of the Rapid Fertilizer Use Assessment (RFUA) and the fertilizer offtake data presented in the tabular form were linked with vector data of the districts for spatial-cum-attribute data analysis. Scenarios of fertilizer use were developed to study response with regard to yields of various crops at district level in the province.

Data Visualization

The layout of the Atlas was prepared incorporating all necessary mapping details. The soil fertility status and fertilizer offtake data was mapped under different sections of the atlas for general overview and presentation. The fertilizer use information was illustrated in the atlas in aggregated and cartographic form as well as tabular statistics per crop per district.

Soil Fertility Status

Fauji Fertilizer Company Limited (FFCL) has been providing Advisory Services to the farming community throughout Pakistan since 1981, for increasing the agriculture production and economic returns at the farm-gate level. The Company is providing soil and water testing facilities all over the country through its five mobile Farm Advisory Centers. As of today, these centers are located at Hassan Abdal, Sahiwal, Multan, Bahawalpur and Sukkur. The laboratories are periodically relocated in order to facilitate the farming community of each district. The soil fertility data from January 2001 to February 2014 in terms of soil electrical conductivity (EC), soil reaction (pH), organic matter (OM), available phosphorus (P) and extractable potassium (K) was obtained and disaggregated by districts. It was assumed that EC, pH, OM, P and K values are the indicative of the overall soil fertility status of each district. The farmers of the respective district may plan nutrient management strategy accordingly. However, they should consult the Soil and Water Testing Laboratories and Agriculture Advisory Services before sowing of any crop(s).

SUMMARY AND WAY FORWARD

Agriculture is the backbone of Pakistan's economy. Thus, national development is possible through efficient use and conservation of natural resources, particularly the soil/land which is non-renewable. Unfortunately, unsustainable management practices have led to loss of soil fertility and health, compelling the use of chemical fertilizers which too is not efficient to the desirable level. The resource base of raw materials for fertilizer production is also depleting fast. These scenarios warrant adoption of best management practices to enhance fertilizer use efficiency and improve soil fertility for sustaining agricultural productivity. The Soil Fertility Atlas for the Punjab Province is a comprehensive document that provides detailed information on cropping patterns, management practices, soil fertility status, trends of fertilizer use, advisory services/facilities available to the farmers in the province, and also suggests the strategies to maximize productivity while sustaining the soil health and environmental quality.

This Atlas reveals that the use of nutrients is skewed towards nitrogen, phosphorus and proportional use of potassium is less than 1% as compared to the application of nitrogen and phosphorus. Use of micronutrients and organic sources of nutrients is not common among most of the farmers. Overall, <10% of the farmers use organic sources of nutrients predominantly in wheat-occupied cropping systems whereas <20% farmers across the Punjab apply micronutrients regardless of the product quality (largely in rice-based cropping system) out of five crops under observation. Nevertheless, burning of crop residues and lack of scientific application of both inorganic and organic sources of nutrients still remained a concern. Indeed, the district-wise disaggregation of NFDC offtake data did not reflect the actual usage of the fertilizers at the farm-gate level. This divergence when compared with the Rapid Fertilizer Use Assessment (RFUA) was attributed to the storage of fertilizers at various locations in the Punjab. Overall, except one crop production region, i.e. Mixed Cropping (vs. Cotton-Wheat), the cumulative usage of fertilizers/nutrients in all of the regions for five crops followed the same trend: Rice-Wheat > Pulses-Wheat > Maize-Wheat-Oilseeds. About 70% higher nutrient use was figured out from RFUA for all crop production regions except in the rice-wheat based cropping system than the processed NFDC offtake data. This is to note that, farmers reported nutrient(s) application in eight different combinations across the Punjab (N only; NP; NPK; NP + MN; NP + FYM; NP + MN + FYM; NPK + MN; NPK + MN + FYM). Moreover, the addition of each nutrient to individual nutrient use scenario was not translated into the increased yield for four selected crops. However, the increased use of nutrients presumably enhanced yield in case of wheat. Therefore, further investigations are required in the specific crop production region(s) to determine suitable nutrient use scenarios for improved efficiency and yield.

Soil-related constraints weighted 40% in the problem-matrix that could hamper productivity were reported by the farmers at the provincial scale. However, the degree of soil constrains varied from 43 to 50% in regional scenarios. For example, soil-constraints in cotton-wheat were reported 50% followed by mixed crops (48%) and rice-wheat (43%). While in Thal and rainfed areas, canal water shortage and high inputs prices emerged as the principal components impacting productivity and farmers' satisfaction. The generation of soil maps for regional scenarios to identify the limiting soil constraints in the consistently poor performing areas may be helpful. In addition, development of supporting database/archives would allow moving towards non-destructive approaches for problem assessment and wisdom driven agriculture. The spatial distribution of constraints at similar scale could also be used to obtain the cost of lost production using soil-constraints matrix. Although crop production in good quality soils is the priority, simultaneous focus should be on agricultural-constrained soils under the changing climate scenarios.

In nutshell, first 2Rs of the desirable 4R Nutrient Stewardship (Right fertilizer/nutrient (Source) at the Right rate at the Right time in the Right place) are usually practiced, but the latter 2Rs are rarely followed by the farming communities, which results in low nutrient use efficiency and economic returns. This is the first step forward in the right direction and similar activities should be undertaken in other provinces of the country for achieving the food security and socio-economic uplift. For this purpose, a network of soil (macro- and micro- nutrients), plant, water, and fertilizer Quality Testing Facilities for the benefit of farming community should be established. The existing testing laboratories may not be enough to facilitate about 4 million farmers of the Punjab. Outreach linkages with the farmers may be strengthened for extensive surveys/assessments at farm-gate level and applying best management practices according to 4R soil constraint-based commodity-specific packages. All the partner organizations are welcomed for collaborative efforts to address the adoption of best methodology for nutrient use, and mapping of most responsive crop growth stage(s). Certainly, this effort would contribute towards setting a national framework and policy intervention for Agriculture and Natural Resources Management in SDGs agenda (specifically Crop Production, Environment, and Soil and Water for agriculture related activities). Let us join hands with federal/provincial agencies as well as private sector for collaborative initiatives to achieve sustainable development.

ACRONYMS

ABEI	Agricultural and Biological Engineering Institute
CAEWRI	Climate Change, Alternate Energy and Water Resources Institute
CAN	Calcium Ammonium Nitrate
DAP	Di-Ammonium Phosphate
dSm^{-1}	DeciSiemens per meter
FAO	Food and Agriculture Organization of the United Nations
FAC	Farmer Advisory Center
FFCL	Fauji Fertilizer Company Limited
FYM	Farm Yard Manure
GAUL	Global Administrative Unit Layers
ICARDA	International Center for Agricultural Research in the Dry Areas
K	Potassium
Km	Kilometer
LRRI	Land Resources Research Institute
mm	Millimeter
MN	Micronutrients
N	Nitrogen
NARC	National Agricultural Research Center
NFDC	National Fertilizer Development Center
NIAB	Nuclear Institute for Agriculture and Biology
P	Phosphorus
PARC	Pakistan Agricultural Research Council
RFUA	Rapid Fertilizer Use Assessment
SAWCRI	Soil and Water Conservation Research Institute
SFRI	Rapid Soil Fertility Survey and Soil Testing Institute, Punjab
USDA	U.S. Department of Agriculture
USAID	U.S. Agency for International Development