SOIL FERTILITY ATLAS OF PAKISTAN

The Sindh Province

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Note for the Readers

The objective of this Atlas is to present information regarding availability of fertilizers, farmers' common practices, and crop yields under different nutrient use scenarios and cropping practices in the Sindh province. Thus, the overall trends and inferences drawn are valid (and justifed) 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 specifc for that crop. Thus, the stated inferences imply necessarily for the area under a specifc crop and not for the whole cropped area in a district. 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-specifc situation. All possible care has been taken in data analysis and presentation; suggestions for improvements are welcome.

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	Farm 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
USDA	U.S. Department of Agriculture
USAID	U.S. Agency for International Development

FOREWORD

Agriculture sector is playing a vital role in driving economic growth in Pakistan. About 67% of the country's population is directly or indirectly dependent on agriculture for their livelihood. The agriculture sector accounts for 45% of employment equivalent to 26 million persons of the national workforce, and 22% of the country's GDP. Adequate and timely use of inputs like balanced fertilizers and certified seeds along with mechanization and provision of agricultural credits are prerequisites for better agricultural output. The Sindh province contributes significantly towards the overall national agricultural production in major crops including rice (36%), cotton (34%), sugarcane (29%), and wheat (15%). Thus, the economic development of Sindh province in the background of ever increasing population largely depends on further growth of agriculture sector.

The promotion of sustainable soil management is essential for meeting overarching human need for food, raw materials and energy. Among the major constraints that are hampering sustainable yields, imbalanced fertilizer use and high fertilizer prices are dominant factors. 4R nutrient stewardship, if duly implemented, can help decrease the cost of production and enhance fertilizer 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 - GCP/PAK/130/USA'. 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.

The loss of soil fertility in many developing countries poses an immediate threat to food security. One of the major causes of depletion of the soil fertility is mining of the essential plant nutrients from the soils due to intensive cultivation and unsustainable soil management practices. 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 fertilizers. However, imbalanced use of fertilizers (Nitrogenous, Phosphatic, Potassic and Micronutrients) and low fertilizer(s) efficiency still remain the major constraints in enhancing crop productivity in the country. The imbalanced use of fertilizers in Pakistan that results in lower incomes of the farmers can rightly be blamed to incorrect ratio of nutrients. Consequently, the agricultural production per unit area especially of grain crops has been stagnant in some of the cropping zones. On the other hand, the population is increasing at an alarming rate; it requires sustainable agriculture intensification. Organic manures, which can help restore soil health and its nutrient status, possess a huge potential. However, organic manures alone cannot meet the sizeable nutrient requirements of major crops. Therefore, the concept of integrated plant nutrition management system is need of the hour. This is especially true for soils that have been depleted of their nutrients for decades by intensive cropping.

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

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 Sindh and beyond.

Sikandar Hayat Khan Bosan
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The editorial comments on the final product were provided by Dr. Kazi Suleman Memon (Professor (Retd.), Sindh Agriculture University, Tandojam), Prof. Dr. Zia-ul-Hassan Shah (Sindh Agriculture University, Tandojam), Dr. Khalid Mahmood (Ex-Deputy Chief Scientist, Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad), Dr. Muhammad Aslam (Principal Scientist, NIAB, Faisalabad), Dr. Munir H. Zia (FFCL), Dr. Arshad Ashraf (NARC), Dr. Nisar Ahmad (NFDC), Dr. Muhammad Salim (PARC) 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), Mr. Francisco Gamarro (Deputy Representative, FAO Pakistan) and Dr. Yuji Niino (Technical Officer, FAO Rome).

INTRODUCTION

Promotion of sustainable soil and crop management practices is crucial to ensure intensive agricultural production and maintain environmental quality - a major challenge being faced by the agriculture sector in Pakistan. Sustainable agricultural production system requires not only efficient use of the natural resources but it also involves recycling of the organic wastes of plant, animal and industrial origin without casting any negative impact on soil and the environment. With respect to fertilizers, the objective is to minimize nutrient losses that occur through leaching of nitrates, volatilization of ammonia, denitrification, soil fixation (due to alkaline calcareous nature, low organic matter content, etc.), soil erosion and to replenish nutrients that have been exhausted from the soil through crop uptake during intensive agricultural practices.

In consideration of the above concerns, Food and Agriculture Organization of the United Nations (FAO) in partnership with the Ministry of National Food Security & Research (MNFSR), Pakistan Agricultural Research Council (PARC) and U.S. Department of Agriculture (USDA) implemented 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 collaborated closely with both the public and private sector partners to:

- Conduct rapid fertilizer use assessment/survey;
- Assess district-wise soil fertility status;
- Identify best management practices that enhance soil health and productivity;
- Collect information related to soils classification;
- Promote 4R nutrient stewardship (commonly known as Right nutrient/fertilizer at the Right rate at the Right time in the Right place) through organizing commodity-based workshops, seminars and policy dialogues for balanced used of inputs;
- Strengthen the provincial and national capacity of relevant agricultural organizations for implementation of sustainable soil management practices with special focus on soil fertility and plant nutrition, and visualization of data;
- Prepare the baseline atlas of current soil fertility and soil health management practices; and
- Use outputs of the above activities for informed decision making at various levels, for example, setting provincial frameworks for Agriculture and Natural Resources Management in achieving Sustainable Development Goals (SDGs).

As an effort towards achievement of the objectives, use of appropriate balanced fertilizer inputs and 4R Nutrient Stewardship was 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 nutrientstewardship for the farming community of Pakistan;
- Use of public-private partnership as a mechanism for sustainable agriculture intensification in the country;
- Include farmers' experiences in devising soil and fertilizer management strategy for sustainable crop production; and
- Collaborative efforts are needed to address such issues in the best interest of the farming community.

This Soil Fertility Atlas for the Sindh province is comprised of four sections: 1) General Maps, 2) Rapid Fertilizer Use Assessment, 3) Mapping NFDC Nutrient Offtake Data, and 4) Soil Fertility Status Mapping. Besides, several annexures offer details of the important parameters of the fertilizers data used. The baseline atlas provides use of different fertilizers/nutrients for major commodities/crops grown in the Sindh 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. The desired soil fertility management changes for sustainable agriculture intensification could, thus, be better understood through identification of hot spots with regard to non-judicious use of nutrient applications (over or less than required) coupled with low use efficiency factors.

Mina Dowlatchahi
FAO Representative
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 Sindh province for gathering information and document experience from the national and provincial stakeholders. Considering the contribution of major crops/commodities in agricultural production, rice, sugarcane, cotton, wheat, mango and banana were selected to monitor the usage of fertilizers and/or yield trends. The 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 described below.

Rapid Fertilizer Use Assessment

The assessment was based on the assumption that Fertilizer Offtake data (a term used by NFDC Pakistan to describe fertilizer consumption based on the marketing of products) does not necessarily reflect the application of fertilizers at the farm-gate level. This communitybased assessment was conducted with the involvement of the Sindh Agriculture Extension Department. A questionnaire was developed in consultation with different stakeholders; and thereafter, district-wise farmers' interviews were conducted. The selection of farmers was presumably skewed towards medium level progressive farmers with whom the agriculture extension workers frequently interact. The sample population (farmers interviewed) was 60 per district. Overall, this sample size was found representative when aggregated at the crop production region and provincial scales. Further, the data 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 in the Sindh province. The validation of such trends in each district was based on field surveys, follow-up interviews and discussions with public and private sector entities/experts.

According to the climatic and soil conditions of Sindh, different areas are suitable for different crops, e.g., lower part of the province is considered best for sugarcane, coconut, banana and papaya plantation. The plains of middle Sindh are suitable for upland crops. In the upper Sindh and right bank areas of the Indus River, rice is grown abundantly. The eastern portions of the province and Kachho areas are suitable for rain-fed crops, like millets and guar. However, for comparison and consistency of presentation with Punjab Atlas, and development of this Atlas, the crop data was disaggregated by districts according to the following crop zones:

- **Cotton-Wheat**

  Ghotki, Khairpur, Shaheed Benazirabad, Naushahro Feroze, Sanghar, and Sukkur

- **Rice-Wheat**

  Badin, Dadu, Jacobabad, Kambar Shahdadkot, Kashmore, Larkana, Shikarpur, Sujawal, and Thatta

- **Mixed Crops**

  Hyderabad, Jamshoro, Karachi, Matiari, Mirpur Khas, Tando Allah Yar, Tando Muhammad Khan, Tharparkar, and Umer Kot

Regarding the application of different nutrient sources, all progressive, medium- and smallholder 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 NFDC offtake 2014-2015 was used for product-wise usage of the fertilizers across Sindh. Moreover, NPK nutrient use for five years outlook (2010-2015) was averaged and trend was monitored in three crop production regions, i.e., cotton-wheat, rice-wheat and mixed crops. Overall trends of one year and five years outlook (offtake of fertilizers) remained comparable across the past several years although minor fluctuations were observed. The patterns 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. The agricultural statistics data and addresses of soil and water testing facilities in the Sindh province have also been documented which would provide a fundamental baseline for future management and planning of nutrient(s) use in the province.

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 by incorporating all necessary mapping details. The soil fertility status and fertilizer offtake were 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 was presented by each crop and district.

Soil Fertility Status

For increasing agriculture production and economic returns at farm level, Fauji Fertilizer Company Limited (FFCL) is providing Advisory Services to the farming community throughout Pakistan since 1981, absolutely free of cost. For this purpose, the company is providing soil and water testing facilities through its five mobile Farm Advisory Centers (FACs). 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. For example, FAC Sukkur has been previously stationed at Hyderabad, Nawabshah, Mirpur Khas, and Hala. 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) were obtained and disaggregated by districts. It was assumed that EC, pH, OM, P and K values are indicative of the overall soil fertility status of each district. The farmers of a district may plan nutrient management practices as per the information mentioned for their respective district. However, the farmers are advised to consult with the nearest 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. National development is possible through efficient use and conservation of natural resources, particularly the soil/land which is nonrenewable. Unfortunately, unsustainable management practices have led to loss of soil fertility and health, compelling the use of chemical fertilizers which 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 Sindh 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 in Sindh is skewed towards nitrogen 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, <30% of the farmers use organic sources of nutrients predominantly in wheat-occupied cropping systems followed by the commodities like cotton, sugarcane and fruit orchards; whereas <15% farmers across the Sindh province apply micronutrients regardless of the product quality. Nevertheless, burning of crop residues and lack of scientific application of both inorganic and organic sources of nutrients still remain a great concern. This is to note that, the farmers in Sindh reported nutrient(s) application in eight different combinations (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, in general, into the increased yield for the 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. The temporal data of banana production shows that overall trends of district-wise banana yield have been similar in different cropping regions. Three districts, viz. Khairpur, Matiari and Thatta are leading with regard to average banana yield. Irrespective of the cropping regions or districts, banana yield has been stagnant over the last few years (2010-2015). In case of mango, data shows that overall trends of district-wise yield have been similar in different cropping regions. Three districts, *viz.* Sanghar, Mirpur Khas and Badin are leading with regard to average mango yield. Irrespective of the cropping regions or districts, mango yield has been stagnant over the last few years (2010-2015).

Soil-related constraints weighted 70% in the problem matrix that could hamper productivity, were reported by the farmers at the provincial scale. However, the degree of soil constraints varied in regional scenarios. Thus, 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 data-base/archives would allow moving towards nondestructive approaches for problem assessment and wisdom agriculture. The spatial distribution of constraints at similar scale could also be used to obtain the cost of lost production using soil-constraint 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 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 socioeconomic uplift. For this purpose, a network of soil, 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 farmers associated with 7.83 million acres of farms area in Sindh. Outreach linkages with the farmers may be strengthened for extensive surveys/assessments at the 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 the private sector for collaborative initiatives to achieve sustainable development.