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A Mixed Method Research to Analyze Fertilizer Sources and Application Methods in Nutrient Stewardship Perspective at Farm Level in Rice - Wheat Cropping Zone of Punjab, Pakistan

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Abstract

The present study was carried out in 2020 to analyse the fertilizer management practices pertaining to its sources and application methods in the perspective of 4R approach, at farm level, in the rice-wheat cropping zone of Punjab-Pakistan. Multistage random sampling and cross sectional research design were used to conduct the study in Sheikhupura and Nankana Sahib districts of Punjab were randomly selected. Two tehsils namely Muridke and Shahkot from two districts and 5 rural UCs from each tehsil were randomly selected. A sample size of 400 rice farmers was drawn with 5% confidence interval and 95% confidence level. The data were collected through a well-structured interview schedule which was pretested for validity and reliability. The quantitative data were analyzed through Statistical Package for Social Sciences (SPSS) and qualitative data were analyzed through content analysis. It was found that the efficient usage of fertilizers was hindered by some socio-economic problems and concluded that there was highly significant association between fertilizer management practices and socio-economic variables. It was recommended that the provincial government should encourage local production of the seed and fertilizer drills at subsidized prices so that the farmers can afford to apply efficient fertilizer application methods. It was also recommended that extension wing of agriculture department should design tailor-made training modules about the economic returns of using efficient fertilizer sources and application methods such as placement, fertigation or drill after standardizing them according to local farm conditions.

Keywords: Fertilizer, 4R; BMPs, NPK, basal dose, Top dressing

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Introduction

The basic concept of Nutrient Stewardship also known as 4R, involves the application of plant nutrients from right source, at right rate, at right time and in right place. These four "rights" are all necessary for plant nutrition management in such a sustainable way that consistently increase the crop productivity. The fertilizers 4 Rs including the right source, the right rate, the right time and the right place are interconnected with the sustainable development goals (Majumdar *et al*., 2013). Thereby, to sustain soil fertility so that sufficient amounts of nutrients can be delivered to growing plants, mineral nutrients 4R strategy is adopted. Sustainable management of fertilizers is effective driver for increasing productivity and crop yield (Bom *et al*., 2018). Better fertilizer management practices are important for grain production, particularly in rice and wheat.

Similarly, the 4R nutrient stewardship framework offers four standards for application of fertilizers in a responsible manner (Bryla, 2020), using key scientific principles which include right source, right rate, right time and right place. Selecting the most appropriate fertilizer source (right source) is sometimes considered as a simple task but it is affected by many factors like the availability of various inputs to farmer, particularly small-holders (Mikkelsen et al., 2009). Selection of fertilizer source starts with assessments like site diagnostics, soil or tissue testing, crop removal rates in harvested crops (INPI, 2012). On the other key scientific principles, the right place of nutrient application ensures uptake of a particular nutrient in right amount, at appropriate time and reduce its losses (Mikkelsen et al., 2009; Vollmer-Sanders et al., 2016).

The rice-wheat system is one of the largest crop production system spreading over an area of 13.5 Mha in South Asia (Zia *et al.*, 2000). In Pakistan, rice-wheat cropping system is practiced on 2.2 Mha area which is about 10 % of total farmland of Pakistan. However, a major portion (57%) of rice-wheat area falls primarily in central Punjab, mainly in district of Gujranwala, Gujarat, Mandi Baha-ud-Din, Hafizabad, Sheikhupura, Nankana Sahib, Narowal and Sialkot (FAO, 2017). Punjab, due to its agro-climatic and soil conditions, produces 100% of the Basmati rice in the country. However, both Punjab and Sindh account for nearly 90% of total rice production sharing 53% and 26% of total rice production respectively (USDA, 2019; GoP, 2020).

Farmers use various types of fertilizers for crops in Pakistan, which are either locally synthesized or imported. Fertilizers are mainly used for major crops including wheat, rice, cotton, maize and sugarcane in Pakistan. The application of nitrogenous fertilizers for these crops is nearly 75-80 % according to the recommendations as compared to phosphatic fertilizers for the same crops which is about 20-40%. But when it comes to Potash, barely 1-2% farmers prefer to apply K to their crops (FAO, 2017). Potash is applied to fruits, vegetables or sugarcane crops only. Although, deficiency of micronutrients is quite common in crops, even then less than 5% farmers care to apply the micronutrients to their crops (Ali et al., 2015).

The consumption of NPK fertilizers, in Pakistan, is approximately 144.3 kg/ha which is higher than that of the contemporary world that is 140 kg/ha, but the crop yield is significantly low. Almost 70% higher nutrient use compared to the off-take is observed for all regions in Pakistan, except the rice-wheat cropping system (FAO, 2017). In

Pakistan, low and imbalanced fertilizer nutrients are applied on poor soils while balanced use of nutrient fertilizers is observed mostly on fertile soils. It is contrary to the recommendations, but it might be due to affordability constraints of the farmers having poor soils as compared to those farming on fertile soils (Mubarik *et al.,* 2016).

In today's world, the global economic climate has brought forth the economic aspects pertaining to fertilizer usage along with many other aspects which have evolved the latest concept of fertilizers best management practices having nutrient use efficiency as the major drive (Krauss *et al.,* 2007; Chien *et al.,* 2009). The best management practices have been designed after a long process involving agronomic and soil fertility research, as a package of guiding principles for development and implementation of fertilizer nutrient use. These are the principles which become the scientific basis for the 4R nutrient stewardship concept that is applying the nutrients from right source, at right rate, at right place and at right time. Hence, this concept, developed by the global fertilizer industry, is an essential tool towards the sustainable agriculture systems (Majumdar *et al.,* 2013).

Although, there is no single package of management practices that can be called fertilizer best management practices universally, yet these are often identified by definition as site specific and crop specific. Moreover, they vary from region to region and farm to farm depending upon certain factors like soil, climate, crop / cropping history and proficiency of management. Type of the crop, the cropping system and the soil characteristics are the major factors dictating the most suitable fertilizer application method (Roberts, 2007).

Soils of Pakistan are poor in organic matter (below 1%) and the use of organic fertilizers is not common. Over-application of synthetic fertilizers particularly nitrogen is a common problem in Asian countries and Pakistan is no exception. Although fertilizer consumption has increased threefold in Pakistan, during the past 30 years, yet it is neither according to the soil and crop requirements nor according to recommendations. The major factors for inefficient fertilizer usage in Pakistan are socio-economic problems like unavailability of specific fertilizers at the required time, price hikes, unawareness of the farmers about needs and benefits of fertilizers application, inadequate methods and inappropriate time of fertilizer applications, uncontrolled adulteration practices and insufficient loans availability for the small farmers (Khaskheli, 2017)

Imbalanced fertilization raises serious concerns regarding sustainability which leads to conducting a systematic study to analyze the fertilizers management practices, at farm level, in the rice-wheat cropping zone of Punjab, Pakistan in perspective of the 4R theoretical frame-work. The objectives of this study are to analyze the use of the fertilizer nutrients sources and application methods at farmers field through the lenses of 4R nutrient stewardship framework and suggest an appropriate strategy for improvement of fertilizer management at farm level.

Methodology

Cross sectional design was used in the research. Both quantitative and qualitative methods of data collection were employed. The universe for this study consisted of all farmers of rice-wheat zone of Punjab province of Pakistan. Two districts namely Sheikhupura and Nanakana Sahib and subsequently one tehsil from each district were selected randomly from the rice-wheat zone of the Punjab. In the next step 5 union

councils (UCs) were selected randomly from each of tehsil Muridke and Shahkot. The list of farmers was obtained from the Director Agriculture Extension Lahore division,
A representative sample consisting of 400 respondent famers was accrued through online software www.surveysystems.com with 5% confidence interval and 95% confidence level. Hence 315 and 75 respondents were selected from tehsil Muridke and Shahkot respectively in proportion to population of each tehsil. Quantitative data were collected with the help of a well-structured interview schedule which was pretested. Sample from each selected district and tehsil were taken proportionately and then distributed over selected UC equally.

$$\text{Proportionate sample} = \frac{\text{Group size x sample size}}{\text{total population}}$$

The Statistical Package for Social Sciences (SPSS) was used to analyze the quantitative data.
The qualitative data were collected through the interviews of farmers and key informants and field observations. For collecting the qualitative data 25 key informants from public and private sectors were interviewed. Qualitative data were analyzed using content analysis technique

Results and Discussion

Types / sources of fertilizers

The respondent farmers were asked about their preference for different types of fertilizers sources applied to wheat and rice crops in their farm using a 5-point Likert scale (1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always). The purpose of asking this question was to identify whether they have the basic comprehension about fertilizer sources in 4R nutrient stewardship context. Their responses are shown in Table 1.

Table 1. Weighted score, mean, standard deviation and rank order of different sources of fertilizers applied to the wheat and rice crops

Fertilizer Sources		Wheat			Rice		
		WS	*Mean*	*SD*	*WS*	*Mean*	*SD*
Nitrogenous fertilizers	*Urea*	1984	4.96 [1]	0.231	1988	4.97 [1]	0.191
	Amm. Nitrate	420	1.05 [2]	0.287	408	1.02 [3]	0.210
	CAN	416	1.04 [3]	0.274	412	1.03 [2]	0.191
Phosphatic	*SSP*	452	1.13 [1]	0.471	404	1.01 [1]	0.132
	TSP	400	1.00 [2]	0.000	400	1.00 [2]	0.000
Mixed fertilizers	*DAP*	1992	4.98 [1]	0.111	1992	4.98 [1]	0.131
	NP	404	1.01 [2]	0.137	404	1.01 [2]	0.129
Potash	*MOP*	424	1.06 [1]	0.385	404	1.01 [1]	0.000
	SOP	400	1.00 [2]	0.000	400	1.00 [2]	0.099
Micronutrients	Zinc	420	1.05 [1]	0.228	1608	4.02 [1]	0.342
	Gypsum	400	1.00 [2]	0.000	408	1.02 [2]	0.111
	Boron	400	1.00 [3]	0.000	404	1.01 [3]	0.148
Organic sources	*Crop Residues*	1984	4.96 [1]	0.184	1984	4.96 [1]	0.855
	Green Manure	1084	2.71 [2]	0.160	432	1.08 [3]	0.425
	Poultry waste	452	1.13 [3]	0.646	428	1.07 [4]	0.177
	FYM	420	1.05 [4]	0.350	512	1.28 [2]	0.438

Scale: 1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always

Table 1 indicate that among nitrogenous fertilizers, urea has always been preferred to be applied in the field for the purpose of getting bumper crop and better production. It is quite evident from the mean value 4.96 for wheat crop. Moreover, ammonium nitrate and calcium ammonium nitrate are the fertilizers rarely used by the respondents. Similarly, as indicated with low mean value of 1.13 and 1 for phosphate fertilizers: single superphosphate (SSP) and triple superphosphate (TSP) respectively, suggests negligence in terms of their usage. DAP was found to be applied always as indicated by the mean value of 4.98. Potash fertilizers and micronutrients including zinc, boron and gypsum were among never applied fertilizers for wheat crop as evident from the mean values of 1.05, 1 and 1 respectively.

The respondents were also asked about application of the organic sources of fertilizers and it was found that crop residues application was a preferred practice indicated mean value of 4.96. This process involves leaving stubbles and stalks, leaves and seed pod in the field without burning them to increase soil organic matter. The next preference of organic source of the respondents is the application of farmyard manure as indicated by the mean value of 2.71 (tendency towards sometimes). Application of poultry waste and FYM were among the neglected as indicated by the mean values of less than 1.2.

Results indicate that farmers were aware of the sources of fertilizer for wheat crop but they mostly prefer urea and DAP. The reasons for this were probed from key informants. A progressive farmer told:

"Urea is preferred by common farmers due to its comparatively low price to other nitrogenous fertilizers. The common farmers don't treat different fertilizers as different sources of N, P, K nutrients. The common farmer thinks that these are all the same with same function. A very small number of farmers take them as different sources of nutrients. The role of marketers is important because whatever they make available for selling to the farmers, they would purchase it having no other choice. Same is the case with urea and DAP.

Another key informant (farmer) responding to the same question commented:

"The farmers have to get fertilizers on credit from a dealer or Arhati (middleman) who gives no choice other than urea DAP. In that case, what a common poor farmer do is to take whatever is being granted. Moreover, the common farmer with limited resources having doubts in mind is not convinced about having higher crop yield and profits if he uses all the same recommended dosage of fertilizer. He needs to be convinced that he would get as much crop yield as to pay back the debt of the dealer and have something in his own pocket as well. That is why common farmer skips the use of K fertilizer, uses less quantity of other fertilizers and thinks that he has secured his investment to some extent."

The above remarks clearly indicate that the small farmers have little or no choice when choosing fertilizers source due to certain constraints. The major constraint being affordability, farmers manage farm on credit and depend solely on the dealers or Arhatis (middlemen) for the inputs. They take whatever the dealers provide. That is why they do not go for the costlier fertilizers like potash and prefer relatively cheaper fertilizers like urea and DAP.

Whereas, 4R nutrient stewardship recommends that optimal nutrient management rarely relies on a single practice, but rather a combination of practices. Selecting the best combination is the goal of all nutrient management that addresses profitable crop production while protecting the environment from nutrient loss (Hochmuth et al., 2015). However our results show that farmers in the study area mostly use N and P fertilizers but neglect the K fertilizer for wheat and crop.

In the opinion of fertilizer experts, the selection of right source of the fertilizer is the key to nutrient management. In response to the question as to why farmers in the rice-wheat zone preferred Urea and DAP over other fertilizers, one of the key informants (officer from Agricultural Extension Department) commented,

"*Farmers find it profitable to use these fertilizers (urea and DAP) as compared to others. In the past Agriculture Extension Department as well as some private fertilizer companies were advocating to the farmers that DAP fertilizer increase the pH level of the soil. For a long time they had been discouraging the rice growers to use DAP. But now, they have amended their recommendations because the myth about DAP has been proved wrong in repeated research findings".*

Another expert from to Soil Fertility wing gave similar opinion and said,

"The farmers in rice-wheat zone prefer urea and DAP due to some common reasons. One of the reasons is that these are easily available to the farmers from market and other is the better crop yield after using these fertilizers as compared to other sources of N and P". (I have not seen such thing ever in scientific papers)

The results clearly indicate that farmers in the study area were not following the fertilizer management practices according to crop and soil requirements, as dictated by the 4R nutrient stewardship concept. When it comes to the selection of right source of the fertilizer nutrient which is the first right of the 4Rs, it was observed that the farmers have adopted the use of DAP and Urea as a conventional practice which in their opinion is beneficial. Thus, they hesitate to take risk of using other sources of N and P for their crops. The reason being lack of resources, unaffordability, unawareness and laggardness of the common farmers.

Fertilizers use in rice crop was more or less similar to that of wheat crop with a little variation (Table 1). Urea among the nitrogenous fertilizers and DAP among phosphate fertilizers were preferably being used by the respondent for better rice crop production as it is evident from the mean value of 4.97 and 4.98 respectively. Potassium sulphate and potassium chloride were fertilizers rarely applied as evident from the mean value of 1.01 and 1 respectively.

In contrast to the wheat crop, Zinc was found to be one of the micronutrients applied regularly in the rice crop as it is very clear from the mean value of 4.02 (Table 1) while, in the case of wheat crop, Zinc was rarely applied fertilizers. It also was found that crop residues were also used as a source of organic matter (mean value of 4.96) followed by farmyard manure with mean value of 1.28 indicating rarity in its application. Green manure and poultry waste were among "never applied" fertilizers for rice crop same as in case of wheat crop.

The results were endorsed by one of the key informants from fertilizer industry. While expressing his views about the farmers practices for using micronutrients and organic source of fertilizers he commented,

"Zinc is also under dosed but they are using it in rice. Whereas boron use is low due to unawareness. Zn is even recommended for wheat now a days. As Zn deficiency is being seen in human body. But boron is still not used in the wheat. Their use in high value crops is in vogue".

"Whereas, farmers are aware about organic sources but FYM is mostly less available. The shortage of time is also a factor in case of organic sources. The gap between rice harvesting and wheat sowing is less that is why green manuring is skipped. Moreover, todays new varieties need early sowing which compel farmers not to opt for the green manuring. Hence, the green manuring is mostly not being practiced".

The above remarks indicate the reasons of low adoption of recommended sources of fertilizer nutrients. The basic reasons are similar to those noted in case of wheat crop. However, the use of micronutrients particularly Zn is in practice at farmers field. The green manuring is also neglected by the farmers as they have short time for wheat sowing after harvesting the paddy crop. If the farmers go for green manuring, the wheat sowing will be delayed which is generally late due to late maturity of some rice varieties.

Nutrient management in line with the 4R nutrient framework potentially result in better crop yield and better quality of produce, reduction in production cost and labour. Moreover it is also environment friendly with less soil degradation and nutrient losses especially leaching. All these advantages conclude in better financial outputs (Bryla, 2020; Johnston and Bruulsema, 2014).

Fertilizers application methods

The methods of fertilizer application by the farmers in the study area were also explored. The respondents were asked about the method or 'right place' for fertilizer application to wheat and rice crop. Respondent were to respond using 5 points Likert scale (1: never, 2: rarely, 3: sometimes, 4: often, 5: always) for different indicators of right place of fertilizer application in the light of 4R nutrient stewardship for rice and wheat crops. The results are given in Table 2.

Table 2. Weighted score, mean, standard deviation and rank order of different methods of fertilizers applied to wheat and rice crops

Fertilizers application method	Wheat			Rice		
Application in solid form						
Broadcasting						
Basal application	WS	Mean	SD	WS	Mean	SD
N	1992	4.98	.111	1988	4.97	.103
P	1972	4.93	.347	1920	4.80	.289
K	412	1.03	.333	420	1.05	.321
Top dressing						
N	1992	4.98	.111	1900	4.75	.329
P	424	1.06	.351	500	1.25	.236
K	404	1.01	.124	400	1.00	.000
Placement with drill						
Plough sole						
N	400	1.00	.000	400	1.00	.000
P	400	1.00	.000	400	1.00	.000
K	400	1.00	.000	400	1.00	.000
Sub-soil						
N	400	1.00	.000	400	1.00	.000
P	400	1.00	.000	400	1.00	.000
K	400	1.00	.000	400	1.00	.000
Band placement drill						
N	400	1.00	.000	400	1.00	.000
P	400	1.00	.000	400	1.00	.000
K	400	1.00	.000	400	1.00	.000
Side dressing						
N	400	1.00	.000	400	1.00	.000
P	400	1.00	.000	400	1.00	.000
K	400	1.00	.000	400	1.00	.000
Application in liquid form						
Foliar application						
N	400	1.00	.000	400	1.00	.000
P	400	1.00	.000	400	1.00	.000
K	400	1.00	.000	400	1.00	.000
Fertigation / Application with irrigation water						
N	400	1.00	.000	400	1.00	.000
P	400	1.00	.000	400	1.00	.000
K	400	1.00	.000	400	1.00	.000

Scale: 1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always

Table 2 indicates different fertilizers application methods preferred by the respondents for wheat and rice crop farms. The application methods used by both wheat and rice farmers were more or less the same with a little variation. It was found that nitrogen and phosphorus were being broadcasted in form of basal application on priority basis as evident from the mean value of 4.98 and 4.93 in case of wheat while, 4.97 and 4.80 in case of rice. There was no trend regarding application of potash as basal dose for wheat and rice crop. The practice of top dressing the nitrogen was adopted by the respondents on priority basis both in case of rice and wheat as obvious from the mean value of 4.75 and 4.98 respectively. As top dressing of phosphorus and potash were neglected, placement of fertilizers through plough soil, band placement drill and side dressing were rare applied methods by the respondents. Similarly, foliar application and fertigation were also among the never applied methods of fertilizer application by the respondents.

On the question as to why farmers are sticking to broadcasting method of fertilizer application against the recommended methods, one of the key informants from Soil Fertility wing commented,

"Farmers are not aware of the recommended technology. Farmers should be told that kera method, pora method and side placement should be adopted for fertilizer application. In that way the efficiency of fertilizers would be enhanced. Particularly the deficiency of P is most common in soils of rice tract due to low efficiency of applied P which is only 25% available for plants. In calcareous soils the remaining P goes permanently fixed at soil adsorption pool. In that case if farmer broadcast the fertilizer, the adsorption of P increases which means the applied fertilize will go wasted. But if P is applied near the seed, the efficiency of P is increased as it becomes easily available to plants."

Another key informant from fertilizer industry gave almost similar opinion in response to the above question,

"The method of application depends largely on the awareness. For instance we say band placement is the best method, other one is the drill sowing but farmer use broadcasting. Where mechanical way of sowing and fertilizer application is efficient, the farmer go for it. For example the drill sowing is not efficient in case of wheat because it takes much more time. However broadcasting is preferred by farmers because it is efficient. Whereas, the mechanical sowing is efficient in case of maize, cotton and potato. But in rice and wheat manual sowing is an efficient method."

Whereas the opinion of extension officer was different who said, *"Farmers are well aware of the recommended production technology as the recommended fertilizer application method is being efficiently taught to the farmers by extension field staff. In fact the rice-wheat farmers find it convenient to apply the fertilizer through broadcast method. Moreover, in rice-wheat cropping pattern broadcasting method of fertilizer application gives better results and the other methods are not suitable in case of rice and wheat crops."*

Thus, from qualitative data it was concluded that farmers were not adopting the recommended application method for the fertilizer application. The broadcast method was the most preferred fertilizer application method in both of rice and wheat crops. One of the major reasons is the unawareness of the advantages of recommended methods of fertilizer application. The other reasons were that the farmers found convenience in broadcast method and perceive other methods of fertilizer application unsuitable for rice

and wheat crops. Moreover, the broadcast method was easy, cost and time efficient way of fertilizer application in case of wheat and rice crops. That was why farmers preferred broadcasting method of fertilizer application over the other methods and ignored the recommendations devised through scientific research.

Conclusion

Nutrient Stewardship framework offers four key-scientific principles for fertilizer application that sustain soil fertility and attaining profitable crop production. The four principles include right source, right rate, right time and right place. This research embarks on analyzing fertilizer source and method of application in Nutrient Stewardship perspective at farm level of rice-wheat zone of Punjab, Pakistan. On the basis of overall results it was found that the balanced and efficient usage of fertilizers were hindered by some socio-economic problems including unawareness of the farmers about needs and benefits of right fertilizer sources and inadequate methods of fertilizer application.

The results of this study indicate that farmers in the study area were not following the fertilizer management practices according to crop and soil requirements, as dictated by the 4R nutrient stewardship concept. When it comes to the selection of right source of the fertilizer nutrient which is the first right out of 4Rs, it was found that the farmers have adopted the use of DAP and Urea as a conventional practice which is beneficial in their opinion and they hesitate to take risk of using other sources of N and P for their crops. The reasons being lack of resources, unaffordability, unawareness and laggardness of the common farmers. The basic reasons were almost same for both wheat and rice crops. However, the use of micronutrients particularly Zn is in practice in case of rice crop. The green manuring was also neglected by the farmers as they have short time for wheat sowing after harvesting the paddy crop. If the farmers go for green manuring, the wheat sowing is more delayed which is mostly delayed every year due to late maturity of fine rice varieties.

Moreover, it was found that farmers were not adopting the recommended application method for the fertilizer application. The broadcast method was the most preferred fertilizer application method in both of rice and wheat crops. One of the major reasons was unawareness about the advantages of recommended methods of fertilizer application. The other reason was that the farmers found convenience in broadcast method and perceive other methods of fertilizer application unsuitable for rice and wheat crops. Moreover, the broadcast method was found to be easy, cost and time efficient way of fertilizer application as far as wheat and rice crops are concerned. That was why farmers preferred broadcasting method of fertilizer application over the other methods ignoring the recommendations devised through scientific research.

Recommendations

Based on the results, this study recommends that;

The government should subsidize the potash and phosphatic fertilizers and reduce the indirect taxes on these fertilizers so that the small farmers can apply in their fields according to recommended methods which will ultimately come out in increased per acre yield and overall production of wheat and rice at provincial and country level. When fertilizers are available at affordable prices, it is easier for the extension workers to

convince the farmers to use the fertilizers according to the best management practices and 4R nutrient management.

- The soil and water testing laboratories at district level should be upgraded and extend this service (pick-up points) at the UC level so that it could be in access of maximum number of farmers.
- The provincial government should encourage local production of the seed and fertilizer drills at subsidized prices so that the farmers can afford to apply efficient fertilizer application methods.
- The extension wing of agriculture department should design comprehensive program for training farmers with regard to the 4Rs of fertilizers for both wheat and rice crops, where farmers will be practically educated through demonstration methods.
- Future researchers need to focus on finding out ways of adoption of conservation technologies, higher crop yields, reduced input cost, restoring the biodiversity and sustainable development of social and human capital. the similar research should be extended to other cropping zones of the Punjab as well as to other provinces of Pakistan to have a systematic review of the country's situation regarding 4R nutrient stewardship and sustainability.

References

Ali, M., Ahmed, F., Channa, H., & Davies, S. (2015). *The role of regulations in the fertilizer sector of Pakistan* (No. 1008-2016-79970).

van der Bom, F., Magid, J., & Jensen, L. S. (2019). Long-term fertilisation strategies and form affect nutrient budgets and soil test values, soil carbon retention and crop yield resilience. *Plant and Soil*, *434*(1), 47-64.

Bryla, D. R. (2020). 4R nutrient stewardship in fruit crops. In *Fruit Crops* (pp. 509-519). Elsevier.

FAO. (2017). Investing in Sustainable Crop Intensification: The Case for Soil Health. Report of the International Technical Workshop, FAO, Rome, July. Integrated Crop Management, Vol. 6. Rome. Available online with update at http://www.fao.org/ag/ca/.

GoP. (2020). Agricultural Statistics Year Book 2019-20. Economic Survey of Pakistan. Economic advisory wing finance division, Government of Pakistan, Islamabad, Pakistan.

Hochmuth, G., Mylavarapu, R., & Hanlon, E. (2015). The four Rs of fertilizer management. *Nutrient management of vegetable and row crops handbook. Institute of Food and Agricultural Sciences (IFAS), University of Florida, Gainesville, FL, USA*, 5-7.

Bruulsema, T. W., Fixen, P. E., & Sulewski, G. D. (Eds.). (2016). *4R plant nutrition: a manual for improving the management of plant nutrition*. International Plant Nutrition Institute.

Johnston, A. M., & Bruulsema, T. W. (2014). 4R nutrient stewardship for improved nutrient use efficiency. *Procedia Engineering*, *83*, 365-370.

Khaskheli, M.A. (2017). Sustainable agriculture and fertilizer practices in Pakistan. Available online with update at https://agrinfobank.com.pk/sustainable-agriculture-fertilizer-practices-pakistan/Sustainable agriculture and fertilizer practices in Pakistan.

Majumdar, K., Johnston, A. M., Dutt, S., Satyanarayana, T., & Roberts, T. L. (2013). Fertiliser Best Management Practices. *Indian Journal of Fertilisers*, *14*.

Mikkelsen, R., Schwab, G., & Randall, G. (2009). The four fertilizer rights: Selecting the right source. *Crops Soils*, *42*(3), 28-32.

Mubarik, A., A. Faryal, C. Hira & S. Davies. (2016). Pakistan's fertilizer sector: structure, policies, performance, and impacts. IFPRI-Discussion Papers, p.1516.

Roberts, T. L. (2007). Right product, right rate, right time and right place… the foundation of best management practices for fertilizer. *Fertilizer best management practices*, *29*, 1-8.

USDA. (2019). Pakistan grain and feed annual: Grain and feed annual. USDA Foreign Agricultural Service.

Vollmer-Sanders, C., Allman, A., Busdeker, D., Moody, L. B., & Stanley, W. G. (2016). Building partnerships to scale up conservation: 4R Nutrient Stewardship Certification Program in the Lake Erie watershed. *Journal of Great Lakes Research*, *42*(6), 1395-1402.

Zia, M. S., Ali, A., Aslam, M., Baig, M. B., & Mann, R. A. (1997). Fertility issues and fertilizer management in rice wheat system. *Farm management Notes.,FAO Reg. Off. Asia and Pacific, Bangkok, Thailand*, (23).

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