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Minimizing productivity gaps of major crops by improving farmers' knowledge, adoption of recommended packages and investment in Pakistan

Dr. Abid Hussain
Principal Scientific Officer, Agricultural Economics Research Program, Social Sciences Research Institute, PARC-National Agricultural Research Centre, Park Road, Islamabad
abid.parc@gmail.com
Dr. Nadeem Akmal
Principal Scientific Officer/ Program Leader, Agricultural Economics Research Program, Social Sciences Research Institute, PARC-National Agricultural Research Centre, Park Road, Islamabad
nadeemakmal@gmail.com
Ms. Quratulain Altaf
Research Fellow, Social Sciences Research Institute, PARC-National Agricultural Research Centre, Islamabad
Quratulain@spopk.org

Abstract
Crop sub-sector has the second largest share in agricultural economy of Pakistan. Improvement in productivity of major crops is urgently needed for enhancing food production, and sustaining the crop sub-sector's share in agricultural GDP. Through this research study productivity gaps of major crops viz. wheat, rice, maize, cotton and sugarcane in the country have been determined. Along with this, farmers' knowledge gaps, adoption levels of recommended production packages and investment gaps in the adoption of these packages have also been ascertained. The research is based on primary data collected from 639 farmers of major crops selected through purposive random sampling technique. Added feature of the study is bifurcation of productivity gaps into research and extension gaps. It is found that productivity gaps in Punjab province, are ranged from 28.0% for spring maize to 63.0% for sugarcane. Similarly, knowledge gaps of the farmers in Punjab province ranged from 25.8% in spring maize to 58.8% in sugarcane crop. In Sindh province, productivity gaps are ranged from 34.5% for coarse rice to 66.0% for sugarcane. While, knowledge gaps of the farmers in the province ranged from 54.7% for rice crop to the highest of 60.9% for wheat crop. Productivity gap is the highest for sugarcane crop in Khyber Pakhtunkhwa (66.7%), with a lowest for wheat crop (44.8%). In the province, knowledge gaps of the farmers are ranged from 31.6% for maize crop to the highest of 54.7% for sugarcane crop. In all the provinces, investment gaps were the highest for sugarcane crop, ranged from 22.4% in Khyber Pakhtunkhwa to 34.1% in Sindh province. It is found that investment gaps for adoption of recommended production packages of major crops are much low as compared to productivity gains that can be obtained through adoption of these packages. Moreover, investment gaps mainly depend on food or cash nature of the crops including their production durations. Findings

of the study are useful for devising suitable policy and programmes to boost and sustain production of major crops in the country.

Keywords: Adoption, Extension Gaps, Major Crops, Productivity, Pakistan, Recommended Technologies, Research Gaps

Introduction

An increase in demand of food grains is expected in future at global level, which could be met by further agricultural intensification rather than expansion of cultivated area (Meng *et al*., 2013). Agriculture is a crucial sector for flourishment of the economy of Pakistan like other developing countries. It is reported that one percent increase in the sector could result in 2.83 percent in GDP growth of the country (Usman, 2016). Secondly, crop production expansion could not be achieved through area expansion, as it not only affects the production and prices of other crops, but also causes other distortions in the economy. This implies that improvement in productivity frontier of major crops is urgently needed for enhancing crop production and sustaining the crop sub-sector's share in agricultural GDP. This could also result in crop diversification by sparing area for cultivation of minor crop likes pulses, oilseeds, vegetables and fruits.

Crop sub-sector has second largest share in agriculture economy of Pakistan (33%) followed by livestock (63%). Major crops contribute 18.23 percent in the agricultural value added. In the country, growth of major crops has declined overtime. Major crops exhibited a mean growth of 3.63% in first decade of 21st century. Which decreased to 1.30% in second decade of the century. Though growth of the major crops has improved in recent years, mean growth in first three years of current decade i.e. from 2021 to 2023 is 2.68% mainly due to announcement of support prices for wheat and sugarcane as well efforts made through PSDP project for productivity enhancement of major crops along with pulses (Anonymous, 2023).

On the technology generation frontier, both the provincial and national agriculture research systems are working hard for shifting productivity frontiers of major crops by evolving new crop production and management technologies, through developing new crop varieties and devising better crop management practices. The time gap between technology generation and its actual adoption by a critical mass of the farming community varies across the crops and the technologies. This implies that a productivity gaps persist at various levels ranging from the scientific potential of a technology down to the productivity level at an average farmer's field (Figure 1). Science gap in the crop productivity is the difference between science potential and the world average yield. Science gap exists due to new scientific discoveries e.g. agricultural biotechnology, precision agriculture, climate smart crop varieties, synthetic biology and data-driven farming etc. At national level, the productivity gaps also exist between yield at research station vis-à-vis progressive farmers' fields called research gap, and between progressive farmers' fields and average farmer of the same locality known as extension gap. Narrowing these gaps involve considerable potential for enhancing average national yields and achieving higher growth rates.

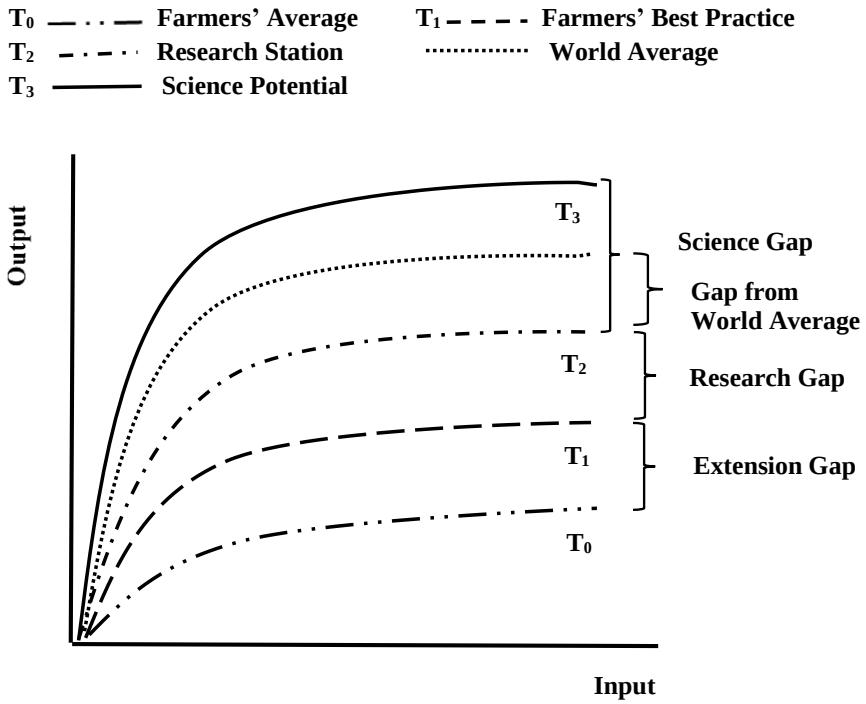


Figure 1. Crop yield levels and gap types; Extension Gap = T_1-T_0, Research Gap = T_2-T_1 and Science Gap = T_3-T_2; While, productivity gap consists of extension and research gaps combined i.e. T_2-T_1. The figure has been adopted and modified from Evenson (2002); Iqbal and Ahmad (2005).

There is a dire need to study the factors which are hindering our farmers to achieve potential yield of major crops. One of these is limited adoption of crop production technologies developed by national and provincial research systems. Famers' capacity to adopt recommended production packages has also been affected by their knowledge level, financial status as well as higher input prices and depressed commodity prices. The situation demands effective information flow from researchers to farmers and vice-versa. There is a need to assess information/ knowledge, productivity gaps i.e. research & extension gaps, and investment gaps for adoption of recommended production packages. Through this research study information, productivity and financial limitations of the farmers have been assessed for major cops viz. wheat, rice, sugarcane, cotton and maize by farm size categories across main cropping zones of the country. Information generated through the research study is useful for public sector policy formulation in devising effective institutional and financial support services for the farmers. This can revolutionize our agricultural economy, and can place it on sound and stable footings.

In this reference, a few attempts have been made in the country to highlight agricultural productivity issues. Few of these are based on review of literature or secondary data, e.g. Aslam, 2016, and cropping system modelling e.g. Khaliq *et al.*, 2019. While others are narrow in scope with a focus on one of the major crops with geographic specification e.g. Mahmood *et al.* 2006; Meng *et al.*, 2013; Hussain *et al.* 2014; Noonari *et al.*, 2015 etc. or small holder farmers e.g. Zhang *et al.*, 2016. Moreover, economic analysis of recommended production technologies is needed for convincing farmers for their successful departure from the already adopted production

practices. The need for such information has been strongly felt since long, as the farmers of all farm size categories do question about how much net-monetary gains they will get by leaving the existing production practices and shifting to the new ones. To address this information gap, the study is aimed at documenting the economic analysis of both the recommended technologies and the average farm level practices to identify the degree of achievable potentials for the farmers (in terms of more production and income) and the country (in terms of achieving higher production targets and sustaining the higher growth rates in the crop sector).

Determination of exploitable productivity gaps in current intensive production systems is indispensable to ensure food security (Meng *et al.* 2013). Furthermore, an understanding of the size and causes of yield gaps is fundamental in focusing research and extensions systems in formulating appropriate region-specific technologies and recommendations for various categories of farmers (Ittersuma *et al.,* 2013). Though, policy analysis reports for major crops (wheat, rice, sugarcane and cotton) are published annually by Agriculture Policy Institute, Islamabad. However, these reports do not cover all details of production practices and costs, specifically by farm size categories. An added advantage of the study is analysis of production of important crops by farm size categories, instead of one size fits all type of policy recommendations contained in these policy analysis reports. It is a priori anticipated that the information so generated shall be used for calibrating research agenda in the crop specific research institutes, adoptive research and agricultural extension departments of the provinces, and at the policy formulation as well as execution levels.

The study has been designed with an overall objective to determine extension gaps in productivity & investment gaps for major crops for effective policy formulation. Following are specific objective of the study: to determine level of farmers' knowledge, extension and research gaps in productivity of major crops in Pakistan; to determine cost of recommended technologies and existing farm practices of major crops and find out investment gaps in adoption of recommended production packages by farm size categories in the country; and to determine adoption level of recommended production technologies of major crops in main cropping zones of the country.

Materials and Methods

Yield gap analysis through field survey has advantage over field studies as it provides variability of difference between crop yield potential and actual farm yields. Furthermore, field studies have limited utility as up-scaling such evaluations are based on single crop species rather than crop production systems having different crop rotations (Wart *et al.,* 2023). In the first step to achieve the study objectives, its complete process has been contemplated and finalized. Time sequence for the coverage of crops from provinces was chalked out to undertake activities accordingly. In the crop production sector of the country, the information on recommended technologies i.e. that have passed through a series of experimentation for solving various farming issues and problems is available from different sources like, brochures/pamphlets of the provincial departments of Agricultural Extension, leaflets of various national and multi-national companies, scientific publications and research articles, and electronic & print media, etc. Thus, it seems plausible to consider all information sources like: brochures/pamphlets of the provincial Agricultural Extension Departments, adoptive research wings of these departments and annual reports of various agricultural research institutions. Moreover, technical discussions with the scientists working for the crops under consideration in various agricultural research institutes of

the country were held in face-to-face meetings. In this way, latest production technologies in relevance with crop years for each crop were acquired from provincial research and extension institutions. Generalized coverage of crop production areas by research and extension systems. Arrows show coverage by the systems. Research system mainly covers production and management technologies, develop varieties and identify better management practices. While, Adaptive Research wings of Agricultural Extension departments deals with crop management practices, timing of crop production practices, input use levels, timing of input application and mechanisms as well as harvesting time and post-harvest handling of the produce to finalize recommended production packages of the crops.

In this reference, Cereal Crop Research Institute (CCRI), Pir Sabak, Nowshera; Sugar Crops Research Institute (SCRI), Mardan in Khyber Pakhtunkhwa; Rice Research Institute and PARC-Rice Program, Kala Shah Kaku, Sheikhupra; Maize and Millets Research Institute (MMRI), Yusufwal, Sahiwal in Punajb, and Agricultural Research Institute, Tandojam, Sindh were visited to finalize reference recommended production packages in consultation with crop experts of major crops for the research study. Similarly, these packages were discussed with other relevant scientists in National Agricultural Research System (NARS)/ Crop Sciences Institute (CSI), NARC, Islamabad, Ayub Agricultural Research Institute (AARI), Faisalabad, extension agents and advisory service providers and verified. Next questionnaires were designed keeping in view detailed production packages of major crops, then pretested in the field and finalized. Finally, primary data about varietal adoption, existing production practices, and inputs use levels along with prices at farm level for the crops was collected in year 2021, 2022 and 2023.

Proposed sample for the study included; 200 maize farmers (from main districts by area Okara/ Pakpatan from Punjab, Abbottabad/Mardan from Khyber Pakhtunkhwa), 200 rice farmers (from Sheikhupura/Gujranwala from Punjab and Shikarpur/ Thatta from Sindh), 200 cotton farmers (Vehari/Rahim Yar Khan from Punjab, Sanghar/ Khairpur from Sindh), 200 sugarcane farmers (Faisalabad/Rahim Yar Khan from Punjab and Tando Muhammad Khan/Badin from Sindh and Mardan district from Khyber Pakhtunkhwa. Moreover, 200 wheat farmers (50 maize, rice, cotton, sugarcane growing farmers each, who also sown wheat crop) were planned to interview about wheat production practices. The sample of study fell short of proposed target of 800 farmers due to movement restricts because of outbreak of Covid-19 pandemic in year 2020, price inflation in general, rise in fuel prices in particular along with increase in survey costs etc. Similarly, floods in year 2022 caused unavoidable delay in undertaking field surveys and subsequent research activities like data editing, entry, analysis and description of results etc. Thus, research study is based on primary data collected from 639 farmers through purposive random sampling technique, including 262 farmers of major crops from Punjab viz. wheat, rice, sugarcane, cotton and maize (Table 1), 160 farmers of major crops from Sindh viz. wheat, rice, sugarcane and cotton, and 217 farmers of major crops from Khyber Pakhtunkwa province viz. wheat, sugarcane and maize. It is worth mentioning here that in Punjab and Sindh, farmers are categorized small, medium and large as having less than 12.5 acre, 12.5 to less than 25.0 acre and more than 25.0 acre, respectively. While in Pakhtunkhwa, farmers are categorized small, medium and large as having less than 5.0 acre, 5.0 to less than 10.0 acre and more than 10.0 acre, respectively. Sample details for the study is presented in Table 1.

Table 1. Sample details of farmers of major crops by farm size categories, districts and provinces (Number)

Provinces/ crops	Crop season & year	Districts	Sample by Farm Size Categories			
			Small	**Medium**	**Large**	**Total**
Punjab						
Wheat	Rabi 2020-21	Sheikhupura, Gujranwala, Sialkot & Faisalabad (Rice Wheat + Mix Zones)	29 (17+12)	15 (6+9)	19 (8+11)	63 (31+32)
Rice	Kharif 2021	Sheikhupura, Gujranwala & Sialkot (Fine + Coarse Varieties)	33 (22+11)	13 (4+9)	13 (7+6)	59 (33+26)
Mazie	Spring 2021	Chinote, Okara & Sahiwal	36	14	10	60
Cotton	Kharif 2022	Rahim Yar Khan & Vehari	12	8	20	40
Sugarcane	Year 2022-23	Chinote, Faisalabad & Rahim Yar Khan	24	8	8	40
Total			134 (51)	59 (23)	69 (26)	262 (100)
Sindh						
Wheat	Rabi 2021-22	Shaheed Benazirabad & Tando Allahyar	17	5	18	40
Rice	Kharif 2022	Shikarpur (Fine + Coarse Varieties)	34 (18+16)	2 (2+0)	4 (4+0)	40 (24+16)
Cotton	Kharif 2022	Khairpur	26	6	8	40
Sugarcane	Year 2022-23	Tadno Allahyar, Dadin & Tando, M. Khan	21	9	10	40
Total			98 (61)	22 (14)	40 (25)	160 (100)
Khyber Pakhtunkhwa						
Wheat	Rabi 2019-20	Charsadda, Mardan & Swabi	40	22	22	84
Mazie	Kharif 2020	Mardan & Swabi	40	34	10	84
Sugarcane	Year 2020-21	Charsadda & Mardan	20	14	15	49
Total			100 (46)	70 (32)	47 (22)	217 (100)

Note: Figures in parenthesis in the provincial totals are percentages

Thereafter, data editing and entry was made, then analysis was carried out, and finally tabulation and description of results was made. Knowledge gaps of the farmers are determined by asking them about different knowledge indicators such as land preparation, seed varieties, seed rate and sowing operations, sowing time, irrigation application (specifically at critical stages of crop production), fertilizer application, irrigation stoppage time before harvesting, harvesting time & practices, and post harvesting handling & marketing etc. Management practice wise score are assigned for measuring knowledge gap, such as 0 = 'no knowledge', 0.5 = 'partial knowledge' 1 = 'complete knowledge' in the knowledge test. This deviation is then expressed in percentage as the proportion to the farmer's maximum possible score (equal to total number of indicators). The knowledge gaps are computed by using knowledge gap index technique as used by Kamruzzaman *et al.,* 2001; Ironkwe *et al.,* 2008; Tomar *et al.,* 2012; Kundu *et al.,* 2013 and Farooq *et al.,* 2019 and as given by expression 1.

$$KGI = \frac{K_p - K_o}{K_p} \times 100 \quad \text{--------(1)}$$

Where, KGI= Knowledge Gap Index

K_p= Maximum possible score of a grower, equal to total number of indicators, and

K_o= Knowledge score obtained by an individual grower

Adoption levels of individual production practices by farm size categories have been determined as per following scores; not / poorly adopted (zero), partially adopted (0.5), and completely adopted (1.0). It is worth mentioning here that over use of inputs like seed, fertilizer, chemical sprays etc. and excessive levels of production practices like number of ploughings for land

preparation and number of irrigations etc. are considered as poor adoption. In the last section of Results, to give better insight into adoption levels of recommended production practices, just full adoption level of production has been reported with a hope that it will give better insight into the adoption, as otherwise production practices are poorly or partially adopted by the farmers.

Results

Productivity Gap in Production of Major Crops

Wheat Crop Production

Wheat crop is sown on about 22 million acres in the country with annual production of more or less 28 million tonnes. Thus, productivity of the crop is 31.5 maunds per acre (Anonymous, 2023a). Punjab is the leading province in wheat production with annual production of the crop of 21 million tonnes (81.0%), followed by Sindh 3.9 m.t. (15.0%) and Balochistan 1.52 m.t. (5.8%) and Khyber Pakhtunkhwa (KP) 1.48 m.t (5.6%). Productivity gaps in the crop's production by provinces are presented in Figure 2. Potential productivity of the crop in mixed and rice-wheat cropping zones of the country is 70 and 65 maunds per acre, respectively. It is important to highlight that productivity potential of the crop in rice-wheat zone has been adjusted by considering the average yield difference in mixed and rice-wheat cropping zones. (Hussain *et al.,* 2015; Anonymous, 2022). Potential wheat productivities in Sindh and KP provinces are 70 and 57 maunds per acre (Subhan *et al.,* 2022; Anonymous, 2023). Wheat farmers gain about half (48.4 to 57.7%) of productivity potential of the crop in the country. Extension gaps in the productivity ranges from 16.6 percent in rice-wheat zone of Punjab to 39.3 percent in KP province (Figure 3). While, research gaps in the productivity ranges from 12.3 percent in KP to the highest of 23.1 percent in rice-wheat cropping zone of Punjab. Thus, by taking the lower limits of extension and research gaps i.e. 16.6% and 12.3%, respectively; wheat production can be increased from current production level, average of last three year of 27.3 million tonnes to 30.3 million tonnes by covering extension gaps, and further to 35.2 million tones by covering both extension and research gaps in the productivity, respectively. Farm size wise extension and productivity gaps of wheat and other crops are presented in Table 2 and 3, respectively.

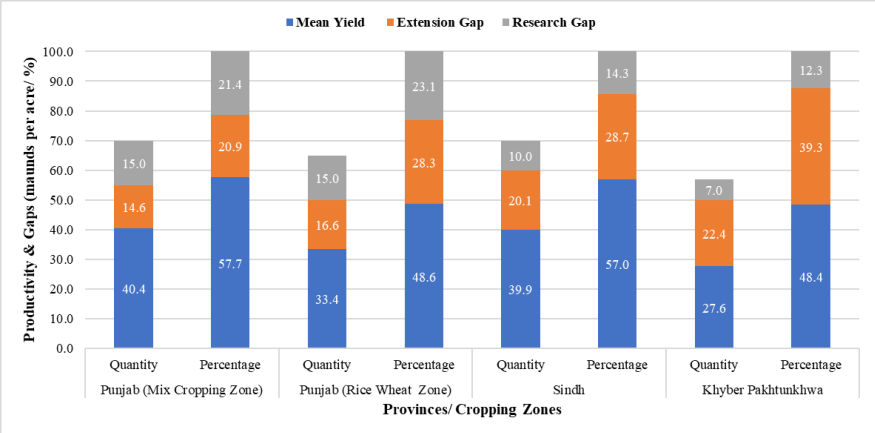


Figure 2. Productivity gaps in wheat crop production across provinces; these are the lowest in Mix-cropping zone of Punjab province (21.4+20.9 = 42.3%), followed by in Sindh province (14.3+28.7 = 42.6%), Rice-Wheat cropping zone of Punjab province (23.1+28.3 = 51.4%) and Khyber Pakhtunkhwa province (12.3+39.3 =51.6%)

Table 2. Extension gaps in productivity by farm size categories across provinces (maunds/acre)

Crops		Potential Yield	Farm Size Categories											
			Small			Medium			Large			All		
			Maxi-mum Yield	Mean Yield	Gap	Maxi-mum Yield	Mean Yield	Gap	Maxi-mum Yield	Mean Yield	Gap	Maxi-mum Yield	Mean Yield	Gap
I. Punjab Province (n=262)														
i. Wheat (n=63)	Mix Cropping Zone	70.0	55.0	40.1	14.9 (21.3)	40	37.5	2.5 (3.6)	45	43.1	1.9 (2.7)	55	40.4	14.6 (20.9)
	Rice-Wheat Zone	65.0	42.0	33.9	8.1 (12.5)	45	34.7	10.3 (15.8)	50	31.7	18.3 (28.2)	50	33.4	16.6 (25.5)
ii. Rice (n=59)	Fine	70.0	38.0	28.6	9.4 (13.4)	42	33.0	9.0 (12.9)	60	33.1	26.9 (38.4)	60	30.1	29.9 (42.7)
	Coarse	90.0	55.0	46.2	8.8 (9.8)	65	45.6	19.4 (21.6)	48	34.2	13.8 (15.3)	65	43.2	21.8 (24.2)
iii. Maize-Hybrid (n=60)		135.0	125.0	97.3	27.7 (20.5)	130	89.9	40.1 (29.7)	133	110.6	22.4 (16.6)	133	97.2	35.8 (26.5)
iv. Cotton (n=40)		45.0	39.0	34.5	4.5 (10.0)	21.0	16.5	4.5 (10.0)	38	24.9	13.1 (29.1)	39	26.1	12.9 (28.6)
v. Sugarcane (n=40)		2500.0	1575.0	875.1	699.9 (28.0)	1450	1046.6	403.4 (16.1)	1150	935.8	214.2 (8.6)	1575	921.0	654 (26.2)
II. Sindh Province (n=160)														
i. Wheat (n=40)		70.0	60.0	37.1	22.9 (32.7)	46	41.9	4.1 (5.9)	52.0	42.0	10.0 (14.3)	60	39.9	20.1 (28.7)
ii. Rice (n=40)	Fine	70.0	60.0	37.6	22.4 (32.0)	34	34.0	0 (0.0)	40	38.0	2.0 (2.9)	60	38.0	22.0 (31.4)
	Coarse	90.0	66.0	52.4	13.6 (15.1)	-	-	-	-	-	-	66	52.4	13.6 (15.1)
iii. Cotton (n=40)		50.0	40.0	27.1	12.9 (25.8)	28	23.7	4.3 (8.6)	45	29.4	15.6 (31.2)	45	27.1	17.9 (35.8)
iv. Sugarcane (n=40)		2000.0	1200.0	920.1	279.9 (14.0)	1450	880.1	569.9 (28.5)	1150	855.8	294.2 (14.7)	1450	894.9	555.1 (27.8)
III. Khyber Pakhtunkhwa (n=217)														
i. Wheat (n=84)		57.0	50.0	26.8	23.2 (40.7)	48	29.8	18.2 (31.9)	47	27.0	20.0 (35.1)	50	27.6	22.4 (39.3)
ii. Maize (n=84)		125.0	100.0	40.3	59.7 (47.8)	86	43.8	42.2 (33.8)	50	40.5	9.5 (7.6)	100	42.1	57.9 (46.3)
iii. Sugarcane (n=49)		1860.0	1470.0	859.0	611 (32.8)	1225	888	337 (18.1)	1470	745	725 (39.0)	1470	833	637 (34.2)

Note: Figures in parenthesis are the productivity gaps in percentage terms

Table 3. Research gaps in productivity by farm size categories across provinces (maunds/acre)

Provinces/ Crops		Potential Yield	Farm Size Categories							
			Small		Medium		Large		All	
			Yield	Gap	Yield	Gap	Yield	Gap	Yield	Gap
I. Punjab Province (n=262)										
i. Wheat (n=63)	Mix Cropping Zone	70	55	15 (21.4)	40	30 (42.9)	45	25 (35.7)	55	15 (21.4)
	Rice-Wheat Zone	65	42	23 (35.4)	45	20 (30.8)	50	15 (23.1)	50	15 (23.1)
ii. Rice (n=59)	Fine	70	38	32 (45.7)	42	28 (40.0)	60	10 (14.3)	60	10 (14.3)
	Coarse	90	55	35 (38.9)	65	25 (27.8)	48	42 (46.7)	65	25 (27.8)
iii. Maize-Hybrid (n=60)		135	125	10 (7.4)	130	5 (3.7)	133	2 (1.5)	133	2 (1.5)
iv. Cotton (n=40)		45	39	6 (13.3)	21	24 (53.3)	38	7 (15.6)	39	6 (13.3)
v. Sugarcane (n=40)		2500	1575	925 (37.0)	1200	1300 (52.0)	1250	1250 (50.0)	1575	925 (37.0)
II. Sindh Province (n=160)										
i. Wheat (n=40)		70	60	10 (14.3)	46	24 (34.3)	52	18 (25.7)	60	10 (14.3)
ii. Rice (n=40)	Fine	70	60	10 (14.3)	34	36 (51.4)	40	30 (42.9)	60	10 (14.3)
	Coarse	90	66	24 (26.7)	-	-	-	-	66	24 (26.7)
iii. Cotton (n=40)		50	40.0	10 (20.0)	28.0	22 (44.0)	45.0	5 (10.0)	45.0	5 (10.0)
iv. Sugarcane (n=40) I		2000	1200	800 (40.0)	1450	550 (27.5)	1150	850 (42.5)	1450	550 (27.5)
II. Khyber Pakhtunkhwa (n=217)										
i. Wheat (n=84)		57	50	7 (12.3)	48	9 (15.8)	47	10 (17.5)	50	7 (12.3)
ii. Maize (n=84)		125	100	25 (20.0)	86	39 (31.2)	50	75 (60.0)	100	25 (20.0)
iii. Sugarcane (n=49)		1860	1470	390 (21.0)	1225	635 (34.1)	1470	390 (21.0)	1470	390 (21.0)

Note: Figures in parenthesis are the productivity gaps in percentage terms

Rice Crop Production

Rice crop is planted on about 7.4 million acres in the country with a production of 7.3 million tonnes (Anonymous, 2023a). Thus, productivity of the crop is 24.6 maunds per acre, against the yield potential of fine and coarse varieties of the 70 and 90 maunds per acre, respectively (Anonymous, 2021; Anonymous, 2022a). Punjab is the leading province in the rice production with total production of 5.07 m.t. (69.2%), followed by Sindh with total production of 2.01 m.t. (27.5%), and 0.24 m.t. KP & Balochistan (3.3%). Thus, Punjab and Sindh are main rice producing provinces of the country. Productivity gaps in the production of rice in Punjab and Sindh province are presented in Figure 3. Rice farmer in Punjab and Sindh province obtain 43.0 and 54.3 percent of the yield potential of fine varieties of the crop, respectively. Similarly, they obtain 48.0 and 58.2 percent of the productivity potential of coarse varieties of rice, respectively. In fine varieties, extension gaps in the productivity are 42.7 and 31.4 percent in Punjab and Sindh, respectively. While, research gap is 14.3 percent both in Punjab and Sindh. In coarse varieties of rice, extension gaps are 24.2 and 15.1 percent in Punjab and Sindh, respectively. While, research gaps in the productivity are 27.8 and 26.7 percent in Punjab and Sindh, respectively. By considering a moderate yield gap of forty percent, rice production in the country can be increased from current level (mean production of last three years) i.e. of 8.4 million tonnes to about 11.7 million tonnes. Farm size wise extension and productivity gaps of rice are presented in Table 2 and 3, respectively.

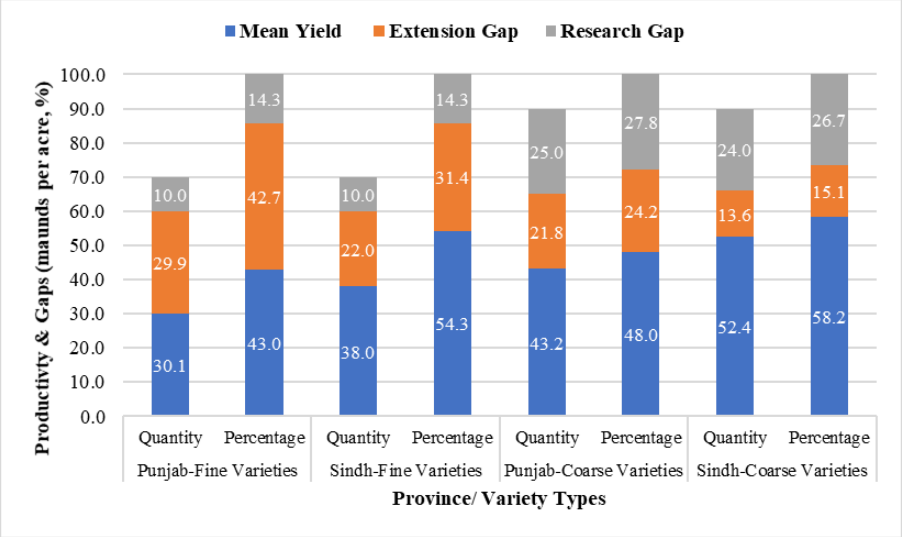


Figure 3. Productivity gaps in rice crop production across provinces; these are the lower in Sindh province than in Punjab province both in case of fine varieties (14.3+31.4 = 45.7% versus 14.3+42.7 = 57.0%) and coarse varieties (26.7+15.1 =41.8% versus 27.8+24.2 =52.0%).

Maize Crop Production

Maize crop is sown on about 4.3 million acre in Pakistan, with total production of about 11.0 million tonnes. Productivity of the crop is 63.7 maunds per acre (Anonymous, 2023). Which is much less than productivity potential of hybrid varieties in KP (125 maunds per acre) for seasonal maize (Anonymous, 2023c) and in Punjab province (135 maunds per acre) for spring maize (Anonymous, 2023d).Punjab province shares 91.5 percent in maize production with total production of 10.06 million tonnes per annum, followed by KP 0.92 m.t. (8.4%), and Sindh & Balochistan 0.006 m.t. (0.05% each), (Anonymous, 2023a). In Punjab province extension gap in the productivity of the maize crop is much less (26.5%) than in the KP province (46.3), (Figure 4). Similarly, research gap in the productivity in Punjab is considerably low (2%) in Punjab than in KP (20%). By considering current productivity gaps in maize production (37.8%), it can be stated that

maize production in the country can be enhanced from mean production level of last three years of 9.8 million tonnes to about to about 13.5 million tonnes by covering both extension and research gaps in the productivity of the crop.

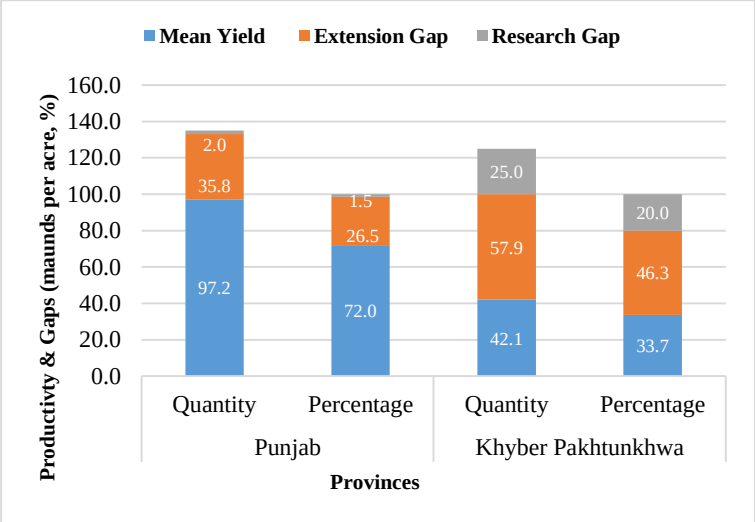


Figure 4. Productivity gaps in maize crop production across provinces; these are low in Punjab province (1.5+26.5 =28.0%) than in Khyber Pakhtunkhwa province (20.0+46.3 = 66.3%)

Cotton Crop Production

Cotton crop productivity varies from year to year, average production of the crop in last three years was 6.8 million bales of lint cotton/ about 1.1 million from an area allocation of about 5.1 million acre and productivity of 17 maunds of seed cotton per acre (Anonymous, 2023a). In the year 2022-23, Punjab was the leading cotton producing province of Pakistan with a share in total production of sixty-six percent, followed by Sindh (32%) and Balochsitan (2%). In this way, Punjab and Sindh are main cotton producing provinces in Pakistan. Productivity gaps in the production of cotton crop in Punjab and Sindh province are presented in Figure 5. Potential yield of the crop in Punjab and Sindh province is 45 and 50 maunds per acre, respectively (Anonymous, 2023e and Anonymous, 2023f). Cotton farmers in Punjab and Sindh province obtain 58.1 and 54.2 percent of the yield potential of the crop, respectively. Extension gaps in the productivity are 28.6 and 35.8 percent in Punjab and Sindh, respectively. While, research gaps are 13.3 percent and 10.0 in Punjab and Sindh, respectively. By taking into account a yield gap of 45.8 percent, cotton production in the country can be enhanced from 6.8 million bales to about 10.0 million bales. Farm size wise extension and productivity gaps of the crop are presented in Table 2 and 3, respectively.

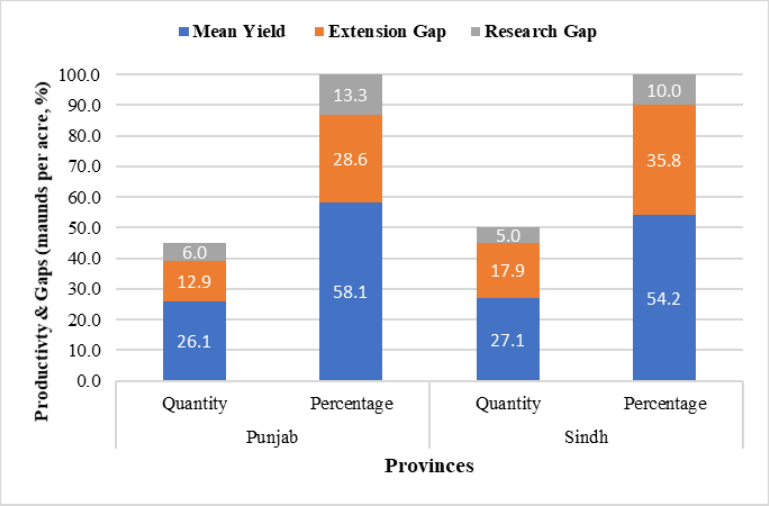
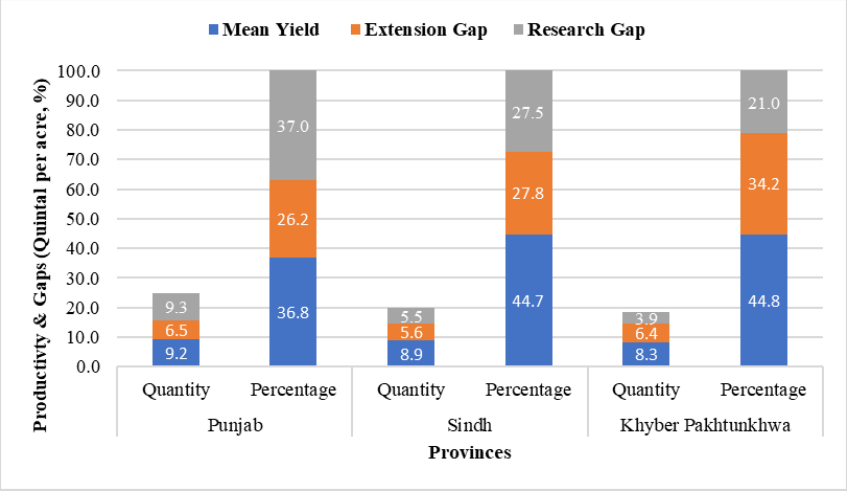


Figure 5. Productivity gap in cotton crop production across provinces; it is lower in Punjab province (13.3+28.6 = 41.9%) than in Sindh province (10.0+35.8 = 45.8%)

Sugarcane Crop Production

In the year 2022-23, sugarcane crop was planted on 3.3 million acre, with total production of 88.0 million tonnes and productivity of 723 maunds per acre. Punjab province produced 66.9 million tonnes sugarcane (76.1%), followed by Sindh 16.2 m.t. (18.4%) and KP 4.8 m.t. (5.5%). Thus, Punjab is the main sugarcane producing province of the country. Potential productivity of sugarcane is 2500, 2000 and 1860 maunds per acre in Punjab, Sindh and KP provinces, respectively (Anonymous, 2020; Anonymous, 2022b; Anonymous, 2023g). Which has also been reaffirmed by considering national level productivity potentials of available varieties and the average productivity of the crop in provinces. Productivity gaps in the sugarcane production in Punjab and Sindh province are presented in Figure 6.



Figures 6. Productivity gaps in sugarcane crop production across provinces; these are almost at par in Khyber Pakhtunkhwa province (21.0+34.2 = 55.2%) and Sindh province (27.5+27.8 = 55.3%), with the highest in Punjab province (37.0+26.2 = 63.2%)

Sugarcane farmer in Punjab, Sindh and KP province obtain just 36.8, 44.7 and 44.8 percent of the yield potential of fine varieties of the crop, respectively. Extension gaps in the productivity are 26.2, 27.8 and 34.2 percent in Punjab, Sindh and KP, respectively. While, research gaps are 37.0, 27.5 and 21.0 percent in Punjab, Sindh and KP, respectively. By taking into account a yield gap of fifty-five percent, sugarcane production in the country can be increased to 136.4 million tonnes.

Farm size wise extension and productivity gaps of sugarcane crop are presented in Table 2 and 3, respectively.

Cost of Recommended Production Packages and Investment Gaps in the Adoption

Cost of recommended technologies of major crops approved by respective provincial agricultural research/ extension departments in the country by crop seasons have been given in third column of Table 4. The cost of sugarcane recommended technology was the highest in all the provinces, followed by cotton, rice in Punjab and Sindh, and spring maize in Punjab and kharif maize in KP. Cost of the recommended technologies of wheat crop in Punjab and KP was the lowest as compared to other crops. While, cost of the recommended production package of the wheat crop was almost at par with that of rice in Sindh province. Costs of existing farm practices of major crops exhibit almost similar pattern as was observed for their recommended technologies. Cost of existing farm practices of wheat, rice and cotton crops in Punjab province were the lowest at medium size farms, having land holdings equal to or greater than 12.5 acre but less than 25 acre (Table 4).

While, in case of spring maize it was the lowest at small farms, having operational land holding less than 12.5 acre. In case of sugarcane crop it has direct relationship with operational holding size of the sample farmers i.e. it is the lowest at small farms, followed by medium farms with the highest at large farms. In Sindh and KP provinces, costs of existing farm practices of wheat crop were also the lowest at medium size farms. Costs of existing farm practices of fine varieties of rice crop in Sindh province and sugarcane crops both in Sindh and KP provinces were the lowest at large size farms. While, costs of production of cotton in Sindh province and that of kharif maize crop in KP were directly related with farm size.

Investment gaps i.e. difference between cost of recommended technologies and farm practices depends on nature of the crop including its duration and production for food/ cash purpose etc. In Punjab province, as well as other provinces investment gaps were the highest for sugarcane crop, ranged from 22.4% in KP to 34.1% in Sindh (Table 4). Investment gaps for the wheat crop were second highest in Punjab and Sindh after sugarcane crop i.e. 19.0 and 17.2 percent, respectively. In Punjab province, investment gaps for other major crops viz. rice-fine, rice-coarse, maize and cotton were 13.0, 12.4, 12.7 and 12.6 percent, respectively. In Sindh province, investment gaps in production of other major crops were ranged from 8.5 in rice-fine to 14.1 percent in cotton. In KP province investment gaps for wheat and maize crops were 9.7 and 16.5 percent, respectively. Farm size wise investment gaps are presented in Table 4.

Table 4. Investment gaps in production of major crops by farm size categories across provinces (Rs./acre)

Provinces/ Crops	Crop Season & Year	Cost of Recommended Package	Farm Size Categories: Small Mean Cost	Small Gap	Medium Mean Cost	Medium Gap	Large Mean Cost	Large Gap	All Mean Cost	All Gap
I. Punjab Province **(n=262)**										
i. Wheat **(n=63)** Rice-Wheat Zone	Rabi, 20-21	84885	72142	12743 (15.0)	64877	20008 (23.6)	78452	6433 (7.6)	68764	16121 (19.0)
Mix Cropping Zone		87024	79298	7726 (8.9)	77700	9324 (10.7)	82470	4554 (5.2)	79842	7182 (8.3)
ii. Rice **(n=59)** Fine	Kharif, 21	117143	101556	15587 (13.3)	98202	18941 (16.2)	108010	9133 (7.8)	101867	15276 (13.0)
Coarse		112221	100640	11581 (10.3)	93117	19104 (17.0)	94120	18101 (16.1)	98276	13945 (12.4)
iii. Maize-Hybrid **(n=60)**	Spring, 21	111903	96593	15310 (13.7)	103720	8183 (7.3)	101511	10392 (9.3)	97716	14187 (12.7)
iv. Cotton **(n=40)**	Kharif, 22	226773	209583	17190 (7.6)	179414	47359 (20.9)	197483	29290 (12.9)	198158	28615 (12.6)
v. Sugarcane **(n=40)**	22-23	412911	292416	120495 (29.2)	323290	89621 (21.7)	338215	74696 (18.1)	309279	103632 (25.1)
II. Sindh Province **(n=160)**										
i. Wheat **(n=40)**	Rabi, 21-22	107149	93356	13793 (12.9)	75073	32076 (29.9)	86716	20433 (19.1)	88749	18400 (17.4)
ii. Rice **(n=40)** Fine	Kharif, 22	103699	95723	7976 (7.7)	101939	1760 (1.7)	86529	17170 (16.6)	94924	8775 (8.5)
Coarse		110555	97161	13394 (12.1)	-	-	-	-	97161	13394 (12.1)
iii. Cotton **(n=40)**	Kharif, 22	163066	132167	30899 (18.9)	144610	18456 (11.3)	146557	16509 (10.1)	140024	23042 (14.1)
iv. Sugarcane **(n=40)**	22-23	391693	256407	135286 (34.5)	261276	130417 (33.3)	232225	159468 (40.7)	258266	133427 (34.1)
III. Khyber Pakhtunkhwa **(n=217)**										
i. Wheat **(n=84)**	Rabi, 19-20	76131	66958	9173 (12.0)	64877	11254 (14.8)	78452	-2321 (-3.0)	68764	7367 (9.7)
ii. Maize **(n=84)**	Kharif, 20	84209	69235	14974 (17.8)	69676	14533 (17.3)	76579	7630 (9.1)	70298	13911 (16.5)
iii. Sugarcane **(n=49)**	20-21	207876	160600	47276 (22.7)	166333	41543 (20.0)	159675	48201 (23.2)	161298	46578 (22.4)

Note: Figures in parenthesis are percentages

Knowledge Gaps

Knowledge gaps of the farmers in Punjab province ranged from 25.8 percent in spring maize crop to 58.8 percent in sugarcane crop. These were comparatively higher in other provinces as compared to Punjab province. In Sindh knowledge gaps of the farmers ranged from 54.7 percent for rice crop to the highest of 60.9 percent for wheat crop. Similarly, in KP province, knowledge gaps of the farmers were 31.6, 51.4 and 54.7 percent for kharif maize, wheat and sugarcane crops, respectively. Farm size wise details are presented in Table 5.

Adoption Levels of Recommended Technologies

Adoption of main production practices of major crops to the full level as per recommendations of research/ extension department are given in Table 6. Land preparation, seed rate, sowing operation are comparatively better adopted for spring maize in Punjab province in comparison to other crops. Similarly, seed rate is well adopted for spring maize in Punjab province compared to other crops. About, one-fifth to one-fourth (20-25%) of the farmers treat seed with fungicides for wheat, cotton and sugarcane crops in Punjab, and for cotton crop in Sindh. About one-third of both the rice and cotton growers (28%) in Sindh and one-fifth of spring maize farmers in Punjab (18%) reported to apply chemical fertilizers as per recommendation of the respective provincial agricultural departments.

Table 5. Mean knowledge gaps of farmers of major crops by farm size categories across provinces (Percent)

Provinces/ Crops	Farm Size Categories							
	Small		Medium		Large		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
i. Punjab Province (n=262)								
Wheat (n=63)	58.9	12.6	51.3	11.3	45.4	12.8	53.0	13.5
Rice (n=59)	42.9	15.6	47.8	12.6	49.8	12.3	45.4	14.4
Maize-Hybrid (n=60)	24.8	10.0	29.5	10.3	24.0	14.8	25.8	10.9
Cotton (n=40)	47.6	13.9	39.7	9.3	46.7	14.6	45.5	13.5
Sugarcane (n=40)	62.2	14.8	55.6	16.2	51.9	7.6	58.8	14.4
ii. Sindh Province (n=160)								
Wheat (n=40)	67.3	8.8	57.7	3.6	55.8	13.7	60.9	12.1
Rice (n=40)	56.4	9.9	51.6	2.0	42.1	9.3	54.7	10.4
Cotton (n=40)	62.4	12.8	56.0	10.7	56.0	10.8	60.2	12.3
Sugarcane (n=40)	54.4	7.2	49.3	6.2	60.6	19.7	54.8	11.9
iii. Khyber Pakhtunkhwa (n=217)								
Wheat (n=84)	52.5	22.5	50.0	18.8	50.7	12.0	51.4	19.1
Maize (n=84)	34.4	20.3	30.4	12.4	25.0	13.2	31.6	16.9
Sugarcane (n=49)	76.9	5.3	53.0	8.9	26.3	4.8	54.7	14.7

Table 6. Full extent adoption of recommended crop production practices of major crops across provinces (% Farmers)

Crops	Land Prepar-ation	Seed Rate	Sowing Oper-ation	Seed Treat-ment	Fertilizer Appli-cation	Weed Control		Irri-gation Appli-cation	Disease Control	Insect Pest Control	Harvest-ing
						Cultural	**Chemical**				
i. Punjab Province											
Wheat	41	35	-	19	5	-	89	11	27	48	95
Rice	34	32	-	-	2	75	52	73	52		78
Maize	60	88	90	-	18	91	63	81	43		100
Cotton	10	29	-	22	5	-	63	20	18	18	-
Sugar-cane	20	33	-	20	3	-	2	15	3	42	-
ii. Sindh Province											
Wheat	8	28	-	3	5	-	76	10	63		-
Rice	13	5	-	-	28	5	42	20	8	30	79
Cotton	30	13		25	28	-	80	35	18	40	-
Sugar-cane	8	55	-	12	0	18	-	40	15	15	-
iii. Khyber Pakhtunkhwa											
Wheat	38	-	-	-	1	-	36	11	25	14	95
Maize	20	83	-	-	4	56	83	32	-	-	-
Sugar-cane	23	-	34	-	4	67	2	14	-	-	-

Cultural weed control is better adopted for spring maize and rice crops in Punjab province, and kharif maize and sugarcane crops in KP province. Chemical weed control is well adopted for all major crops except sugarcane, as mostly the growers rely on cultural weed control. Irrigation application as per recommended levels are better adopted in rice and spring maize production in Punjab province, cotton and sugarcane crop in Sindh province and kharif maize production in KP province. Disease and insect pest control measures are comparatively well adopted for wheat, spring maize and sugarcane crops in Punjab and cotton crop in Sindh. Crop harvesting at proper crop maturity stage is practiced by ninety-five percent of wheat farmers in Punjab and KP, all the farmer of spring maize crop in Punjab and about four-fifth of the rice growers in both Punjab (78%) and Sindh (79%) reported to harvest these crops at recommended time.

DISCUSSION

It is stated that improvement in crop yield potential in unstressed environments for main cereal crops (maize, wheat and rice) is well below the rates required to meet projected demand of cereals in 2050 viz. 1.16 to 1.31 percent per year (Hall and Richards, 2013). Same is true for fiber and sugar crops. Understanding yield gaps is important for two reasons. First, it helps predict future crop yields, as existing productivity near upper limit may indicate that growth rates are likely to slow in future (Pingali *et al.,* 1999; Pingali and Heisery, 1999). Second, identifying factors contributing to yield gaps allows for targeted efforts to boost production efficiency (Lobell *et al.,* 2019). It also helps to minimize the knowledge gaps between researchers, extension agents and farmers for developing and using viable mechanisms to transfer new knowledge and techniques from researchers to farmers and collect feed-back to re-orient research on issues critical to farmers (Balasubramanian *et al.* 2000).

The chances to use new and marginal lands for crop production are meager as huge investment are needed to bring these under cultivation. Additionally, it may be uneconomical and unsustainable to improve productivity of these lands (Fullbrook, 2010). Furthermore, conversion of new and marginal lands to expand cultivated land increases greenhouse gas emissions and impacts biodiversity and ecosystem services (Pradhan *et al.,* 2015). There exist large yield gaps at farm level. It is said that biophysical, socioeconomic, management, institutional and policy factors are responsible for yield and profit gaps (Balasubramanian *et al.* 2000). Closing yield gaps may be a viable option to increase global crop production. In this perspective, quantification of yield gaps is carried out for improving food and fiber production. Whereas, in developing countries, smallholder farming dominates and magnitude of yield gaps is particularly large (Pradhan *et al.,* 2015; Zhang *et al.,* 2016). Finding of current study, are in accordance with previous studies in case of wheat crop in mix-cropping zone of Punjab and in other provinces, extension gaps in productivity of small farmers were higher than their counter parts. Same is the true in case of sugarcane in Punjab, rice in Sindh and maize in Khyber Pakhtunkhwa. Whereas, extension gaps in the productivity are higher at medium and large farms in case of wheat crop in rice-wheat zone, rice, maize hybrid and cotton crops in Punjab. Same is the case of cotton crop in Sindh, and sugarcane crop both in Sindh and Kyber Pakhtunkhwa.

In these settings, poor agronomic practices stem from farmers' rational perception of high risks and low returns. Regardless of their need for information, they believe these factors do not justify the additional investment in labor and inputs needed for systematic agronomic practices (George, 2014). While, through adoption of proper agronomic practices not only higher production is obtained but natural resources and environmental quality are also protected for future generations (Ittersuma *et al*., 2013). Pakistan is a lower-middle income country, with a poverty rate of 40.1 percent (US$3.65/day at 2018 Purchasing Power Parity) for the year 2023-24 (World Bank, 2024). The country faces major challenge in feeding its growing population, with 47% of the population categorized as food insecure (Khaliq et al., 2019). Reducing yield gaps for major crops through adoption of improved technologies and production practices are important drivers of agricultural development, rural transformation and poverty reduction in countries like Pakistan. It is required to meet the multifaceted goals of productivity/ efficiency, profitability, environmental sustainability and climate resilience (Kumar *et al.,* 2020). Increasing agricultural productivity is directly linked with Sustainable Development Goal (SDG) 12, i.e. Responsible Consumption and Production, while it has indirect bearings on SDG-1; No Poverty, SDG-2; Zero Hunger, SDG-10; Reduced Inequalities and SDG-15; Life on Land.

Increase in productivity of major crops is needed to meet food requirement of the population growing at a burgeoning rate of 2.55 percent per annum (Anonymous, 2024). It is projected that

population of the country will increase to 310 million by 2050 (United Nations, 2015) from 241.5 million i.e. in year 2023-24 (Anonymous, 2024). While, production of major food grains (wheat, rice and maize) has grown by 1.20 percent per annuum in first twenty-two years of current century, mainly due to increase in productivity of 2.40 percent per annum and expansions in areas under these crops of 0.81 percent per annum. Similarly, during same time period, production of sugarcane and cotton has grown up by 0.43 and 2.20 percent per annum (Anonymous, 2010; Anonymous, 2023g). Thus, minimizing productivity gaps of major crops is required to fulfill food grains, sugar and fiber requirement of the country in future and to avoid burden on economic exchequer resulting from imports of these commodities. There is need to facilitate growers to adopt recommended technologies and production practices to harness potential yield of these crops. This will not only result in higher production viz. increased availability of better qaulity food grains, fiber and sugar produce.

In Pakistan, two-third of the farmers operate on small scale and face resource constraints. Thus, agricultural policies and programs in the country should be designed keeping in view their needs (Abid *et al.* 2016). Availability of quality of inputs needs improvement e.g. supply of quality seed is inadequate, chemical inputs (insecticides, micro-nutrients and fertilizers) are also low in quality and improperly used (Sattar, 2012). In the same way, adoption of modern technologies in Pakistan and other developing countries is constrained with farmrs' limited market access, insufficient knowledge and resource capacity (Kumar *et al*., 2020). Smallholder farmers are unable to attain productivity gains offered by plant genetic improvement (Tittonel and Giller, 2013). It is found that short term credit has highly significant impact on agricultural productivity in the country (Rehman *et al.* 2015; Chandio *et al.* 2018). Similarly, seed subsidies encourage farmers to adopt modern technologies (Kumar *et al.* 2020). In the same way, greater management skills for farmers and other involved in crop production are also essential (Fischera and Connorb, 2018).

Similarly, Rhebergen *et al*. (2018) professed that poor management practices are the main factor contributing to yield gaps. In this reference, Ortiz-Ferrara *et al*., (2008) reported an increase of 15-70 percent in the productivity by resource poor wheat farmers in South Asian region through the adoption of new varieties and resource conservation technologies (RCTs) like zero tillage. While, Tittonell and Giller (2013) stated that continued cropping without sufficient inputs of nutrients and organic matter leads to soil in degraded and non-responsive stage. It is said that larger land holdings may reflect the household's ability to take risks (Kumar *et al.* 2020). Thus, low risk setting for small and medium farmers is needed for sustainable adoption of high-yield practices (George, 2014). Similarly, greater management skills for farmers and all other involved in crop production are essential for sustainable agricultural development (Fischer and Connor, 2018). Investment to reduce yield gaps by appropriate agronomic practices has been also emphasized by Rhebergen *et al.* (2018). In the same way, Abid *et al.* (2016) stressed on short term and less costly measures along with provision of proper support and information to farmers to increase crop productivity in the face of climate change. Management practices related yield gaps allow the prioritization of most effective intervention areas (Belachew *et al.* 2022). Similarly, Tadele (2017) stressed that improved crop varieties alone do not boost crop productivity, unless supplemented with optimum soil, water and plant management practices, as well as the promotion of policies pertaining to inputs, credit, extension, and marketing.

There is need to increase investment on agricultural research and development. Pakistan currently spend just 0.18% of its agricultural GDP to agricultural research and development, which is far below the recommended global benchmark of 1-2% (Stads *et al*., 2015). Similarly, Anik *et al.,* (2017) accentuated importance of investment in research and development,

technology and human capital to enhance agricultural productivity and sustain growth in resource constrained regions like South Asia. While diffusion of technologies commonly occurs through informal networks or farmer to farmer knowledge exchange. Whereas, contribution of extension services remained insufficient (Kumar *et al.,* 2012). It is found that largescale farmers adapt more than small-scale farmers (Abid *et al.*, 2016). Their findings are in line with the results of current study.

In wheat crop, productivity gap was the highest in rice-wheat zone of Punjab (57%), followed by in Khyber Pakhtunkhwa (52%), Sindh (43%) and mixed-cropping zone of Punjab (42%). It is found that farmers achieve 43% of the yield potential of fine rice in rice-wheat zone of Punjab province. The findings are in line with Khaliq *et al*., (2019), they stated that farmers in Narowal and Gujranwala districts in rice-wheat zone of Punjab achieve only around 36-67% of potential yield of rice. Similarly, they found that wheat yield potential achieved by the farmer in the zone was 48-56%. As per findings of the current study, farmers in mixed cropping and rice-wheat zone have yield gaps of 42% (in Faisalabad district) and 57%, respectively. The results are also in line with Hussain *et al.,* (2014), they reported wheat yield gaps of 33% in mixed cropping zone (Okara district) and 51% in rice-wheat zones of the province, respectively. Wheat yield gap in Sindh province is 43% based on data from cotton and sugarcane growing districts. The results are in line with Noonari *et al.* (2015), who reported 33% yield gap in cotton growing district of Shaheed Benazirabad in Sindh. In Khyber Pakhtunkhwa, wheat yield gap is 52%. Thus, productivity gap in wheat was highest in rice-wheat zone of Punjab, followed by in KP and Sindh. Productivity gaps in rice production are comparatively higher in Punjab (57% in fine & 52% in coarse varieties) than in Sindh province (46% in fine and 42% in coarse varieties). In case of maize crop, productivity gaps are much lower in Punjab (28%) than in Khyber Pakhtunkhwa (66%). In cotton crop, Punjab has less productivity gap (42%), than in Sindh (46%). While in sugarcane crop, Sindh and Khyber Pakhtunkhwa have less productivity gaps (55% each) than in Punjab (63%).

The role of effective extension services is critical in dissemination of recommended production packages of major crops and increasing agricultural productivity. It is found that knowledge gaps of the farmers are comparatively low in Punjab province than their counterparts in other provinces. The reason might be relatively better extension system in Punjab province as compared to other provinces. Knowledge gaps of the maize farmers were the lowest (25.8%) as compared to farmers of other major crops. The reasons include; commercial production nature of the crop, better contact of the farmers with extension agents and higher number of visits to extension department by the farmers as compared to farmers other crops. As, Muddassir *et al.,* 2020 reported that 48.3% of the maize farmer respondents had obtained information about agricultural practices from extension agents, and that 65% of the respondents regularly visited the agricultural extension department in Punjab. Thus, farmers having contacts with extension agents or making regular visits to them have knowledge about recommended production practices. As per finding of current study sugar farmer in Mardan and Charsadda districts have knowledge gap of 54.7%. The results are in line with Farooq *et al*., 2019, they reported that sugarcane farmers in Mardan district of Khyber Pakhtunkhwa had 52.8% knowledge gap about recommended sugarcane production practices.

In the country, few farmers use recommended fertilizers levels. The most severe and widespread specific constraints for the crop production is high cost and poor management of fertilizers (Waddington *et al.,* 2010). The results of current study are in line with these findings, as maximum percentage of farmers who reported to use fertilizers as per recommendation of the departments is only 28 in case of both rice and cotton in Sindh province, followed by hybrid-maize farmers in Punjab, 18% (Table 6). While, to attain potential crop production at substantial

increase in the use of synthetic fertilizer is required. For instance, Pradhan *et al*., (2015) stated to increase N fertilizer application by 45-73%, P_2O_5 by 22-46% and K_2O by 2-3 times compared to year 2010 to obtain potential crop production at global level. In this perspective, overuse of nitrogen fertilizer is also declared detrimental to crop the sustainability of crop production. Pakistan is among the top four in terms of Nitrogen fertilizer use but has low mean yields, with lowest Nitrogen use efficiency and highest Nitrogen surplus (Shahzad *et al.* 2019). It is emphasized that adoption of agronomic practices including integrated soil-crop management can help narrow gaps between experiment station and average farmer yield (Meng *et al.*, 2013).

Conclusions

There exist substantial productivity gaps in the production of major crops in the country. These gaps range from about one-fourth (28.0%) in spring maize in Punjab province to two-third (66%) in sugarcane in Sindh province. Determination of these gaps reveals untapped potential productivities due to persistent extension gaps and research gaps. It also helps to identifying factor contributing to productivity gaps. Thus, allows for targeted efforts to boost production efficiency. Closing these gaps could results significant increase in production of food grains, fiber and sugar produce in the country. The productivity gaps have been bifurcated into research and extension gaps. There exist vast knowledge gaps about recommended production practices of major crops. Similarly, most of the production practices are poorly adopted by the farmers. The study reveals that investment gaps for adoption of recommended production packages of major crops are much low as compared to productivity gains that can be obtained through adoption of these packages. Moreover, investment gaps mainly depend on food or cash nature of the crops including their production durations. These findings provide valuable insights for formulating suitable policies and effective programmes to enhance and maintain production of major crops in the country. A dual focus on research (to raise potential yields) and extension (to bridge adoption gaps) is critical for food security and export growth.

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