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Assessment and Analysis of Agriculture Technology Adoption and Yield Gaps in Wheat Production in Sub-Tropical Punjab

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ABSTRACT

Yield gap analysis evaluates magnitude and variability of difference between crop yield potential and yield obtained at farmers' fields. The magnitude of yield gap and related causes vary substantially, and depends upon technology gap generated by partial or incomplete adoption of locally optimized technology. Periodic survey (2013-16) revealed that ~6-22 per cent of wheat area in Mansa (Punjab)during 2012-16 was under un-recommended varieties. More than 1/3rd (~35%) of farmers were using un-treated wheat seed and therefore, experienced infestation of seed borne diseases at their fields. About 28 per cent farmers were using higher seed rate than recommended (100 kg seed ha^{-1}), constitutes majority of those farmers who had retained seed from previous year harvest. Only 1/10th of farmers apply fertilizer N to wheat at recommended rate (125 kg N ha^{-1}). About 81 per cent farmers did not apply basal N dose, therefore, appearance of N deficiency on lower wheat leaves occur commonly, resulting in a significant set-back on crop grain yield. Data revealed that 91, 79 and 67 per cent of farmers did not apply K, Zn and Mn, respectively to wheat, albeit of their deficiency in the soils. An assessment of yield gap showed a potential to increase the wheat grain yield upto 0.91t ha^{-1}.Seed treatment before sowing resulted in an increase in wheat grain yield by 0.30 t ha^{-1} (6.1 %). Nitrogen application at sowing increased wheat grain yield by 0.62 t ha^{-1} (13.6 %), compared with plots without basal N application. Results of the survey showed a potential to increase wheat grain yield from 0.28-1.08 t ha^{-1} (6.5-25.6 %) with foliar application of $MnSO_4$.Therefore, understanding crop yield potentials and exploitable gaps in crop production is essential to increase grain yield.

Keywords: Technology gap, nutrient management, varietal evaluation, wheat production, yield gap

INTRODUCTION

Crop production needs to increase by ~60 per cent by 2050 to meet the increased food demand of tremendously escalating human population (Alexandratos and Bruinsma, 2012). Increase in agricultural production with limited resources could be possible by (i) shifting more area under crop production. (ii) achieving higher crop yield per unit area or (iii) by both (Bruinsma, 2009; Godfray *et al.,* 2010). Increase in crop yield per unit area could be achieved through increases of crop genetic potential and/or through reductions of yield gaps (Fischer *et al.,* 2014). Crop yield obtained at farmers' fields throughout the world are almost always on the lower side, compared with attainable or potential yield by adopting best agricultural management practices (BMPs) that are optimized locally (Fischer *et al.,* 2009; Lobell *et al.,* 2009; Laborte *et al.,* 2012). Attainable crop yield is a result of several factors including environmental, economic and sociological. Yield differences at farmers' fields having the same location, soil type, access to irrigation water and sources, similar crop varieties and level of fertilizer application are exclusively due to the differences in management practices followed at these farms, which in turn is due to the 'technical efficiency gap' (Ahmad *et al.,* 2002). Local lay knowledge still constitutes the backbone of smallholder agriculture as evidences shows that water or nutrient use efficiencies are enhanced through the implementation of such knowledge intensive approaches (Colding *et al.,* 2003; Khan *et al.,* 2010; Altieri *et al.,* 2012). Farmers' priorities and objectives are not always to maximize the crop yields, but sometimes just to minimize production risks (Hardaker *et al.,* 1997). The difference in crop yield at farmers' fields and crops' genetic potential (*i.e.* potential/attainable yield) indicates yield gap (Cassman *et al.,* 2003; Fischer *et al.,* 2009; Fischer and Edmeades, 2010). According to Fischer *et al.,* (2009), yield gaps cannot be reduced to zero because of existing practical and economic constraints in commercial farming. Because of difficulty of increasing crops' yield

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potential over the short-term through genetic improvement (Tollenaar and Lee, 2002), closing the existing yield gaps between attainable potential and farmers' yield is essential to ensure national food security. The magnitude of crop yield gap indicates current land productivity and an estimate of the additional crop production that could potentially be achieved, on an existing cropland area by the adoption of BMPs. An assessment of yield potential and yield gaps can help in identifying yield limiting factors and developing future strategies to improve crop productivity (Bhatia *et al.,* 2008).

The concept of yield gap has been applied in many recent studies (Bhatia *et al.,* 2008; Lobell *et al.,* 2009; Liu *et al.,* 2011) as an indicator for the possibility to increase crop yield in a given region. Since, an average wheat grain yield (4.44 t ha^{-1}) is low in Mansa district of Punjab (India), therefore a comprehensive survey was conducted to analyze and assess the differences in agriculture technologies being adopted at farmers' fields and yield gaps in wheat production, so as to understand potentials and exploitable gaps to increase grain yield.

METHODOLOGY

Mansa district is located in the South-western parts of Punjab (India), occupying a total geographical area of about 2.2 lakh ha, extending between longitude of 29º 59´ and latitude of 75º 23´ (212 m above mean sea level). Mansa has about 1.8 lakh ha of arable land in 5 blocks and 243 villages, and adjoins Bathinda district on the northwest, Sangrur on the northeast and by Haryana state on the southern side. District extends in agro-eco-sub-region AES-1, AES-2 and AES-3 representing Western plain area, Western Area and Flood prone, characterized by sandy loam (0.9 lakh ha) to loamy sand (1.0 lakh ha) texture. Western plain area is tube-well irrigated and western area is tube-well and canal water irrigated. On an about 0.3 lakh ha flood prone area, there has been a problem of sodicity (pH>8.5). Soils are classified as Ustic Haplocambids, Ustic Torripsamments and Ustic Haplocalcids (Raj Kumar *et al.*, 2008).

Annual rainfall in Mansa ranges between 300-450 mm (covering only 15-24 % of potential evapo-transpiration), majority (~80-85 %) is received during summer season extending from mid of July to end of September, and rest during winter season. The climate of an area is typically arid and sub-tropical with hot and dry summers and cold winters. Mean annual temperature ranges between 19° C and 31°C (Figure 1).

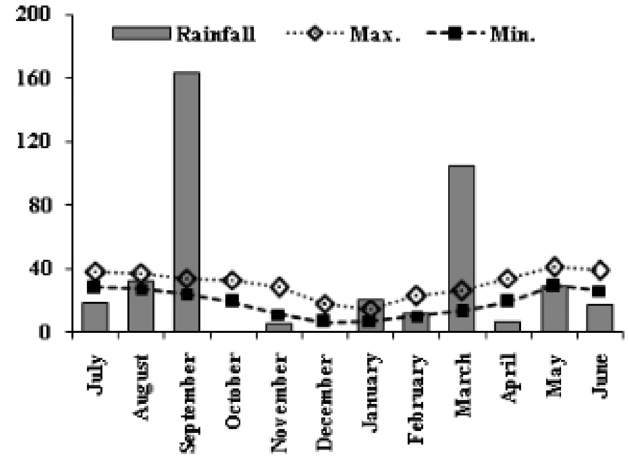


Figure 1. Mean monthly maximum and minimum (oC) empertaure and rainfall (mm) in the region

Winter cereals such as wheat (*Triticum aestivum L.*), oats (*Avena sativa*), barley (*Hordeum vulgare*), millets, pulses, potatoes (*Solanum tuberosum*), and vegetables are the traditional crops in Mansa. Cotton (*Gossypium hirsutum*) and Rice (*Oryza sativa L.*) are the dominant summer season crops. Winter wheat dominates the cereal acreage (170 thousand ha representing about 76 % area), and is grown in rotation with rice (44 % area) and cotton (49 % area), constituting rice-wheat and cotton-wheat cropping systems.

A detailed survey of wheat crop was performed during three consecutive years (2013-14 to 2015-16). A group of 10 farmers from each of 5 villages in5 different blocks *viz.* Mansa, Jhunir, Bhikhi, Budladha and Sardulgarh each year were randomly selected. Thus, a total of 250 farmers (5 blocks X 5 villages X 10 farmers) were interviewed for the survey each year. Farmers participated in the survey were between age group of 26-65 years, having agriculture experience of more than 5 years. Survey information was recorded in questionnaire developed for the purpose of the study. During second and third year (2014-15 and 2015-16),cross validation of the collected information was done by including 5 farmers (one from each block) selected for previous years' survey. Information with more than 10 per cent disparity in data from last year surveywas discarded.

RESULTS AND DISCUSSIONS

Area under different varieties and method of sowing

Periodic survey revealed that nearly 78-94 per cent of wheat area sown was under recommended varieties, while only 6-22 per cent comprised area under un-recommended varieties (Figure 2). Area under recommended varieties increased by 19 per cent during *rabi* 2014-15, compared with wheat area during 2013-14. During *rabi* 2015-16, wheat area under recommended varieties exhibited only a marginal change. Conversely, wheat area under un-recommended varieties declined by 67 per cent during rabi 2014-15, compared with area under wheat during rabi 2013-14. Among the recommended varieties, HD-2967 comprised more than 2/3rd of wheat area during different years (Table 1). It was 69.2 per cent of total wheat area during rabi 2013-14 and increased to 83.8 and 88.7 per cent, respectively during rabi 2014-15 and 2015-16. Wheat variety PBW-621 was sown on 3.3 to 5.9 per cent of area under wheat during different years, and was the second most popular variety among local farmers. Nearly 81 per cent of wheat area in Mansa district was under conventional tillage (CT) and ~14 per cent of wheat was sown with rotavator. Zero-tillage sowing of wheat was the least popular sowing method, as it is practiced on only 6 per cent of total area under wheat. A large proportion of area under CT might be because of weak economic situation of the farmers disabling them to purchase costlier machinery.

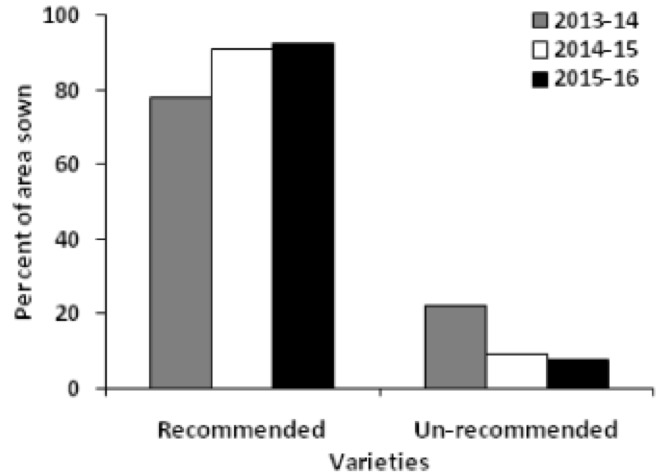


Figure 2. Periodic trend depicting distribution of wheat area under recommended and un-recommended varieties

Table 1: Yearly distribution of area under recommended and un-recommended wheat varieties

Year	Recommended							Un-recommended					
	PBW-502	HD-2967	PBW-621	PBW-550	WH-1105	HD-3086	Total area %	HD-2932	Berbet	Sriram-152	Pb Shingar	HD-2851	Total area %
2013-14	1.69	75.33	4.13	2.19	0.04	-	89.54	2.45	1.35	0.93	0.25	3.20	10.46
2014-15	-	82.15	0.35	1.11	7.18	4.02	91.68	-	0.62	-	0.14	2.15	8.32
2015-16	-	61.79	-	0.56	10.64	17.56	91.16	-	5.77	-	1.65	0.94	8.84

Seed source, seed rateand seed treatment

Survey on seed source for wheatshowed periodic disparity (Figure 3a). About 45 per cent of farmers during rabi 2013-14 had purchased seed from government organizations (P.A.U. and State Department of Agriculture *etc*.), while 35per cent of farmers were using wheat seed retained by them during last year (*rabi* 2013-13) harvest. During *rabi* 2014-15, percentage of farmers using seed purchased from government organizations remained nearly the same (45 %), while the contribution of farmers' own seed increased by ~10per cent over the *rabi* 2013-14 percentage.

This shift in percentage of seed source during two years occurred from share of private traders. During rabi 2015-16, percentage of farmers using their own seed increased to ~57 per cent, while the percentage of farmers used seed purchased from government organizations decreased by about 3-times (Figure 3a).This huge shift was due to lack of purchasing power, owing to failure of cotton crop during *kharif* 2015.

Three years pooled data revealed that 37.4 per cent of farmers were using wheat seed at 87.5-100 kg seed ha^{-1}, while 34 and 25 per cent were using between 100-112.5 and 112.5-125 kg seed ha^{-1}, respectively (Figure 3b). Results showed that 59per cent of farmers were using seed rate recommended(100 kg seed ha-1) by P.A.U., while 27.9 per cent of farmers were using higher seed rate. High seed rate was used by the farmers who had retained their own seed.

Farmers using their previous years' seed seldom grade their seed and therefore, ensures high seed rate to minimize germination risks.

Survey revealed that 35per cent of farmers were using un-treated seed, while 61per cent of farmers were using seed treated with Raxil. Only 4 per cent of farmers were using other chemicals for wheat seed treatment.

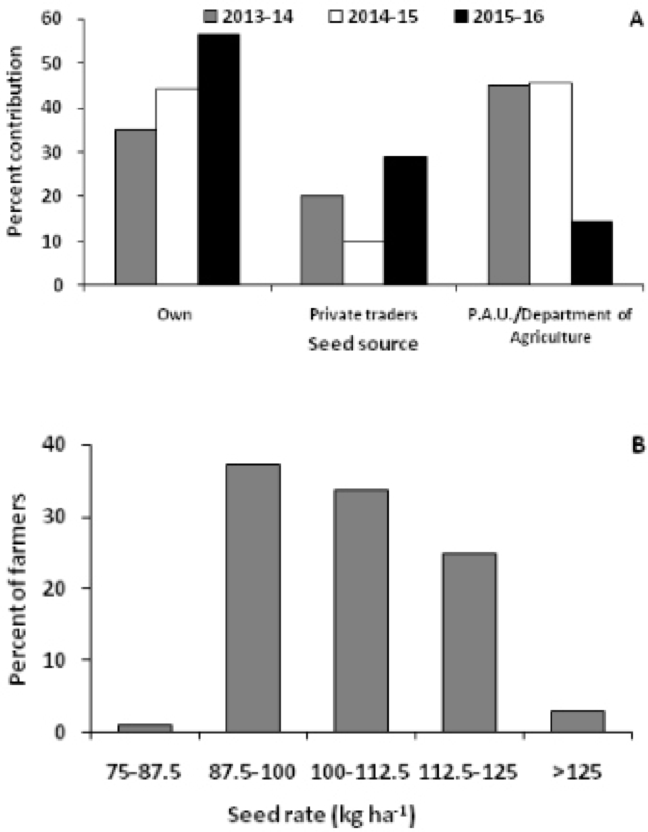


Figure 3. Distribution of farmers among different categories based on seed source and seed rate of wheat crop grown

Herbicide use pattern

Herbicide use pattern (Figure 4) revealed that majority (56 %) of farmers were using a combination of Topik (Cladinofop) +Algrip (Metsulphuron)for chemical weed control of grasses and broad leaf weeds in wheat crop. Use of these herbicides by a large majority could be due to their higher efficacy.A combination of Topik+2,4-Dand Leader (Sulphosufurion) +Safal were used by 7.1 and 8.6 per cent farmers, respectively. Only ~14 per cent of farmers are using only Topik for chemical weed control of gulli danda (*Phalaris minor*). Comparatively less efficient broad weeds especially baathu (*Chenopodium album*) with Algrip was observed in the fields of farmers who used Algrip (Metsulphuron) at 8 g per acre, against 10 g per acre recommended dose.

Time and number of irrigations

Majority (51-56 *per cent*) of farmerswere applying first irrigation to wheat 26-30 days after sowing. Nonetheless, the proportion of farmers giving first irrigation between 21-25, 31-35 and 36-40 days after wheat sowing was nearly the same (Figure 5). Nearly 57 per cent of farmers are applying 5 irrigations to wheat crop, while 28 per cent of farmers are applying 4 irrigations (Figure 5).Only about 3per cent of farmers are applying 3 irrigations, and 9 per cent of farmers are applying 6 irrigations to wheat crop grown in Mansa district. Only 3 irrigations to wheat are applied to the fields in the area where under-ground water table was high and of poor quality. While 6 irrigations were applied to the fields that were extremely light in texture.

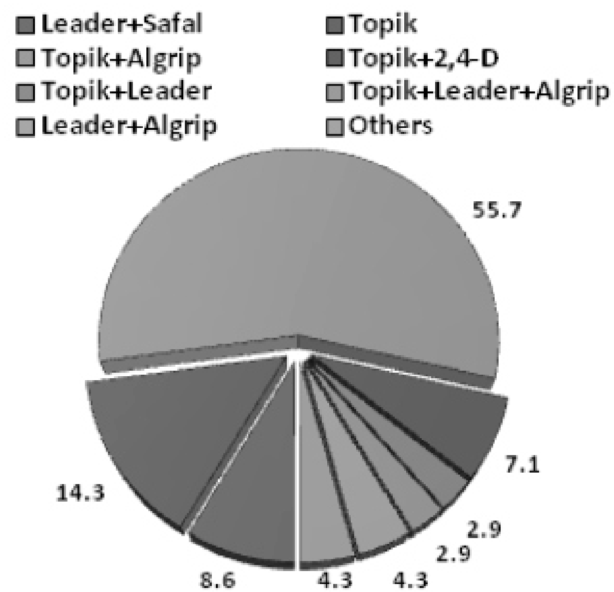
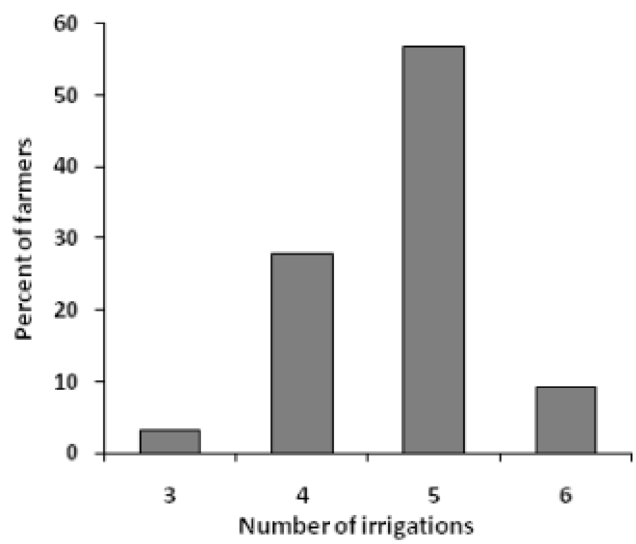


Figure 4. Herbicide use pattern for chemical weed control in wheat grown



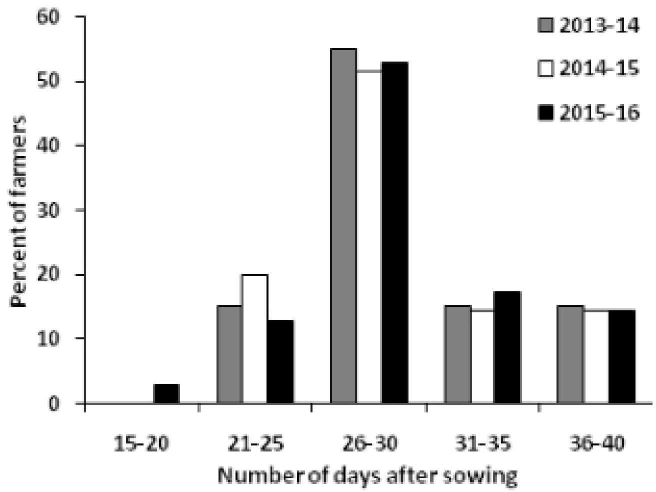


Figure 5. Percent distribution of farmers based upon time (number of days after sowing) and number of irrigations applied to wheat

Nutrient management

Nitrogen (N) use pattern revealed that ~59 per cent of farmers were applying 138-162.5 kg N ha^{-1}, representing over-use (10-30 %) of fertilizer-Nover the recommended rate (125 kg N ha^{-1}) for medium fertile soils (Table 2).

About 30 per cent of farmerswere applying even higher dose of N-fertilizer (163->188 kg N ha-1), accounting for as high as 50 per cent above the recommended fertilizer-N rate. Conversely, only 10 per cent of farmers were applying fertilizer N to wheat at recommended rate, while 1.7 per cent farmers practice under-use of N. Majority (81 %) of farmers did not apply basal fertilizer-N dose, and split N application with first two to three irrigations to crop. Yellowing of lower leaves because of N deficiency was observed in the fields of farmers where basal N dose was not applied. Use of fertilizer-N in wheat at higher rates could be related to greater response of crop, because majority of soils in the district are light in texture with low soil organic C content.

Nearly 88.6 per cent of farmers were applying 50-62.5 kg P_2O_5 ha^{-1}, against recommended rate of 50 kg P_2O_5 ha^{-1} (Table 2). Nearly 8.6 per cent of farmers over-usefertilizer-P (>62.5 kg P_2O_5 ha^{-1}) by25 per cent, over the recommended rate.Unlike over-use of N and P, 91.4 per cent of farmersdid not apply fertilizer-K to wheat. Earlier research showed that continuous cropping resulted in a considerable drain of available K from soils (Ranjha *et al.,* 1990).

Deficiency of micro-nutrients has become a constraint to productivity, stability and sustainability of soils (Bell & Dell, 2008). In Mansa district, 78.6 per cent of farmers did not apply zinc sulphate ($ZnSO_4$), while 17.1 per cent of farmersapply <10 kg $ZnSO_4$.7 $H2O^{ha}$-1(Table 2). About, 4.3 per cent of farmers, on the other hand are applying >10 kg $ZnSO_4$.7H2O ha^{-1}. Although, Zn is the most common micro-nutrient applied in India, nonetheless Zn is the most deficient micro-nutrient (Fageria *et al.,* 2003).

In plants, Zn is essential for several plant biochemical processes including cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation, and membrane integrity etc. (IRRI, 2000).

A significant set-back on plant performance to grow and yield better has been reported frequently in Zn-deficient soils (Singh *et al.,*2006; Alloway, 2007). Nonetheless, Zn application in deficient soils is important because cereals are inherently very low in Zn concentration to meet daily human requirement (Cakmak, 2008).

Soils with DTPA-Mn<3.5 mg kg-1 are considered deficient with respect to their Mn supplying capacity to wheat crop (Chhibba *et al.,*2006). Since, majority of soils in Mansa district are light in texture, Manganese (Mn) deficiency was a serious problem affecting crop growth and production. But, 2/3rd (67.1 %) of farmers did not apply Mn to wheat. About 13 per cent of farmers ensured 2 foliar applications of 0.5 per cent solution of $MnSO_4$ and 14 per cent farmers ensured 3 foliar applications. However, 5.7 per cent of farmers were applying 4 foliar sprays of $MnSO_4$ to wheat.

Manganese deficiency in wheat is generally encountered in coarse textured soils with low soil organic C content and that especially are continuously under rice-wheat cropping sequence for over the last 6 years (Chhibba and Sadana, 2008).

Development of reduced conditions leads to the conversion of Mn to highly soluble form in the surface soil layer during rice growing season results in leaching to lower soil layers. As a consequence, the content of available Mn in surface soil layer reaches to a level that is inadequate to meet the requirements of wheat (Chhibba and Sadana, 2008).

Table 2: Macro-and micro-nutrients use pattern in wheat grown

Nitrogen (N)		Phosphorus (P_2O_5)		Potassium (K_2O)		Zinc ($ZnSO_4.7H_2O$)		Manganese (0.5 % $MnSO_4$solution)	
kg N ha^{-1}	% Farmers	kg ha^{-1}	% Farmers	kg ha^{-1}	% Farmers	kg ha^{-1}	% Farmers	Number of sprays	% Farmers
87.5-112.5	1.7	<50	2.9	Nil	91.4	Nil	78.6	Nil	67.1
113-137.5	9.9	51-62.5	88.6	<25	5.7	<25	17.1	2	12.9
138-162.5	58.8	>62.5	8.6	26-50	2.9	>25	4.3	3	14.3
163-187.5	17.2			>50	0			4	5.7
>188	12.5								

Average grain yield and yield gap

Varietal evaluation showed yield variation between 4.61 and 5.18t ha^{-1}against their yield potential varying between 4.88 and 5.35t ha^{-1} (Table 3). Data from farmers' fields showed a lower wheat grain yield of 0.10 to 0.63 t ha^{-1} (2-10 %), except for wheat variety PBW-502. Average wheat grain yield at farmers' fields in Mansa district was 4.44t ha^{-1} (*rabi* 2012-13), against 5.35t ha^{-1} of P.A.U.s recommended wheat variety HD-2967 (Table 3). Average wheat grain yield of wheat varietal trials conducted under front line demonstration (FLD) programme during rabi 2012-13 was 5.33 t ha^{-1}. Assessment of yield potential showed an averageyield gap of 0.28-0.91 tha-1in Mansadistrict. Adoption of best agricultural management practicesin FLDs resulted in achievement of potential gains in wheat grain yield. Wheat yield at farmers' fieldsdid not differmuchamong conventionally tilled, zero tilled and rotavator tilled and sown wheat (Table 4). However, yield gap estimate sshowed potential to increase grain yield by 0.34-0.42 t ha^{-1} (6.9-7.9 %). Seed treatment of wheat before sowing resulted in anincrease in wheat grain yield by 0.30 t ha^{-1} (6.1 %), although potential of yield increase by 0.47 t ha^{-1} (8.8 %) still exists. Application on fertilizer-N at sowing resulted in a increase in wheat grain yield by 0.62 t ha^{-1} (13.6 %), compared with plots without basal N application. Foliar application of 0.5 per cent M_nSo_4 solution showed a increase in wheat yield, compared with plots without foliar application. Four foliar applications to wheat resulted in a increase in grain yield, compared with two or three foliar applications. Results showed a potential to increase wheat grain yield by 0.28-1.08 t ha^{-1} (6.5-25.6 %) with foliar application of M_nSO_4.Yield differences at farmers' fields having the same location, soil type, access to irrigation water and sources, similar crop varieties and level of fertilizer application are exclusively due to the differences in management practices followed at these farms, which in turn is due to the 'technical efficiency gap' (Ahmad *et al.,*2002). The existence of technical inefficiencies could fully off-set the potential gains of highly superior technologies (Pingali and Heisey, 1999).

Table 3: Average grain yield of different wheat varieties and yield gap from yield potential, state average and demonstration yield at farmers' fields

Variety	Farmers field yield (t ha^{-1})	Yield potential (t ha^{-1})	Variation in yield at farmers' fields over yield potential
HD-2967	4.95	5.35	-0.40 (7.5)#
PBW-621	5.18	5.28	-0.10 (1.9)
PBW-550	4.93	5.20	-0.27 (5.2)
PBW-502	5.13	4.88	+0.25 (5.1)
JK-17	4.61	--	--
WH-1105	5.15	5.78	-0.63 (10.9)
HD-3086	4.88	--	--

Particular	Yield (t ha^{-1})
P.A.U.'s recommended yield *	5.35
State average yield¶	4.72
K.V.K.'s demonstration yield	5.33
Actual yield at farmers' fields**	4.44
Yield gap (A-D)	0.91
Yield gap (B-D)	0.28
Yield gap (C-D)	0.89

*Yield potential of HD-2967 was used in the calculations
** Represent average yield of Mansa district during rabi 4.44 t ha-1 (2012-13)
¶ State average yield recorded during rabi 2012-13
#Values in the parentheses represent percent variation in yield over yield potential

Table 4: Average grain yield of wheat under different agriculture management practices

Management practice	Treatment	Average grain yield (t ha^{-1})	Difference over	
			Yield potential ¶ (t ha^{-1})	Control (T_1) (t ha^{-1})
Sowing method	T_1=Conventional tillage	5.01	-0.34 (6.9)#	
	T_2=Rotavator	4.95	-0.40 (7.5)	-0.06 (1.2)
	T_3=Zero tillage	4.93	-0.42 (7.9)	-0.08 (1.6)
Seed treatment	T_1=Un-treated seed	4.88	-0.47 (8.8)	
	T_2=Treated seed	5.18	-0.17 (3.2)	+0.30 (6.1)
Nitrogen management	T_1=Without basal N application	4.61	-0.74 (13.8)	
	T_2=With basal N application	5.23	-0.12 (2.2)	+0.62 (13.6)
Manganese management	T_1=Without application	4.20	-1.15 (21.5)	
	T_2=2 foliar applications	4.48	-0.87 (16.3)	+0.28 (6.5)
	T_3=3 foliar applications	4.93	-0.42 (7.9)	+0.73 (17.3)
	T_4=4 foliar applications	5.28	-0.07 (1.3)	+1.08 (25.6)

Yield potential of HD-2967 (5.35 t ha-1) was used for calculating variation from yield at farmers' field under different technological scenarios
#Values in the parentheses represent percent variation in yield over yield potential or control (T1)

CONCLUSION

There is always a disparity between the yield realized by the farmer and the potential of a cultivar. The reason could be due to compounded effects of crop management deficiencies attributed to the inadequacies of knowledge and the poor management skills of the farmer. There was poor adoption of recommended doses and time of application of micro and macro nutrients, seed treatment *etc.* The extension agencies can fill this gap by educating farmers regarding role of different nutrients in getting high crop yield. But there are various other reasons that effect farmers' decision regarding crop management. The deliberations with the farmers revealed various constraints contributing to adoption of improved technologies. Some of these components can be adapted but some are beyond the control of the farmer. Farmers used high seed rate as they did not grade seed and therefore, ensured high seed rate to minimize germination risks. Under-dose of herbicide was due hesitation to purchase a new packing, as certain herbicides were available in market in packing that varied from recommended doses. Market availability of different chemicals and their packing sizes also influences farmers' decision regarding doses of herbicides. Thus, reasons for such a discrepancy may be technical, institutional or socio-economic. The yield gap thus observed could only be bridged if technological gaps along with institutional and socio-economic constraints are eliminated.

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