Society for Advancement of Wheat Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Journal of Wheat Research

6(2):138-149

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Yield gap in wheat: Approach, quantification and resetting research priorities in India

Sendhil R[1*], Randhir Singh[1], Ramasundaram P[2], Anuj Kumar[1], Satyavir Singh[1] and Indu Sharma[1]

[1]*ICAR-Indian Institute of Wheat & Barley Research, Karnal 132 001 (Haryana), India*

[2]*National Agricultural Innovation Project, Krishi Anusandhan Bhavan II, Pusa, New Delhi 110 012, India*

Article history

Received: 07 August, 2014

Revised :18 Novemver, 2014

Accepted:18 Novemver, 2014

Citation

Sendhil R, R Singh, P Ramasundaram, A Kumar, S Singh and I Sharma. 2014. Yield gap in wheat: Approach, quantification and resetting research priorities in India. *Journal of Wheat Research* 6(2):138-149

****Corresponding author***

Email: *r.sendhil@gmail.com*

Tel.: *08929063645*

Abstract

Despite the technological breakthrough after Green Revolution, the yield of wheat realized at farmers' fields is much lower than its potential yield at experimental farms. An attempt has been made to quantify the yield gaps and prioritize wheat research in India based on the identified production constraints. The authors have developed a 'hybrid approach' to quantify the yield gaps from 2001-02 to 2010-11. Analysis for the decade indicated that the yield gap has been declining, inter alia, due to incessant efforts done by the research and extension across the country. The study identifies region-specific production constraints accounting for the existing yield gaps and also suggests some research priorities to bridge the yield gaps.

Keywords: Yield gap, wheat, production constraints, quantification, research prioritization

1. Introduction

World agriculture has been facing a daunting task of producing sufficient food to meet its growing demand posed by population growth, diet preferences, climatic vulnerability, farmland degradation and growing competition for water and energy (Ray *et al.*, 2013; Indu Sharma *et al.*, 2013; Godfray *et al.*, 2010). Technology did increase the food grains productivity in India till 1990s, but the subsequent growth rate started to decline (Sendhil *et al.*, 2012a).There is an increasing evidence of stagnation in crop yield potential world over (Duvick *et al.*, 1999; Peng *et al.*, 1999), and that average crop yields in major cereal-producing countries have struck a plateau (Cassman *et al.*, 2003). Further, the increasing population and preference for wheat in rural India has exacerbated the demand(Sendhil *et al.*, 2012b; Nasurudeen *et al.*, 2006). The debate on climate change, depleting natural resources, stress on food and nutritional security in most of the global platform aims to achieve the higher yields with the given resources at farmers' field. Though farmers grow wheat under their self-judged best management coupled with recommended package of practices, yield gap (henceforth 'YG') is still reported in many regions of India (Bhattacharya, 2011; Sarungham and Prasad, 2011; Singh, 2010; Fischer *et al.*, 2009; Aggarwal *et al.*, 2008) and across countries (Mondal, 2011).

Lobell (2009) estimated a range of 20 to 80 per cent YG that include across the major cropping systems of the world. Chandna (2004) found that Indian wheat yields are reduced by late sowing in the eastern Gangetic plains. Fischer *et al.* (2009) estimated that Punjab and Haryana registered around 45 and 35 per cent YG respectively in wheat between farmers yield and research farm potential yield. The crop also registered a YG of 700kg/ha between research farm and farmers field (Aggarwal *et al.*, 2008). Bhattacharya (2011) estimated around 28 per cent YG between potential and India's average yield, 57 per cent YG between potential and state average yield and 0.98 per cent YG between potential and on-farm yield in Uttar Pradesh. Sendhil *et al.* (2012a) observed that only three states in India *viz.*, Haryana, Punjab and Rajasthan recorded yield more than the national average (3140 kg/ha) during 2011-12. Average wheat yield under irrigated condition in northwest India can reach up to 80 per cent of its potential yield. Literature report that the YG extends from 16 to 95 per cent, although the true range is likely narrower owing to measurement errors. However, these regional YGs are attributed to the difference in input levels between farmers' field and demonstration plots (Sarungham and Prasad, 2011), variations in management, site and season (Sendhil *et al.*, 2012a). The causes responsible for yield gap include biotic and abiotic factors, some easy to measure and some difficult to detect, some relate to management and others to soil properties as well as interactions among them (Lobell, 2009). Prevalence of YG and its skewed distribution is a matter of serious concern to bridge the existing gap (Anonymous, 2012; Sendhil *et al.*, 2012a). A better understanding of the existing YGs is mandatory in order to develop suitable research strategies and policies to improve the productivity of wheat. This paper aims to quantify the YG in wheat, prioritize wheat research in India based on the identified constraints in production. It also suggests policies to raise the realized yield, and bridge existing yields gaps.

2. Materials and methods

Field experiments at research stations to release a new variety and demonstrations at farmers' field for released varieties were conducted across India by the Indian Institute of Wheat & Barley Research, Karnal (India) through their cooperating centers. From those experiments and field demonstrations, the present study sourced yield data (2001-02 to 2010-11) of wheat in quintals (q) i.e., 1q = 100kg. Historical data on state and national wheat yield for the same period (10 years) were obtained from the Ministry of Agriculture, Government of India.

YG has been used to quantify the additional yield that can be realized by the farmer with the given level of resources and adoption of improved technologies. It is the difference between observed yield and those attainable in a given region (Nathaniel *et al.*, 2012). The concept is based on the definition and measurement of potential yield (Lobell, 2009) and has its origin from the studies carried out by International Rice Research Institute (IRRI) during the seventies (Mondal, 2011). However, several studies have been carried out with some modifications or customizing the methodological aspectto quantify the yield gaps (Bhattacharya, 2011; Aggarwal *et al.*, 2008; Sarungham and Prasad, 2011; Singh, 2010; Fischer *et al.*, 2009). The authors' brief down the holistic view of the definitions of YG that literature quoted so far. The first component, YG I is the difference between the genetic potential yield (simulation) and research farm potential yield (site specific experiments). However, this component is not exploitable and can be solely credited to research. YG II is the difference between the research farm potential farm yield and demonstration potential yield. YG II arises due to difference in management practices and YG III is the difference between yield from front line demonstration (FLD) and average farm yield (farmers' practice). Barring YG I, rest are exploitable and can be minimized by deploying research and extension approaches coupled with government interventions, especially institutional issues.

However, the present study develops the following hybrid approach (Fig. 1) to estimate the existing yield gaps:

Yield Gap_R or (YG_R) = Experimental yield – FLD yield

Yield Gap_{FP} or (YG_{FP}) = FLD yield – Check plot yield

Yield Gap_{RD} or (YG_{RD}) = State average FLD yield – State average yield

Yield Gap_A or (YG_A) = National or State average FLD yield – National average yield

In this case, experimental yield is the potential yield of the crop and averaged for the year from breeder's trials across regions. FLD or demonstration yield at farmers' field is considered as the potential yield under practices recommended by the scientists and advised by the extension personnel. FLD is the concept of demonstrating a new technology for the first time by the scientists in the farmer's field before being fed into the main extension system. The main objective of FLD is to demonstrate newly released crop production and protection technologies and its management practices in the farmers' field to get the maximum possible yield under different agro-climatic regions and farming situations. Potential yield at experimental farm is under controlled condition at a small scale with no limiting factors and it is difficult to achieve by farmers owing to different management practices and production constraints. Hence, YG_R is attributed to the research component. Whereas, YG_{FP} is a consequence of the difference in the management practice of farmers between the demonstration vis-à-vis check plots. YG_{RD} arises out of the regional differences in the management practices and YG_A is the average gap in the crop productivity comprising YG_{RD} and YG_{FP}.

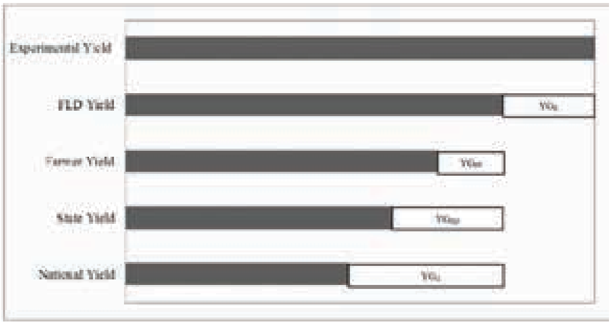

Fig 1. Definition of yield gaps

Data pertaining to wheat production constraints were collected through pre-tested questionnaire mailed to all the coordinating centres conducting FLDs, seeking to report the production constraints on a three point continuum viz., most serious, serious and not serious with associated scores as 3, 2, and 1 respectively. The average score for each constraint was calculated based on total score and sample size, to ascertain the seriousness. However, the present study discusses only the serious constraints recorded consistently. Experts' opinion has been used to identify the research method that addresses a particular production constraint.

3. Results and discussion

3.1 Temporal YG_R: The yield and the existing YG_R have been furnished in Fig. 2 and Fig. 3. Starting with a narrow gap in 2001-02, the YG_R increased to the maximum in 2006-07. Thereafter the YG_R started to decline drastically with the exception of 2009-10. This clearly indicated that experimental yield struck about its crossroad. *Inter alia*, aberration in climatic conditions has also contributed to the YG_R oscillation.

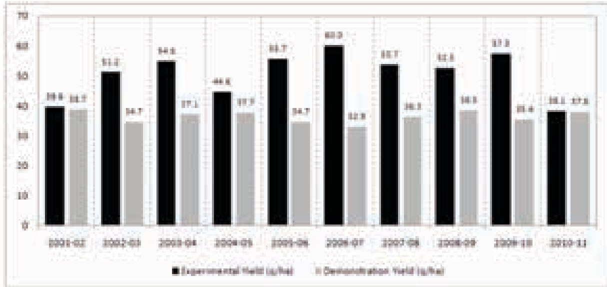

Fig 2. Yield levels of wheat at experimental farms and demonstration plot

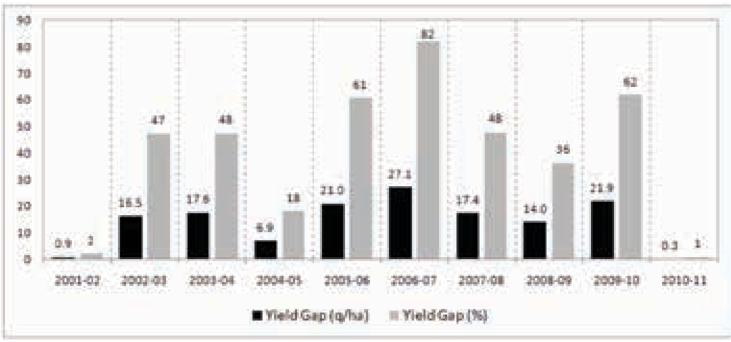

Fig 3. Yield gap between experimental and demonstration plot (YG_R)

Table 1. State wise yield of improved wheat varieties in q/ha under FLDs

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Assam	21.71	27.85	39.79	25.48	21.30	29.05	25.87	29.52	27.68	28.80	18.55
Bihar	37.38	35.23	31.94	37.14	32.69	35.69	39.79	39.83	40.37	41.18	8.69
Chhattisgarh	31.03	NC	25.46	32.88	24.65	25.22	30.13	40.97	32.49	42.11	20.28
Delhi	48.51	NC	51.65	50.43	47.33	NC	NC	51.89	43.40	50.84	6.16
Gujarat	44.05	33.21	45.39	40.08	43.74	39.70	46.01	36.40	38.85	36.33	10.70
Haryana	48.58	50.94	48.32	46.87	46.85	47.63	48.77	54.24	49.28	49.09	4.46
Himachal Pradesh	NC	28.49	25.60	27.07	22.41	23.00	24.41	23.91	18.18	31.31	15.23
Jammu & Kashmir	NC	NC	NC	NC	NC	30.24	21.22	31.69	27.28	30.87	15.12
Jharkhand	36.46	NC	40.05	44.33	42.43	15.41	38.04	38.40	35.58	23.89	26.73
Karnataka	41.57	35.80	36.00	36.45	37.97	36.12	40.20	40.30	37.55	39.51	5.52
Madhya Pradesh	26.55	38.67	31.05	42.32	25.29	27.48	39.04	38.89	35.60	42.11	18.88
Maharashtra	30.45	25.17	36.96	40.97	35.31	32.54	36.42	27.06	27.87	34.77	15.38
Punjab	48.55	45.59	51.47	44.58	44.45	NC	49.03	50.46	47.52	48.95	5.25
Rajasthan	59.90	36.91	33.58	43.92	39.29	43.53	42.25	41.46	42.47	44.51	16.18
Tamil Nadu	NC	34.39	23.66	24.62	23.59	28.94	27.09	31.20	31.11	36.77	16.30
Uttar Pradesh	41.17	40.81	41.08	44.04	45.59	46.77	46.12	45.87	42.69	45.00	5.23
Uttarakhand	45.14	37.28	30.71	39.59	27.33	32.48	34.55	31.94	31.58	33.61	14.77
West Bengal	19.39	15.38	38.08	19.38	29.22	NC	27.98	NC	27.87	20.60	29.80
India	38.70	34.69	37.11	37.66	34.67	32.92	36.29	38.47	35.41	37.79	5.23

Note: NC indicates that FLDs were not conducted in those states during that period.

Yield under FLD, check plot, state and national average yield were presented in Table 1 to 3 and the existing yield gaps were furnished from Table 4 to 6. Perusal of Table 1 and 2 indicated that demonstrations fetched more yield under standard management practices in comparison to yield of regional checks under farmers practice. The highest yield was recorded in Rajasthan (59.90 q/ha) during 2001-02 and lowest in West Bengal (15.38 q/ha) during 2002-03. However, the yield recorded in check plots in respective states was lower by 10.6 q/ha and 2.44 q/ha under corresponding years. On an average, the FLD yield ranged from 38.70 q/ha (2001-02) to 32.92 q/ha (2006-07).

Table 2. State wise yield of check wheat varieties in q/ha

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Assam	15.28	19.48	21.7	20.35	16.39	23.65	20.87	26.41	21.37	23.09	15.80
Bihar	34.83	30.54	24.9	26.7	28.14	32.16	31.72	35.41	35.45	37.86	13.31
Chhattisgarh	13.65	NC	13.12	17.6	16.93	17.53	20.92	27.82	24.03	20.71	24.85
Delhi	41.62	NC	49.71	44.53	44.12	NC	NC	49.55	40.4	44.53	7.96
Gujarat	39.01	27.29	39.98	35.68	40.61	37.6	43.65	34.34	35.3	32.82	12.63
Haryana	44.69	47.74	46.15	44.2	44.63	45.61	47.54	52.26	47.62	47.19	5.03
Himachal Pradesh	NC	20.15	22.24	23.39	18.78	20	21.61	18.5	14.65	25.52	15.33
Jammu & Kashmir	NC	NC	NC	NC	NC	21.11	17.83	23.45	24.52	24.37	12.69
Jharkhand	NC	NC	34.63	26.54	31.34	13.41	27.01	26.22	29.32	16.01	28.53
Karnataka	31.09	27.34	29.44	26.05	31.5	32.03	34.42	34.1	31.85	35.01	9.47
Madhya Pradesh	21.14	29.14	30.18	34.55	18.1	16.66	25.31	32.64	27.4	32.86	23.63
Maharashtra	26.21	21.96	31.13	33.94	30.19	30.15	31.1	23.66	24.42	30.96	14.04
Punjab	39.22	41.02	48.56	42.6	42.18	NC	47.39	45.08	43.88	46.01	6.94
Rajasthan	49.3	33.87	31.77	41.66	35.96	39.82	38.3	35.7	36.53	36.32	12.88
Tamil Nadu	NC	18	10.65	10.5	12.5	NC	NC	NC	NC	NC	27.19
Uttar Pradesh	32.69	28.01	36.16	28.19	40.74	41.59	40.8	40.19	38.82	37.96	14.12
Uttarakhand	34.04	17.81	26.01	32.44	20.76	19.52	29	24.28	22.43	25.05	21.42
West Bengal	14.1	12.94	31.86	18.53	27.57	NC	21.27	NC	23.35	18.6	30.67
India	31.21	26.81	31.07	29.85	29.44	27.92	31.17	33.10	30.67	31.40	6.05

Note: NC indicates that check varieties were not tested in those states during that period.

Table 3. State wise average wheat yield in q/ha

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Assam	11.81	11.30	10.43	10.66	10.74	11.17	12.68	10.90	10.87	11.64	5.98
Bihar	20.65	18.96	17.76	16.09	16.17	19.08	20.58	20.43	20.84	19.48	9.43
Chhattisgarh	10.57	10.63	10.24	8.53	8.86	10.02	10.59	10.40	10.86	11.44	8.70
Delhi	35.10	40.05	35.15	39.44	43.39	43.41	43.54	43.51	43.52	NA	8.78
Gujarat	24.35	19.66	26.81	24.82	27.00	24.98	30.13	23.77	26.79	31.55	12.86
Haryana	41.03	40.53	39.37	39.01	38.44	42.32	41.58	43.90	42.13	46.24	5.72
Himachal Pradesh	17.38	13.79	13.80	18.90	18.94	13.85	13.76	15.20	9.28	15.30	19.22

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Jammu & Kashmir	13.25	16.46	18.04	19.10	17.90	18.93	17.82	17.35	10.03	15.35	17.36
Jharkhand	17.65	16.25	15.73	23.81	13.40	15.29	16.21	15.41	17.37	16.43	16.39
Karnataka	7.63	5.98	4.15	7.40	8.58	7.62	9.46	9.18	8.87	10.94	23.92
Madhya Pradesh	16.20	14.56	18.00	17.35	16.13	18.35	16.12	17.23	19.67	17.57	8.36
Maharashtra	13.88	12.95	11.70	13.44	13.93	13.25	16.59	14.83	16.10	17.61	12.72
Punjab	45.32	42.00	42.07	42.21	41.79	42.08	45.07	44.62	43.07	46.93	4.19
Rajasthan	27.93	27.09	27.94	28.39	27.62	27.51	27.49	31.75	31.33	29.10	5.73
Tamil Nadu	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Uttar Pradesh	27.55	25.96	27.94	25.02	26.27	27.21	28.17	30.02	28.46	31.13	6.62
Uttarakhand	19.33	18.25	18.77	20.38	16.33	20.49	20.50	20.03	21.39	23.15	9.31
West Bengal	22.15	21.89	23.15	21.03	21.09	22.82	26.02	24.90	26.80	27.60	10.15
India	27.62	26.10	27.13	26.02	26.19	27.08	28.02	29.07	28.39	29.89	4.75

Note: NA indicates the non-availability of the yield data.

Among states, maximum average yield during the decade under FLD was 49.15 q/ha in Delhi followed by Haryana (49.06 q/ha) and Punjab (47.84 q/ha), whereas, the minimum average yield for the decade was recorded in West Bengal (24.74 q/ha) followed by Himachal Pradesh (24.93 q/ha), Assam (27.71 q/ha) and Jammu and Kashmir (28.26 q/ha). The Table 1 also indicates that the variation in yield under FLDs was less in major wheat producing states. It ranged from 4.46 per cent in Haryana to 29.80 per cent in West Bengal. Similar kind of pattern was observed for the yield under check plots and state average. For the country as a whole, variation in yield was found to be less in state average followed by FLDs and check plots.

3.2 Spatial and temporal yield gaps: The estimated YG_{FP} was highest in Chhattisgarh (21.40 q/ha) during 2010-11 (Table 4). Few states like Haryana, Punjab and Bihar registered low yield gaps and the scope for increasing the production arises from Uttar Pradesh, Rajasthan and Uttarakhand (Table 4). For the country as a whole, YG_{FP} range between 4.74 - 7.88 q/ha during the decade. The results indicated that all the wheat growing states have the potential to increase their yield level through improved farmers' management practices, given the existing resources and improved crop production technology. The percentage gap as evident from Table 4 was more in Tamil Nadu (134.48 % in 2004-05) followed by Chhattisgarh (127.33 % in 2001-02). The table also shows that variation in YG_{FP} was more irrespective of wheat growing states.

Over the decade (Table 5), the YG_{RD} was more in Karnataka (33.94 q/ha in 2001-02) and low in West Bengal (-7 q/ha in 2010-11). Surprisingly, FLDs revealed low yield than the state average of West Bengal for a majority of the years. The possible reason was due to organising demonstrations at marginal lands and the site varies from year to year. On an average, the yield gap for the whole country during the decade ranged from 11.64 to 5.84 q/ha. High yielding states like Haryana, Punjab and Rajasthan on an average exhibited about 9q/ha YG_{RD}. Barring West Bengal, the rest of the state's FLDs shown a considerable difference in the crop yield. On an average, the regional differences in the crop yield could have been increased by 32.15 per cent during the decade (Table 5). It ranged from 21.57 per cent (2006-07) to 44.74 per cent (2004-05). The highest per cent YG_{RD} was noticed in Karnataka (768.19 %) which shows that the state has immense potential to minimise the yield gap. The results also indicated that the per cent YG_{RD} was low in major wheat producing states like Haryana, Punjab and Rajasthan. Variation in YG_{RD} across states though ranged from 728.42 per cent (West Bengal) to 5.83 per cent (Karnataka), average of all states stood at 20 per cent.

Table 4. Estimated YG_{FP} in q/ha for wheat growing states

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Assam	6.43	8.37	18.09	5.13	4.91	5.4	5	3.11	6.31	5.71	60.94
	(42.08)	(42.97)	(83.36)	(25.21)	(29.96)	(22.83)	(23.96)	(11.78)	(29.53)	(24.73)	
Bihar	2.55	4.69	7.04	10.44	4.55	3.53	8.07	4.42	4.92	3.32	45.57
	(7.32)	(15.36)	28.27	(39.10)	(16.17)	(10.98)	(25.44)	(12.48)	(13.88)	(8.77)	

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Chhattisgarh	17.38	NE	12.34	15.28	7.72	7.69	9.21	13.15	8.46	21.4	38.36
	(127.33)	NE	(94.05)	(86.82)	(45.60)	(43.87)	(44.02)	(47.27)	(35.21)	(103.33)	
Delhi	6.89	NE	1.94	5.9	3.21	NE	NE	2.34	3	6.31	48.83
	(16.55)	NE	(3.90)	(13.25)	(7.28)	NE	NE	(4.72)	(7.43)	(14.17)	
Gujarat	5.04	5.92	5.41	4.4	3.13	2.1	2.36	2.06	3.55	3.51	37.25
	(12.92)	(21.69)	(13.53)	(12.33)	(7.71)	(5.59)	(5.41)	(6.00)	(10.06)	(10.69)	
Haryana	3.89	3.2	2.17	2.67	2.22	2.02	1.23	1.98	1.66	1.9	33.75
	(8.70)	(6.70)	(4.70)	(6.04)	(4.97)	(4.43)	(2.59)	(3.79)	(3.49)	(4.03)	
Himachal Pradesh	NE	8.34	3.36	3.68	3.63	3	2.8	5.41	3.53	5.79	40.99
	NE	(41.39)	(15.11)	(15.73)	(19.33)	(15.00)	(12.96)	(29.24)	(24.10)	(22.69)	
Jammu & Kashmir	NE	NE	NE	NE	NE	9.13	3.39	8.24	2.76	6.5	47.38
	NE	NE	NE	NE	NE	(43.25)	(19.01)	(35.14)	(11.26)	(26.67)	
Jharkhand	NE	NE	5.42	17.79	11.09	2	11.03	12.18	6.26	7.88	52.91
	NE	NE	(15.65)	(67.03)	(35.39)	(14.91)	(40.84)	(46.45)	(21.35)	(49.22)	
Karnataka	10.48	8.46	6.56	10.4	6.47	4.09	5.78	6.2	5.7	4.5	32.44
	(33.71)	(30.94)	(22.28)	(39.92)	(20.54)	(12.77)	(16.79)	(18.18)	(17.90)	(12.85)	
Madhya Pradesh	5.41	9.53	0.87	7.77	7.19	10.82	13.73	6.25	8.2	9.25	43.42
	(25.59)	(32.70)	(2.88)	(22.49)	(39.72)	(64.95)	(54.25)	(19.15)	(29.93)	(28.15)	
Maharashtra	4.24	3.21	5.83	7.03	5.12	2.39	5.32	3.4	3.45	3.81	32.34
	(16.18)	(14.62)	(18.73)	(20.71)	(16.96)	(7.93)	(17.11)	(14.37)	(14.13)	(12.31)	
Punjab	9.33	4.57	2.91	1.98	2.27	NE	1.64	5.38	3.64	2.94	61.94
	(23.79)	(11.14)	(5.99)	(4.65)	(5.38)	NE	(3.46)	(11.93)	(8.30)	(6.39)	
Rajasthan	10.6	3.04	1.81	2.26	3.33	3.71	3.95	5.76	5.94	8.19	57.35
	(21.50)	(8.98)	(5.70)	(5.42)	(9.26)	(9.32)	(10.31)	(16.13)	(16.26)	(22.55)	
Tamil Nadu	NE	16.39	13.01	14.12	11.09	NE	NE	NE	NE	NE	16.21
	NE	(91.06)	(122.16)	(134.48)	(88.72)	NE	NE	NE	NE	NE	
Uttar Pradesh	8.48	12.8	4.92	15.85	4.85	5.18	5.32	5.68	3.87	7.04	53.15
	(25.94)	(45.70)	(13.61)	(56.23)	(11.90)	(12.45)	(13.04)	(14.13)	(9.97)	(18.55)	
Uttarakhand	11.1	19.47	4.7	7.15	6.57	12.96	5.55	7.66	9.15	8.56	46.88
	(32.61)	(109.32)	(18.07)	(22.04)	(31.65)	(66.39)	(19.14)	(31.55)	(40.79)	(34.17)	
West Bengal	5.29	2.44	6.22	0.85	1.65	NE	6.71	NE	4.52	2	60.63
	(37.52)	(18.86)	(19.52)	(4.59)	(5.98)	NE	(31.55)	NE	(19.36)	(10.75)	
India	7.49	7.88	6.04	7.81	5.23	5	5.12	5.37	4.74	6.39	20.00
	(24.00)	(29.39)	(19.44)	(26.16)	(17.76)	(17.91)	(16.43)	(16.22)	(15.45)	(20.35)	

Note: NE indicates the non-estimation of yield gap due to non-availability of data and figures within parentheses indicate the corresponding percentage of yield gap.

Table 5. Estimated YG_{RD} in q/ha for wheat growing states

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Assam	9.90	16.55	29.36	14.82	10.56	17.88	13.19	18.62	16.81	17.16	32.91
	(83.76)	(146.37)	(281.55)	(139.09)	(98.32)	(160.07)	(104.02)	(170.87)	(154.57)	(147.50)	
Bihar	16.73	16.27	14.18	21.05	16.52	16.61	19.21	19.40	19.53	21.70	13.26
	(81.00)	(85.79)	(79.82)	(130.76)	(102.23)	(87.03)	(93.34)	(94.93)	(93.72)	(111.40)	
Chhattisgarh	20.46	NE	15.22	24.35	15.79	15.20	19.54	30.57	21.63	30.67	28.07
	(193.51)	NE	(148.74)	(285.46)	(178.30)	(151.65)	(184.53)	(293.75)	(199.05)	(267.96)	
Delhi	13.41	NE	16.50	10.99	3.94	NE	NE	8.38	-0.12	NE	69.41
	(38.22)	NE	(46.92)	(27.85)	(9.09)	NE	NE	(19.26)	(-0.28)	NE	

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Gujarat	19.70	13.55	18.58	15.26	16.74	14.72	15.88	12.63	12.06	4.78	28.93
	(80.90)	(68.88)	(69.28)	(61.47)	(62.01)	(58.93)	(52.73)	(53.15)	(45.03)	(15.15)	
Haryana	7.55	10.41	8.95	7.86	8.41	5.31	7.19	10.34	7.15	2.85	29.78
	(18.40)	(25.69)	(22.74)	(20.15)	(21.87)	(12.55)	(17.30)	(23.55)	(16.96)	(6.16)	
Himachal Pradesh	NE	14.70	11.80	8.17	3.47	9.15	10.65	8.71	8.90	16.01	36.65
	NE	(106.60)	(85.57)	(43.27)	(18.32)	(66.08)	(77.41)	(57.27)	(95.92)	(104.65)	
Jammu & Kashmir	NE	NE	NE	NE	NE	11.31	3.40	14.34	17.25	15.52	44.15
	NE	NE	NE	NE	NE	(59.74)	(19.09)	(82.63)	(171.86)	(101.07)	
Jharkhand	18.81	NE	24.32	20.52	29.03	0.12	21.83	22.99	18.21	7.46	49.25
	(106.63)	NE	(154.56)	(86.19)	(216.72)	(0.78)	(134.66)	(149.26)	(104.81)	(45.39)	
Karnataka	33.94	29.82	31.85	29.05	29.39	28.50	30.74	31.12	28.68	28.57	5.83
	(444.72)	(498.44)	(768.19)	(392.79)	(342.69)	(373.96)	(325.10)	(338.89)	(323.37)	(261.11)	
Madhya Pradesh	10.35	24.11	13.05	24.97	9.16	9.13	22.92	21.66	15.93	24.54	38.33
	(63.87)	(165.60)	(72.49)	(143.91)	(56.76)	(49.77)	(142.19)	(125.71)	(81.00)	(139.67)	
Maharashtra	16.57	12.22	25.26	27.53	21.38	19.29	19.83	12.23	11.77	17.16	29.73
	(119.40)	(94.40)	(215.92)	(204.86)	(153.42)	(145.58)	(119.53)	(82.42)	(73.15)	(97.50)	
Punjab	3.23	3.59	9.40	2.37	2.66	NE	3.96	5.84	4.45	2.02	54.72
	(7.13)	(8.55)	(22.34)	(5.61)	(6.36)	NE	(8.79)	(13.09)	(10.33)	(4.31)	
Rajasthan	31.97	9.82	5.64	15.53	11.67	16.02	14.76	9.71	11.14	15.41	49.97
	(114.46)	(36.25)	(20.19)	(54.70)	(42.27)	(58.23)	(53.69)	(30.56)	(35.56)	(52.95)	
Uttar Pradesh	13.62	14.85	13.14	19.02	19.32	19.56	17.95	15.85	14.23	13.87	15.90
	(49.45)	(57.17)	(47.02)	(76.05)	(73.54)	(71.86)	(63.71)	(52.82)	(49.98)	(44.55)	
Uttarakhand	25.81	19.03	11.94	19.21	11.00	11.99	14.05	11.91	10.19	10.46	35.28
	(133.56)	(104.29)	(63.65)	(94.25)	(67.37)	(58.55)	(68.51)	(59.50)	(47.62)	(45.16)	
West Bengal	-2.76	-6.51	14.93	-1.65	8.13	NE	1.96	NE	1.07	-7.00	728.42
	(-12.48)	(-29.74)	(64.46)	(-7.86)	(38.53)	NE	(7.55)	NE	(3.98)	(-25.37)	
India	11.08	8.59	9.97	11.64	8.49	5.84	8.27	9.40	7.01	7.91	20.06
	(40.10)	(32.93)	(36.76)	(44.74)	(32.40)	(21.57)	(29.50)	(32.34)	(24.70)	(26.45)	

Note: NE indicates the non-estimation of yield gap due to non-availability of data and figures within parentheses indicate the corresponding percentage of yield gap.

Table 6. Estimated YG_A in q/ha

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Assam	-5.91	1.75	12.66	-0.54	-4.89	1.97	-2.15	0.45	-0.71	-1.09	3301.35
	(-21.40)	(6.70)	(46.65)	(-2.06)	(-18.66)	(7.28)	(-7.68)	(1.54)	(-2.52)	(-3.63)	
Bihar	9.76	9.13	4.81	11.12	6.50	8.61	11.77	10.76	11.98	11.29	24.78
	(35.33)	(34.98)	(17.72)	(42.76)	(24.83)	(31.80)	(41.99)	(37.01)	(42.18)	(37.79)	
Chhattisgarh	3.41	NE	-1.67	6.86	-1.54	-1.86	2.11	11.90	4.10	12.22	138.52
	(12.34)	NE	(-6.16)	(26.39)	(-5.87)	(-6.87)	(7.52)	(40.93)	(14.42)	(40.90)	
Delhi	20.89	NE	24.52	24.41	21.14	NE	NE	22.82	15.01	20.95	15.05
	(75.63)	NE	(90.37)	(93.84)	(80.73)	NE	NE	(78.49)	(52.85)	(70.11)	
Gujarat	16.43	7.11	18.26	14.06	17.55	12.62	17.99	7.33	10.46	6.44	36.97
	(59.48)	(27.24)	(67.29)	(54.06)	(67.02)	(46.61)	(64.19)	(25.21)	(36.82)	(21.56)	
Haryana	20.96	24.84	21.19	20.85	20.66	20.55	20.75	25.17	20.89	19.20	8.94
	(75.88)	(95.17)	(78.09)	(80.16)	(78.90)	(75.89)	(74.04)	(86.58)	(73.55)	(64.26)	
Himachal Pradesh	NE	2.39	-1.53	1.05	-3.78	-4.08	-3.61	-5.16	-10.21	1.42	151.08
	NE	(9.16)	(-5.65)	(4.05)	(-14.43)	(-15.06)	(-12.89)	(-17.75)	(-35.97)	(4.77)	

State	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	C.V. (%)
Jammu & Kashmir	NE	NE	NE	NE	NE	3.16	-6.80	2.62	-1.11	0.98	1752.91
	NE	NE	NE	NE	NE	(11.67)	(-24.27)	(9.01)	(-3.93)	(3.29)	
Jharkhand	8.84	NE	12.92	18.31	16.24	-11.67	10.02	9.33	7.19	-6.00	136.63
	(32.00)	NE	(47.61)	(70.40)	(62.02)	(-43.09)	(35.75)	(32.09)	(25.31)	(-20.06)	
Karnataka	13.95	9.70	8.87	10.43	11.78	9.04	12.18	11.23	9.16	9.62	15.67
	(50.50)	(37.16)	(32.69)	(40.11)	(44.99)	(33.39)	(43.46)	(38.63)	(32.24)	(32.20)	
Madhya Pradesh	-1.07	12.57	3.92	16.30	-0.90	0.40	11.02	9.82	7.21	12.22	87.14
	(-3.88)	(48.16)	(14.44)	(62.67)	(-3.43)	(1.48)	(39.32)	(33.78)	(25.38)	(40.90)	
Maharashtra	2.83	-0.93	9.83	14.95	9.12	5.46	8.40	-2.01	-0.52	4.88	105.34
	(10.24)	(-3.56)	(36.22)	(57.48)	(34.83)	(20.17)	(29.97)	(-6.92)	(-1.85)	(16.34)	
Punjab	20.93	19.49	24.34	18.56	18.26	NE	21.01	21.39	19.13	19.06	9.43
	(75.77)	(74.67)	(89.70)	(71.36)	(69.74)	NE	(74.97)	(73.57)	(67.36)	(63.79)	
Rajasthan	32.28	10.81	6.45	17.90	13.10	16.45	14.23	12.39	14.08	14.62	44.38
	(116.87)	(41.42)	(23.77)	(68.82)	(50.03)	(60.75)	(50.77)	(42.62)	(49.57)	(48.93)	
Tamil Nadu	NE	8.29	-3.47	-1.40	-2.60	1.86	-0.93	2.13	2.72	6.88	272.11
	NE	(31.76)	(-12.80)	(-5.36)	(-9.92)	(6.87)	(-3.33)	(7.32)	(9.56)	(23.03)	
Uttar Pradesh	13.55	14.71	13.95	18.02	19.40	19.69	18.10	16.80	14.30	15.11	14.19
	(49.05)	(56.36)	(51.41)	(69.28)	(74.09)	(72.72)	(64.58)	(57.79)	(50.35)	(50.57)	
Uttarakhand	17.52	11.18	3.58	13.57	1.14	5.40	6.53	2.87	3.19	3.72	78.58
	(63.43)	(42.84)	(13.19)	(52.18)	(4.36)	(19.94)	(23.30)	(9.87)	(11.22)	(12.46)	
West Bengal	-8.23	-10.72	10.95	-6.64	3.03	NE	-0.04	NE	-0.52	-9.29	276.41
	(-29.80)	(-41.07)	(40.35)	(-25.51)	(11.58)	NE	(-0.15)	NE	(-1.85)	(-31.07)	
India	11.08	8.59	9.97	11.64	8.49	5.84	8.27	9.40	7.01	7.91	20.06
	(40.10)	(32.93)	(36.76)	(44.74)	(32.40)	(21.57)	(29.50)	(32.34)	(24.70)	(26.45)	

Note: NE indicates the non-estimation of yield gap due to non-availability of data and figures within parentheses indicate the corresponding percentage of yield gap.

YG_A indicated that the wheat productivity could have been increased by 8.82 q/ha during the decade (Table 6). The YG_A ranged from as high as 11.64 q/ha (2004-05) to as low as 5.84 q/ha (2006-07) following a skewed pattern. It is as high as 3301 per cent in Assam and as low as 9 per cent in Haryana. The present analysis indicated that many wheat producing states have immense potential to bridge the existing yield gaps driving the nation to be in a more commendable position in terms of productivity.

3.3 Estimated additional production from average yield gaps: In Table 7 furnishes the quantity of additional wheat that would have been produced during the decade by bridging the existing YG_A between average demonstration yield and national yield. The additional wheat production (yield gap X proportion of area under irrigated wheat) indicated that the country would have produced wheat ranging from 14.75 to 25.50mt during the study period. However, a skewed distribution was observed in the yield gap over years. In terms of monetary value, the additional wheat production would have fetched a revenue generation ranging from Indian National Rupee (INR) 103250 to 238200 million to the government exchequer.

Table 7. Estimated additional production and its monetary value during 2001-02 to 2010-11

Year	National average FLD yield (kg/ha)	National average yield (kg/ha)	YG_A (kg/ha)	Area (mha)	Proportion of area irrigated (%)	Estimated additional production (mt)	Support price (INR/tonne)	Value of additional production (million INR)
2001-02	3870	2762	1108	26.34	87.40	25.50	6100	155550
2002-03	3469	2610	859	25.20	88.00	19.06	6200	118172
2003-04	3711	2713	997	26.60	88.40	23.45	6200	145390
2004-05	3766	2602	1164	26.38	89.40	27.45	6300	172935
2005-06	3467	2619	849	26.48	89.60	20.13	6400	128832
2006-07	3292	2708	584	27.99	90.20	14.75	7000	103250

Year	National average FLD yield (kg/ha)	National average yield (kg/ha)	YG_A (kg/ha)	Area (mha)	Proportion of area irrigated (%)	Estimated additional production (mt)	Support price (INR/tonne)	Value of additional production (million INR)
2007-08	3629	2802	827	28.03	90.90	21.06	8500	179010
2008-09	3847	2907	940	27.75	91.30	23.82	10000	238200
2009-10	3541	2839	701	28.46	91.30*	18.23	11000	200530
2010-11	3779	2989	791	29.07	91.30*	20.98	11200	234976

*Note: * Wheat area under irrigation pertains to 2008-09.*

3.4 Production constraints and research priorities: Yield gap across states indicated that low yield in many places were due to the location specific constraints. Hence, an attempt has been made to list out the state wise serious and consistent constraints in wheat production based on the scoring technique (Table 8) and prioritize research accordingly (Table 9). From the Table 8 it is clear that many of the constraints were bound to be same across India but with different magnitudes. Imbalance in fertiliser application, inefficient and poor water management, inadequate use of manures, incidence of pests and diseases were found to be most common production constraints. Identification and listing of these constraints will give a clue to the wheat researchers and policy makers to formulate new or reset research priorities for additional wheat production by bridging the existing yield gaps. Research should reflect consideration of field constraints in development of varieties. Yield variability can be minimised by optimum fertilizer use and irrigation coupled with favourable climate (Nathaniel *et al.*, 2012). Farmers should be provided with location specific improved technologies and information to bridge the yield gap. Apart from technological innovations and interventions, investment on agricultural R&D should be increased rather than slipping into a technological orphanage (Chadha *et al.*, 2013).

Table 8. State wise identified serious and consistent production constraints between 2001-02 and 2010-11

States	Constraints
Assam	Leaf blight, aphids, bathua (*Chenopodium album*), water stress, rodents, birds, termite, poor quality fertilizers, low plant population, poor quality seed and late sowing.
Bihar	*Phalaris minor,* water logging, late sowing, poor quality seed, bathua, zinc deficiency, wild oat, low plant population, motha (*Cyprus rotundus*), water stress, aphid, poor quality fertilizers, poor quality chemicals, aphid, rodents, termite, hot wind with high velocity during milking stage and stem borer.
Chhattisgarh	Late sowing, poor quality chemicals, rodents, water stress, stem borer, aphid, bathua, zinc deficiency, poor quality seed, termite, motha, lodging, leaf blight, loose smut, *Phalaris minor,* poor quality fertilizer, wild oat (*Avena sativa*), termite, low plant population, grain discoloration, brown rust, late sowing, high temperature and birds.
Delhi	*Phalaris minor*, bathua, wild oat, zinc deficiency, poor quality seed, poor quality fertilizer, poor quality chemicals, termite and rodents, water stress and brackish water.
Gujarat	Water stress, rodents, stem borer, termite, lodging, bathua, grain discoloration, motha, abnormal climatic conditions, zinc deficiency, late sowing, poor quality seed, low plant population, brackish water, *Phalaris minor,* loose smut, birds, wild oat and aphid.
Haryana	*Phalaris minor*, yellow rust, aphid, termite, powdery mildew, aphid, heat stress, shriveled grain, wild oat, loose smut, lodging, bathua, stem borer, termite, motha, brackish water, zinc deficiency,high temperature and late sowing.
Himachal Pradesh	Yellow rust, late sowing, wild oat, aphid, bathua, Zn deficiency, low temperature, water stress, non-availability of fertilizer, low plant population, *Phalaris minor*, powdery mildew, loose smut, rodents, birds and grain discoloration.
Jammu and Kashmir	Yellow rust, late sowing, water stress, loose smut, low plant population, wild oat, birds, rodents, aphid, *Phalaris minor*, bathua, zinc deficiency, poor quality chemicals, lodging, erratic power supply, non-availability of fertilizers, stem borer and termite
Jharkhand	Motha, bathua, water stress, late sowing, rodents, birds, poor quality seed, poor quality fertilizer, poor quality chemicals, zinc deficiency, *Phalaris minor*, wild oat, aphid, low plant population, lodging, loose smut, termite and leaf blight.

States	Constraints
Madhya Pradesh	Water stress, late sowing, poor quality seed, bathua, termite, lodging, rodents and water logging.
Punjab	*Phalaris minor*, yellow rust, aphid, termite, wild oat, motha, rodents, bathua, high temperature at maturity, erratic power supply, Karnal bunt, water stress, poor quality seeds, leaf blight, late sowing in cotton belt, Mn deficiency, lodging and water logging.
Rajasthan	Water stress, zinc deficiency, poor quality seed, late sowing, lodging, poor quality fertilizer, low plant population, *Phalaris minor*, wild oat, termite, termite, high temperature, temperature, rodents, leaf blight, birds, poor quality seeds, motha, brackish water and high seed rate.
Uttar Pradesh	Late sowing, poor quality chemicals, low plant population, broadcasting, poor quality seeds, motha (*Cyprus rotundus*), bathua, rodents, brown rust, loose smut, water stress, nematode, Zn deficiency, wild oat, *Phalaris minor*, leaf blight, lodging and termite.
Uttarakhand	Yellow rust, water stress, use of local varieties, imbalance fertilization, low fertilizer use, low temperature, poor quality of inputs, weeds (*Cyprus rotundus*, *Phalaris minor, Avena sativa* and *Chenopodium album*), late sowing, aphid, zinc deficiency and low plant population.
West Bengal	Leaf blight, grain discoloration, termite, motha, bathua, water stress, late sowing, stem borer, poor quality chemicals, poor quality of seed, lodging, low plant population and rodents.

Table 9. Research methodologies identified for major constraints in wheat

Production Constraints	Methods of Research
Yellow rust, leaf blight, aphids, termite, poor quality seed, Karnal bunt, stem borer, loose smut, brown rust, powdery mildew and nematodes	Biotechnology, conventional breeding, chemical and cultural method
Low plant population, birds, brackish water and high seed rate, erratic power supply, abnormal climatic conditions, water logging late sowing in cotton belt, hot wind with high velocity during milking stage, broadcasting, non-availability of fertilizers and use of local varieties	Cultural method
Grain discoloration and shriveled grain	Biotechnology and conventional breeding
Water stress, lodging, high temperature, high temperature at maturity and heat stress	Biotechnology, conventional breeding and cultural method
Phalaris minor, motha, zinc and manganese deficiency, wild oat and bathua	Chemical and Cultural
Poor quality chemicals and fertilizer	Chemical formulations
Late sowing	Conventional breeding and cultural method

Temporal and spatial yield gaps have been quantified and the analysis indicated that the country would have produced additional wheat ranging from 14.75 to 25.50 mt. Constraints across wheat growing states need immediate attention of policy makers and wheat scientists to enhance the wheat production. The study also suggests some research methodologies to bridge the existing yield gaps. Convergence in yield gaps shows that the maximum realizable yield of the potential has almost been achieved in the resourceful and early innovator states like Punjab and Haryana. The strategy for this region is to break the yield barrier by harnessing the potential of cutting edge sciences, cost cutting by optimal use of resources. This requires the integration of scientists working on conventional breeding coupled with biotechnological tools and natural resource management. In intensive cropping areas, legumes should be introduced in the cropping system to trade-off the soil fatigue. For areas with marginal soil condition, researchers should focus on developing a variety for low input conditions. Among the prioritized research activities, conventional breeding coupled with biotechnological tools followed by cultural methods and discovery of new formulation of plant protection chemicals emerge to be a preferred method in solving a majority of the production constraints. Nevertheless, extension services to increase the adoption of improved varieties and to disseminate contingent information of plant protection and other advisories related to soil heath, climate becomes crucial to bridge the existing yield gap. Clearly, the future allocation of research resources must be inclined more towards crop improvement and resource management coupled with additional investment on extension services.

Acknowledgements

The authors submit their due acknowledgements for all the coordinating centers in data collection and reporting.

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