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Wheat Production and Sustainability in Punjab: Growth and Varietal Diversity[†]

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Rice and wheat have come to contribute around three-fourth of India's foodgrains production in 2000, up from just one-half in 1950; with the foodgrains production itself having increased by four times from 50 million tonnes in 1950 to 200 million tonnes in 2000. The agricultural and rural development in India has passed through a policy design revolving around the food security of the country and of the individual households (Bhalla and Singh, 1997). And rice - wheat in this context has assumed greater significance. So much so, some regions little known for rice (like Punjab) and/or wheat (like West Bengal) were being applauded from time to time, for having excelled some stipulated targets in the production of these foodgrains. But the growth of such crops pushed beyond the capacity of natural resources of soil and water (groundwater) to sustain the growth levels engulfed the scenario with issues of sustainability. The pollution of atmosphere and underground water with extensive use of chemicals, degrading quality of produce, underground water going down leading to increasing costs for going deeper for water and environmental pollution aggravated with the burning of crop residues, etc. (Singh and Kalra, 2002). The over-riding concern of day is: whether the rice-wheat based cropping system is sustainable. Little wonder, the green revolution, so successfully achieved and lauded till some decade or so earlier, is being now argued that it was "not the green revolution" but only the "grain revolution". The remarkable success story of growth in grain production is bearing the burden of high, rather excessive, increase in the cost of production in terms of financial, social, economic and natural resource exploitation. Since the mid-1980s, there have been high-powered committees, discussions, conferences and policy dialogues on how to contain the situation. This paper examines the following issues: (i) the temporal changes in the rates of growth of area, productivity and production of wheat. (ii) the characteristics of dynamics of wheat production system and economies in relation to farm size. (iii) the adoption of different technology practices over time and their impact on the productivity of rice and wheat. Does it offer any scope for further rationalisation?, (iv) the varietal development, adoption and diversity pattern over time. Does the diversity have any

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explanation for productivity improvements? And, (v) the environmental implications of wheat expansion beyond certain limits? What are these limits?

The sources of data include the secondary sources on aggregate area, production and productivity in the State[1] as well as the household data from primary sources. The cost of cultivation data collected under the scheme, "Comprehensive Scheme for Cost of Cultivation of Principal Crops in Punjab" was analysed for 1985-86 and 1995-96. These data are collected from 300 farmers in 30 cluster villages, 10 farmers from each cluster, i.e., 2 farmers from each of the five farm size groups in each cluster by cost accounting method. In addition we also had the access to the plot wise data under the crop cutting experiments, about 2,000 every year for wheat, which were used for enlisting the details of adoption, yield levels and diversity in terms of different varieties over time along with some associated characteristics. Finally, another additional survey was also conducted in 1999 to investigate the issues pertinent to sustainability of natural resources and environmental concerns.

Growth Rates of Area, Production and Productivity of Wheat

Wheat has been in the news in Punjab for a long time in history.[2] The epic of "golden grains", signifying the country as "golden sparrow" might have emerged from this region. Little wonder the pride of agricultural development in Punjab revolves more around the development and hence production of wheat than any other crop or enterprise. Its productivity increased by more than five times in five decades, from 901 kgs per ha in 1950-51 to 4,696 kgs per ha in 1999-2000 (Table 1). The increase was consistent, continuous and significant. The area under wheat almost increased by three times in the first three decades with only little further potential/actual increase in area thereafter. It crossed 3 million (m) ha in 1982-83 and was 3.388 mha in 1999-2000. And the total production increased by fifteen times in fifty years. Wheat contributed more than 60 per cent of the States' foodgrains production, crossing even 70 per cent in some years and the minimum not going below 58 per cent. Between 1950-51 and 1999-2000, the point-to-point growth rate of area, yield and production of wheat has been 2.25, 3.43 and 5.46 per cent per annum respectively, which as a long-term growth rate is a significant historical achievement in itself.

With the high-yielding varieties released since the mid-sixties, the graph of wheat showed growth rates of 5.25 per cent of area, 6.82 per cent of yield and 12.42 per cent of production during the 1960s, which were more than double of those during the 1950s. It is significant to note that the growth rate of production of wheat during any decade has been more than 3 per cent in spite of the fact that the growth rate of area had come down during the successive decades to 1.87 per cent during 1970s, to 1.53 per cent in 1980s and to almost nil at 0.38 per cent in 1990s. The growth rate of productivity after having achieved a double jump in 1960s over 1950s, declined to 1.27 per cent in 1970s. It is important that it recovered thereafter again to 3.13 per cent in the 1980s and has been 2.64 per cent even in the 1990s, when the growth of

productivity in other crops in Punjab has been very low or even negative in some cases (Government of Punjab, 2002; Singh, 2003).

TABLE 1. IMPORTANT STATISTICS RELATING TO WHEAT IN PUNJAB, 1971-72 TO 1997-98

Year	Area '000 ha	Per cent of net area sown	Product-ion '000 tonnes	Per cent of State's foodgrain production	Yield State data (kgs/ha)	Yield Cost of cultivat-ion data (kgs/ha)	Cost of product-ion (Rs./qtl)	MSP (Rs./qtl)	TFP 1971-72 =100
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1971-72	2,336	57.31	5,618	70.89	2,406	2,463	59.71	-	
1972-73	2,404	58.84	5,368	69.79	2,233	2,260	183.08	-	
1973-74	2,338	56.68	5,181	67.47	2,216	2,487	74.34	-	
1974-75	2,207	53.93	5,286	59.88	2,395	2,780	87.86	-	
1975-76	2,439	58.66	5,788	61.98	2,373	2,311	99.45	-	
1976-77	2,630	63.11	6,392	61.72	2,430	2,274	101.39	-	
1977-78	2,617	62.74	6,642	56.89	2,538	2,661	107.57	110	
1978-79	2,739	65.55	7,439	62.48	2,516	2,740	181.45	112	
1979-80	2,813	67.26	7,868	66.07	2,797	2,791	102.88	115	
1980-81	2,811	67.07	7,674	57.67	2,730	2,528	124.78	117	
1981-82	2,914	72.69	8,544	71.67	2,932	3,075	118.77	130	129.39
1982-83	3,052	72.63	9,168	68.84	3,004	3,075	125.19	142	128.19
1983-84	3,124	74.17	9,422	66.48	3,015	2,949	137.47	151	131.90
1984-85	3,094	73.86	10,176	68.83	3,289	3,345	136.33	152	134.45
1985-86	3,112	74.15	10,988	68.26	3,531	3,560	129.29	157	151.53
1986-87	3,185	75.80	9,447	58.26	2,966	3,032	151.49	162	132.66
1987-88	3,131	75.32	11,084	64.85	3,540	3,414	139.95	166	160.09
1988-89	3,152	75.08	11,578	67.85	3,668	3,651	150.01	173	148.56
1989-90	3,247	77.44	11,666	60.72	3,593	3,693	164.24	183	140.05
1990-91	3,273	77.60	12,159	63.27	3,715	3,622	190.79	215	140.45
1991-92	3,237	76.80	12,309	62.70	3,803	3,834	210.41	225	136.67
1992-93	3,283	79.32	12,399	61.82	3,770	3,708	250.72	250	132.62
1993-94	3,334	79.12	13,374	61.99	4,011	4,394	275.24	330	118.01
1994-95	3,311	78.65	13,542	62.23	4,090	3,941	298.68	350	137.11
1995-96	3,257	78.33	12,738	64.10	3,884	3,606	342.83	360	132.55
1996-97	3,230	76.29	13,680	63.44	4,235	-	-	380	
1997-98	3,301	77.38	12,751	60.26	3,853	-	-	475	
1998-99	3,278	77.99	14,192	62.54	4,332	-	-	510	
1999-2000	3,388	79.96	15,910	63.12	4,696	-	-	550	
Growth rates (per cent)									
1950s	2.10		5.46		3.28				
1960s	5.25		12.42		6.82				
1970s	1.87		3.17		1.27				
1980s	1.53		4.71		3.13				
1990s	0.38		3.03		2.64				
Overall	2.25		5.46		3.43				

Source: Statistical Abstracts of Punjab (various issues).
For TFP, Bala (2000).
Government of India, *Reports of the Commission for Agricultural Costs and Prices* (various issues).

Thus wheat is probably the only major crop in Punjab that has a clearly ascending graph of productivity all throughout since 1950 and even during the 1990s notwithstanding the small decline in the two bad weather years of 1994-95 and 1997-

98. Thus it is still defying the plateauing in spite of the area expansion having become almost negligible during the latest decade. In fact, during the season (October to April, i.e., winter - known locally as *rabi season*) the wheat is grown in Punjab, it is the only major crop. It occupied as much as 74 per cent of *rabi* cropped area in 1970-71 which increased to 86 per cent in 1999-2000. Thus during the winter season, what one sees in Punjab fields is only the wheat crop with small stretches here and there under other crops like fodders, sugarcane, etc. The additional area under wheat has mainly come from the increase in the cropping intensity, the area under other *rabi* crops almost remaining constant between 1970-71 and 1990-91. But during the 1990s, there had been substitution even of other *rabi* crops which in proportionate terms had been reduced to 20 per cent in 1990-91; the area under all these other *rabi* crops put together was 826 thousand ha in 1970–71, 837 thousand ha in 1990-91 and declined to 654 thousand ha in 1998-99. Although, as would be shown later, wheat as such is not a major problem in terms of natural resources use, but the over extension in the 1990s, though to a limited extent, still needs to be diversified back to other crops.

Economics of Wheat in Relation to Farm Size

This section is based on the data from the "Comprehensive Scheme on Cost of Cultivation of Principal Crops in Punjab" for 1985-86 and 1995-96. It is important to note that the data were not for the same farms but similar farms, because the sample is redrawn following the same procedure, after every three years. Since rice-wheat is the most predominant farming system in the area, this analysis was also restricted to the data for this system. There are five farm size groups and although there were 30 cluster villages in the sample with two farmers in each farm size group from each cluster, the selected sub-sample for rice-wheat system was less than 60 farmers in each farm size group. Also, it may be noted that although all the area under rice was not followed by wheat, in our sample, both for 1985-86 and 1995-96, all the farmers who had grown rice had also grown wheat. The reverse was not true.

Although on an average, the average wheat yield on the largest farm size group was a little higher than on the smallest farm size group, there was no association of yield with farm size in 1985-86 (Table 2). But during 1995-96, leaving aside the smallest farm size group, there was a positive association with farm size. The yield of wheat on the farm size group II was 3,598 kgs per ha, which increased to 3,823 kgs per ha on the largest farm size group V. Thus the largest farm size group V had yields of wheat higher by 225 kgs per ha than the small farm size group. The coefficient of variation of yield of wheat was just above 20 per cent on different farm size groups in 1985-86, it had declined over time, particularly on the large three farm size groups where it was even less than 16 per cent during 1995-96. It shows the fairly uniform achievement of technology potentials in the case of wheat across different farm size groups. It also means the constraints to efficiency have to be found more in terms of

the structure and level of inputs use rather than the achievement of outputs in the case of wheat in the rice-wheat system.

TABLE 2. ECONOMICS OF WHEAT CULTIVATION IN RELATION TO FARM SIZE OVER TIME

Item (1)	Farm size group (2)	1985-86 (3)	1995-96 (4)	Percentage increase (5)
Yield (kgs / ha)	I	3,702 (20.7)	3,752 (20.6)	+1.4
	II	3,742 (19.7)	3,598 (18.2)	-3.8
	III	3,645 (23.9)	3,640 (15.4)	-0.1
	IV	3,715 (20.2)	3,755 (15.7)	+1.1
	V	3,820 (20.3)	3,823 (15.9)	+0.1
	Overall	3,728	3,722	0
Gross returns (Rs.)	I	7,141	16,782	+135
	II	7,195	16,411	+128
	III	6,967	16,448	+136
	IV	7,096	16,739	+136
	V	7,150	16,632	+133
	Overall	7,107	16,599	+134
Gross margins	I	3,910	9,357	+139
	II	3,782	8,625	+128
	III	3,791	8,614	+127
	IV	3,876	9,101	+135
	V	4,129	9,412	+128
	Overall	3,903	9,028	+131
Net returns (Rs.)	I	1,397	2,699	+93
	II	1,257	1,576	+25
	III	1,289	1,606	+25
	IV	1,483	1,462	-1.5
	V	1,687	2,285	+35
	Overall	1,435	1,910	+33
Increase in size Group V over Group II* (absolute)	Yield	78	225	
	Gross returns	-45	221	
	Gross margins	347	787	
	Net returns	430	709	
Increase in size Group V over Group II (per cent)	Yield	2.1	6.3	
	Gross returns	-0.4	1.3	
	Gross margins	9.1	9.1	
	Net returns	34.2	45.0	
Important factor inputs	Labour (man-hrs)	450	341	-24
	Machine expenses (Rs./ha)	677	1,554	+129
	Operational costs	3,204	7,571	+136
	Fixed costs (Rs./ha)	2,468	7,119	+188
	Total costs (Rs./ha)	5,672	14,690	+159
	Cost C2 (Rs./qtl)	133	341	+155
Factor shares	Labour	32.34	35.92	+ 11
	Machinery	25.26	23.10	- 9
	Fertilisers	32.28	30.79	- 5
	Weedicides	2.68	5.26	+ 96
	Irrigation	7.35	4.93	- 33

Source: Compiled from the data available from the scheme, "Comprehensive Scheme for Cost of Cultivation of Principal Crops in Punjab".

The relationship of gross returns with farm size was also the same as in case of yield. However, the small farmers, have abundant labour, and thus are better placed in harvesting (not burning) the by-products of both rice and wheat. Thus the little yield advantage of the largest farm size group of 3 per cent in 1985-86 and 2 per cent in 1995-96 was nullified, albeit even more than that in 1995-96, by the smallest farm size group earning more from the by-product.

The cost efficiency in relation to farm size was measured in terms of operational costs, fixed costs and total costs per ha as well as the overall Cost C_2 per qtl. on different farm size groups. During 1985-86, there was no association of efficiency with farm size though the cost on the largest farm size group was distinctly less than on other farm size groups. And in 1995-96, the operational costs first increased with the increase in farm size and then declined as farm size increased finally ending up with the largest farm size group incurring lower costs than any other farm size group. The gross margins per ha also exhibited positive association with farm size, again with the smallest farm size group excluded. Thus the gross margins on the largest farm size group were higher by 9.2 per cent, both in 1985-86 and 1995-96 than the farm size, which had the lowest gross margins, that was farm size group II in 1985-86 and farm size group III in 1995-96. Thus there were no particular uniform trends of various efficiency parameters as associated with farm size and differences between the large and small farmers were very narrow, which means the technology adoption and efficiency of production, in relation to farm size are much more stable and improved for wheat. This also means that the inefficient farmers are dispersed in all farm size groups, who need to be identified for more directed extension services input as the future source of growth in wheat.

In terms of factor shares, labour continues to be the most important factor at a little above 35 per cent in the case of wheat. The share of machinery remained more than 20 per cent. This is a reflection of the fact that mechanisation of Punjab agriculture had already reached high levels by mid-1980s, when the over-capitalisation of Punjab farms had become the pep talk. Fertilisers share was above 30 per cent. The change in factor shares is very contrasting. The share of labour increased, reflecting the relatively higher increase in wages. In case of machinery, it was the opposite. Its share declined by 9 per cent. The share of fertiliser decreased and that of weedicides increased. The share of irrigation declined significantly. It shows that the structural dynamics of farmers in Punjab has been adjusting significantly even in as short a period as one decade (Singh and Jain, 2002).

TECHNOLOGY ADOPTION AND WHEAT YIELDS

This section is based on the crop cut experiments data, which are extensively conducted, basically to estimate the average yield at 5 per cent level of significance at the district level and at 1 per cent level of significance at the state level. Some additional information is also collected about the farmer, farm and the plot where the crop-cutting experiments happen to come about randomly. There were more than

2000 crop-cutting experiments in Punjab for wheat during different years, which were analysed to identify the important determinants of wheat yields in Punjab.

Yield of Wheat in Rice - Wheat vis-à-vis Other Cropping Systems

The variety of seed and fertilisers are the two most important technological inputs, which determine the yield of the crop. Different cropping systems demand some other adjustments for maximising the yield and returns. The yield of wheat in rice-wheat system was found to be the highest as compared with other cropping systems for the most dominant variety, which was WL 711 in 1980-81, HD 2329 in 1990-91 and PBW 343 in 1998-99 (Table 3). In 1980-81, it was higher by 3.1 per cent than the maize-wheat system, which was the next highest yielder. The use of fertilisers was the same in the two systems. In 1990-91, fallow-wheat system was the per cent. This was achieved with a higher fertiliser use of 13 per cent of N, 6 per cent of P and 11 per cent as overall. In 1998-99 again, fallow-wheat was the next highest yielder when the rice-wheat system had a yield advantage of 5.8 per cent with exactly the same dose of fertilisers used in the two systems. Thus it could be concluded that the rice-wheat system, which is the most dominant system in Punjab, is also the best yielder for wheat.

TABLE 3. YIELD OF WHEAT IN RICE-WHEAT VIS-À-VIS OTHER CROPPING SYSTEMS 1980-81, 1990-91 AND 1998-99

Cropping system	Number of observations	Yield (kgs/ha)	N (kgs/ha)	P (kgs/ha)	N+P+K (kgs/ha)
(1)	(2)	(3)	(4)	(5)	(6)
Wheat variety WL 711 in 1980-81					
Rice – Wheat	530	2,997	107	54	164
		(30)	(35)	(56)	(35)
Maize – Wheat	140	2,906	105	56	165
		(33)	(39)	(82)	(43)
Cotton – Wheat	314	2,858	100	54	156
		(24)	(36)	(39)	(31)
Fallow – Wheat	240	2,763	94	50	146
		(34)	(44)	(60)	(42)
Fodder – Wheat	98	2,679	98	48	149
		(36)	(46)	(69)	(46)
Bajra - Wheat	34	2,671	95	53	150
		(31)	(40)	(48)	(39)
Wheat variety HD 2329 in 1990-91					
Rice - Wheat	1,178	3,983	138	63	201
		(19)	(24)	(26)	(20)
Fallow - Wheat	88	3,654	122	59	181
		(20)	(30)	(21)	(23)
Fodder - Wheat	62	3,469	131	62	193
		(27)	(31)	(38)	(30)
Maize - Wheat	77	3,395	99	48	149
		(25)	(42)	(48)	(36)
Cotton - Wheat	371	3,390	130	59	190
		(19)	(19)	(18)	(16)

(Contd.)

TABLE 3. *(Concld.)*

Cropping system	Number of observations	Yield (kgs/ha)	N (kgs/ha)	P (kgs/ha)	N+P+K (kgs/ha)
(1)	(2)	(3)	(4)	(5)	(6)
Wheat variety PBW 343 in 1998-99					
Rice - Wheat	1,393	4,487 (29)	56	24	80
Fallow - Wheat	46	4,242	56	24	80
Cotton - Wheat	224	4,187 (27)	53	23	76
Fodder - Wheat	58	4,092 (44)	51	22	73
Maize - Wheat	69	3,807 (69)	48	17	65

Source: Crop-cutting experiments data.
Note: Figures in parentheses are the coefficients of variation.

Sowing Time and Wheat Yields

In case of wheat, about 5 per cent area is sown by the end of October, which increased to 12 per cent in 1998-99 (Table 4). Since, 1995-96, the average yield of wheat sown during the month of October had been the highest. The maximum area is sown in November. The yield of wheat sown in the first fortnight of November had been higher than that sown in the second fortnight. The area sown in the first fortnight increased from about 28 per cent in the mid-eighties to 42 per cent by 1990-91, to 50 per cent in 1995-96 and further to 62 per cent in 1998-99. Correspondingly, the area sown in the second fortnight of November has come down from 50 per cent during mid-eighties to about one-third (33 per cent) by late 1990s. The more the delay in wheat sowing, lower the yield. Area sown in the first fortnight of December has come down from about 16 per cent in mid-1980s to about 5 per cent by late 1990s. About 3 per cent area during the last 5 years has been sown later than December 15. The area seems to be small but the yield disadvantage over the last five years on an average had been almost one tonne per ha.

On an average, the wheat yield for the second fortnight of November sown wheat was 223 kgs per ha less than that sown during the first fortnight of November. A fortnight later the yield drops down by another about 300 kgs per ha. And the yield of wheat sown during the next fortnight declines by another above 400 kgs per ha. Thus upto 1991-92, as much as 20 per cent area was sown after December which came down to 15 per cent during the next 3-4 years and has further declined to about 10 per cent. A one per cent increase in area to timely sown (i.e., to reduce area under late sown wheat) out of about 3.3 million ha, getting a yield advantage of more than 300 kgs per ha, priced at Rs. 600 per quintal means improving the farmers' income in Punjab annually by about Rs. 6 crores. This factor has contributed significantly to the mechanisation in Punjab. Upto 1992-93, less than 50 per cent wheat area was sown by the first fortnight of November (at best it was 48 per cent), which has increased to 57 per cent during the last five years. This 10 per cent increase in area to timely sown

situation means additional Rs. 60 crores per year that accounts for about 16 per cent of the tractors in Punjab,[3] which is almost about the number that has been added during the 1990s (Singh, 1998).

TABLE 4. EFFECT OF SOWING TIME ON YIELD OF WHEAT, 1984-85 TO 1998-99

(kgs/ ha)

Year	Up to 31st October	1-15th November	16-30th November	1-15th December	After 15th December
(1)	(2)	(3)	(4)	(5)	(6)
1984-85	-	2,628	3,336	2,938	2,782
		(28)	(50)	(16)	(6)
1985-86	-	3,649	3,607	3,335	3,088
		(28)	(50)	(17)	(5)
1986-87	-	3,136	3,009	2,638	2,491
		(34)	(47)	(15)	(4)
1987-88	-	3,764	3,616	3,146	2,742
		(42)	(38)	(13)	(7)
1998-89	3,657	3,877	3,736	3,396	3,055
	(5)	(35)	(39)	(14)	(7)
1989-90	3,455	3,747	3,596	3,244	2,985
	(5)	(45)	(35)	(10)	(8)
1990-91	3,575	3,931	3,736	3,261	2,915
	(3)	(42)	(31)	(10)	(6)
1991-92	3,792	4,015	3,820	3,454	3,189
	(4)	(44)	(32)	(12)	(8)
1992-93	3,846	3,958	3,747	3,393	3,259
	(5)	(43)	(32)	(12)	(3)
1993-94	4,146	4,121	4,017	3,573	3,210
	(6)	(7)	(33)	(10)	(4)
1994-95	4,203	4,256	3,994	3,893	3,606
	(5)	(46)	(36)	(8)	(5)
1995-96	4,012	4,004	3,830	3,536	3,011
	(4)	(50)	(36)	(7)	(3)
1996-97	4,502	4,372	4,108	3,698	3,620
	(7)	(48)	(34)	(8)	(3)
1997-98	4,093	4,002	3,768	3,521	3,072
	(8)	(46)	(35)	(7)	(1)
1998-99	4,499	4,390	4,208	3,775	3,057
	(12)	(62)	(21)	(4)	(1)
Average 1994-95 to 1998-99	4,262	4,205	3,982	3,685	3,273
	(7)	(50)	(33)	(7)	(3)

Source: Crop-cutting experiments.

Note: Figures in parentheses are percentage of area under crop/experiments.

Effect of Weedicides

The use of weedicides increased from 7 to 78 per cent during the period 1980-81 to 1992-93 and further to 83 per cent in 1998-99 (Table 5). The wheat yield with weedicides was 31 per cent higher in 1980-81 and 24 per cent higher in 1992-93. The yield advantage came down to 8 per cent only in 1998-99. This is due to the selective application of weedicides-where-needed-the-most principle followed by the farmers based on their long experience (Singh, 1998).

TABLE 5. YIELD OF WHEAT IN RESPONSE TO USE OF WEEDICIDES PUNJAB, 1980-81, 1992-93 AND 1998-99

Year	Particulars	Weedicide		Per cent yield advantage
		Used	Not used	
(1)	(2)	(3)	(4)	(5)
1980-81	Number of observations	125	1,569	
	Per cent area	7.38	92.62	
	Yield (kgs/ha)	3,458	2,790	23.94
		(22.91)	(30.80)	
1992-93	Number of observations	1,550	429	
	Per cent area	78.32	21.68	
	Yield (kgs/ha)	4,069	3,201	27.12
		(16.17)	(23.94)	
1998-99	Number of observations	1,829	383	
	Per cent area	82.69	17.31	
	Yield (kgs/ha)	4,385	4,054	8.16
		(13.72)	(18.05)	

Source: Crop-cutting experiments data.
Note: Figures in parentheses are the coefficients of variation.

Impact of Balanced Fertilisation on Wheat

About 10 per cent of the farmers were using nitrogen alone in 1984-85. They also used 12 kgs of nitrogen per ha less than those farmers who used P also, which on the average was 57 kgs per ha. The farmers using both N and P had a yield advantage of more than 10 per cent in that year, which was much more than the cost of fertilisers. Realising that, the farmers using N alone came down to 4 per cent in two years and has remained at about that level since then. The yield advantage of using both N and P had been around 22 per cent during most of the years (Table 6).

TABLE 6. ROLE OF BALANCE FERTILISER APPLICATION OVER TIME, WHEAT, 1984-85 TO 1998-99

Year	Nitrogeneous fertilisers alone		Nitrogeneous and phosphatic			Percentage increase in yield	No fertiliser
	Rate (kg/ha)	Average yield (kg/ha)	Rate (kg/ha)		Average yield (kg/ha)	due to better balanced fertiliser use	Average yield (kg/ha)
			N	P			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1984-85	90	3,090	102	57	3,404	10.2	1,337
		(10)			(87)		(3)
1985-86	80	2,970	116	60	3,613	21.6	2,209
		(6)			(92)		(2)
1986-87	77	2,649	120	60	2,997	13.1	2,445
		(4)			(94)		(2)
1987-88	85	2,834	116	58	3,592	26.7	1,697
		(4)			(94)		(2)
1988-89	77	3,053	129	59	3,739	22.5	1,905
		(4)			(94)		(2)
1989-90	118	3,017	138	60	3,628	20.2	2,005
		(5)			(94)		(1)
1990-91	92	3,072	130	63	3,767	22.6	1,922
		(4)			(95)		(1)

(Contd.)

TABLE 6. *(Concld.)*

Year	Nitrogeneous fertilisers alone		Nitrogeneous and phosphatic			Percentage increase in yield	No fertiliser
	Rate (kg/ha)	Average yield (kg/ha)	Rate (kg/ha)		Average yield (kg/ha)	due to better balanced fertiliser use	Average yield (kg/ha)
			N	P			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1991-92	90	3,159	138	64	3,841	21.6	2,572
		(4)			(94)		(2)
1992-93	93	3,194	131	59	3,818	19.5	2,134
		(6)			(93)		(1)
1993-94	107	3,298	136	62	4,046	22.7	2,254
		(4)			(95)		(1)
1994-95	84	3,426	436	60	4,187	22.2	2,573
		(4)			(95)		(1)
1995-96	90	3,138	134	59	3,922	24.9	2,857
		(4)			(95)		(1)
1996-97	83	3,489	136	59	4,260	22.1	2,417
		(4)			(96)		(0.5)
1997-98	87	3,218	139	59	3,914	21.6	2,974
		(3)			(97)		(0.3)
1998-99	94	3,116	137	59	4,385	40.7	2,166
		(4)			(96)		(0.3)

Source: Crop-cutting experiments.
Figures in parentheses are percentage of area under experiments.

Development and Adoption of High-Yielding Varieties

The history of adoption of the high-yielding varieties of wheat in Punjab shows that majority of the farmers, in general look for significant change in one or more of the following three factors in the new variety: (i) High yield potential of the new variety, (ii) Better grain quality and/or (iii) The better resistance to diseases and pests.

This section is also based on the crop-cutting experiments data for the period 1984-85 to 1998-99. Based on the three characteristics, viz., better yield, better grain quality and better resistance, the main landmarks of adoption of HYV wheat in Punjab can be encapsulated as given in the Box. It is interesting to note that the most promising/significant variety has been introduced afresh in the middle of the decade during each of the last four decades, reached the pinnacle of coverage and remained on the scene significantly for one decade and tapered off thereafter. Thus up to mid 1960s the varieties C 303 and C 306 with yield potential of 2.5 t/ha and excellent grain quality covered 70 per cent of the area under wheat. The jump in productivity is associated with the semi-dwarf wheats. Kalyan Sona and PV 18 with yield potential of 4.5 t/ha were released in 1966 and 1967 and dominated upto mid-1970s. In 1970-71, Kalyan Sona (K 227) alone covered 80 per cent of the wheat area. The susceptibility to rusts was increasing; in 1976 variety WL 711, which also had a better grain quality was released and it covered 73 per cent of wheat area in 1980-81.

Landmarks of HYVs of wheat and their peak adoption levels

Period/ year	Variety	peak area covered (per cent)	Main characteristics
Up to mid 60s	C303 / C306	80	Potential yield (PY) 2.5 t/ha
1966 to mid 70s	Kalyansona	80	PY: 4.5 t/ha
1967 to mid 70s	PV 18		Better grain quality
1976 to mid 80s	WL 711	80	Better resistance; PY: 4.5 t/ha
1985 to mid 90s	HD 2329	80	Better resistance; PY: 5 t/ha
1995 to date	PBW 343	86	Better resistance; PY: 5.5 t/ha

Again, the release of HD 2329 in 1985, which had better resistance than WL 711 and was also marginally better yielder, it replaced WL 711 and came to cover 85 per cent area in 1994-95. Lastly, the variety PBW 343, released in 1996 shot up in two years to cover 82 per cent area in 1998-99 and 86 per cent in 1999-2000, some surveys place it even at 89 per cent.

Thus the real landmark variety developed by Punjab Agricultural University in the 1990s for timely sown irrigated conditions is PBW 343. This bread wheat variety PBW 343 was identified by the All India Wheat Research Workers Workshop in 1994 and released for general cultivation in the entire North Western Plains Zone including Punjab in 1995. PBW 343 is the highest yielding variety in the country and has ranked first in All India Coordinated wheat varietal trials for eight consecutive years from 1991-92 onwards. This new plant type has a higher number of grains through either a higher number of heads/m^2 or through bigger heads, produce vigorous progenies, tiller profusely, have more surviving spikes, are robust in appearance, and keep their leaves healthy for a longer period. These lines keep their canopies cooler than the surrounding environment, show higher stomatal conductance, and are photosynthetically more efficient.

Durum wheat varieties, which have a better export market, released subsequently in Punjab have been maintaining the yield level. In fact, these durum wheats even outyielded bread wheat variety HD 2329 under favourable conditions. Although very good quality varieties of durum wheats are available and research is being done to improve further, but their large scale adoption is going to remain a question mark until export oriented marketing infrastructure is developed in the State which could offer premium price/profitability advantage and assured marketing because the domestic market for such wheats is too limited.

Varietal Distribution and Adoption

The variety wise area and average yield of wheat from 1970-71 to 1998-99 at the State level is given in Table 7. For the period 1970-71 to 1984-85, the information was analysed only for some selected years (1970-71, 1975-76 and 1980-81) from the original plot wise data. From 1984-85 onwards, the State level limited analysis was already available from the Directorate of Agriculture, Government of Punjab but more detailed analysis was also done for 1985-86, 1990-91 and 1998-99.

TABLE 7. VARIETY WISE AREA AND AVERAGE YIELD OF WHEAT, 1970-71 TO 1998-99

Variety	Year of release	1970-71	1975-76	1980-81	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
C 164			1,814							
			(0.1)							
C 273		1,533	1,250	1,636						
		(2)	(1)	(0.25)						
C 306	1965	1,812	1,149	3,094						
		(1.2)	(1.4)	(0.15)						
C 591			1,610							
			(0.5)							
K 227	1967	2,311	2,189	2,505						
		(80.4)	(28)	(0.76)						
PV 18	1966	2,810	2,352	1,656						
		(2.6)	(11.8)	(0.05)						
UP 310			1,104							
			(0.1)							
WG 357	1971		2,255	2,441						
			(36.0)	(2.48)						
WG 377				2,407						
				(2.63)						
R.R.21	1968	3,007	2,322	1,994	2,313	2,425	-	2,559	-	-
		(0.15)	(5.3)	(2.12)	(2)	(2)		(1)		
W.L. 410				3,108						
				(4.05)						
W.L. 711	1976			2,919	3,409	3,634	3,035	3,623	3,665	3,771
				(72.80)	(54)	(53)	(45)	(25)	(16)	(5)
H.D.2009	1976		3,975	2,729	3,349	3,688	2,959	3,299	3,456	3,434
			(0.2)	(4.36)	(7)	(4)	(8)	(6)	(4)	(3)
KSML 3	1977			1,695						
				(0.25)						
W.L.1562	1979			2,848	3,490	3,509	2,901	3,344	3,409	3,331
				(0.41)	(22)	(20)	(15)	(12)	(7)	(4)

(Contd.)

TABLE 7. (*Contd.*)

Variety	Year of release	1970-71	1975-76	1980-81	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
H.D.2285	1982				-	-	-	-	3,367 (4)	3328 (1)
H.D. 2329	1985				-	-	* (10)	* (44)	3,844 (58)	3672 (76)
P.B.W.34	1985				-	-	-	-	3,734 (1)	3439 (1)
P.B.W.120	1985				-	-	-	-	3,692 (1)	-
P.B.W.138	1985				-	-	-	-	-	-
P.B.W.154	1987				-	-	-	-	3,813 (2)	3473 (3)
PBW 343	1994				-	-	-	-	-	-
P.B.W.222	1990				-	-	-	-	-	-
P.B.W.542	1993				-	-	-	-	-	-
DWL.5023				4,730 (0.05)	3,134 (1)	4,011 (1)	-	-	-	-
S. 306				631 (0.05)						
S. 308		2,425 (2.9)	2,210 (8.3)	1,991 (10.27)	2,533 (4)	2,584 (6)	2,187 (6)	2,413 (4)	2,615 (3)	2,401 (1)
H.D.1553			3,405 (0.3)	2,756 (1.45)	2,976 (1)	2,858 (1)	2,991 (1)	-	-	-
Other HYV				2,008 (0.35)	3,188 (8)	3,714 (13)	3,109 (13)	3,508 (6)	3,427 (5)	2,985 (5)
Local variety		1,254 (10.8)	1,464 (7.1)	2,089 (1.35)	1,836 (1)	-	2,265 (1)	2,457 (2)	2,205 (1)	2,380 (1)
S.3004					-	-	-	-	-	-

(Contd.)

TABLE 7. (*Contd.*)

Variety (1)	Year of release (2)	1990-91 (12)	1991-92 (13)	1992-93 (14)	1993-94 (15)	1994-95 (16)	1995-96 (17)	1996-97 (18)	1997-98 (19)	1998-99 (20)
C 164										
C 273										
C 306	1965									
C 591										
K 227	1967									
PV 18	1966									
UP 310										
WG 357	1971									
WG 377										
R.R.21	1968	-	-	-	-	-	-	-	-	-
W.L. 410										
W.L. 711	1976	3,923 (3)	3,751 (3)	4,149 (1)	4,313 (1)	4,326 (1)	4,006 (1)	-	-	-
H.D.2009	1976	3,105 (2)	3,372 (2)	-	3,848 (1)	-	-	-	-	-
KSML 3	1977									
W.L.1562	1979	3,512 (2)	3,339 (2)	3,229 (1)	3,061 (1)	3,492 (1)	3,554 (1)	3,891 (1)	-	-
H.D.2285	1982	2,700 (2)	3,042 (2)	3,566 (2)	3,266 (1)	3,446 (1)	3,401 (1)	4,219 (1)	-	-
H.D. 2329	1985	3,789 (80)	3,883 (80)	3,797 (85)	4,043 (86)	4,137 (85)	3,904 (84)	4,216 (75)	3,708 (56)	4,047 (11)
P.B.W.34	1985	3,761 (2)	3,779 (1)	4,367 (1)	4,371 (2)	4,100 (2)	3,749 (2)	4,436 (2)	3,747 (1)	3,604 (0.4)
P.B.W.120	1985	-	-	-	-	-	-	-	-	-
P.B.W.138	1985	-	3,290 (2)	3,456 (2)	3,311 (1)	3,853 (1)	3,473 (1)	3,274 (1)	3,252 (1)	3,021 (1)
P.B.W.154	1987	3,725 (1)	3,589 (2)	3,798 (2)	3,680 (2)	3,659 (1)	2,954 (1)	3,764 (1)	-	-

(Contd.)

TABLE 7. (*Concld.*)

Variety	Year of release	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
(1)	(2)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
PBW 343	1994	-	-	-	-	-	-	4,770 (6)	4,219 (31)	4,443 (82)
P.B.W.222	1990	-	3,973 (2)	3,743 (1)	-	4,120 (1)	-	-	-	-
P.B.W.542	1993	-	-	-	-	4,528 (2)	4,237 (4)	4,382 (8)	3,916 (6)	4,157 (2)
DWL.5023		-	-	-	-	-	-	-	-	-
S. 306										
S. 308		2,229 (1)	2,255 (1)	2,076 (1)	3,488 (1)	-	-	-	-	--
H.D.1553		-	-	-	-	-	-	-	-	-
Other HYV		3,154 (4)	3,234 (3)	3,464 (3)	3,514 (2)	4,084 (2)	3,543 (3)	3,618 (4)	3,432 (4)	3,256 (3)
Local variety		2,959 (1)	2,347 (1)	2,734 (1)	2,782 (1)	3,027 (1)	-	-	-	2,149 (0.7)
S.3004		-	-	-	-	3,500 (2)	3,780 (2)	3,931 (1)	3,533 (1)	-

Source: Crop-cutting experiments.

Figures in parentheses are percentage of experiment which approximate percentage of area. (ii) In case a variety reappears, it is not taken as new variety.

* Variety was not officially released in Punjab although farmers had adopted it.

K 227 was the dominant variety in 1970-71 with an area coverage of 80 per cent and its original version PV 18 was only 3 per cent. In those days, it may be recalled that the field workers as well as the farmers were not very well conversant with the identification of the variety but this may not be too much off the mark. By 1975-76, K 227 and PV 18 varieties put together covered 40 per cent of the area, closely followed by WG 357 covering 36 per cent area. PV 18 was better yielder, but K 227 had better grain quality. WL 711 which was released in 1976 had better yield as well as better grain quality and by 1980-81, it covered 73 per cent area, K 227 and PV 18 were almost eliminated and quite a number of other varieties which were released after 1975 appeared on areas ranging from 2 to 4 per cent. The adoption pattern since 1984-85 is available for all the years and a more critical commentary can be attempted. Even in 1984-85, WL 711 variety dominated covering 54 per cent area. WL 1562 released in 1979 reached its mild peak of 22 per cent area in 1984-85. HD 2329 was released in 1985 but was not officially released in Punjab till 1988-89. Its area coverage was available but not the yield. It had the same yield potential but was more resistant to rusts. The area under HD 2329 increased consistently to reach 80 per cent in 5 years and stayed marginally above that for another 5 years. PBW 343 was released in 1995, which was better yielder and better resistant and it covered 80 per cent area in three years and that under HD 2329 fell sharply to 11 per cent in 3 years. PBW 343 showed yield advantage of 13 per cent, 14 per cent and 10 per cent over HD 2329 during 1996-97 through 1998-99 respectively.

The adoption pattern of the most important/dominant varieties in Punjab during the last three decades shows that the varietal adoption in Punjab has been one of reaching the top of coverage (80 per cent) or even higher in 5 years outdoing the previous best variety. Also, interestingly the dominant variety had remained on the scene for another five years only. When one (new) variety, which has the potential for large scale adoption appears/is released, it picks up quickly replacing the old variety, which on the opposite also slides down quickly. Thus the ascending part of all the three main varieties during the past three decades is almost similar/parallel to each other. It also shows that the varieties (prominent ones) have been picking up almost at the same rate, but the latest ones have been picking up faster. Thus the ascending percentage of adoption for variety HD 2329 is faster than that of WL 711 and that of PBW 343 is further faster than that of the HD 2329. Thus the variety PBW 343 has picked up in three years instead of five years taken by the earlier varieties.

Age of the Variety

The average age of the variety at any point of time, measured as the age in terms of number of years since the release of the variety weighted by the percent area under the respective varieties, shows the fluctuating trend overtime.[4] It varied between 9.84 years as the maximum to as low as 5.35 years as the minimum (Table 8). It was 4 to

7 years in the 1970s, which increased to 6 to 9 years in the 1980s and upto about 10 years in 1990s. This means the varieties during the 1980s and 1990s lasted more than those during the 1970s. The average age during 1990-91 to 1996-97 increased from 6.03 to 9.84 years. It is interesting to note that the average age at the middle of the decade when the new landmark variety had been on the threshold of release during each of the last three decades has been increasing. The average age of the variety in 1975 was 6.98 years, which increased to 8.81 years in 1985. It also means that there were more new (and competing with each other) varieties on the scene in the mid-1970s than in the mid-1980s. And this trend further continued in the mid-1990s when the average age of the variety further increased to 9.84 years. The trend in-between has been one of U-type; when the new landmark variety starts replacing the earlier ones, the average age of the varieties in the field declines for a few years, which shows faster adoption rate. As the new variety, in full adoption continues and becomes older, the average age of the variety increases again. Thus, since mid-1990s, with the new PBW 343 variety, the average age, though first declined as usual, but is increasing very sharply. This phenomenon read along with the sharply declining varietal diversity index has the significant policy implications in terms of the risks involved and thereby the challenge for the wheat breeders. This is important to give a strong priority given the fact that in the past there have been new varieties taking over just on account of better resistance characteristics inspite of not having any breakthrough in the yield potential.

TABLE 8. AVERAGE AGE OF THE VARIETY AND VARIETAL DIVERSITY INDICES OF WHEAT, 1970-71 TO 1998-99

Year	Varieties			Entropy Index	Modified Entropy Index	Composite Entropy Index	CEI weighted with average age of the variety	CEI weighted with average age and newness of the variety
	Total Number	New ones	Average age					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1984-85	9		7.80	0.608	0.637	0.566	0.449	0.449
1985-86	8		8.77	0.604	0.669	0.586	0.522	0.522
1986-87	8	1	8.56	0.701	0.777	0.680	0.591	0.624
1987-88	8		6.64	0.674	0.747	0.653	0.441	0.441
1988-89	11	4	5.79	0.643	0.617	0.561	0.330	0.403
1989-90	10		5.35	0.448	0.448	0.403	0.219	0.219
1990-91	10		6.01	0.392	0.392	0.353	0.216	0.216
1991-92	12	2	6.65	0.421	0.390	0.358	0.242	0.269
1992-93	11		7.27	0.328	0.315	0.286	0.211	0.211
1993-94	11		8.33	0.310	0.298	0.271	0.229	0.229
1994-95	12	2	9.00	0.336	0.311	0.285	0.261	0.290
1995-96	10		9.84	0.333	0.333	0.300	0.300	0.300
1996-97	10	1	9.84	0.445	0.445	0.400	0.400	0.422
1997-98	7		8.63	0.488	0.577	0.495	0.434	0.434
1998-99	7		5.35	0.299	0.353	0.303	0.165	0.165

Note: CEI in 1970-71, 1975-76 and 1980-81 was 0.331, 0.612 and 0.456 respectively.

Composite Entropy Index:

The Composite Entropy Index (C.E.I.), which is a measure of (varietal) diversity,[5] along with the average age of the variety is also given in Table 8 for the period 1970-71 to 1998-99. This needs to be interpreted along with the adoption pattern of the dominant variety. It was seen that the C.E.I. was 0.331 in 1970-71 when K 227 was at its peak of 80 per cent area. By 1975, when WG 357 variety was also important along with the PV 18 and RR 21 varieties (in addition to K 227), the C.E.I. increased to 0.612, which showed much better varietal diversity than in 1970-71. The C.E.I. again decreased in 1980-81 when there was very high adoption of WL 711 (73 per cent area) and might have been still less in 1981-82 when WL 711 would have been at its peak, expected to have covered 80 per cent area.

Again, when varieties like WL 1562 was adopted to some significant level (say, of more than 10 per cent), the C.E.I. started improving. Thus the C.E.I. which was 0.566 in 1984-85 and 0.586 in 1985-86 and to 0.680 in 1986-87. In 1986-87, new variety HD 2329 also appeared. As the adoption of HD 2329 increased almost in the same pattern as that of WL 711, the C.E.I. started declining and touched the lowest at 0.271 in 1993-94 which almost shows the specialization in one variety. Again when PBW 343 appeared (along with some other but not so dominant varieties), the C.E.I. increased consistently but slowly than earlier, to 0.495 in 4 years (in 1997-98) but again dropped sharply to 0.303 in 1998-99 due to extreme specialisation (say, mesmerisation) for one new variety. As some other preliminary surveys (independent of crop-cutting experiments reported - not yet published) place the adoption of PBW 343 at 86 per cent in 1999-2000 (some other surveys have placed this figure even higher at 89 per cent) and expected to be still higher in 2000-2001, the C.E.I. might have touched all time low to be very close to zero. Thus at any peak time of one variety, which comes again and again in a short period of about one decade in Punjab, there is extreme dependence on one variety and this phenomenon during the past three decades has become even faster over time.

Varietal Diversity and Yield of Wheat

It is important to consider the limitation of the observed pattern of the average age of the variety at a given point of time and the C.E.I. in relation to the trend in yield. It has been already discussed that the growth rate of yield of wheat in Punjab has been positive throughout the period of study. Typically, during the life span of an important/landmark variety, considered in terms of adoption - area under the variety, which first increases, reaches the maximum and then declines when the new better important/landmark variety takes over), the C.E.I. first increases, then declines and again starts increasing like the cyclical fluctuations. In such cases, the simple correlation of yield with the C.E.I. and the average age of the variety might not yield any policy implication and therefore it should be studied in a multiple regression format along with some other important variables.

The average State level yield of wheat for the period 1984-85 to 1998-99 was regressed upon the Entropy Indices (Entropy Index - E.I., Modified Entropy Index - M.E.I. and Composite Entropy Index - C.E.I.) alongwith other variables like fertilizer, Rainfall, Newness of variety (i.e., if there was a new variety added) and the average age of the variety which were included in stages. The Entropy Index, was found to be negatively associated with yield, it alone explained 55 per cent of the variation in the average yield at the State level during 1984-85 to 1998-99 (Table 9).

TABLE 9. REGRESSIONS OF STATE AVERAGE YIELD OF WHEAT ON VARIETAL DIVERSITY INDEX AND OTHER VARIABLES, 1984-85 TO 1998-99

Sr. No.	Intercept	Entropy index	Modified entropy index	Composite entropy index	Fertiliser	Rainfall	Newness of variety	Age of variety	R^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.	3.487	-0.245							0.5845
	(164.5)	(4.28)							0.5525
2.	3.503		-0.208						0.5305
	(176.9)		(3.83)						0.4944
3.	3.488			-0.219					0.5506
	(155.2)			(3.99)					0.5160
4.	2.908	-0.182			0.262				0.6065
	(4.11)	(1.90)			(0.82)				0.5409
5.	2.656		-0.133		0.381				0.5889
	(4.09)		(1.71)		(1.31)				0.5204
6.	2.725			-0.147	0.345				0.5954
	(4.12)			(1.78)	(1.15)				0.5279
7.	2.706	-0.130			0.354	0.027			0.6943
	(4.09)	(1.40)			(1.18)	(1.78)			0.6109
8.	2.564		-0.100		0.421	0.029			0.6939
	(4.37)		(1.39)		(1.60)	(1.94)			0.6104
9.	2.606			-0.110	0.399	0.028			0.6953
	(4.32)			(1.41)	(1.46)	(1.90)			0.6122
10.	2.730	-0.141			0.341	0.026	0.007		0.7008
	(3.96)	(1.42)			(1.09)	(1.60)	(0.46)		0.5811
11.	2.553		-0.101		0.426	0.029	0.003		0.6947
	(4.13)		(1.33)		(1.54)	(1.82)	(0.17)		0.5726
12.	2.596			-0.111	0.403	0.028	0.004		0.6969
	(4.10)			(1.36)	(1.41)	(1.77)	(0.23)		0.5757
13.	2.702	-0.138			0.350	0.026	0.007	0.011	0.7013
	(3.57)	(1.30)			(1.04)	(1.52)	(0.41)	(0.13)	0.5354
14.	2.516		-0.098		0.435	0.029	0.002	0.018	0.6962
	(3.74)		(1.23)		(1.47)	(1.74)	(0.12)	(0.21)	0.5274
15.	2.561			-0.108	0.412	0.028	0.003	0.016	0.6981
	(3.71)			(1.25)	(1.35)	(1.69)	(0.18)	(0.19)	0.5304

Notes: 1. Figures in parentheses are the respective t-values.
2. Figures below the R^2 are the respective adjusted R^2.
3. Varietal diversity index was measured as Entropy Index, Modified Entropy Index and Composite Entropy Index.

When the variable fertiliser was included along with the E.I., R^2 improved but the adjusted R^2 declined. When the rainfall variable was also included to capture the effect of some bad years, not only that its coefficient (in the equation with M.E.I.)

was significant at 0.08 probability level but the t-value of the fertiliser coefficient was also the highest to be significant at 0.14 probability level. The regression equation with the highest adjusted R^2 was the one with C.E.I., fertiliser and rainfall variables, which together explained 61.22 per cent variation in the average state yield.

Further inclusion of the newness of the variety and the average age of the variety at any point of time improved the R^2 but the adjusted R^2 declined. However, both these variables had the positive coefficients, which mean indicatively, that more the number of varieties released and the more the number of years these remain for adoption (which is reflective of their better-ness overtime); the higher would be the average state yield.

Yield Variability and the Adoption of Different Varieties

It is important to study the inter-relationship between the yield variability of different varieties and their adoption pattern, particularly in relation to the important/ landmark varieties (Table 10). The yield variability of the newer varieties, in general, declined over time. It was 40 to 50 per cent in 1970s, which declined to 30 to 45 per cent in 1980-81 for different varieties. In 1985-86, the yield variability of different varieties ranged from 22 to 36 per cent, which came down further to 21 to 28 per cent in 1990-91. And in 1998-99, it further lowered to 17 to 23 per cent. This shows that the inter-farmer (plot) variability in yield of wheat had declined significantly due to better adoption of improved technology package by the majority of the farmers in addition to the wheat breeders giving due cognizance to developing more resistant varieties.

TABLE 10. YIELD VARIABILITY OF DIFFERENT WHEAT VARIETIES, PUNJAB 1970-71 TO 1998-99

Variety	1970-71	1975-76	1980-81	1985-86	1990-91	1998-99
(1)	(2)	(3)	(4)	(5)	(6)	(7)
K 227	2,325					
	(40.58)					
WG 357	2,189	2,255	2,441			
	(51.90)	(40.71)	(37.41)			
WG 377			2,412			
			(32.53)			
RR 21			2,043	2,589		
			(37.29)	(36.30)		
S308			2,001	2,721		
			(44.59)	(33.94)		
WL 1562				3,622		
				(23.19)		
WL 711			2,883	3,678	3,932	
			(29.97)	(24.66)	(20.69)	
HD 2009			2,728	3,674	3,105	
			(34.05)	(25.04)	(28.09)	
HD 2329				4,266	3,803	4,047
				(22.39)	(20.66)	(23.11)
PBW 343						4,443
						(17.13)

It is even more significant to note that at any point of time, the in-coming (newer) variety had lower variability in yield than the out-going (older) one. Thus in 1975-76, variety WG 357 (in-coming variety) had yield variability of 40.71 per cent as compared with 51.90 per cent of that of the K 227 (older) variety. The WG 357 was only marginally better yielder than K 227 variety by 3 per cent.

In 1980-81, the yield variability of WG 357 came down to 37.41 per cent but that of the newer variety WL 711 was only 29.97 per cent. Again, the newer variety WL 711 was much better yielder than WG 357 by as much as 18 per cent in 1980-81 in the farmers' fields.

In 1985-86, although variety WL 711 was still holding the fort, but the new variety HD 2329, which had just been released in that year, showed lower variability in yield (22.39 vs 24.66 per cent) and was also much better yielder than WL 711 (by 16 per cent). And HD 2329 variety, which established completely by 1990-91, still had marginally lower variability in yield than WL 711. The variety HD 2009 did not compete with variety WL 711 either in terms of yield or in terms of yield variability but the variety HD 2329 did.

In 1998-99, the new landmark variety, PBW 343, released since 1996, was, once again having both the desirable characteristics in its favour as compared with that of HD 2329. The variety PBW 343 had lower variability in yield of 17.13 per cent as compared to HD 2329 variety being 23.11 per cent as well as it yielded better by 10 per cent over the variety HD 2329.

Thus it is important to establish in the wheat breeding programme that the newer varieties must be having lower yield variability through better resistance to diseases/ pests, etc. The improvement in yield would be an added advantage/encouragement for increase in its adoption rate. The critical yield advantage turns out to be 10 per cent but it must be accompanied by low yield variability. Secondly, since the yield variability had already come to be very low in Punjab, or the varieties are bearing such a characteristics, the wheat-breeding programme had to be further cognisant of this factor.

SUSTAINABLE AREA UNDER WHEAT IN PUNJAB

Wheat has been the traditional crop of the region, grown almost everywhere over the centuries and has not been reported to be the major ecological or environmental problem causing serious concern. However, of some concern are the problems caused to some extent from the burning of straw. Of late there have been marketing concerns due to gluts of production, not because the country has become surplus but because of the increasing poverty leading to suppressed domestic demand. Also, the volatile international prices particularly when being lower than the domestic prices especially in the era of free trade under WTO/globalisation, have shrunk the exportable avenue for wheat. The increasing carrying costs of foodgrains buffer-stocked in excess of optimal norms in order to keep support price system

going, etc. have also assumed significance in pressurising to cut down some area under wheat (Government of Punjab, 2002).

Regressing the total factor productivity of wheat on area under wheat and estimating the area corresponding to what would be required to yield the maximum total factor productivity approximated the sustainable area under wheat. The TFP of wheat during the period 1981-82 to 1995-96 fluctuated between 118.01 and 160.09 (with base 1970-71=100). The TFP was maximum in 1987-88 when the area under wheat was 3131 thousand hectares. The resultant regression is as follows:

$$TFP_{wheat} = -3417.32 + 2.27676 \text{ area} - 0.0003641 (\text{area})^2 \quad \text{Multiple R} = 0.5575$$
$$(2.16) \quad (2.26) \quad (2.27)$$

(Area is in thousand ha. Figures in parentheses are t-values, which are significant at 0.05 per cent level).

TFP max for area = 3127 thousand ha.

Thus the TFP of wheat was maximised corresponding to an area of 3,127 thousand ha which is very close to the area in 1987-88 (3,131 thousand ha) when the observed TFP was maximum. However, the area under wheat has still been increasing gradually to reach 3,388 thousand ha in 1999-2000. Thus the reduction in wheat area required is only about 2 to 3 lakh ha as compared with some 7 to 8 lakh ha required to be reduced in the case of rice (Singh and Kalra, 2002). Also, the alternatives to the rice crop in *kharif* season in Punjab, provided these are relatively more profitable or supported by institutional systems to be so, are many such as maize, groundnut, soyabean, cotton, etc.

ENVIRONMENT AND ECOLOGICAL ISSUES

It is true that rice, having expanded much more beyond limits of sustainability, has created many issues of environmental and ecological concerns such as depletion of ground water, burning of straw, etc. The problem has also been confounded with the extension of wheat area to limits that ultimately force burning of straw, etc. This section aimed at investigating such concerns is based on the supplementary information collected from 720 farmers in the cost of cultivation sample villages during October 1999. In addition to the 10 farmers in each cluster, another 20 farmers were selected and the survey could be done in 24 clusters only (out of 30). The findings abridged in Table 11, are based on asking the farmers to report only one choice for the following issues: (1) Farmers' views about watertable going down, consequent deepening of tubewells/lowering down the electric motor/diesel engine and the additional cost incurred. (2) Use of harvest combine and burning of straw. (3) Experience about yield trend/decline and the measures adopted to improve the productivity. And (4) Problems faced by the farmers associated with wheat.

TABLE 11. ECOLOGICAL AND ENVIRONMENTAL ISSUES DUE TO OVER EXPANSION OF WHEAT AND RICE

Parameter (1)			Value (2)
Sample size	30 farmers X 24 cluster villages		720
A. Ecological	Per cent farmers having tubewell		92.8
cost of water	Per cent farmers reporting	Upto 1990	4.2
table going	affected by water table	1991-1995	13.8
down	going down	1995-1999	25.0
	Average depth of lowering down (ft)	Upto 1990	8.8
		1991-1995	10.1
		1995-1999	12.6
	Average cost of lowering down	Upto 1990	4,219
	Per deepening tubewell	1991-1995	6,201
	(1999 prices)	1995-1999	8,184
	Average cost per existing tubewell	Upto 1990	177
	of ecological over exploitation.	1991-1995	492
		1995-1999	2,046
B. Use of harvest	Per cent reporting use of harvest combines		75.08
combine and burning of straw	Per cent reporting burning of straw		48.22
C. Farmers reporting	Per cent reporting decline in yield		57.08
decline in yield	Choices by farmers to improve productivity (per cent reporting)		
and measures	Put more fertilisers		42
suggested to	Use new variety		41
improve	Improve timeliness of sowing		3
productivity	Leave land fallow		1
	Spray insecticides		1
	No choice		12
D. Problems	Weeds		44.0
associated	Technology		5.3
with wheat	Bad weather		1.4
(per cent reporting)	Diseases		1.7
	Rice-wheat cropping system		0.8
	No problem		46.8

(i) *Ecological Cost of Water Table Going Down*

As many as 93 per cent farmers in the sample had the tubewells of whom 44 per cent had been adversely affected by the water table having gone deeper. The farmers had to deepen occasionally their tubewell bore and/or place the pump/electric motor at a lower down place like in a well. For this they incur extra cost. The cost of deepening the tubewells at constant 1999 prices, on the average increased from Rs. 4,219 per deepened tubewell (or Rs. 177 per tubewell) prior to 1990 to Rs. 6,201 (Rs. 492) during 1991-1995 and to Rs. 8,184 (Rs. 2,046) post-1995-1999. The increase in costs was due to increase in demand for deepening the tubewells as well as going deeper and deeper over time. With about 8 lakh tubewells in Punjab, it means that more than Rs. 160 crores are being spent by the farmers in deepening their tubewells as an ecologically over-exploitation of the ground water resources resulting in water table going deeper. These costs refer to the year 1999, which are increasing in 1999 prices @ 7.2 per cent per year.

(ii) *Use of Harvest Combine and Burning of Straw*

In the case of wheat, the by-product straw is an important source of dry fodder. Therefore, the use of harvest combine, which means loss of dry fodder, was less than in the case of rice, being about 31 per cent of area only. The burning of wheat straw was also reported by relatively less proportion of farmers, which was 18 per cent compared with 48 per cent in the case of rice.

(iii) *Decline in Yield and the First Priority Measure by the Farmers*

As many as 57 per cent farmers reported that they had been facing the declining trend in the yield. The farmers knew/used more fertiliser (42 per cent) and change the variety (41 per cent), the latter directs for a significant implication, i.e., to increase the biodiversity in terms of more number of varieties even with same (or say, marginally better yields). About 12 per cent knew of no choice (Extension workers to note please).

(iv) *Problems Reported by Farmers Related to Wheat*

About 44 per cent farmers reported the weeds as the major problem in wheat. And majority of the farmers do use weedicides. Significantly, from technology and resource use point of view as many as 47 per cent farmers did not report any significant problem in the case of wheat.

CONCLUSIONS AND POLICY IMPLICATIONS

Punjab has been known for wheat for too long in history. Its productivity increased by more than 5 times in five decades (1950 to 2000), area by three times and the production by more than 15 times. Its productivity continues to increase at the growth rate of more than 2 per cent. Its yield variability across districts has declined over time. Various efficiency parameters were not in any uniform association with farm size. The constraints to efficiency have to be found more in terms of the structure and level of inputs use rather than the achievement of outputs in case of wheat. The share of machinery was already high by mid 1980s, indicating significant levels of mechanisation of Punjab agriculture having taken place by that time.

The yield of wheat was found to be the highest in the rice-wheat system. The use of weedicides has increased from 7 to 83 per cent but the yield advantage came down from 31 per cent to 8 per cent during 1980-81 to 1998-99 showing that the farmers use weedicides only selectively. The yield advantage of using both N and P fertilisers has been around 22 per cent. The timely sowing of wheat improves the wheat yield, which was the highest for the sowing in the first fortnight of November. For every successive fortnight, the yield declined by more than 200 kgs per ha. As a response to this phenomenon, the area sown in the first fortnight of November increased from about 28 per cent in mid-eighties to 62 per cent in 1998-99. The increase in area to timely sown means additional Rs. 60 crores per year that accounts for about 16 per

cent of the tractors in Punjab, which is almost about the number that has been added during the 1990s.

The history of adoption of the high-yielding varieties of wheat in Punjab shows that majority of the farmers are mesmerised by a particular outstanding variety of the day. They look for significant change in one or more of the three factors in the new variety, viz., high-yielding potential of the new variety, better grain quality and/or better resistance to diseases and pests. It is interesting to note that the most promising/significant variety has been introduced afresh at the middle of the decade during each of the last four decades, reached the pinnacle of coverage with area at above 80 per cent in about five years and remained on the scene significantly for another 5 years only. It was varieties C 303 and C 306 up to mid-1960s, Kalyansona and PV 18 up to mid-1970s, WL 711 up to mid-1980s, HD 2329 up to mid-1990s and PBW 343 since then. It is also significant to note that at any point of time, the in-coming (newer) variety had lower variability in yield than the out-going (older) variety.

The average age of the variety, measured as the age in terms of number of years since the release of the variety weighted by the per cent area under the respective varieties, shows the fluctuating trend over time. It was 4 to 7 years in the 1970s, which increased to 6 to 9 years in 1980s and up to about 10 years in 1990s. This means the varieties during the 1980s and 1990s had the staying power than those during the 1970s. The Entropy Index, was negatively associated with yield; it alone explained 55 per cent of the variation in the average at the State level during 1984-85 to 1998-99.

The glut of wheat production in Punjab has created problems of its own, and to some extent of ecological and environmental concerns. The total factor productivity of wheat was maximised corresponding to an area of 3,127 thousand ha which is very close to area in 1987-88 (3,131 thousand ha) when the observed TFP was maximum. However, the area under wheat has still been increasing gradually to reach 3,388 thousand ha in 1999-2000; it has to be cut down. The ecological cost of water table going down has been estimated at about Rs. 160 crores per year, which the farmers incurred in 1999 and is increasing @ 7.2 per cent per year. About 31 per cent of the wheat area is harvested with combines and about 18 per cent farmers reported burning of straw. Weeds was the only major problem reported for wheat by about 44 per cent farmers though more than 80 per cent used weedicides. Majority of the farmers did not envisage any alternative to wheat to a significant level in the near future.

The major policy implications that emerge from this study are: (i) Wheat is not a major problem with ecological and environmental concerns of significance. Only the area under wheat needs to be reduced a little. (ii) The adoption rate for the new wheat varieties and/other technology practices has been very high. However, the inefficient farmers, which are spread across all farm size groups, need to be identified for more aggressive extension input. (iii) The intensive capitalisation/mechanisation of Punjab

farms, which is often referred to as a malaise, has paid off through timeliness of sowing operations alone. However its social abuse needs to be checked. (iv) The plant breeders need to give more focus on incorporating the risk-reduction parameters (reducing yield variability) in the breeding programmes; and (v) Over-dependence on a single variety throughout the State has serious implications. There is need to give more emphasis to evolving/encouraging region-specific varieties in the State.

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NOTES

1. The analysis was done for different districts also, which has been omitted for brevity. However, the interested readers may request for the same from the authors or refer to Singh, Rangi and Kalra, 2002.

2. *The Tribune* (the most important regional English newspaper) of May 8, 1920 (published from Lahore in pre-partition India) carries a news item on "WHEAT FORECAST: A special wheat forecast for 1919-20 shows a total area of 29,537,000 acres as compared with the 23,474,000 acres (revised figures) at the time last year or an increase of 26 per cent. As compared with the final area of last year, the present estimate shows an increase of 24 per cent. The total yield is now estimated at 9,774,000 ton as against the 7,453,000 ton revised estimate during the corresponding period last year, or an increase of 31 per cent. The present estimate of yield is 30 per cent more than the revised final estimate of last year." (To read the units of those days into metric units, a hectare (area) is 2.54 acres, a ton was 28 mds with each md. of 37 kgs. This gives us a yield of 871 kgs in 1919-20 and 835.5 kgs in 1918-19)." "From the pages of *The Tribune*, 75 Years Ago", May 8, 1995. (Compare these yields with 901 kgs/ha in 1950-51).

3. Considering Rs. 2 lakhs as the tractor price with 5 per cent rate of replacement (that means 20 years average life as per field experiences), it gives us more than 60,000 tractors out of about 3.6 lakh tractors in Punjab.

4. For methodology of measurement and significance of the age of the variety, see Brennan and Byerlee (1991).

5. For the methodology of various Entropy Indices, see Shiyani and Pandya (1998).

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