Potential Yields of Rice-Wheat System in the Indo-Gangetic Plains of India

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Abstract

Indo-Gangetic plains have traditionally been responsible for the food security of India. Rice-wheat is the most common cropping system in the region. Understanding and increasing its yield potential is essential to meet the growing food demand. In this paper, potential yields of rice, wheat and rice-wheat systems in various districts/states of the region have been determined using validated crop growth simulation models, spatial weather databases, land use patterns, weather generators, agronomic management details and a GIS. Forty-eight rice-wheat systems consisting of different rice and wheat varieties were simulated for optimal and late plantings. The potential yields of rice varied between 7.3 and 11.5 t ha^{-1} whereas yields of wheat were between 4.8 and 8.3 t ha^{-1}. The potential yield of rice-wheat system was above 18 t ha^{-1} in all districts of Punjab and Haryana and most in Uttar Pradesh. It was 16.4 and 13.4 t ha^{-1} in Bihar and West Bengal, respectively. Late planting of wheat reduced the potential yields of wheat and hence rice-wheat system, on an average, by 1.0 t ha^{-1}. This reduction was higher in those regions where the potential yield of wheat was also higher. These estimates of potential yield provide a yardstick for the possible improvement in the region. Together with evaluation of land degradation status, available rural infrastructure as well as socio-economic conditions of various farmers in the region, potential yield estimates can assist us in determining the optimal food production opportunities.

Introduction

Rice and wheat are the major cereal crops of the Indo-Gangetic region in India. The two crops are grown in rotation in almost 10 million hectares and are a source of food and nutrition security and livelihood for several hundred millions of people in this densely populated region (Paroda et al., 1994). The production of these crops was low and stagnant until early sixties in the last century. The population during the same period increased rapidly resulting in a decreased availability of food per person (Randhawa, 1979). The production of rice and wheat has, however, increased considerably since then due to increase in area, large-scale cultivation of new high yielding semi-dwarf varieties and increased applications of irrigation, fertilisers and pesticides. This Green Revolution technology proved wrong the widely discussed pessimism of Malthus (1798) and others on resolving poverty and hunger problems of the populous regions of the world. India has been food secure during last three decades, at a gross level, largely because of this increase in food production.

The food security of India and other countries in South Asia is, however, now at risk due to continuously increasing population. By 2050, India's population is expected to grow to 1.6 billion people from the current level of 1.0 billion. A large proportion of this increase will be in the Indo-Gangetic plains. This implies a greater demand for food. Although the world as a whole may have sufficient food for everyone, it would need to be produced in the region itself due to socio-economic and political compulsions (Rabbinge, 1999). The cereal requirement of India by 2020 will be between 257 to 296 million tons depending on income (Kumar, 1998; Bhalla et al., 1999). The demand for rice and wheat, the predominant staple foods, is expected to increase to 122 and 103 million tons, respectively by 2020, assuming a medium income growth (Kumar, 1998). This will have to be produced from the same or even shrinking land resource because there is no additional land available for cultivation. Thus, by 2020 the average yields of rice and wheat need to be increased by 56 and 62%, respectively.

Although there is now a pressure to increase production, there has lately been a significant slow-down of the growth rate in the cultivated area, production and yield. The annual rate of growth of cereal production and yield showed a peak during the early years of the green revolution but since 1980s there has been a decline in it in several intensive farming districts of Punjab and Haryana (Sinha et al., 1998). Adding to the worry of food planners is that grain yields in experimental farms are also stagnating. The potential yield of rice in the tropics has not increased above 10 t ha^{-1} since IR8 was released 30 years ago, despite significant achievements in attaining yield stability, increasing per day productivity and improving grain quality (Aggarwal et al., 1996). In wheat, however, some studies have shown an increase in yield potential with time (Nagarajan, 1998; Rajaram, 1998). A review of data of the regional statistics, agronomists' experiments, long-term field trials, breeders' variety evaluation trials and simulation studies also showed stagnation of yields in rice and wheat in northern India (Aggarwal et al., 2000). Such a stagnation in yield at many places raises the question- have we reached the genetic yield ceiling in rice and wheat or are there some other factors that are not allowing yields to increase?

The gradual increase in environmental degradation in intensive cropping systems is further compounding the problem. There is now a great concern about decline in soil fertility, change in water table depth, rising salinity, resistance of harmful organisms to many pesticides and degradation of irrigation water quality in north-western India (Sinha et al., 1998).

Thus, there is a tremendous challenge facing agricultural scientists to develop technologies for increasing food production in the coming decades. Poverty reduction and food security represent the major challenges of mankind in the new millennium. There is an urgent need to secure the past yield gains and further increase the potential yield of major food crops. It is very important to know how much additional cereal, particularly rice and wheat, the staple food crops, can be produced in different regions to meet the increasing demand. Estimates of these potentials can assist in quantifying the carrying capacity of agro-ecosystems. For population rich and low-income regions as the Indo-Gangetic plains, it is also important to know where and at what cost this food can be produced with current technology and/or what alternative technologies will be needed to meet the desired production targets. The objective of this paper is, therefore, to estimate the magnitude of potential yields of rice-wheat systems in different administrative regions of the Indo-Gangetic plains considering the spatial and temporal variation in climatic features and available agricultural technology. Potential yield can be interpreted as the upper limit that can be achieved by the current varieties in a no constraint environment. Adequate water and nutrient supply and absence of all yield-reducing factors such as pests and diseases characterise the production system. For determining potential yields, we have used crop growth simulation model, considered to be the most appropriate tool for such quantification.

Methodology

The region

The Indo-Gangetic plains, situated in the north of India, occupy nearly 20% of the total geographical area of India (Figure 1). The states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal constitute the major part of the region. The region has a well-developed canal irrigation system as well as groundwater potential and agriculture is the major land use. In this study, we have considered all major rice - wheat producing districts of these states. The small area under rice-wheat systems in the states of Madhya Pradesh and Himachal Pradesh was ignored.

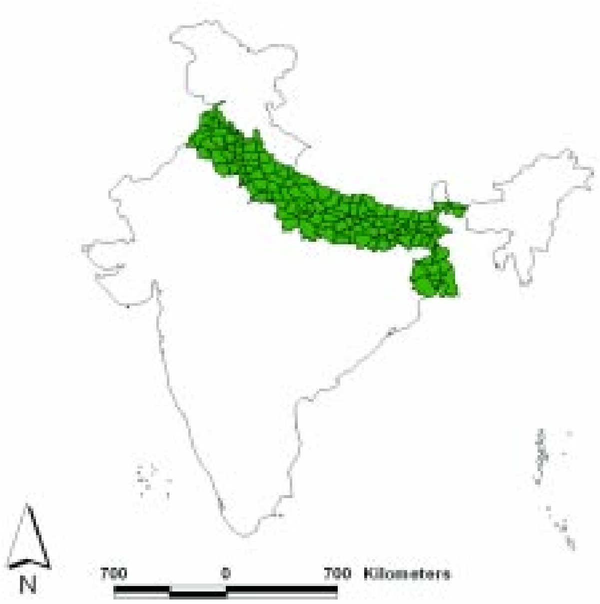

Figure 1. Indo-Gangetic plains of India

The approach

The potential yields of rice-wheat system are dependent upon the spatial and temporal variations in solar radiation, maximum and minimum temperatures during the crop season, and physiological characteristics of the varieties. The main elements of the methodology used for the determination of these yields are shown schematically in Figure 2. Spatial and temporal variations in the climatic features are input in a calibrated and validated rice-wheat growth model to determine potential yields for a large number of locations. These are interpolated for the administrative regions using a GIS.

Weather database

The daily weather data required for simulation was available only for limited locations in the region. Monthly weather data of 135 locations spread all over India including the Indo-Gangetic plains was available. Using this and the WGEN-Weather Generator (Richardson et al., 1984), daily weather data for 10 years was generated for each location. This procedure did not result in any significant bias in estimates of potential yields; the difference between the simulated yields using generated weather data versus actual weather data was less than 3% (Mall and Aggarwal, 2000 unpublished).

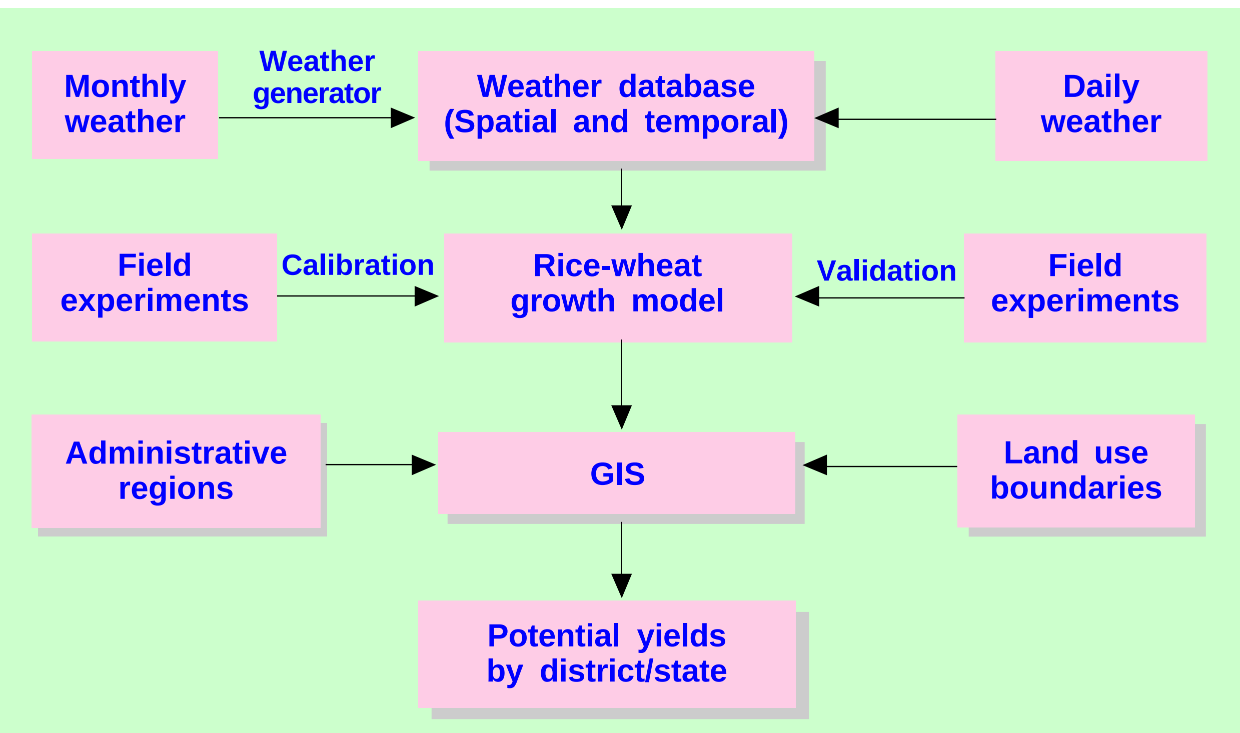

Figure 2. Steps involved in the quantification of potential rice-wheat yields.

Rice-wheat growth model and its validation

Rice-wheat cropping system model consists of two submodels - ORYZA1N for rice and WTGROWS for wheat. ORYZA1N model (Aggarwal et al., 1997), a modification of ORYZA1 (Kropff et al., 1994) is a daily time-step model that was developed to understand and analyse the impact of climatic and plant characteristics and N management on growth and yield of irrigated rice. WTGROWS is also a daily time step model that evaluates the effects of climatic variables, variety, agronomic management, and water and nitrogen availability on crop growth, development and productivity of spring wheat in tropical and sub-tropical environments (Aggarwal et al., 1994). Both models calculate the daily net photosynthesis based on radiation, temperature, leaf area index, photosynthesis rate and maintenance respiration of the crop. The net assimilates are partitioned to different plant parts depending upon the phenological stage. The dry matter accumulated in leaves and stems during different phenological stages influence photosynthetic area as well as the sink capacity. The partitioning of dry matter to grains and ambient temperatures decide grain filling rate and grain yield. Water and nitrogen stresses are estimated following the crop demand and soil supply principles and they effect crop growth and development depending upon their intensity and crop development stage. Water stress is not simulated in ORYZA1N but this does not effect the estimates of potential yields where stresses are assumed to be absent in the production system. Besides requiring inputs of daily weather data, soil characteristics and crop management, the models also require varietal characteristics in terms of rate of development during flowering and grain filling periods, specific leaf area, number of grains per unit dry matter at anthesis and potential grain weight.

The performance of both models has been validated in a large number of diverse agro-environments in India and Southeast Asia contrasting in locations, seasons, varieties and agronomic management. There was generally a good agreement in the simulated and observed time course in leaf area index, dry matter, grain yield and phenological development (Aggarwal et al., 1994; Mall and Aggarwal, 2000, unpublished).

Simulation of rice-wheat systems

Twenty-one days old rice seedlings were planted in a 20 * 15 cm density with 3 seedlings per hill. Seed rate for wheat was assumed to be 100 and 120 kg/ha for the optimal and late wheat sowings, respectively. It was assumed that pests were controlled and there was abundant supply of water and nutrients. Other constraints such as waterlogging, salinity and sodicity were ignored.

Varieties

We have simulated the performance of key rice and wheat varieties grown at present in the Indo-Gangetic plains. These varieties were identified in consultation with rice and wheat breeders and based on literature review. For rice, these were medium duration (130-140 days) varieties -PR 106, Pusa 44, Pant Dhan 4, Sita, Sarju 52 and Saket 4. Basmati rice-wheat system although common in the region, was not simulated since its potential yield is known to be lower than the modern semi-dwarf varieties grown in typical rice-wheat systems. The dominant wheat varieties used in different regions at present were- PBW 343, HD 2329, WH 542, WL 711, HUW 206, K 8804, HP 1731, HD 2285 and Sonalika. It was assumed that the potential yields of other varieties used in the region were well represented by the short-listed ones.

Different farmers in the region grow these rice and wheat varieties in all possible combinations. Forty-eight rice-wheat systems consisting of all possible combinations of six selected rice varieties and eight wheat varieties were simulated. Simulation was done with 10 years of generated data for these 48 systems for each location. Genotypic coefficients of rice and wheat varieties for crop models were estimated by calibration based on past field experiments (Mall et al., 2000 unpublished).

Planting dates

In the Indo-Gangetic plains, rice is generally transplanted in the first week of July unless it is delayed by the onset of rains as in rainfed areas of eastern India. Sowing date of wheat is dependent upon the rice planting time and duration, availability of labour and machinery, and the time needed for field preparation after rice harvest. Wheat sowing gets delayed in 50% area in Haryana and almost 20% in Punjab (Mehla et al., 2000). There is no statistics available on the magnitude of late planted wheat in the entire Indo-Gangetic plains, but in general, wheat sowing gets delayed in many regions. We have, therefore, simulated two types of rice-wheat systems- a) where both crops are planted at optimal time and b) where wheat sowing gets delayed.

Optimal rice-wheat planting system

In this system, rice was transplanted on July 1. The maturity date of the crop varied with variety, year and location. In the model, wheat sowing was done 15 days after the maturity date of rice crop but was not allowed before 7th November. This was assumed as the minimum period required to prepare the fields for wheat sowing, although zero tillage practises can further minimise this (Hobbs et al., 1997). In general, this resulted in wheat sowings between 10th and 15th November, considered as the optimal time for wheat sowing (Singh et al., 1986; Aggarwal and Kalra, 1994).

Rice- late wheat planting system

Rice was transplanted on July 1 in this system as well. Wheat sowing was delayed to 1 December to allow more time for land preparation.

Spatial data management and analysis

The mean yield of each of the 48 rice-wheat systems in both planting systems over 10 years was calculated. The highest simulated yield of these was taken as the potential yield of the rice-wheat system for that location. The gridded surfaces of potential yields of rice, wheat and rice-wheat systems were made in ARCVIEW and extracted for the Indo-Gangetic region. A land use map was overlaid on this to determine potential yields for agricultural areas only. Finally, a 1991 dated districts/states map of the Indo-Gangetic plains was overlaid on this to determine the weighted mean potential yields by the administrative regions.

Results and Discussion

Optimal rice-wheat planting system

Potential rice-wheat yields

The combined simulated potential yield of the system varied between 12.0 and 19.3 t ha^{-1} depending upon the district (Appendix 1). The average potential yield of the entire Indo-Gangetic plains was 16.7 t ha^{-1}. Amritsar district in Punjab had the highest potential yield of 19.3 t ha^{-1}. Punjab state had the highest potential yield of 18.3 t ha^{-1} whereas the West

Table 1. Potential state yields of rice-wheat systems in the Indo-Gangetic plains.

State	Average potential yield, t ha^{-1}					
	Optimal rice-wheat planting system			Rice-late wheat planting system		
	Rice-wheat	Rice	Wheat	Rice-wheat	Rice	Wheat
Punjab	18.29	10.60	7.69	17.18	10.60	6.58
Haryana	17.87	10.53	7.34	16.87	10.53	6.33
Uttar Pradesh	17.48	10.34	7.14	16.46	10.34	6.12
Bihar	16.43	9.73	6.70	15.47	9.73	5.75
West Bengal	13.37	8.07	5.30	13.35	8.07	5.28
Indo-Gangetic plains	16.70	9.88	6.82	15.85	9.88	5.97

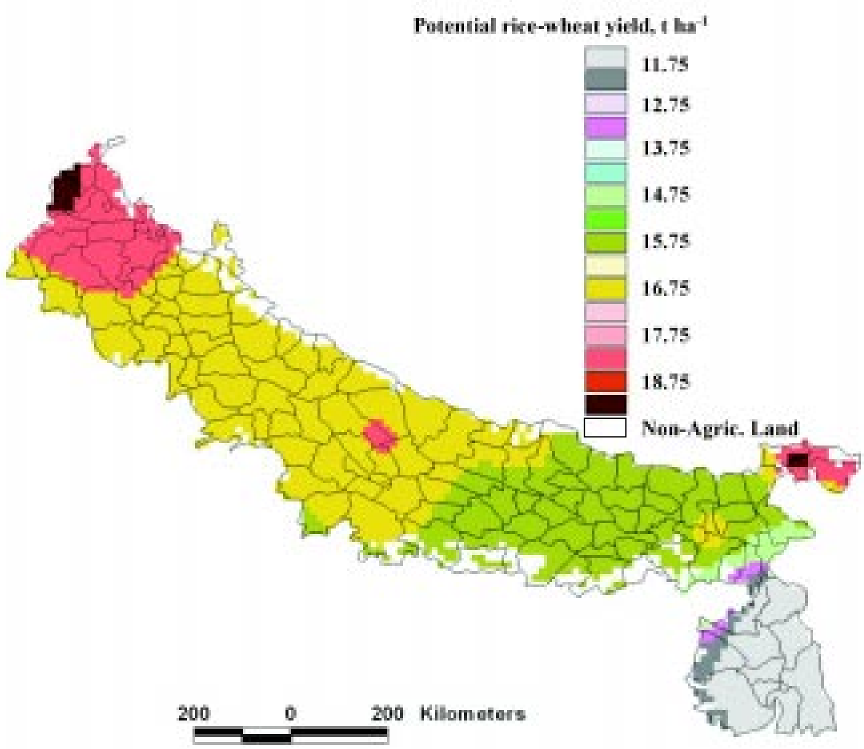

Figure 3. Potential yields (t ha^{-1}) of rice-wheat system in the Indo-Gangetic plains of India. The average values for each district are listed in Appendix 1 and for the state in Table 1. Values are the mid-points of the 0.5 t ha^{-1} classes.

Bengal had the lowest yield of 13.4 t ha^{-1} (Table 1). All districts of Punjab had atleast 18 t ha^{-1} potential yield of the system, whereas this was between 17.5 and 18.0 for Haryana. The western and central parts of Uttar Pradesh had a potential yield of 18 t ha^{-1}, which decreased to 16 t ha^{-1} in eastern districts (Figure 3). Most Bihar districts had a potential yield between 16 and 17 t ha^{-1} except Godda and Sahibganj, where it was relatively much lower. The potential yield of the system was only 12 t ha^{-1} for most coastal districts of West Bengal; it increased in inland, northern districts reaching almost 19 t ha^{-1} in Jalpaiguri.

Potential rice yields

The simulated potential grain yield varied between 7.3 and 11.5 t ha^{-1} depending upon the district. In general, potential yields decreased in eastward direction in the Indo-Gangetic plains (Figure 4). All districts in Punjab and Haryana had 10 t ha^{-1} or more potential yield, the average for the state being 10.5 - 10.6 t ha^{-1} (Table 1). Districts Gurdaspur and Amritsar had a potential yield greater than 11 t ha^{-1}. In the state of Uttar Pradesh, most districts in western and central parts had a potential yield between 10.0 and 10.8 t ha^{-1}. In the eastern districts, this decreased to 9 - 10 t ha^{-1}. The average potential yield of the state as a whole was only slightly lower than the Punjab and Haryana state. In Bihar, the average potential yield of the state as well as of most districts was about 9.7 t ha^{-1}. In West Bengal, northern districts of Jalpaiguri, Darjiling and Kochbihar had a high potential yield of 11.5 t ha^{-1}, which was comparable to the best district yields in Punjab (Appendix 1). Both maximum and minimum temperatures at these places were almost 2-3 °C lower than the rest of the state, allowing greater crop duration, growth and hence yield. Maldah and west Dinajpur had a potential yield of 9-9.5 t ha^{-1}. By comparison, most coastal districts had a

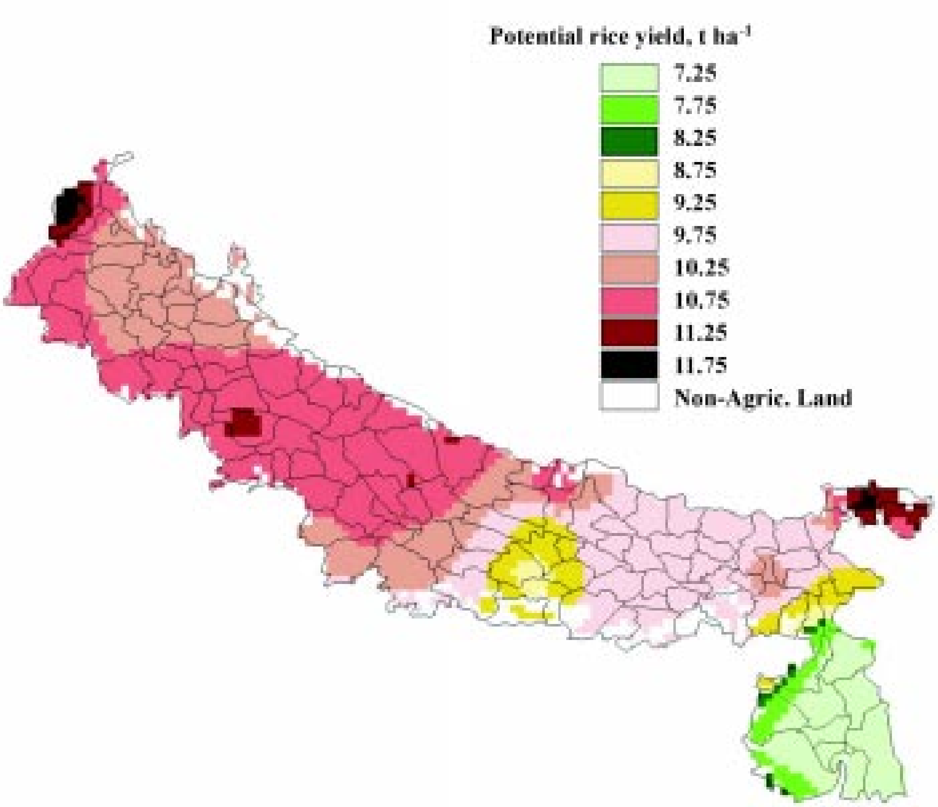

Figure 4. Potential yields (t ha^{-1}) of rice in the Indo-Gangetic plains of India. The average values for each district are listed in Appendix 1 and for the state in Table 1. Values are the mid-points of the 0.5 t ha^{-1} classes.

modest potential yield of 7 - 8 t ha^{-1}. As a consequence, the average potential rice yield of the state was the lowest in the Indo-Gangetic region (8 t ha^{-1}).

Potential wheat yields

The potential yield of wheat was, in general, 2/3rd of the rice crop and followed the same declining trend from north-west to east along the transact. It varied between 4.8 and 8.3 t ha^{-1} depending upon the district (Appendix 1). The state of Punjab as well as its districts had the highest potential yield of 7.5 t ha^{-1} to 8.3 t ha^{-1}; the state average being 7.7 t ha^{-1} (Figure 5, Table 1). Rupnagar district in Punjab and Chandigarh were the only two districts where the potential yield was greater than 8 t ha^{-1}. As was the case with rice, Haryana state and its districts had slightly lower potential yield than Punjab. In Uttar Pradesh and Bihar, the potential yield of most districts as well the state was 7- 7.3 t ha^{-1} and between 6.3 and 6.8 t ha^{-1}, respectively. The gradient in potential wheat yields within the state of West Bengal was similar to that of rice yields (Figures 4 and 5). Northern, inland districts had relatively cooler temperatures as compared to southern coastal districts and hence larger grain filling duration and yield.

Rice- late wheat planting system

In this system, rice yields were the same as in the optimal system. Potential wheat yields in all districts and hence the rice-wheat system yields as well were lower than in the optimal planted system by almost 0.6 to 1.4 t ha^{-1}. The average decrease for most states was 1.0 t ha^{-1}, except for the West Bengal where no reduction was apparent (Table 1). The magnitude of reduction in yield was related to the potential yield under optimal conditions. There was no reduction in the yield under late planting when the weather

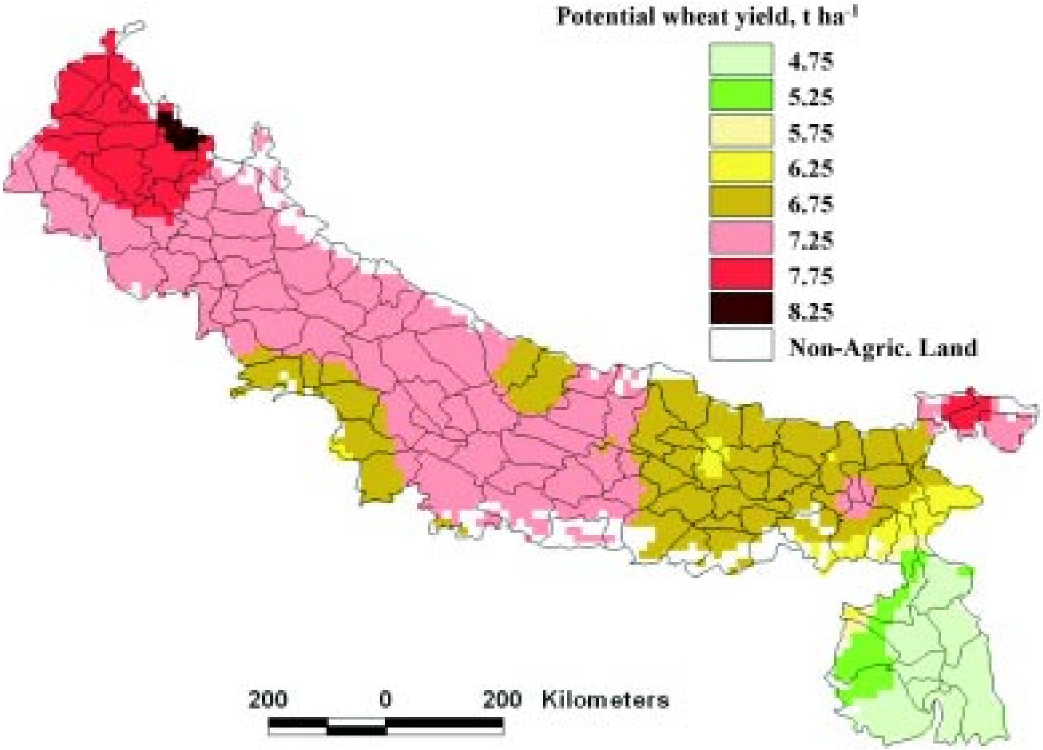

Figure 5. Potential yields (t ha^{-1}) of wheat in rice-wheat system in the Indo-Gangetic plains of India. The average values for each district are listed in Appendix 1 and for the state in Table 1. Values are the mid-points of the 0.5 t ha^{-1} classes.

restricted wheat potential yield to less than 5.5 t ha^{-1} as was the case in West Bengal. As the potential yield increased above this limit, there was a reduction in late sown crops of 0.5 t ha^{-1} per ton increase in grain yield. Thus, in Uttar Pradesh and Bihar where wheat potential yield was 7 t ha^{-1} under optimal sowing, the reduction under late planting was between 0.75 to 1.0 t ha^{-1}. In Haryana and Punjab districts, where the potential yield of wheat varied between 7.0 and 8.3 t ha^{-1} under optimal conditions, the reduction was 1.0 to 1.3 t ha^{-1}.

Conclusions

The results have shown that in most parts of the Indo-Gangetic plains of India where rice-wheat is currently produced, climatic factors allow a potential yield between 12.0 and 19.5 t ha^{-1}. The potential is higher in the north-western regions compared to the eastern regions and is related to temperatures and solar radiation during crop season. These results are based on the mean weather data. Therefore, small deviations in these estimates are possible at some locations due to climatic variability.

These estimates can be used to calculate the magnitude of current yield gap in different regions and the possibility of bridging them to increase food production. Many farmers in north-western India now harvest almost 16 t ha^{-1} from the rice-wheat system indicating negligible yield gaps with current genetic technology. These yields on a per day as well as annual basis are comparable to the best in world considering the level of inputs used. Research for such farmers/regions must now focus on increasing potential yield and input use efficiency. Our results also show that several districts of Uttar Pradesh have potential yields similar to Punjab and Haryana. Yet in most cases farmers of this region are not able to attain higher yields because of sub-optimal input use and land degradation status.

Average yields of rice + wheat in the Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are now 7.5, 6.1, 4.5, 3.3 and 4.4 t ha^{-1}, respectively (1998-99 data). This indicates that at the regional level there still exist considerable yield gaps in most parts of the plains. In Uttar Pradesh and Bihar, there is a large untapped potential for rice and wheat production. Greater focus on these regions in future will help sustain food security of the country for a long time.

Limits to food production may, however, reach much earlier than indicated by the biophysical studies such as ours due to land degradation and socio-economic or political constraints. Many parts of the region are saline/sodic and suffer from waterlogging. These factors restrict the realisation of climatic yield potential. Attempts to realise potential yields in all farmers' fields may also not be economically and environmentally viable. Increased food production without increase in area would need intensification and thus greater resource use including irrigation, capital and energy. Our recent studies have shown, for example, that the Haryana state although theoretically capable of producing 39 million tons of rice and wheat can not produce more than 11.5 million tons per year with available genetic technology due to constraint of irrigation water and capital (Aggarwal et al., 2000a).

With current emphasis on sustainable ecoregional development and the free market economy, agricultural objectives are rapidly changing. For example, attaining the potential yield in farmers' fields may not be the key question; rather, economic and environmental costs associated with different levels of yield potential may be asked. There is a need to determine optimal food production opportunities considering the potential yields, land degradation status as well as socio-economic status of the farmers in a region. The systems approach with its well-developed analytical framework, databases and powerful simulation models can greatly assist us in this endeavour.

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Potential yields (t ha^{-1}) of rice-wheat systems in different districts in the Indo-Gangetic plains. Estimation of these yields assumes absence of all biotic and abiotic constraint.

S.No.	State	District	Rice	Wheat	Rice-wheat
1	Punjab	Amritsar	11.51	7.75	19.26
2	Punjab	Bathinda	10.59	7.52	18.11
3	Punjab	Faridkot	10.72	7.51	18.23
4	Punjab	Firozpur	10.77	7.48	18.25
5	Punjab	Gurdaspur	11.10	7.75	18.85
6	Punjab	Hoshiarpur	10.54	7.82	18.36
7	Punjab	Jalandhar	10.40	7.75	18.15
8	Punjab	Kapurthala	10.75	7.75	18.50
9	Punjab	Ludhiana	10.25	7.75	18.00
10	Punjab	Patiala	10.25	7.80	18.05
11	Punjab	Rupnagar	10.25	8.10	18.35
12	Punjab	Sangrur	10.25	7.75	18.00
13	Chandigarh	Chandigarh	10.25	8.25	18.50
14	Haryana	Ambala	10.25	7.83	18.08
15	Haryana	Bhiwani	10.75	7.25	18.00
16	Haryana	Faridabad	10.75	7.25	18.00
17	Haryana	Gurgaon	10.75	7.25	18.00
18	Haryana	Hissar	10.46	7.28	17.74
19	Haryana	Jind	10.28	7.43	17.71
20	Haryana	Kaithal	10.25	7.71	17.96
21	Haryana	Karnal	10.25	7.30	17.55
22	Haryana	Kurukshetra	10.25	7.50	17.75
23	Haryana	Panipat	10.39	7.25	17.64
24	Haryana	Rohtak	10.75	7.25	18.00
25	Haryana	Sirsa	10.75	7.25	18.00
26	Haryana	Sonipat	10.71	7.25	17.96
27	Haryana	Yamunanagar	10.25	7.25	17.50
28	Delhi	Delhi	10.75	7.25	18.00
29	Uttar Pradesh	Agra	10.75	6.75	17.50
30	Uttar Pradesh	Aligarh	10.97	7.25	18.22
31	Uttar Pradesh	Allahabad	9.69	7.25	16.94
32	Uttar Pradesh	Azamgarh	9.18	7.25	16.43
33	Uttar Pradesh	Bahraich	10.77	6.98	17.76
34	Uttar Pradesh	Ballia	9.75	6.75	16.50
35	Uttar Pradesh	Banda	10.16	7.22	17.38
36	Uttar Pradesh	Barabanki	10.62	7.25	17.87
37	Uttar Pradesh	Bareilly	10.75	7.25	18.00
38	Uttar Pradesh	Basti	9.97	7.25	17.22
39	Uttar Pradesh	Bijnor	10.43	7.25	17.68
40	Uttar Pradesh	Budaun	10.75	7.25	18.00
41	Uttar Pradesh	Bulandshahr	10.77	7.25	18.02
42	Uttar Pradesh	Dehradun	10.25	7.25	17.50
43	Uttar Pradesh	Deoria	9.91	6.78	16.69
44	Uttar Pradesh	Etah	10.75	7.25	18.00
45	Uttar Pradesh	Etawah	10.75	6.75	17.50
46	Uttar Pradesh	Faizabad	9.75	7.23	16.98
47	Uttar Pradesh	Farrukhabad	10.75	7.25	18.00
48	Uttar Pradesh	Fatehpur	10.56	7.25	17.81
49	Uttar Pradesh	Firozabad	10.75	6.86	17.61
50	Uttar Pradesh	Ghaziabad	10.75	7.25	18.00
51	Uttar Pradesh	Ghazipur	9.28	7.10	16.38
52	Uttar Pradesh	Gonda	10.38	6.84	17.22
53	Uttar Pradesh	Gorakhpur	10.02	7.19	17.21
54	Uttar Pradesh	Hamirpur	10.25	6.88	17.13
55	Uttar Pradesh	Hardoi	10.77	7.25	18.02
56	Uttar Pradesh	Hardwar	10.25	7.25	17.50
57	Uttar Pradesh	Jalaun	10.42	6.72	17.13
58	Uttar Pradesh	Jaunpur	9.05	7.25	16.30
59	Uttar Pradesh	Kanpur Dehat	10.75	7.15	17.90
60	Uttar Pradesh	Kanpur Nagar	10.75	7.25	18.00
61	Uttar Pradesh	Kheri	10.75	7.25	18.00
62	Uttar Pradesh	Lucknow	10.75	7.25	18.00

(Continued)

S.No.	State	District	Rice	Wheat	Rice-wheat
63	Uttar Pradesh	Maharajganj	10.75	7.25	18.00
64	Uttar Pradesh	Mainpuri	10.75	6.97	17.72
65	Uttar Pradesh	Mathura	10.80	7.11	17.91
66	Uttar Pradesh	Mau	9.31	7.13	16.44
67	Uttar Pradesh	Meerut	10.63	7.25	17.88
68	Uttar Pradesh	Mirzapur	9.25	7.25	16.50
69	Uttar Pradesh	Moradabad	10.75	7.25	18.00
70	Uttar Pradesh	Muzaffarnagar	10.25	7.25	17.50
71	Uttar Pradesh	Pilibhit	10.75	7.25	18.00
72	Uttar Pradesh	Pratapgarh	9.87	7.25	17.12
73	Uttar Pradesh	Rae Bareli	10.25	7.25	17.50
74	Uttar Pradesh	Rampur	10.75	7.25	18.00
75	Uttar Pradesh	Saharanpur	10.25	7.25	17.50
76	Uttar Pradesh	Shahjahanpur	10.75	7.25	18.00
77	Uttar Pradesh	Siddharthnagar	10.52	7.25	17.77
78	Uttar Pradesh	Sitapur	10.75	7.25	18.00
79	Uttar Pradesh	Sultanpur	9.89	7.25	17.14
80	Uttar Pradesh	Unnao	10.71	7.25	17.96
81	Uttar Pradesh	Varanasi	9.07	7.25	16.32
82	Bihar	Araria	9.75	6.75	16.50
83	Bihar	Aurangabad	9.75	6.75	16.50
84	Bihar	Begusarai	9.75	6.75	16.50
85	Bihar	Bhagalpur	9.68	6.68	16.36
86	Bihar	Bhojpur	9.75	6.75	16.50
87	Bihar	Darbhanga	9.75	6.75	16.50
88	Bihar	Gaya	9.75	6.75	16.50
89	Bihar	Godda	9.13	6.29	15.42
90	Bihar	Gopalganj	9.75	6.75	16.50
91	Bihar	Jehanabad	9.75	6.75	16.50
92	Bihar	Katihar	9.65	6.63	16.28
93	Bihar	Khagaria	9.95	6.95	16.90
94	Bihar	Kishanganj	10.07	6.83	16.89
95	Bihar	Madhepura	10.08	6.97	17.06
96	Bihar	Madhubani	9.75	6.75	16.50
97	Bihar	Munger	9.75	6.61	16.36
98	Bihar	Muzaffarpur	9.75	6.70	16.45
99	Bihar	Nalanda	9.75	6.75	16.50
100	Bihar	Nawada	9.75	6.75	16.50
101	Bihar	Pashchim Champaran	9.92	6.75	16.67
102	Bihar	Patna	9.75	6.75	16.50
103	Bihar	Purbi Champaran	9.75	6.69	16.44
104	Bihar	Purnia	9.86	6.86	16.71
105	Bihar	Rohtas	9.67	6.79	16.46
106	Bihar	Saharsa	9.84	6.77	16.60
107	Bihar	Sahibganj	8.42	5.68	14.10
108	Bihar	Samastipur	9.75	6.75	16.50
109	Bihar	Saran	9.75	6.50	16.25
110	Bihar	Sitamarhi	9.75	6.75	16.50
111	Bihar	Siwan	9.75	6.71	16.46
112	Bihar	Vaishali	9.75	6.75	16.50
113	West Bengal	Bankura	7.66	5.28	12.94
114	West Bengal	Barddhaman	7.48	4.95	12.43
115	West Bengal	Birbhum	7.65	5.11	12.76
116	West Bengal	Calcutta	7.25	4.75	12.00
117	West Bengal	Darjiling	11.04	7.50	18.54
118	West Bengal	Haora	7.25	4.75	12.00
119	West Bengal	Hugli	7.25	4.78	12.03
120	West Bengal	Jalpaiguri	11.36	7.59	18.95
121	West Bengal	Kochbihar	11.08	7.28	18.35
122	West Bengal	Medinipur	7.44	4.89	12.33
123	West Bengal	Maldah	8.95	6.08	15.03
124	West Bengal	Murshidabad	7.31	4.81	12.11
125	West Bengal	Nadia	7.25	4.75	12.00
126	West Bengal	North 24 Parganas	7.25	4.75	12.00
127	West Bengal	South 24 Parganas	7.25	4.75	12.00
128	West Bengal	West Dinajpur	9.43	6.41	15.84

Foreword

Rice-wheat cropping system is one of the most important food production systems in South Asia. This system has enabled the countries of the region to aftain food security during last three decades. This cropping system has provided livelihood to millions of farming families in recent times. This was possible due to development of a symphonic package of practices that included modern high yielding varieties, applications of irrigation, inorganic nutrients and pesticides, and government policy support.

The productivity of this system has now started showing signs of decline at few places and stagnation at many places in the Indo-Gangetic plains. There are also concerns of declining soil health and other related environmental problems. At the same time, food demand in the region is rapidly increasing due to increasing population and income growth. It is therefore very important that the potential yields of these important staple food crops when grown in rotation are quantified. This will enable us to determine where and at what costs additional food can be produced.

I am very happy to note that Dr Aggarwal and his group at the Centre of Applications of Systems Simulation have come up with this report that precisely addresses these issues. Spatial and temporal diversity in climatic features, varieties and crop management have been addressed for determining potential yields through the use of Information Technology tools such as models, databases and GIS. It is hoped that the information provided in this publication would be useful to scientists, extension workers and agricultural planners in years to come.

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Potential Yields of Rice-Wheat System in the Indo-Gangetic Plains of India

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The initial support from the Asian Development Bank and the International Fund for Agricultural Development provided the groundwork for establishment of the RWC in 1994 and formalizing the collaborations between the NARS, IARCs and ARIs. The NARS-driven strategic ecoregional research initiatives with financial support from the Governments of the Netherlands, Sweden, Switzerland, Australia and the US Agency for International Development and the World Bank have grown over the years into a dynamic agenda of resource conservation technologies appropriate to different transects of the Indo-Gangetic Plains. The on-going successes in scaling-up resource conservation technologies for enhancing productivity and sustainability of the rice-wheat systems are beginning to create a revolution and favorably benefit large areas and more numbers of farm families.