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Report no. 31

Yield Gap Analysis of Soybean, Groundnut, Pigeonpea and Chickpea in India Using Simulation Modeling

International Crops Research Institute for the Semi-Arid Tropics

Comprehensive Assessment of Water Management in Agriculture

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Abstract

In India, cultivation of legumes forms an integral part of the rainfed production systems; however, their productivity over the years has remained low and unstable. Soybean and groundnut are the major oilseed crops and pigeonpea and chickpea are the major pulse crops of the country. In the present study, we have: a) characterized the distribution of these legumes in different production zones, agro-ecological zones (AEZs) and states of India; b) estimated the rainfed (water-limited) potential, achievable and current levels of farmers' yields; c) quantified yield gaps between farmers' yields and rainfed potential yields; and d) suggested possible ways to abridge the yield gaps.

Using CROPGRO and APSIM (for pigeonpea) suite of crop models and historical weather data, rainfed potential yields and water balance of the four legumes were estimated for selected locations representing different production zones in India. The simulated rainfed potential yields were supplemented with the research station yield data of rainfed trials of the All India Coordinated Research Projects (AICRP) for respective crops. Achievable yields of the crops for the locations were taken from the Front Line Demonstrations conducted on-farm with improved technology. District average yields were considered as the farmers' yields. Based on these data, the yield gaps between potential and achievable yields (YG I), between achievable and farmers' yields (YG II) and total yield gaps between potential and farmers' yields were estimated.

The farmers' average yield of crops is 1040 kg ha^{-1} for soybean, 1150 kg ha^{-1} for groundnut, 690 kg ha^{-1} for pigeonpea and 800 kg ha^{-1} for chickpea in India. Large spatial and temporal variability was observed in the yield gaps of the four legumes across the production zones. Total yield gap for the production zones ranged from 850 to 1320 kg ha^{-1} for soybean, 1180 to 2010 kg ha^{-1} for groundnut, 550 to 770 kg ha^{-1} for pigeonpea and 610 to 1150 kg ha^{-1} for chickpea. YG II formed a significant part of the total yield gap of the four legumes, indicating the need to scale-up the improved crop production technologies from on-farm demonstration sites to farmers in the production zones. Total yield gaps of legumes for the AEZs and states of India were in the similar range as for the production zones. Simulated rainfed potential yields and total yield gaps across different locations for the four legumes showed a positive and significant curvilinear relationship with crop season rainfall. Estimated surface runoff constituted 11 to 54% of total rainfall received during growing period of the rainy season legumes. To abridge the yield gaps of legumes, integrated watershed management approach comprising of *in-situ* soil and water conservation, water harvesting and groundwater recharging for supplemental irrigation and improved crop management technologies is needed.

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Contents

Executive Summary

Rainfed agroecosystem, which accounts for 67% of the net cultivated area in India is bypassed (has virtually remained untouched) by the Green Revolution. Productivity of the major rainfed crops and the socioeconomic conditions of the small and marginal farmers living in the region continues to remain pathetic. Legume crops play an important role in rainfed agriculture due to their low input requirements and inherent tolerance to inadequate soil moisture as compared to many other cereal crops. Among the legume crops, soybean and groundnut are the major oilseed crops, which together contribute 62% of the total oilseed production. Similarly, chickpea and pigeonpea are the major pulse crops, which together contribute up to 60% of the total production of pulses in the country. There are several biophysical, technical and socioeconomic constraints, which limit the productivity of these legume crops to less than 1 t ha^{-1}. In order to overcome these limitations, it is essential to assess the potential productivity of these crops in relation to their achievable and current levels of productivity realized by average farmers. This in turn helps to assess the gaps between potential and actual yields, and to analyze the factors associated with these yield gaps in a given environment.

The present study was undertaken mainly: a) to assess the distribution of each crop into different regions (production zones, agroecological zones (AEZs) and states across India); b) to estimate the water limited (rainfed) potential, achievable and current levels of farmers' average yields in these regions; c) to quantify the yield gaps ranging from average farmers yields to rainfed potential yields; and d) to find out the possible reasons and ways to mitigate these yield gaps. The long-term (10 to 30 years depending on the availability of weather data) average rainfed potential yields and water balance components of soybean, groundnut contributing 62% of the total oil production, and pigeonpea and chickpea contributing 60% of total pulse production in India for 20 to 35 locations representing different regions across India, was estimated using CROPGRO (for soybean, groundnut and chickpea) and APSIM (for pigeonpea) models. To supplement the simulated potential yields, the maximum experimental station yields taken from the annual reports of the All India Coordinated Research Projects of the respective crops were used. Achievable yields for locations across India were taken from the on-farm trials conducted under Front Line Demonstrations with improved technology. District yields were taken as the average farmers yields (actual yields). Based on rainfed potential yield, achievable and average farmers yields, YG I (the difference between potential and achievable yields) and YG II (the difference between achievable and average farmers yields) were estimated for different locations as well as different regions across India.

Presently, these crops are grown under a wide range of agroclimatic conditions and soil types. Soybean is predominantly grown in the states of Madhya Pradesh, Maharashtra, Rajasthan and Karnataka encompassing AEZs 5 and 6 of semi-arid and 10 of sub-humid ecosystems. Groundnut area is primarily concentrated in the states of Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu and Maharashtra (AEZs 2 and 3 of arid and 5 to 8 of semi-arid ecosystems). The major area under pigeonpea is in the states of Maharashtra, Karnataka, Uttar Pradesh, Gujarat, Madhya Pradesh and Andhra Pradesh (AEZs 4 to 8 of semi-arid and 9 to 12 of sub-humid ecosystems). Chickpea, a postrainy season (*rabi*) crop is largely grown in the states of Madhya Pradesh, Rajasthan, Uttar Pradesh, Maharashtra, Andhra Pradesh and Karnataka (AEZs 2 of arid, 4 to 6 of semi-arid and 10 of sub-humid ecosystems). Soybean, groundnut, pigeonpea and chickpea are cultivated in 148, 273, 315 and 322 districts, respectively, in India. However, among these large numbers of districts, only 11, 13, 26 and 30 districts contribute to 50% of the total area (primary production zone) of these crops in the country, respectively, indicating greater concentration of these crops in relatively a small number of districts across the country.

Because of variable agroclimatic conditions, large spatial and temporal variations were observed in long-term simulated and reported experimental station yields among the locations across India. However, the average simulated rainfed yields and reported experimental station yields indicated a much higher yield potential of these crops than currently being realized by the average farmers. The average simulated, experimental station, on-farm and average farmers yields across the locations ranged from 290 to 3430, 1160 to 3580, 980 to 2130 and 600 to1260 kg ha^{-1} for soybean; 800 to 4460, 1050 to 3620, 1130 to 2460 and 580 to 1880 kg ha^{-1} for groundnut; 300 to 2770, 910 to 2180, 620 to 1690 and 130 to 990 kg ha^{-1} for pigeonpea; and 910 to 2480, 1050 to 2620, 880 to 2180 and 510 to 1140 kg ha^{-1} for chickpea, respectively. Similarly, average simulated rainfed potential yields of different production zones, AEZs and states ranged from 1850 to 2330, 1810 to 2250 and 1340 to 2200 kg ha^{-1} for soybean; 2320 to 3170, 790 to 3750 and 1200 to 3490 kg ha^{-1} for groundnut; 1350 to 1530, 550 to 2220 and 830 to 1960 kg ha^{-1} for pigeonpea; and 1010 to 1900, 830 to 2050 and 1250 to 2120 kg ha^{-1} for chickpea, respectively. On an average, the yields reduced by 15% from experimental station to on-farm and by 47% from on-farm to average farmers yield in all the four legume crops studied.

Large temporal and spatial variability was observed in YG I and YG II for all the four crops across the locations and regions of India. The magnitude of YG I across different production zones, AEZs and states of India ranged from 130 to 380, 0 to 870 and 0 to 570 kg ha^{-1} for soybean; 570 to 1410, 0 to 1290 and 660 to 1850 kg ha^{-1} for groundnut; 30 to 230, 0 to 570 and 0 to 360 kg ha^{-1} for pigeonpea; and 0 to 260, 0 to 580 and 0 to 1100 kg ha^{-1} for chickpea, respectively. Similarly, the extent of YG II across different production zones, AEZs and states of India ranged from 690 to 850, 410 to 920 and 620 to 1200 kg ha^{-1} for soybean; 0 to 670, 0 to 1390 and 460 to 820 kg ha^{-1} for groundnut; 320 to 740, 330 to 1160 and 70 to 1190 kg ha^{-1} for pigeonpea; and 610 to 890, 530 to 920 and 560 to 1020 kg ha^{-1} for chickpea, respectively. YG I is generally considered to be difficult to abridge because of nontransferability of some technologies from experiment station to on-farm situations. YG II on the other hand is manageable as it is mainly due to the differences in the management practices and extent of input use among farmers. Hence, the magnitude of YG II with a large variability observed across locations/regions indicates the potential to increase the productivity of these legumes with improved management practices.

The water balance analysis of rainy season crops (soybean, groundnut and pigeonpea) showed a high degree of runoff potential at many locations, which on an average ranged from 11 to 54% of the total rainfall received during the cropping period among the locations. Hence, there is an urgent need to harvest and conserve this water for supplemental irrigation as well as to minimize soil erosion.

The average simulated rainfed yield and total yield gap across different locations for all the four legumes showed a significant and positive but curvilinear relationship with average crop season rainfall. However, the degree of relationship varied among crops as the regression coefficient (R^2) values ranged from 0.16 to 0.61. The relationships, on one hand, point to the limitation caused by the availability of inadequate soil moisture to the potential productivity of these crops in a rainfed environment. On the other hand, higher magnitude of yield gaps with increasing crop season rainfall indicates that the farmers' average productivity does not increase even in favorable seasons/ locations. Hence, the levels of productivity under these situations are limited by the non-adoption of improved management practices by them. Based on the potential and achievable yields, and the degree of yield gaps observed, it is concluded that there is a scope to improve the productivity of these legume crops to the tune of about 800 kg ha^{-1} through improved crop management practices in average farmers fields. However, improvement in the productivity is likely to be of higher magnitude in good rainfall regions/seasons or with supplemental irrigations.

1. Background

Rainfed agroecosystem constitutes 67% of the net cultivated area (Singh et al. 2000) and occupies an important place in Indian agriculture. It accounts for nearly 40% of India's population and 44% to the national food basket. Though, India has made major strides in food production since 1960s, the gains have come mainly from the irrigated agroecosystem with large scale cultivation of high yielding varieties of cereals and increased application of fertilizers and pesticides. However, rainfed agroecosystem has remained untouched by the Green Revolution and the productivity of the major rainfed crops (about 1 t ha^{-1}) and the socioeconomic conditions of the farmers have remained very poor. The demand for food would continue to rise as the population of India increases from the current 1.0 billion to the expected 1.6 billion by 2050. As rainfed agriculture accounts for nearly 70% of oilseeds, 90% of pulses and 70% of cotton (Abrol et al. 1994), there is a growing realization that further gains in productivity of crops and livestock will have to emanate from the rainfed regions. Further, it has been estimated that even if the full irrigation potential of the country will be realized, 50% of the net sown area will continue to remain rainfed. Hence, it will be necessary to increase the productivity levels of the major rainfed crops to meet the ever-increasing demand of food, which emphasize the critical importance of rainfed agriculture in Indian economy and food security (Katyal et al. 1996).

Rainfed agriculture suffers from a number of biophysical and socioeconomic constraints, which limit the productivity of crops. These constraints include erratic and unpredictable rainfall, excess and deficit moisture within the same season, harsh thermal regime, land degradation, low level of input use, low level of technology adoption and resource poor farmers. Further, the per capita land availability in rainfed areas is very low and is further expected to reduce from existing 0.28 ha to 0.12 ha by 2020 (CRIDA Perspective Plan, 1997). Under these circumstances, legumes have a special place in the rainfed agriculture due to their low input requirement, inherent tolerance to inadequate soil moisture as compared to many other cereal crops. Legume crops add to the nutritional security and economic gains to poor farmers. Of the major legumes, soybean and groundnut are the major oilseed crops of India, together contributing 62% of total oilseed production of the country. Similarly, chickpea and pigeonpea are the major pulse crops of rainfed agriculture in India, together contributing 60% of total pulses area and production in the country. Despite their large area under cultivation and critical importance in oil economy and protein requirement of India's poor farmers, the per capita availability of pulses and edible oils has been constantly declining due to stagnant productivity and continuous increase in the population of the country (Bharti et al. 2003).

In order to develop suitable strategy to improve the productivity levels of legumes, it is imperative to assess the potential yield and yield gaps between the potential and actual yields. Determination of potential productivity requires a thorough understanding of crop growth and development, which in turn depends on several climatic, edaphic, hydrological, physiological and management factors. Potential productivity of a crop for a given location is determined by solar radiation, temperature, photoperiod, atmospheric carbon dioxide concentration and genotype characteristics (yield determining factors) assuming that water and nutrients (yield limiting factors) and pests and diseases (yield reducing factors) are not limiting crop growth and development. This is referred to as water non-limiting potential yield (potential yield). Under rainfed situation where the water supply for crop production is not essentially under the control of the grower, water-limiting yield may be considered as the rainfed potential yield for yield gap analysis assuming other factors are not limiting crop growth. Once the yield gap between rainfed potential yield and actual yield is determined, then the relative contribution of major constraints and limitations, other than water availability, responsible for yield gap can be assessed. This would help to focus on the priority research or crop management needs, to abridge the yield gap.

Rainfed potential yield for a site could be determined by growing crops without any growth constraints, except water availability. Large number of field and on-farm trials are conducted every year under All India Coordinated Research Projects for each crop and the yields reported in these trials can be used for determining potential productivity. However, yields reported in these experiments/trials conducted over locations and seasons are sometimes confounded because of inadequate considerations to genotype, climatic factors and their variability and agronomic management across locations and trials. Alternatively, crop growth models, which integrate the effect of different factors on yield, could be used to estimate the potential productivity for a large number of diverse locations, provided the required soil and climate data for the sites are available for model execution. In the present study, we have estimated the potential yields and the gaps between potential and actual yields of soybean, groundnut, chickpea and pigeonpea crops across different locations and regions in India using both the experimental station data and the data generated through simulation techniques. Soil water balance of crop growing sites has also been simulated to assess the potential of water harvesting and groundwater recharge to provide supplemental irrigation to the crop when needed.

2. Definitions, Data Sources and Methods

2.1 Delineation of Production Zones

For classification of crop areas into different production zones, district-wise available data on area and production of the four legume crops for the last three normal years (1995–96 to 1997–98) was used. The total area under a crop was classified into four production zones, namely, primary, secondary, tertiary and 'others' based upon the area under the crop in each district. To classify districts into various production zones for a crop, all the districts of India growing the particular crop were arranged in a descending order based on the area under the crop. The top districts covering 50% of the total cropped area were categorized into primary production zone; the next group of districts covering 35% (50 to 85%) of the total area were categorized into secondary production zone. Out of the remaining districts, the districts having negligible area (<1000 ha) under the crop were put under the category 'others'. The left over districts were classified as belonging to the tertiary production zone. Hence, the primary production zone indicates the districts where the crop intensity is the highest followed by secondary and tertiary production zones, respectively. All the district-wise data on area and production of each legume crop was classified into the above categories and average productivity (yield in kg ha^{-1}) and the associated coefficient of variation were calculated for each zone. Similarly, the experimental and frontline demonstration sites for each crop were also categorized into four zones for assessing the potential yields and yield gaps for the production zones.

2.2 Experimental Station Yield

This is the maximum possible rainfed yield (observed rainfed potential yield) of an improved cultivar under the field conditions when the factors other than water availability are not limiting crop growth. These are the yields usually obtained at the experimental stations in research plots under good care and supervision. To find out the reported maximum yields, the annual reports of the All India Coordinated

Research Projects (AICRPs) on soybean, groundnut, pigeonpea and chickpea for the past ten years were reviewed. The yields obtained for the top five entries of each crop in the plant breeding varietal trials (Spanish type for groundnut; early, medium and late maturing genotypes for pigeonpea; and *desi* type for chickpea) conducted under rainfed conditions were collected and averaged for each year to calculate the potential rainfed yield. These were further averaged over the years and compared with the on-farm and district level average yields for the estimation of yield gaps.

2.3 On-Farm Yield

This is the large-area yield (or achievable yield) obtained on-farm under rainfed conditions when the progressive farmers have adopted all the elements of improved technology. This data was obtained from the AICRPS reports on Front Line Demonstration (FLD) trials conducted in 15 to 20 farmers' fields by each research center. The mean yields obtained by the farmers under improved technologies were recorded and further averaged over the years and compared with the district level average yields for the estimation of yield gap.

2.4 Data sets of Experimental Stations and On-Farm Yields of Soybean

The details of the locations for which experimental station yield and on-farm yield data were reported in the Annual Reports of the All India Coordinated Research Project on Soybean between 1994 to 2003 (AICRPS, 1994–2003) are presented in Table 1. Experimental station yield data of plant breeding trials of AICRPS were available for 25 diverse locations across India. These locations represented different production zones (primary, secondary, tertiary and others), major ecosystems, agroecological zones (AEZs) and states across India. The latitudes of these locations ranged from 11.0° (Coimbatore, Tamil Nadu) to 32.11°N (Palampur, Himachal Pradesh) indicating a wide diversity among locations. Out of 25 locations, data of 14 locations was available for 10 years, of 8 locations for 6 to 9 and of remaining three locations for 3 to 4 years.

The on-farm yield data of FLDs was available for only 13 locations representing all the crop production zones (except secondary), major ecosystems, AEZs and states across India (Table 1). The number of years for which on-farm data was available ranged from 7 to 10 years at these locations.

2.5 Data Sets of Experimental Stations and On-Farm Yields of Groundnut

The details of the locations for which experimental station yield and on-farm yield data were reported in the Annual Reports of the All India Coordinated Research Project on Groundnut between 1993 to 2001 (AICRPG, 1993–2003) are presented in Table 2. Experimental station yield data of plant breeding trials (Spanish type) of the AICRPG was available for 24 diverse locations. These locations represented different crop production zones, major ecosystems, AEZs and states across India. The latitudes of these locations ranged from 9.18°N (Kayamkulam, Kerala) to 29.62°N (Hanumangarh, Rajasthan), indicating a wide diversity among the locations. Out of 24 locations, data of 11 locations was available for 9 years, of 12 locations for 6 to 8 years and of one location for 4 years.

The on-farm yield data of FLDs was available for only eight locations (Table 2) representing all the crop production zones, major ecosystems, AEZs and major states across India. The number of years for which on-farm data was available ranged from 3 to 8 years at these locations.

Table 1. Geographical details of locations and number of years of data collected from centers under All India Coordinated Research Project on Soybean (AICRPS).

Location	Latitude (°N)	Longitude (°E)	State	Eco-system	AEZ	AICRP zone*	No. of years data available (1994–2003)	
							Exptl.	FLD
Primary Zone								
Sehore	23.20	77.08	Madhya Pradesh	Sub-humid	10	CZ	10	10
Indore	22.72	75.83	Madhya Pradesh	Semi-arid	5	CZ	10	9
Kota	25.18	75.83	Rajasthan	Semi-arid	5	CZ	10	10
Amlaha	23.12	76.90	Madhya Pradesh	Sub-humid	10	CZ	6	-
Nagpur	21.15	79.10	Maharashtra	Sub-humid	10	CZ	10	-
Secondary Zone								
Amravati	20.93	77.75	Maharashtra	Semi-arid	6	CZ	8	-
Tertiary Zone								
Jabalpur	23.17	79.95	Madhya Pradesh	Sub-humid	10	CZ	10	9
Raipur	21.23	81.65	Chattisgarh	Sub-humid	11	NEZ	10	7
Parbhani	19.13	76.83	Maharashtra	Semi-arid	6	CZ	10	10
Dharwad	15.47	75.02	Karnataka	Semi-arid	6	SZ	9	9
Pantnagar	29.05	79.52	Uttaranchal	Sub-humid	9	NPZ	10	10
Jalna	19.83	75.88	Maharashtra	Semi-arid	6	CZ	6	-
Others								
Pune	18.53	73.85	Maharashtra	Semi-arid	6	SZ	10	10
Bangalore	12.97	77.58	Karnataka	Semi-arid	8	SZ	10	9
Palampur	32.11	76.53	Himachal Pradesh	Humid	14	NHZ	10	-
Lam	16.40	80.25	Andhra Pradesh	Semi-arid	7	SZ	9	8
Almora	29.77	79.77	Uttaranchal	Humid	14	NHZ	10	-
Kangra	32.17	76.25	Himachal Pradesh	Humid	14	NHZ	4	-
Berhampore	24.10	88.25	West Bengal	Humid	15	NEZ	4	-
Coimbatore	11.00	76.97	Tamil Nadu	Semi-arid	8	SZ	10	8
Ludhiana	30.93	75.85	Punjab	Sub-humid	9	NPZ	8	7
Imphal	24.83	93.95	Manipur	Per-humid	17	NEZ	3	-
Delhi	28.58	77.20	Delhi	Semi-arid	4	NPZ	8	-
Hisar	29.17	75.73	Haryana	Arid	2	NPZ	6	-
Ranchi	23.38	85.33	Jharkhand	Sub-humid	12	NEZ	10	-

*CZ – Central Zone, NEZ – North Eastern Zone, SZ – Southern Zone, NPZ – Northern Plain Zone, NHZ – Northern Hill Zone

2.6 Data Sets of Experimental Stations and On-Farm Yields of Pigeonpea

The details of the locations for which experimental station yield data (each for early, medium and late maturing genotypes) and on-farm yield data were reported in the Annual Reports of the All India Coordinated Research Project on Pigeonpea (AICRPP, 1991–2003) are presented in Table 3. Experimental station yield data of plant breeding trials that included early, medium and late maturing pigeonpea genotypes was available for 32 diverse locations across India. These locations represented different crop production zones, major ecosystems, AEZs and states across India. The latitude ranged from 10.5° (Vamban, Tamil Nadu) to 32.6° N (Samba, Jammu and Kashmir) indicating a wide spatial variability among these locations. Out of 32 locations, data of 10 locations was available for 8 to 10 years, of 9 locations for 5 to 7 years and of the remaining locations for 3 to 4 years.

Table 2. Geographical details of locations and number of years of data collected from centers under All India Coordinated Research Project on Groundnut (AICRPG).

Location	District	Latitude (°N)	Longitude (°E)	State	Eco-system	AEZ	AICRP zone*	No. of years data available (1993–2001)	
								Exptl.	FLD
Primary Zone									
Junagadh	Junagadh	21.52	70.47	Gujarat	Semi-arid	5	II	7	6
Dharwad	Dharwad	15.47	75.02	Karnataka	Semi-arid	6	V	9	3
Amreli	Amreli	21.62	71.23	Gujarat	Semi-arid	5	II	7	-
Kadiri	Anantapur	14.12	78.17	Andhra Pradesh	Arid	3	V	9	-
Secondary Zone									
Durgapura	Jaipur	26.90	75.82	Rajasthan	Semi-arid	4	I	9	6
Digraj	Sangli	16.87	74.57	Maharashtra	Semi-arid	6	V	9	3
Chiplima	Sambalpur	21.90	81.73	Orissa		12	IV	9	4
Vriddhachalam	Cuddalore	11.50	79.33	Tamil Nadu	Semi-arid	8	V	8	-
Chintamani	Kolar	13.40	78.07	Karnataka	Semi-arid	8	V	9	4
Raichur	Raichur	16.20	77.37	Karnataka	Semi-arid	6	V	7	-
Jagtial	Karimnagar	18.80	78.93	Andhra Pradesh	Semi-arid	7	V	7	3
Khargone	Khargone	21.82	75.60	Madhya Pradesh	Semi-arid	5	III	9	-
Aliyarnagar	Coimbatore	11.00	76.97	Tamil Nadu	Sub-humid	8	V	7	-
Palem	Mahabubnagar	16.73	77.98	Andhra Pradesh	Semi-arid	7	V	6	-
Tertiary Zone									
Udaipur	Udaipur	24.58	73.68	Rajasthan	Semi-arid	4	II	7	-
Jalgaon	Jalgaon	21.05	76.53	Maharashtra	Semi-arid	6	III	9	8
Hanumangarh	Hanumangarh	29.62	74.30	Rajasthan	Arid	2	I	9	-
Akola	Akola	20.70	77.33	Maharashtra	Semi-arid	6	III	9	-
Latur	Latur	18.40	76.58	Maharashtra	Semi-arid	6	V	7	-
Mainpuri	Mainpuri	27.23	79.00	Uttar Pradesh	Semi-arid	4	I	9	-
Others									
Jhargram	Mednipur	22.45	86.98	West Bengal	Sub-humid	15	IV	8	-
Kanke	Ranchi	23.43	85.30	Jharkhand	Sub-humid	12	IV	8	-
Ludhiana	Ludhiana	30.90	75.85	Punjab	Sub-humid	9	I	4	-
Kayamkulam	Alappuzha	9.18	76.50	Kerala	Humid	19	V	8	-

*Zone I = Rajasthan, Haryana, Punjab, Uttar Pradesh; II = Gujarat and Western Rajasthan; III = Northern Maharashtra and Madhya Pradesh; IV = Bihar, West Bengal, Orissa, Coastal Andhra Pradesh; V = South Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu

The on-farm yield data of FLDs were available only for 13 locations (Table 3), which represented all the production zones, most of the AEZs and major states in India. The number of years for which the on-farm data was available at these stations ranged from 4 to 8 years.

Table 3. Geographical locations and number of years of data collected from centers under All India Coordinated Research Project on Pigeonpea (AICRPP).

Location	District	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP zone	No of years data available (1991–2003) Exptl.	FLD
Primary Zone									
Bharuch	Bharuch	21.70	72.97	Gujarat	Semi-arid	5	CZ	5	-
Vadodara	Vadodara	22.30	73.20	Gujarat	Semi-arid	5	CZ	4	-
Gulbarga	Gulbarga	17.33	76.83	Karnataka	Semi-arid	6	SZ	6	8
Akola	Akola	20.50	77.17	Maharashtra	Semi-arid	6	CZ	-	5
Badnapur	Jalna	19.38	74.65	Maharashtra	Semi-arid	6	CZ	9	6
Jalna	Jalna	19.83	75.88	Maharashtra	Semi-arid	6	CZ	6	-
Parbhani	Parbhani	19.13	76.83	Maharashtra	Semi-arid	6	CZ	3	-
Secondary Zone									
Lam	Guntur	16.40	80.25	Andhra Pradesh	Semi-arid	7	SZ	5	-
Madhira	Khammam	17.25	80.15	Andhra Pradesh	Semi-arid	7	SZ	4	-
Patancheru	Medak	17.53	78.27	Andhra Pradesh	Semi-arid	7	SZ	4	-
Warangal	Warangal	18.00	79.58	Andhra Pradesh	Semi-arid	7	SZ	-	7
Anand	Kheda	22.57	72.93	Gujarat	Semi-arid	5	CZ	4	-
Khargone	Khargone	21.82	75.60	Madhya Pradesh	Semi-arid	5	CZ	10	4
Rahuri	Ahmednagar	19.38	74.65	Maharashtra	Semi-arid	6	CZ	9	8
Berhampore	Ganjam	19.32	84.78	Orissa	Sub-humid	12	NEPZ	7	-
Kanpur	Kanpur	26.40	74.85	Uttar Pradesh	Semi-arid	4	NEPZ	6	-
Varanasi	Varanasi	25.33	83.00	Uttar Pradesh	Sub-humid	9	NEPZ	9	-
Tertiary Zone									
Dholi	Muzaffarpur	25.85	85.78	Bihar	Sub-humid	13	NEPZ	4	-
Pusa	Samastipur	25.98	85.68	Bihar	Sub-humid	13	NEPZ	7	-
Raipur	Raipur	21.23	81.65	Chattisgarh	Sub-humid	12	NEPZ	3	4
Junagadh	Junagadh	21.32	70.47	Gujarat	Semi-arid	5	CZ	4	-
SK Nagar	Banaskantha	24.25	72.50	Gujarat	Arid	2	CZ	8	6
Bangalore	Bangalore	12.97	77.58	Karnataka	Semi-arid	8	SZ	4	7
Sehore	Sehore	23.20	77.08	Madhya Pradesh	Sub-humid	10	CZ	8	7
Ludhiana	Ludhiana	30.93	75.85	Punjab	Semi-arid	4	NWPZ	8	6
Coimbatore	Coimbatore	11.00	76.97	Tamil Nadu	Semi-arid	8	SZ	8	6
Vamban	Pudukkottai	10.50	78.83	Tamil Nadu	Semi-arid	8	SZ	4	6
Modipuram	Meerut	28.98	77.70	Uttar Pradesh	Semi-arid	4	NWPZ	4	-
Others									
New Delhi	New Delhi	28.58	77.20	Delhi	Semi-arid	4	NWPZ	10	-
Hisar	Hisar	29.17	75.73	Haryana	Arid	2	NWPZ	8	-
Samba	Samba	32.57	75.12	Jammu & Kashmir	Sub-humid	14	NWPZ	4	-
Faridkot	Faridkot	30.67	74.75	Punjab	Semi-arid	4	NWPZ	5	-
Sriganganagar	Ganganagar	29.17	73.83	Rajasthan	Arid	2	NWPZ	3	-
Pantnagar	Nainital	29.05	79.52	Uttaranchal	Sub-humid	9	NWPZ	7	-

*Zone I = Rajasthan, Haryana, Punjab, Uttar Pradesh; II = Gujarat and Western Rajasthan; III = Northern Maharashtra and Madhya Pradesh; IV = Bihar, West Bengal, Orissa, Coastal Andhra Pradesh; V = South Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu

2.7 Data Sets of Experimental Station and On-farm Yields of Chickpea

The details of the locations for which experimental station yield data (*desi* type, rainfed trials) were reported in the annual reports of the All India Coordinated Research Project on Chickpea from 1993 to 2002 (AICRPC, 1993–2002) are presented in Table 4. Experimental station yield data were

Table 4. Geographical details of locations and number of years of data collected from centres under All India Coordinated Research Project on Chickpea (AICRPC).

Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP zone*	No. of years data available (1993–2002)	
							Exptl.	FLD
Primary Zone								
Sehore	23.20	77.08	Madhya Pradesh	Sub-humid	10	CZ	10	5
Durgapura	26.91	75.82	Rajasthan	Semi-arid	4	NWPZ	6	8
Sriganganagar	29.17	73.83	Rajasthan	Arid	2	NWPZ	5	8
Gulbarga	17.33	76.83	Karnataka	Semi-arid	6	SZ	8	7
Diggi	26.37	75.43	Rajasthan	Semi-arid	4	-	7	-
Hisar	29.17	75.73	Haryana	Arid	2	NWPZ	-	6
Secondary Zone								
Bharari	27.45	78.58	Uttar Pradesh	Semi-arid	4	CZ	8	5
Dharwad	15.47	75.02	Karnataka	Semi-arid	6	SZ	4	-
Jabalpur	23.17	79.95	Madhya Pradesh	Sub-humid	10	CZ	6	-
Kota	25.18	75.83	Rajasthan	Semi-arid	5	CZ	3	-
Bhopal	23.27	77.40	Madhya Pradesh	Sub-humid	10	CZ	-	4
Rahuri	19.38	74.65	Maharashtra	Semi-arid	6	CZ	-	7
Akola	20.50	77.17	Maharashtra	Semi-arid	6	CZ	-	8
Tertiary Zone								
Raipur	21.23	81.65	Chattisgarh	Sub-humid	12	NEPZ	5	8
Badnapur	19.38	74.65	Maharashtra	Semi-arid	6	CZ	7	7
Lam	16.42	80.25	Andhra Pradesh	Semi-arid	7	SZ	-	5
Bawal	28.08	76.58	Haryana	Arid	2	NWPZ	4	-
Bathinda	30.20	74.95	Punjab	Arid	2	NWPZ	3	-
Faridkot	30.67	74.75	Punjab	Semi-arid	4	NWPZ	5	-
Berhampore	24.10	88.25	West Bengal	Humid	15	NEPZ	3	-
Arnej	22.58	72.28	Gujarat	Semi-arid	4	CZ	5	-
Coimbatore	11.00	76.97	Tamil Nadu	Semi-arid	8	SZ	5	-
Faizabad	26.75	82.13	Uttar Pradesh	Sub-humid	9	NEPZ	-	5
Varanasi	25.33	83.00	Uttar Pradesh	Sub-humid	9	NEPZ	-	6
Kanpur	26.43	80.37	Uttar Pradesh	Semi-arid	4	NEPZ	-	7
Junagadh	21.32	70.47	Gujarat	Semi-arid	5	CZ	-	6
Others								
New Delhi	28.58	77.20	Delhi	Semi-arid	4	NWPZ	5	4
Bangalore	12.97	77.58	Karnataka	Semi-arid	8	SZ	9	8
Samba	32.57	75.12	Jammu & Kashmir	Sub-humid	14	NWPZ	6	5
Warangal	18.00	79.58	Andhra Pradesh	Semi-arid	7	SZ	3	-
Dholi	26.16	85.42	Bihar	Sub-humid	13	NEPZ	5	-
Pantnagar	29.05	79.52	Uttaranchal	Sub-humid	9	NWPZ	-	5
Ludhiana	30.93	75.85	Punjab	Semi-arid	4	NWPZ	-	8

*CZ – Central Zone, NEZ – North Eastern Zone, SZ – Southern Zone, NPZ – Northern Plain Zone, NHZ – Northern Hill Zone available for 22 diverse locations across India. These locations represented different crop production zones, major ecosystems, AEZs and states across India. The latitudes of these locations ranged from 11.0° (Coimbatore) to 30.93°N (Ludhiana, Punjab) indicating a wide diversity among the locations. The period for which experimental station data was available ranged from 3 to 10 years at these locations.

The on-farm yield data of FLDs was available for 21 locations representing all the crop production zones, major AEZs and states across India (Table 4). The period for which on-farm data was available ranged from 3 to 10 years at these locations.

2.8 Simulated Rainfed Potential Yields

This is the potential yield of an improved variety simulated by the crop growth model under perfect management conditions, except that water availability to the crop is the main limiting factor for crop growth. These yields are expected to be higher or close to the research station experimental yields.

Though the experimental station yields provide fairly good estimation of potential rainfed yields of the crops at a given location, the number of locations representing a zone could be limiting. Another limitation could be the number of years of data available for each location and the differences in agronomic management of these trials across locations and years at each location. Simulation tools provide a better opportunity for estimating potential rainfed yield by keeping agronomic management conditions constant, and depending on the availability of soil and weather data, potential yields for a greater number of locations and years could be determined.

To simulate the potential yields of soybean, groundnut and chickpea, crop growth simulation models available in the Decision Support System for Agro-technology Transfer (DSSAT) v3.5 (Hoogenboom et al. 1999) were used. The long-term potential rainfed yields of pigeonpea were estimated using APSIM (Agricultural Production Systems Simulator) (McCown et al. 1996). These models need inputs of daily weather data (solar radiation, maximum and minimum temperatures and rainfall), soil data and cultivar-specific parameters (genetic coefficients) to simulate plant growth and resource use by the crops. If the solar radiation data were not available, these were estimated either from sunshine hours or maximum and minimum temperatures using Bristow and Campbell (1984) method. Whenever the weather data were missing for a few days it was either substituted with normal values or not used for model simulation. The soil data were obtained from the soil survey reports published by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur (Lal et al. 1994). For a given location the data of the nearest soil series was used for this analysis. The soil data needed for the crop models was created using the soils parameters estimator program available in DSSAT v3.5.

2.9 Simulation of Soybean Yields

The CROPGRO model of soybean available in DSSAT v3.5 was calibrated and validated for soybean cultivar JS 335 using phenology, growth and yield data from the diverse experiments carried out between 2000 to 2003 at National Research Centre for Soybean, Indore and ICRISAT, Patancheru, Andhra Pradesh. Cultivar JS 335 matures in about 95 days in Central India and is the most popular cultivar covering over 60% of the total soybean area in the country.

For simulating potential rainfed yields, 34 locations across India were selected (Table 5). Besides several common sites for which experiment station data were collected, these locations equally represented different crop production and agroecological zones in major soybean growing states of

Table 5. Geographical details, weather and soil data used for simulation of soybean yields in India.

	Geographical details						Weather data		Soils data			
Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP zone*	Period	No. of years	Series	Type	Depth (cm)	Max. extractable water (mm)
Primary Zone												
Dhar	22.60	75.30	Madhya Pradesh	Semi-arid	5	CZ	1973–96	24	Sarol	Vertisol	160	195
Hoshangabad	22.75	77.72	Madhya Pradesh	Sub-humid	10	CZ	1975–97	23	Jamra	Vertisol	140	165
									Saunther	Vertisol	77	90
Indore	22.72	75.83	Madhya Pradesh	Semi-arid	5	CZ	1975–03	29	Sarol	Vertisol	160	195
									Kamliakheri	Inceptisol	45	54
Kota	25.18	75.83	Rajasthan	Semi-arid	5	CZ	1965–66, 1968–74, 1976–96	30	Chambal	Vertisol	188	224
Nagpur	21.15	79.10	Maharashtra	Sub-humid	10	CZ	1969–96	28	Linga	Vertisol	144	160
Rajgarh	24.00	76.72	Madhya Pradesh	Sub-humid	10	CZ	1969–93, 96	26	Jamra	Vertisol	140	165
									Saunther	Vertisol	77	90
Shajapur	23.50	76.25	Madhya Pradesh	Sub-humid	10	CZ	1969–93, 96	26	Sarol	Vertisol	160	195
									Saunther	Vertisol	77	90
Ujjain	23.42	75.50	Madhya Pradesh	Semi-arid	5	CZ	1969–96	28	Sarol	Vertisol	160	195
Secondary Zone												
Amravati	20.93	77.75	Maharashtra	Semi-arid	6	CZ	1976–94	19	Jambha	Vertisol	240	283
Betul	21.83	77.83	Madhya Pradesh	Sub-humid	10	CZ	1975–96	22	Jambha	Vertisol	240	283
Bhopal	23.27	77.40	Madhya Pradesh	Sub-humid	10	CZ	1974–03	30	Jamra	Vertisol	140	165
									Saunther	Vertisol	77	90
Guna	24.50	77.50	Madhya Pradesh	Sub-humid	10	CZ	1975–95	21	Jamra	Vertisol	140	165
									Saunther	Vertisol	77	90
Raisen	23.33	77.80	Madhya Pradesh	Sub-humid	10	CZ	1975–91	17	Jamra	Vertisol	140	165
Ratlam	23.32	75.05	Madhya Pradesh	Semi-arid	5	CZ	1969–95	27	Sarol	Vertisol	160	195
Sagar	23.83	78.72	Madhya Pradesh	Sub-humid	10	CZ	1969–96	28	Jamra	Vertisol	140	165
Vidisha	23.53	77.82	Madhya Pradesh	Sub-humid	10	CZ	1970–96	27	Jamra	Vertisol	140	165

Continued...

Table 5. *Continued*

	Geographical details						Weather data		Soils data			
Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP zone*	Period	No. of years	Series	Type	Depth (cm)	Max. extractable water (mm)
Wardha	20.83	78.60	Maharashtra	Sub-humid	10	CZ	1975–92	18	Sukali	Inceptisol	150	178
Tertiary Zone												
Akola	20.50	77.17	Maharashtra	Semi-arid	6	CZ	1969–96	28	Jambha	Vertisol	240	283
Belgaum	15.87	74.50	Karnataka	Semi-arid	6	SZ	1975–92	18	Achmatti	Vertisol	170	189
Dharwad	15.47	75.02	Karnataka	Semi-arid	6	SZ	1975–03	29	Hogaluru	Vertisol	195	234
									Achmatti	Vertisol	170	189
Jhabua	22.77	74.60	Madhya Pradesh	Semi-arid	5	CZ	1969–96	28	Sarol	Vertisol	160	195
Jabalpur	23.17	79.95	Madhya Pradesh	Sub-humid	10	CZ	1975–96	22	Kheri	Vertisol	150	177
Nanded	18.92	77.50	Maharashtra	Semi-arid	6	CZ	1969–94	26	Jambha	Vertisol	240	283
Parbhani	19.13	76.83	Maharashtra	Semi-arid	6	CZ	1975–03	29	-	Vertisol	240	270
Pantnagar	29.05	79.52	Uttaranchal	Sub-humid	9	NPZ	1980–00	21	Haldi	Mollisol	128	205
Raipur	21.23	81.65	Chattisgarh	Sub-humid	11	NEZ	1973–99	27	Clay Loam	Entisol	160	190
Others												
Bangalore	12.97	77.58	Karnataka	Sub-humid	8	SZ	1985–01	17	Channasandra	Alfisol	146	97
Coimbatore	11.00	76.97	Tamil Nadu	Sub-humid	8	SZ	1990–98	9	Coimbatore	Inceptisol	124	144
Pune	18.53	73.85	Maharashtra	Semi-arid	6	SZ	1985–01	17	Dholwad	Inceptisol	150	126
									Nimone	Vertisol	139	144
Delhi	28.58	77.20	Delhi	Semi-arid	4	NPZ	1970–98	29	Daryapur	Inceptisol	165	201
Hisar	29.17	75.73	Haryana	Arid	2	NPZ	1983–94	11	Hisar	Inceptisol	168	194
Hyderabad	17.38	78.87	Andhra Pradesh	Semi-arid	7	SZ	1975–03	29	Kasireddipalli	Vertisol	127	183
									Kasireddipalli	Vertisol	112	153
Ludhiana	30.93	75.85	Punjab	Semi-arid	4	NPZ	1971–73, 81–84, 86–98	26	Fatehpur	Inceptisol	165	199
Nimuch	24.73	74.43	Madhya Pradesh	Semi-arid	6	CZ	1969–96	28	Jamra	Vertisol	140	165

India. Depending upon the availability of weather data for a given location, simulations were carried out for 9 to 30 years (Table 5). The details of the soil type used for simulation at each location and their characteristics are also presented in Table 5. Many of the districts to which these locations belonged have more than one soil type (Lal et al. 1994) where soybean is grown. Therefore, simulation for such site was carried out with each dominating soil series of the district.

For long-term simulation of potential yield and water balance components of soybean, the seasonal analysis program of DSSAT v3.5 was used. In the seasonal analysis program, there is no carry over effects of water or nutrients balance from one season to another. Each year the model starts with the same initial conditions at the defined starting date. The model simulations were initiated on 15 May each year and the soil profile was considered to be at the lower limit of water availability (SLLL) on that day. The sowing window assumed was 1 June to 30 July (except for Coimbatore for which window was extended up to 30 August) considering the spatial and temporal variations in the onset of rainy season in the target region. The simulated crop was sown on the day when the soil moisture content in the top 30 cm soil depth reached at least 40% of the extractable water-holding capacity during the sowing window – a condition considered necessary for good seed germination and plant stand establishment. Sowing was not done until this condition was satisfied. The plant population of 35 plants m^{-2} at 30 cm row spacing was considered throughout the simulation study. A soil fertility factor (SLPF) of 1.0 was used for all sites to simulate the crop yields without any soil fertility limitations. The model outputs for each year were: sowing and harvest dates, biomass and seed yields, and water balance components of soybean.

2.10 Simulation of Groundnut Yields

The CROPGRO model of groundnut (Boote et al. 1987) available in DSSAT v 3.5 was calibrated and validated for groundnut cultivar Robut 33-1 (Spanish type) using phenology, growth and yield data from the diverse experiments carried out between 1987 to 1992 at four locations in India ranging in latitude, longitude and elevation (Singh et al. 1994 a, b). These locations included Anand (Gujarat), Patancheru, Anantapur (Andhra Pradesh) and Coimbatore (Tamil Nadu) and provided a wide range of environments for testing the groundnut model as they differed in soils, rainfall and other elements of climate.

For simulating potential rainfed yields, 20 locations across India were selected (Table 6). Besides several common sites for which experiment station data was collected, these locations equally represented different crop and AEZs in major groundnut growing states of India. Depending upon the availability of weather data for a given location, simulations were carried out for 11 to 30 years (Table 6). The details of the soil type used for simulation at each location and their characteristics are also presented in Table 6. Many of the districts to which these locations belonged have more than one soil type (Lal et al. 1994) where groundnut is grown. Therefore, simulation for such sites was carried out for each dominating soil series of the district.

For long-term simulation of potential yield and water balance components for *kharif* groundnut, the seasonal analysis program of DSSAT v3.5 was used. The model simulations were initiated on 15 May each year and the soil profile was considered to be at the lower limit of water availability (SLLL) on that day. The sowing window assumed was 1 June to 30 July for northern and Central parts and June 1 to August 31 for southern parts of the country considering the spatial and temporal variations in the onset of rainy season in the target region. The plant population of 30 plants m^{-2} at 30 cm row spacing was considered throughout the simulation study. The other sowing conditions used and the model outputs were the same as for the soybean model.

Table 6. Geographical details, weather and soil data used for simulation of groundnut yields in India.

Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP Zone	Weather data: Period	Weather data: No. of years	Soils data: Series	Soils data: Type	Soils data: Depth (cm)	Soils data: Max. extractable water (mm)
Primary Zone												
Dharwad	15.43	75.12	Karnataka	Semi-arid	6	V	1975–02	28	Achmatti	Vertisol	170	189
									Hogaluru	Vertisol	195	234
Anantapur	14.68	77.62	Andhra Pradesh	Arid	3	V	1965–94	30	-	Alfisols	180	129
Junagadh	21.31	70.36	Gujarat	Semi-arid	5	II	1985–95	11	-	Vertisol	165	198
Kurnool	15.48	78.48	Andhra Pradesh	Semi-arid	7	V	1984–01	18	-	Vertisol	174	197
									-	Alfisols	174	141
Rajkot	22.30	70.78	Gujarat	Arid	2	II	1994–04	11	Semla	Vertisol	156	182
									Bhola	Inceptisol	96	105
Secondary Zone												
Raichur	16.20	77.37	Karnataka	Semi-arid	6	V	1986–96	11	Raichur	Vertisol	150	182
Jaipur	26.92	76.82	Rajasthan	Semi-arid	4	I	1994–04	11	Chomu	Entisol	170	155
Pune	18.53	73.87	Maharashtra	Semi-arid	6	III	1985–01	17	Otur	Vertisol	120	139
									Nimone	Vertisol	139	144
Jhansi	25.43	78.58	Uttar Pradesh	Semi-arid	4	I	1994–03	10	Haripur	Inceptisol	140	179
Bijapur	16.67	75.92	Karnataka	Semi-arid	6	V	1983–97	12	Jamakhandi	Alfisol	176	141
Warangal	18.00	79.83	Andhra Pradesh	Semi-arid	7	V	1992–00	13	Patancheru	Alfisol	145	198
Tertiary Zone												
Jalgaon	21.05	76.53	Maharashtra	Semi-arid	6	III	1960–79	20	Jambha	Vertisol	240	283
Akola	20.50	77.17	Maharashtra	Semi-arid	6	III	1969–96	28	Jambha	Vertisol	240	283
Patancheru	17.38	78.87	Andhra Pradesh	Semi-arid	7	V	1975–03	29	Patancheru	Alfisols	145	141
Kota	25.18	75.83	Rajasthan	Semi-arid	5	I	1976–96	21	Chambal	Vertisol	188	224
Coimbatore	11.00	76.97	Tamil Nadu	Semi-arid	8	V	1985–98	14	Coimbatore	Inceptisol	124	144
									Palathurai	Alfisol	68	71
Surat	20.97	72.90	Gujarat	Semi-arid	5	II	1994–04	11	Haldar	Vertisol	145	168
									Kabilpura	Inceptisol	141	173
									Sisodra	Inceptisol	145	171
Dhar	22.60	75.30	Madhya Pradesh	Semi-arid	5	III	1973–81, 84–93	19	Bajatta	Inceptisol	78	91
Jhabua	22.77	74.60	Madhya Pradesh	Semi-arid	5	III	1969–80, 83–96	16	Bajatta	Inceptisol	78	91
Thanjavur	10.80	79.15	Tamil Nadu	Semi-arid	8	V	1971–98	28	Kalathu	Vertisol	120	152

2.11 Simulation of Pigeonpea Yields

The pigeonpea crop growth model available in APSIM software was calibrated and validated for pigeonpea cultivar ICPL 87119, using phenology, growth and yield data from the diverse experiments carried out between 1987 to 1992 at ICRISAT, Patancheru, and during 2002 at National Research Centre for Soybean, Indore. The cultivar ICPL 87119 is a medium-duration variety and when planted in June-July, matures in November-December at Hyderabad and in January-February at Indore.

For estimating simulated potential rainfed yields, 35 locations were selected across India (Table 7). Besides several common sites for which experiment station data was available, these sites equally represented different crops and AEZs in major pigeonpea growing states of India. Depending upon the availability of weather data for a given location, simulations were carried out for 8 to 30 years (Table 7). The details of the soil type used for simulation at each location and their characteristics are also presented in Table 7. Many of the districts to which these selected locations belong have more than one soil type (Lal et al. 1994) where pigeonpea is grown. Therefore, simulation for such locations was carried out for each dominating soil series of the districts.

For long-term simulation of potential yield and water balance components of pigeonpea, the model was operated as pigeonpea-fallow system. The model simulations were initiated on 15 May for the first year and the soil profile was considered to be at the lower limit of water availability (SLLL) on that day. Thus the initial conditions at sowing of crops in the following seasons were simulated by the model itself. For each season the sowing window assumed was 1 June to 31 July. Sowing was considered to have occurred when the total rain in the consecutive 5 days was at least 30 mm and extractable water in the soil profile was at least 30 mm. The plant population of 6 plants m^{-2} at 60 cm row spacing was considered throughout the simulation study. Every season 20 kg N ha^{-1} and 26 kg P ha^{-1} were applied to the crop at sowing.

2.12 Simulation of Chickpea Yields

Soybean-chickpea is the most popular cropping system followed by many farmers in Central and peninsular India where chickpea area is concentrated. Therefore, for long-term simulation of potential yield of chickpea, model simulations were performed for the soybean-chickpea sequential system using sequential analysis program of DSSAT v3.5. In this program the CROPGRO models of soybean and chickpea were operated in sequence such that the water and nutrient balance effects of the previous crop were carried over to the next crop in rotation. In this analysis, soybean was sown in the rainy season followed by chickpea crop in the postrainy season. The respective crop growth models were calibrated and validated for soybean cultivar JS 335 and chickpea cultivar JG 218 using phenology, growth and yield data from the diverse experiments carried out between 2000 to 2003 at National Research Centre for Soybean, Indore and ICRISAT, Patancheru, Andhra Pradesh. Soybean cultivar JS 335 matures in about 90–95 days and chickpea cultivar JG 218 matures in about 110–120 days in Central and peninsular India. The initial conditions estimated by the soil parameter estimator program were organic carbon content, mineral nitrogen (N) content and soil water at the start of simulation, which were applied only to the first year of simulation as the soil-water and nutrient status effects are carried over from one season or crop to the subsequent season or crop. The model simulations were initiated on 15 May and the soil profile was considered to be at the lower limit of water availability (SLLL) on that day. The sowing window assumed for soybean was 1 June to 30 July considering the spatial and temporal variations at the onset of rainy season in the target region. The simulated crop was sown on the day when the soil moisture content in the top 30 cm soil depth

Table 7. Geographical details, weather and soil data used for simulation of pigeonpea yields in India.

Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP zone	Weather data: Period	Weather data: No. of years	Soils data: Series	Soils data: Type	Soils data: Depth (cm)	Soils data: Max. extractable water (mm)
Primary Zone												
Akola	20.50	17.17	Maharashtra	Semi-arid	6	CZ	1969–95	27	Jambha	Vertisol	240	283
Amravati	20.90	77.80	Maharashtra	Semi-arid	6	CZ	1976–94	19	Jambha	Vertisol	240	283
Bharuch	21.70	72.97	Gujarat	Semi-arid	5	CZ	1991–96, 98–00	10	Haldar	Vertisol	145	168
									Sisodra	Inceptisol	145	150
Gulbarga	17.33	76.83	Karnataka	Semi-arid	6	SZ	1969–92	24	Kagalgomb	Vertisol	200	235
Nagpur	21.15	79.10	Maharashtra	Sub-humid	10	CZ	1969–95	27	Linga	Vertisol	140	160
Nanded	18.92	77.50	Maharashtra	Semi-arid	6	CZ	1969–94	26	Jambha	Vertisol	240	283
Parbhani	19.13	76.83	Maharashtra	Semi-arid	6	CZ	1969–03	35	-	Vertisol	240	270
Raichur	16.20	77.35	Karnataka	Semi-arid	6	SZ	1986–96	11	Raichur	Vertisol	150	182
Wardha	20.83	78.60	Maharashtra	Sub-humid	10	CZ	1975–92	18	Sukali	Inceptisol	150	178
Secondary Zone												
Anantapur	14.40	77.40	Andhra Pradesh	Arid	3	SZ	1965–94	30	Sandy loam	Alfisol	180	128
Belgaum	15.87	74.50	Karnataka	Semi-arid	6	SZ	1975–92	18	Jamkhandi	Alfisol	175	198
Bellary	15.15	76.85	Karnataka	Semi-arid	3	SZ	1969–92	24	Achmatti	Vertisol	170	189
Bijapur	16.82	75.72	Karnataka	Semi-arid	3	SZ	1983–94	12	Jamkhandi	Alfisol	176	198
Kurnool	15.48	78.48	Andhra Pradesh	Semi-arid	7	SZ	1984–00	18	Patancheru	Vertisol	145	143
Dharwad	15.47	75.02	Karnataka	Semi-arid	6	SZ	1975–00	26	Achmatti	Vertisol	170	189
Patancheru	17.38	78.87	Andhra Pradesh	Semi-arid	7	ZSZ	1975–03	29	Kasireddipalli	Vertisol	127	183
Rahuri	19.38	74.65	Maharashtra	Semi-arid	6	CZ	1976–95	17	Otur	Vertisol	120	139
Warangal	18.00	79.58	Andhra Pradesh	Semi-arid	7	SZ	1992–00	9	Kasireddipalli	Vertisol	145	183
Betul	21.83	77.83	Madhya Pradesh	Sub-humid	10	CZ	1975–95	21	Jambha	Vertisol	240	283
Kanpur	26.40	74.85	Uttar Pradesh	Semi-arid	4	NEPZ	1990–98	8	-	Alfisol	170	198
Raisen	23.33	77.80	Madhya Pradesh	Sub-humid	10	CZ	1975–90	16	Jamra	Vertisol	140	165
Varanasi	25.33	83.00	Uttar Pradesh	Sub-humid	9	NEPZ	1985–96	12	-	Alfisol	170	190

Continued...

Table 7. *Continued.*

							Weather data		Soils data			
Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	AICRP zone	Period	No. of years	Series	Type	Depth (cm)	Max. extractable water (mm)
Tertiary Zone												
Aduturai	11.03	79.48	Tamil Nadu	Sub-humid	8	SZ	1973–97	25	Kalathur	Vertisol	120	132
Bangalore	12.97	77.58	Karnataka	Sub-humid	8	SZ	1985–2000	16	Vijaypura	Alfisol	152	159
Coimbatore	11.00	76.97	Tamil Nadu	Sub-humid	8	SZ	1998–2000	13	Coimbatore	Inceptisol	124	144
									Palathurai	Alfisol	68	71
Jhabua	22.77	74.60	Madhya Pradesh	Semi-arid	5	CZ	1969–95	27	Sarol	Vertisol	160	195
Indore	22.72	75.83	Madhya Pradesh	Semi-arid	5	CZ	1995–03	29	Sarol	Vertisol	160	195
Jhansi	25.43	78.58	Uttar Pradesh	Semi-arid	4	CZ	1994-02	9	Haripur	Inceptisol	140	179
Junagadh	21.32	70.47	Gujarat	Semi-arid	5	CZ	1985-97	13	-	Vertisol	165	198
Ludhiana	30.93	75.85	Punjab	Sub-humid	4	NWPZ	1971–83, 86–00	26	Fatehpur	Inceptisol	165	199
Rajkot	22.30	70.78	Gujarat	Arid	2	CZ	1994–04	11	Semla	Vertisol	156	182
									Bhola	Inceptisol	96	105
Faizabad	26.80	82.10	Uttar Pradesh	Sub-humid	9	NEPZ	1985–96	12	-	-	170	190
Others												
Pantnagar	29.05	79.52	Uttaranchal	Semi-arid	9	NEPZ	1980–99	10	Haldi	Mollisol	128	205
Delhi	18.58	77.20	Delhi	Semi-arid	4	NWPZ	1970–97	28	Daryapur	Inceptisol	165	202
Hisar	29.17	75.73	Haryana	Arid	2	NWPZ	1983–90, 1993–94	10	Hisar	Inceptisol	168	195

reached at least 40% of the extractable water-holding capacity during the sowing window. The sowing window assumed for chickpea was 10 October to 30 November. The simulated crop was sown within this window after the harvest of soybean crop and tested if the soil moisture content in the top 30 cm depth was having at least 30% of the extractable water-holding capacity (EWHC). Chickpea could not be sown for many years and in many locations as the soil moisture after soybean harvest reached much below 30% of EWHC. Therefore, another set of simulation was carried out for all the locations with the provision of pre-sowing irrigation to chickpea with 60 mm water, in case the soil moisture was less than 40% of EWHC in the top 30 cm soil layer after the harvest of soybean crop. Pre-sowing irrigation (*Paleva)* is a common practice followed by the chickpea-growing farmers' and the same was also adopted at the experimental stations, from where the yield data was collected from rainfed trials under AICRP on chickpea. A plant population of 30 plants m^{-2} at 30 cm row spacing was considered throughout the simulation study.

For estimating simulated potential rainfed yields, 30 locations were selected across India (Table 8). These locations represented different production and agroecological zones in major chickpea growing states of India. Depending upon the availability of weather data for a given location, simulations were carried out for 10 to 30 years (Table 8). The details of the soil type used for simulation at each location and their characteristics are presented in Table 8. The model outputs for each year were: sowing and harvest dates, biomass and seed yields and water balance components of soybean and chickpea crops.

2.13 District Average Yields

Yields obtained at district level represent the average farmers yields (actual yields). The data on district yields for the past 10 to 15 years were collected from the reports published by Bureau of Economics and Statistics of different states. To calculate the district average yields of different locations across India, yields of their respective districts were averaged over the same time period for which the experimental station and on-farm data were available (Annexure II, IV, VI and X). These district average yields were utilized to calculate the yield gaps for different locations across India. For analysis of yield gaps at regional level, the district-wise yield data based on three normal years (1995–96 to 1997–98) were used. Yields of all the districts constituting a region (production zones, AEZs and states) were averaged out to represent the district average yield of a region (sections 3.4, 4.4, 5.4 and 6.4). For calculating the total yield gaps based on the long-term simulated average yields of different locations across India, the same database (1995–96 to 1997–98) of their respective districts was used.

2.14 Quantification of Yield Gaps

Yield gap analysis at a given location involves three components of yield. These components are potential, achievable and actual farmers yields (De Datta 1981); and these yields for the present study were obtained from experimental stations/simulations, farmer's yields under improved management practices and district average yields, respectively. The difference between potential (water-limiting in this case) and achievable yield is termed as yield gap I (YG I). YG I is generally considered to be due to factors that are non-transferable and cannot be narrowed (De Datta 1981). The difference between achievable yield and farmers average yield is termed as yield gap II (YG II). YG II is mainly the result of differences in the management practices followed by the traditional farmer, such as use of sub-optimal doses of inputs and cultural practices, as compared to the improved practices followed

Table 8. Geographical details, weather and soil data used for simulation of chickpea yields in India.

	Geographical details					Weather data		Soils data			
Location	Latitude (°N)	Longitude (°E)	State	Ecosystem	AEZ	Period	No. of years	Series	Type	Depth (cm)	Max. extractable water (mm)
Primary Zone											
Durgapura	26.91	75.82	Rajasthan	Semi-arid	4	1994–03	10	Chomu	Entisol	170	160
Guna	24.50	77.50	Madhya Pradesh	Sub-humid	10	1975–94	20	Jamra	Vertisol	140	165
Hoshangabad	22.75	77.72	Madhya Pradesh	Sub-humid	10	1975–95	21	Jamra	Vertisol	140	165
Raisen	23.33	77.80	Madhya Pradesh	Sub-humid	10	1975–91	16	Sarol	Vertisol	140	195
Rajgarh	24.00	76.72	Madhya Pradesh	Sub-humid	10	1969–92	24	Jamra	Vertisol	140	165
Sagar	23.83	78.72	Madhya Pradesh	Sub-humid	10	1969–95	27	Jamra	Vertisol	140	165
Shajapur	23.50	76.25	Madhya Pradesh	Sub-humid	10	1969–93	25	Sarol	Vertisol	160	195
Ujjain	23.42	75.50	Madhya Pradesh	Semi-arid	5	1969–95	27	Sarol	Vertisol	160	195
Vidisha	23.53	77.82	Madhya Pradesh	Sub-humid	10	1970–95	26	Jamra	Vertisol	140	165
Secondary Zone											
Akola	20.50	77.17	Maharashtra	Semi-arid	6	1969–95	27	Jambha	Vertisol	240	283
Amravati	20.93	77.75	Maharashtra	Semi-arid	6	1976–93	18	Jhamba	Vertisol	240	283
Betul	21.83	77.83	Madhya Pradesh	Sub-humid	10	1975–95	21	Jhamba	Vertisol	240	283
Bhopal	23.27	77.40	Madhya Pradesh	Sub-humid	10	1974–03	30	Jamra	Vertisol	140	165
Dhar	22.60	75.30	Madhya Pradesh	Semi-arid	5	1973–95	23	Sarol	Vertisol	160	195
Dharwad	15.47	75.02	Karnataka	Semi-arid	6	1975–02	28	Hogaluru	Vertisol	195	234
Indore	22.72	75.83	Madhya Pradesh	Semi-arid	5	1975–03	29	Sarol	Vertisol	160	195
Jhabua	22.77	74.60	Madhya Pradesh	Semi-arid	5	1969–95	28	Sarol	Vertisol	160	195
Jabalpur	23.17	79.95	Madhya Pradesh	Sub-humid	10	1975–95	21	Marha	Vertisol	180	210
Kota	25.18	75.83	Rajasthan	Semi-arid	5	1976–94	19	Chambal	Vertisol	188	224
Nagpur	21.15	79.10	Maharashtra	Sub-humid	10	1969–95	27	Linga	Vertisol	140	160
Nanded	18.92	77.50	Maharashtra	Semi-arid	6	1969–94	26	Jambha	Vertisol	240	283
Parbhani	19.13	76.83	Maharashtra	Semi-arid	6	1975–95	21	Vertisols	Vertisol	240	270
Ratlam	23.32	75.05	Madhya Pradesh	Semi-arid	5	1969–94	26	Sarol	Vertisol	160	195
Wardha	20.83	78.60	Maharashtra	Sub-humid	10	1975–91	17	Sukali	Inceptisol	150	178
Tertiary Zone											
Belgaum	15.87	74.50	Karnataka	Semi-arid	6	1975–91	17	Achmatti	Vertisol	170	189
Hyderabad	17.38	78.87	Andhra Pradesh	Semi-arid	7	1975–03	29	Kasireddipalli	Vertisol	127	183
Raipur	21.23	81.65	Chattisgarh	Sub-humid	11	1973–96	24	-	-	160	190
Others											
Delhi	28.58	77.20	Delhi	Semi-arid	4	1972–97	26	Daryapur	Inceptisol	128	205
Ludhiana	30.93	75.85	Punjab	Semi-arid	4	1972–78, 81–83, 1986–98	23	Fatehpur	Inceptisol	165	199
Pantnagar	29.05	79.52	Uttaranchal	Sub-humid	9	1980–99	20	Haldi	Mollisol	128	205

by the progressive farmer. Hence, YG II is manageable and can be narrowed down by deploying more efforts on research and extension services as well as on appropriate government interventions.

3. Yield Gap Analysis of Soybean

3.1 Abstract

For the past three and a half decade there has been a phenomenal rise in area and production of soybean (*Glycine max* L. Merr.) in India. It has emerged as the third most important oilseed crop and a major cash crop in the rainfed agroecosystem of Central India. However, its productivity has stagnated to less than one t ha^{-1}. To develop suitable strategy to improve the productivity levels of soybean it is imperative to assess the potential yield in the region of interest and gap between the potential and actual yield obtained by the farmers. For the present study, the long-term average rainfed potential yield and water balance of soybean for 34 locations representing different regions across India, was estimated using CROPGRO-soybean model. Based on long-term simulated potential yields, reported experiment station yields, on-farm achievable yields and average farmer's yield, yield gap I and yield gap II were estimated for different locations and regions across India. Depending upon the agroclimatic conditions, large spatial and temporal variations were observed in the average simulated rainfed potential yield, which ranged from 290 to 3430 kg ha^{-1} among the locations across India. The average simulated rainfed potential yield across major production zones, AEZs and states of India ranged from 1850 to 2330, 1810 to 2250 and 1340 to 2200 kg ha^{-1}, respectively. Yield gap I, ranged from 130 to 380, 0 to 870 and 0 to 570 kg ha^{-1} across different soybean production zones, AEZs and states of India, respectively. Yield gap II, ranged from 690 to 850, 410 to 920 and 620 to 1200 kg ha^{-1} across different soybean production zones, AEZs and states of India, respectively. The extent of yield gap II and a high degree of spatial and temporal variability observed in it, indicate the potential to increase soybean productivity with improved management under rainfed situation. The water balance analysis showed a high degree of runoff at some of the locations, which ranged from 8 to 38% of the total rainfall, indicating the need to harvest and conserve this water for supplemental irrigation to the soybean crop or recharging groundwater. The average simulated yields, average farmers yields as well as total yield gap across different locations showed a significant ($P \leq 0.01$) and positive but curvilinear relationship with average crop season rainfall (R^2 =0.41, 0.49 and 0.37, respectively). However, the rate of increase with increased average rainfall was higher for simulated yield which increased linearly up to ~ 900 mm as compared to average farmers yield where the rate of increase was linear only up to ~ 650 mm. Consequently, the yield gaps were of higher magnitude at locations with higher amount of average seasonal rainfall. Hence, these relationships clearly indicate that with improved management (such as improved variety, soil fertility management and integrated pest and disease management) higher increase in yield would be possible in good rainfall years; and in addition supplemental irrigation would enhance productivity in low rainfall years. Various constraints limiting soybean yields across different regions are identified and ways to abridge large yield gaps are discussed.

3.2 Introduction

Soybean [*Glycine max* (L.) Merr] is by far the most important legume *cum* oilseed crop of the world. It has a good adaptability to a wide range of soils and climates. In addition, it constitutes an important source of high quality cheap protein and oil. The protein content (40%) in soybean is the highest among all the food crops and its oil content (18%) is second only to groundnut among food legumes. Soybean in India has experienced a phenomenal growth both in area and production during the last three and half decades. Starting from 3000 ha in 1969, the area is hovering now around six million hectares with a production of nearly 5 to 6 million tons. The rapid growth in soybean cultivation has placed India on the world map. Presently, India ranks fifth in the world in area and production after USA, Brazil, Argentina and China and the crop is placed in competition with groundnut and rapeseed/mustard in India. Grown largely as a rainfed crop in the Central and peninsular India, soybean has attained a vital status in agriculture and oil economy of India. It has played an important role in supplementing the edible oil to the extent of 13% of national production. The crop also helps the country to earn foreign exchange worth Rs 24,000 million (US $ 67 million) by way of exporting De-Oiled Cake (DOC) (Bhatnagar and Joshi 2004). Coupled with soya-based agro-industry soybean cultivation has also generated notable employment opportunities in the country. Being the cheapest source of high quality protein, soybean has potential to play an important role in mitigating the large-scale problem of protein malnutrition particularly in children and women in the rural areas of the country. With all the stated multifarious benefits, soybean farming has revolutionized the rural economy and has resulted in improved socioeconomic status of the soybean farmers in India (Paroda 1999, Bhatnagar and Joshi 2004, Goel 2004). However, unlike the tremendous rise in area and production of soybean in the past three and half decades, the growth in productivity remained low, which is a cause of concern. As compared to other countries, the current level (2002) of productivity of soybean in India (0.76 t ha^{-1}) is less than half of China (1.9 t ha^{-1}) and less than one third of the USA, Brazil and Argentina (2.6 t ha^{-1}).

In the present study we have estimated the potential rainfed yield of soybean using both the experimental data and the data generated through simulation techniques and assessed the gaps between potential, achievable and average farmers yields across different locations/regions in India.

3.3 World Trends in Soybean Production

Soybean is a major source of vegetable oil and protein in the world. It plays an important role in world food trade. A continuous rise in the global area and production of soybean has been observed (Fig. 1). Its total area and production was about 45 M ha and 30 M t in 1970, which rose to 79 M ha and 182 M t by 2002, respectively. The rapid increase in area under soybean in the last few decades has mainly come from the tropical and subtropical regions. However, its large-scale cultivation is mainly concentrated in a few countries. The USA alone contributes to 36 and 41% of global soybean area and production, respectively (Table 9). Other countries such as Brazil, Argentina, China, India, Paraguay and Canada, along with the United States of America together contribute to about 96% of the total world soybean production (Table 9). Global average yield of soybean has also increased continuously but there is large variability in it among the countries. Among the major soybean producing countries, the average yield of the United States of America, Brazil and Argentina is more than 2.5 t ha^{-1}, which is considerably higher as compared to 1.8 and 0.7 t ha^{-1} in China and India, respectively.

Figure 1. Trends in area, production and productivity of soybean in world.
Source: FAOstat data, 2004.

Table 9. Global soybean area, production and productivity during 2002–03.

Country	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
USA	28.31	74.82	2550
Brazil	16.37	42.12	2570
Argentina	11.41	30.00	2630
China	8.72	16.51	1890
India	5.68	4.30	760
Paraguay	1.45	3.30	2280
Canada	1.02	2.34	2280
Bolivia	0.66	1.30	1980
Nigeria	0.62	0.44	700
Indonesia	0.54	0.60	1240
World	78.83	181.74	2300

Source: FAOstat data, 2004.

3.4 Soybean Production in India

3.4.1 Area, production and productivity in the country

Starting from 3000 hectares in 1969, the area under soybean in India has steadily increased over the years to 6.22 M ha by 2001 (Fig. 2). Soybean has shown a spectacular growth in India and the compound growth rate during the decade 1981–1991, for area, production and productivity was 17.89, 20.51 and 2.22%, which slowed down to 6.61, 7.72 and 1.04%, respectively, in the following decade (1991–2001) (Mruthyunjaya and Singh 2003). The production of soybean continued to increase till 1999 (Fig. 2) largely due to rapid growth in area (82%) and modest yield enhancement (18%) (Bhatnagar and Joshi 2004). However, the production declined between 2000 and 2002 largely due to reduction in area as well as productivity on account of consecutive and unusual droughts.

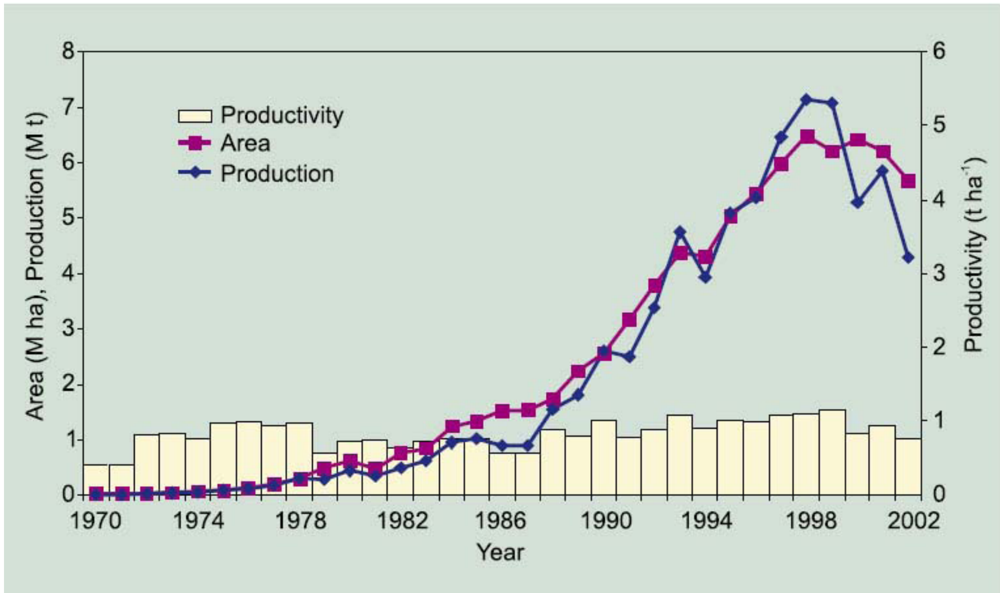

Figure 2. Trends in area, production and productivity of soybean in India.
Source: FAOstat data, 2004.

3.4.2. Area, production and productivity in crop production zones

Soybean is grown in 148 districts across India on an average 5.70 M ha area with an average production of 5.93 M t (Table 10). However, of the total area under cultivation, only 11 districts contribute 50% of total area (primary zone) and 17 districts fall in secondary zone contributing another 35% of area under soybean in the country. The rest 120 districts contribute only 15% to the total area under soybean of which 69 districts have less than 1000 ha under cultivation. This clearly indicates a very high concentration of soybean cultivation in a few districts and such a pattern needs to be analyzed in terms of differences in natural resources and socioeconomic infrastructure. Interestingly, the average productivity levels of these zones, which ranged from 1000 to 1074 kg ha^{-1}, do not vary significantly. However, the coefficient of variation is lowest in primary zone (9%) and increased substantially in secondary (24%) and tertiary zone (36%); while the maximum variation (46%) is seen among the districts, which are grouped as others and have less than 1000 ha under cultivation. Out of 11 districts in primary zone nine are in western Madhya Pradesh and one each in Rajasthan (Kota) and Maharashtra (Nagpur) (Fig. 3). Similarly, the majority of districts in the secondary zone are in the western Madhya Pradesh and some in the adjoining Maharashtra while districts in the rest of the

Table 10. Area, production and productivity of soybean in different production zones of India (1995–96 to 1997–98).

Production zone	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Primary	11	2.84	3.05	1074	9
Secondary	17	1.97	1.98	1005	24
Tertiary	51	0.88	0.89	1011	36
Others	69	0.01	0.01	1000	46
Total	148	5.70	5.93	1040	36

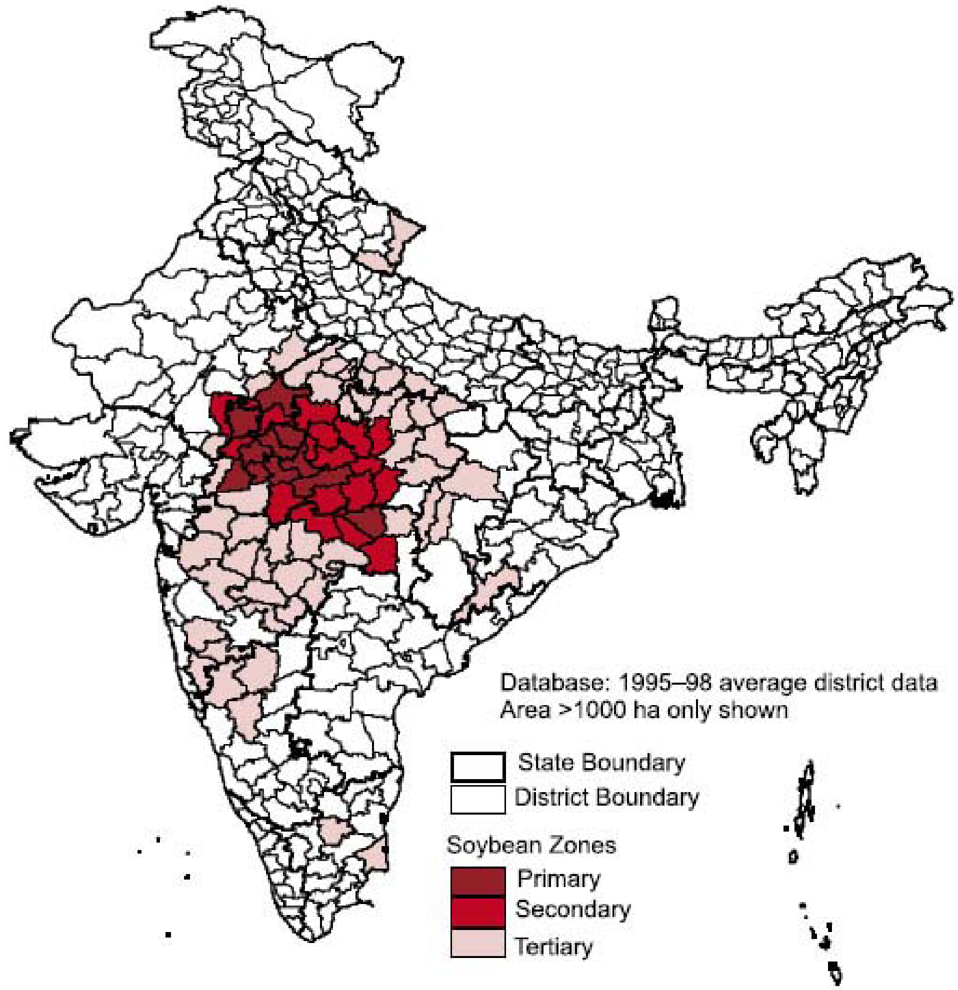

Figure 3. Primary, secondary and tertiary production zones of soybean in India.

zones are spread in Maharashtra, Karnataka, Tamil Nadu and some northern states of India (Fig. 3). The initial spread of soybean in the early eighties (Bhatnagar and Joshi 2004) was mainly in districts falling under primary zone. One of the reasons for low variability among the districts could be the longer period of experience/understanding and uniform adoption of technology by the farmers of these zones as compared to districts in other zones. On the other hand, in rest of the districts the soybean crop is new and understanding and adoption of new technologies among the farmers is not as uniform as in the case of primary districts. Nonetheless, the similarity in mean yields and the large coefficient of variation values of the production zones does indicate that there is a lot of scope for improving the productivity of some districts in these zones.

3.4.3 Area, production and productivity in agroecological zones

Classification of soybean area into different crop production zones gives an indication of the geographical area where the crop is most concentrated and where the intervention can lead to maximum gains in the production of crop. However, in each crop zone, districts may have diverse ecological background and variability in their productivity may largely be governed by the variability in the climatic conditions of these districts. Based on uniformity in climate, soils, length of growing period and physiography, the whole country has been divided into 20 AEZs (Sehgal et al. 1995). Here, an attempt has been made to look into the spread of area, production and productivity of soybean in these AEZs (Table 11, Fig. 4).

Table 11. Area, production and productivity of soybean in different agroecological zones of India (1995–96 to 1997–98).

Ecosystem	AEZ	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Semi-arid	4	26	0.12	0.10	870	45
Semi-arid	5	14	2.21	2.39	1080	21
Semi-arid	6	27	0.52	0.69	1330	39
Semi-arid	8	22	0.01	0.00	500	42
Sub-humid	9	7	0.01	0.01	770	27
Sub-humid	10	27	2.76	2.69	970	25
Sub-humid	11	5	0.05	0.04	690	38
Others	-	20	0.01	0.01	420	51
Total		148	5.70	5.93	1040	36

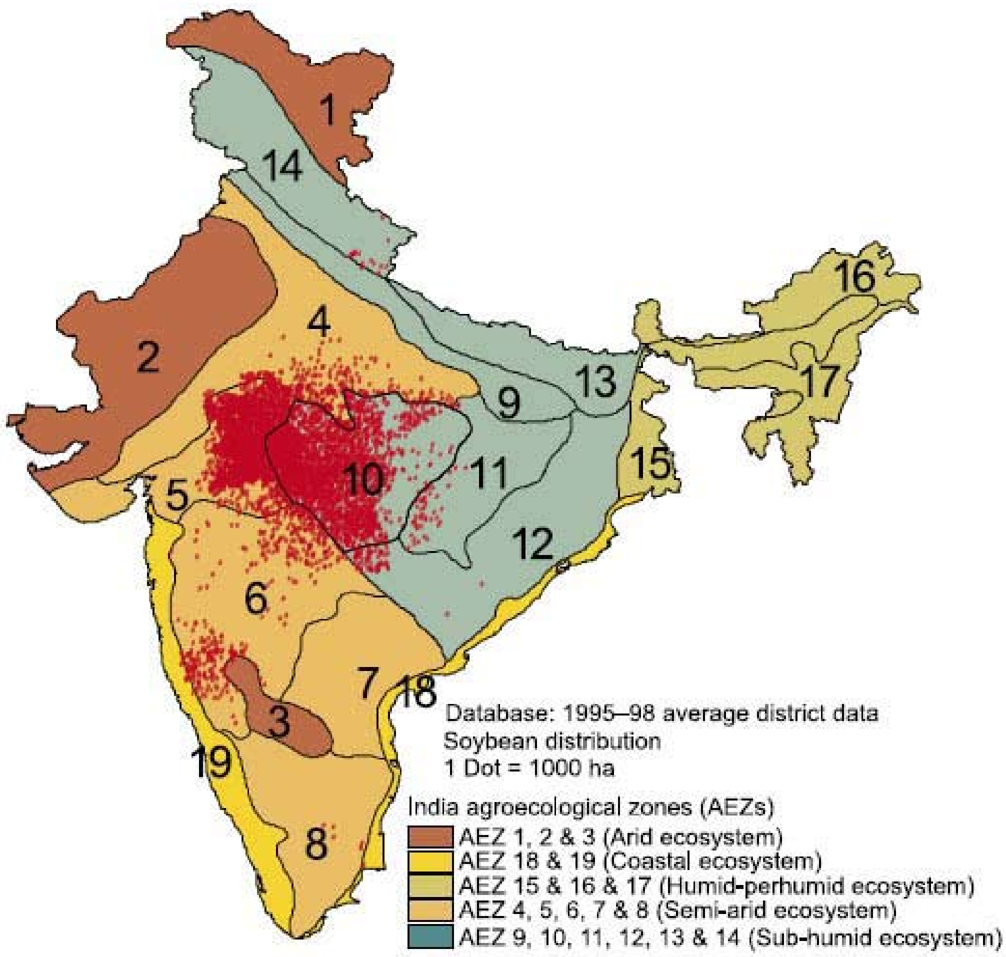

Figure 4. Distribution of soybean in different agroecological zones of India.

The AEZs of interest for soybean are mainly 5 and 10, which together contribute to about 85% of total area and production in the country. AEZ 5 has large area under soybean and is located in Central (Malwa) highlands on Vertisols and Vertic Inceptisols; the climate is semi-arid (moist) and length of growing season varies from 120 to 150 days. AEZ 10 consists of Central highlands and Maharashtra plateau having Vertisols and Vertic Inceptisols. Climate is hot sub-humid (dry) and length of growing season varies from 120 to 180 days. Compared to AEZ 5 (2.21 M ha in 14 districts), area is more in AEZ 10 (2.76 M ha in 22 districts), the density of the crop and the productivity levels are higher in the former. In recent years, there has been a continuous rise in the area under soybean in the AEZ 6 (0.52 M ha), which appears to be most promising for soybean. It has registered highest productivity levels (1330 kg ha^{-1}) among all the AEZs. This zone of the Deccan plateau is spread into Maharashtra, Karnataka and parts of Andhra Pradesh; climate is hot semi-arid having Vertic Inceptisols and Vertisols and length of growing season is 90 to 150 days. In this AEZ, Maharashtra has shown the maximum increase in area and productivity and districts such as Kolhapur, Sangli, Satara and Yevatmal have registered district average yields as high as 1700 kg ha^{-1}. The coefficient of variation for productivity is high in all these three zones, viz, 21, 25 and 39% for zone 5, 10 and 6, respectively, which means a large scope for increasing the production levels exists for soybean in India.

3.4.4. Area, production and productivity in the major states

State being an administrative unit, the information on the extent of yield gaps and intervention required to fill these gaps can help the concerned states to take required action. Therefore, an attempt has been made to estimate the existing yield gaps and constraints to soybean production in major soybean growing states of India. Soybean crop is primarily cultivated in three states, viz, Madhya Pradesh, Maharashtra and Rajasthan (Table 12). Together, these three states contribute 98 and 99% of the total soybean area and production of the country, respectively. However, among these three states Madhya Pradesh with 4.23 M ha area and 4.29 M t of production is the dominant state with a net 74 and 72% contribution to total soybean area and production in the country. However, compared to average figures of 1995–98 (Table 12), the area and production figures in 2002 (Table 13) have shown substantial decline in Madhya Pradesh (3.84 M ha and 2.85 M t) and increase in Maharashtra (1.22 M ha and 1.10 M t). This increase in area has resulted in higher contribution by Maharashtra to total area and production (20 and 25%) in the country and a slight reduction for Madhya Pradesh (68 and 66% respectively). Rajasthan and other states have not shown much change in the area and production during this period while the average productivity of soybean in country in 2002 (760 kg ha^{-1}) (Table 13) was less than the average figures of 1995 to 1998 (1040 kg ha^{-1}) (Table 12).

Table 12. Area, production and productivity of soybean in different states of India (1995–96 to 1997–98).

State	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Madhya Pradesh	44	4.22	4.29	1020	30
Maharashtra	25	0.81	0.98	1210	23
Rajasthan	12	0.55	0.59	1070	15
Karnataka	15	0.05	0.03	640	34
Others	52	0.06	0.04	630	47
India	148	5.70	5.93	1040	36

Table 13. Area, production and productivity of soybean in different states of India during 2002–03.

State	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
Madhya Pradesh	3.83	2.85	740
Maharashtra	1.22	1.10	900
Rajasthan	0.42	0.21	500
Karnataka	0.08	0.05	680
Andhra Pradesh	0.04	0.03	690
Chattisgarh	0.04	0.03	670
Others	0.04	0.03	670
India	5.67	4.30	760

Source: Ministry of Agriculture, Govt. of India, 2004.

The initial spread in area of the crop has helped to bring large fallow lands during rainy season into cultivation particularly in Madhya Pradesh. Recent interest shown by many State Governments across India in introducing soybean as one of the major crops, is helping the country to diversify crops. Soybean, hence, has a good potential as an alternative crop in many states with diverse agroecological conditions.

3.5 Observed Rainfed Potential Yield of Soybean

3.5.1 Observed experimental, on-farm and district yields

Average and range of experimental station and on-farm yields over years across different locations of AICRPS in India are presented in Table 14. Across locations, depending upon the rainfall, soil and other location specific factors, the mean experimental station and on-farm yields ranged from 1160 (Imphal) to 3580 (Pune) and 980 (Jabalpur) to 2130 kg ha^{-1} (Indore), respectively. The district average yields for the corresponding years for which experimental station yield were collected for each location ranged from 600 (Berhampore) to 1260 (Parbhani). In general, the experimental station and on-farm yields were considerably higher than the district average yields at all locations. When averaged over all the locations across India, the mean experimental station, on-farm and district average yields were 2300, 1760 and 930 kg ha^{-1}, respectively. Thus, there was on an average 23 and 47% reduction in yield from experimental station to on-farm and from on-farm to district level, respectively.

Minimum and maximum values and the coefficient of variation (CV) for each location presented in the table below indicates the variability observed over the years in the yield of soybean crop at each location. Depending on the location, the CV in yield ranged from 11 to 72, 7 to 35 and 12 to 75% for experimental station, on-farm and district average yields, respectively. Variation in yields over the years at each location reflects the uncertainty of climatic factors in rainfed environment, particularly that of rainfall leading to poor stability in the yield of soybean over years. As the experimental station yields are point observations, its CV is expected to be the same or higher than that of the district average yields, which are based on large area estimation and the crops produced with conservative management. This phenomenon was mostly true for the primary zone. However, the reverse happened for some locations in the tertiary zone which could be attributed to the differences in crop management between locations or supplemental irrigation given to the experimental plots in low rainfall years as indicated by relatively higher values of the minimum yields. Over all the locations, average minimum experimental station yield (1510 kg ha^{-1}) was just half of that of average maximum value (3160 kg ha^{-1}). Similarly, over the locations, the average minimum yields were 47 and 71% less than the maximum on-farm and district average yields, respectively (Table 14).

Table 14. Observed experimental station, on-farm and district average yields (kg ha^{-1}) of soybean at different AICRP locations across India.

	Experimental station				On-farm				District Average[1]			
Location	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]
Primary Zone												
Sehore	1340	2980	2230	25	1340	2390	1790	23	820	1120	960	12
Indore	1390	3230	2310	27	1300	2960	2130	28	880	1490	1100	16
Kota	1750	3600	2380	24	870	3500	1870	35	510	1480	1120	24
Amlaha	1070	3050	2020	42	-	-	-	-	770	1120	980	13
Nagpur	1180	3510	2150	29	-	-	-	-	720	1190	920	14
Secondary Zone												
Amravati	1100	2460	1780	25	-	-	-	-	760	1450	1050	21
Tertiary Zone												
Jabalpur	940	2405	1770	32	720	1440	980	27	580	1110	810	24
Raipur	1740	3220	2390	19	1430	2410	1770	22	670	1110	900	18
Parbhani	2060	3850	3130	16	1660	2230	1980	10	860	1770	1260	23
Dharwad	2480	3140	2660	11	1950	2810	2110	16	400	1090	720	31
Pantnagar	1340	3720	2420	27	580	2440	1890	28	450	1510	790	47
Jalna	2190	3160	2520	14		-	-	-	490	1510	1080	38
Others												
Pune	2810	4280	3580	12	1680	2610	2090	12	670	2000	1100	37
Bangalore	1350	3240	2550	22	1350	2030	1580	13	490	1130	800	23
Palampur	1740	2530	2130	11	790	2180	1630	28	380	1830	910	75
Lam	1680	2980	2150	18	1360	2800	2040	21	320	1050	910	26
Almora	1190	3210	2060	25		-	-	-	500	1080	680	32
Kangra	1480	3410	2570	34		-	-	-	330	1830	1070	68
Berhampore	2210	2820	2600	13		-	-	-	520	750	600	12
Coimbatore	1320	2400	1770	20	1220	1890	1420	17		*	*	*
Ludhiana	1250	3430	2230	34	1310	1510	1400	7		*	*	*
Imphal	400	2050	1160	72		-	-	-		*	*	*
Delhi	1150	4150	2330	47		-	-	-		*	*	*
Hisar	760	3020	2070	40		-	-	-		*	*	*
Ranchi	1930	3130	2520	16		-	-	-		*	*	*
Mean	1510	3160	2300		1260	2370	1760		390	1350	930	
CV[3]	17	36	20		31	24	19		31	25	18	

- FLDs not conducted.
* District/state average yields are not available due to negligible area under soybean.
1 District yields are for the corresponding years for which experimental station data were collected (Annexure II).
2 CV = Coefficient of variation (%) for mean yield of a location over years.
3 CV = Coefficient of variation (%) for mean yield over locations.

3.6 Simulated Rainfed Potential Yields

3.6.1 Potential yield at selected locations

Depending on the climatic conditions and soil type, large variation in mean simulated yield across the locations and over the years at a given location was observed (Table 15). When averaged over all the locations across India, the mean simulated yield was 2090 kg ha^{-1} with a CV of 30% across these locations. The mean simulated yield ranged from 290 (Coimbatore) to 3430 kg ha^{-1} (Pantnagar,

Table 15. Simulated grain yield, crop season rainfall and district average yield of soybean at selected locations across India.

Location	Simulated yield (kg ha^{-1})				Crop season rainfall (mm)				District yield[1] (kg ha^{-1})
	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	
Primary Zone									
Dhar	630	4320	2670	36	600	1490	910	24	950
Hoshangabad (Jamra)	1850	3360	2690	17	570	1980	1180	26	1130
(Saunther)	1430	3190	2300	21	570	1970	1170	26	1130
Indore (Sarol)	920	3410	2520	31	450	1450	930	26	1150
(Kamliakheri)	220	3180	1790	45	450	1450	920	26	1150
Kota	120	3820	1340	76	300	1480	680	39	1140
Nagpur	1010	2770	2050	23	550	1460	950	23	900
Rajgarh (Jamra)	490	2950	1880	39	420	1700	950	30	970
(Saunther)	380	2790	1450	47	420	1700	950	30	970
Shajapur (Sarol)	820	3550	2070	40	590	1750	950	25	1010
(Saunther)	680	3420	1790	47	590	1750	950	25	1010
Ujjain	780	3010	2080	36	450	1820	890	33	1100
Secondary Zone									
Amravati	600	3040	1790	42	500	1150	770	26	1130
Betul	1080	3290	2420	25	570	1540	1090	22	760
Bhopal (Jamra)	820	3260	2410	27	460	1680	1010	27	890
(Saunther)	440	3090	2070	34	460	1680	1020	27	890
Guna (Jamra)	220	3600	2150	49	330	1740	960	32	790
(Saunther)	250	3160	1660	60	330	1740	960	32	790
Raisen	510	4840	3260	16	440	1580	1050	28	1130
Ratlam	630	3190	2080	41	580	1850	1020	30	1250
Sagar	720	3280	2150	30	440	2050	1140	31	840
Vidisha	1030	3640	2540	23	560	1630	950	25	950
Wardha	2030	3940	3060	20	560	1570	970	23	1040
Tertiary Zone									
Akola	140	2640	1510	53	280	1190	700	30	1250
Belgaum	860	2840	1920	31	560	1560	960	23	640
Dharwad (Hogaluru)	0	3040	1740	52	40	780	420	39	630
(Achmatti)	0	2520	1150	66	40	780	420	39	630
Jhabua	160	3070	2260	37	290	1420	790	33	680
Jabalpur	1340	2800	2390	17	590	1990	1240	24	860
Nanded	370	3820	1850	57	310	1510	780	32	1130
Parbhani	1160	3260	2040	27	470	1550	830	36	1130
Pantnagar	3140	3960	3430	7	760	2920	1360	44	780
Raipur	2350	3450	2890	10	630	1640	1050	25	870

Continued...

Table 15. *Continued.*

Location	Simulated yield (kg ha^{-1}) Min	Max	Mean	CV[2]	Crop season rainfall (mm) Min	Max	Mean	CV[2]	District yield[1] (kg ha^{-1})
Others									
Bangalore	790	3190	2200	34	310	900	520	34	670
Coimbatore	30	570	290	65	180	460	300	34	180
Pune (Dholwad)	440	3560	2570	35	300	910	580	31	1560
(Nimone)	140	3380	1760	53	330	910	590	29	1560
Delhi	0	3750	2000	64	190	1170	680	40	*
Hisar	0	1240	310	120	20	960	420	59	*
Hyderabad (Deep)	1050	3470	2720	22	470	1290	720	31	*
(Shallow)	1080	3440	2730	21	470	1290	720	31	*
Ludhiana	0	4240	2120	7	220	1090	590	39	*
Nimuch	230	3000	1790	45	310	1470	750	32	*
Mean	720	3240	2090		420	1490	860		930
CV[3]	94	22	30		40	29	28		24

In parentheses are the soil series.
[1]District yields are average of 1995–96 to 1998–99.
*District/state average yields are not available due to negligible area under soybean.
[2]CV = Coefficient of variation (%) for mean value of a location over years.
[3]CV = Coefficient of variation (%) for mean value over locations.

Uttaranchal). The maximum yield at each location was obtained in those seasons when rainfall was well distributed and the onset of monsoon was timely. The yields thus obtained represented the full yield potential (water non-limiting) of soybean at these sites. The maximum yield across locations ranged from 570 (Coimbatore) to 4840 (Raisen, Madhya Pradesh). Barring a few locations such as Coimbatore and Hisar which had very low average rainfall (300 and 420 mm, respectively), the average yield (about 2000 kg ha^{-1} and above) and maximum yields (about 3000 kg ha^{-1} or more) clearly indicated a good potential for soybean crop at these sites. The minimum yield at these sites was highly variable and at times the crops failed altogether in some of the years at some of the locations (Delhi, Ludhiana, Hisar and Dharwad). Besides rainfall, soil type also plays a critical role in crop production. It was evident that, when at the same location two different but predominant soils series were used, the minimum, maximum and mean yield obtained differed greatly.

It is normally expected that simulated yields will be closer to or slightly higher than the experimental station yields, as all the factors determining the productivity of a crop cannot be controlled under the field conditions. In our study, there were 15 common sites for which both the simulated and experimental station data were available. The mean experimental yields were higher than the simulated yields at some of the locations. Majority of these locations such as Coimbatore, Hisar, Dharwad, Pune and Parbhani are in the agroecological zones where seasonal rainfalls are low. Hence, due to the rainfed nature of experimental station trials, irrigations are provided at times to save the crop from extreme drought-like situations, or in case of complete crop failure the yield data were not reported. This was also evident from the fact that the differences in minimum yields of observed and simulated data were much higher than those for the maximum yields obtained over years at these locations. Another reason for differences between the simulated and observed yields could be that the total number of years accounted for simulation was very high (approx. 30 years). This captured the climatic variability effects on crop yields more than the experimental station data available for limited years.

3.6.2 Potential yield of production zones

Locations situated in different crop production zones; AEZs and states were grouped together. The minimum, maximum and average simulated yield and crop season rainfall among the locations in each group is presented in Table 16. The average potential rainfed yield among the three major production zones (primary, secondary and tertiary) was between 2050 and 2330 kg ha^{-1}. In the production zone designated as 'others', the yield was marginally low (1850 kg ha^{-1}). The CV in potential yield among locations was very low (CV=21%) for the primary and secondary zones as compared to tertiary zone (CV=30%) and 'others' (48%).

3.6.3 Potential yield of agroecological zones

In the major AEZs 5 (semi-arid ecosystem) and 10 (sub-humid ecosystem), covering more than 87% of soybean area of the country, the average potential rainfed yield was 2110 and 2250 kg ha^{-1} respectively (Table 16). In AEZ 6 where a rapid increase in the area under soybean has been observed in recent years, the average potential rainfed yield was marginally low (1810 kg ha^{-1}). However, CV of simulated yield among locations within these three zones was the same (21%).

3.6.4 Potential yield of major states

Among the states, both Madhya Pradesh and Maharashtra, which account for more than 90% of total soybean area and production in the country, the average simulated potential rainfed yield was 2200 and 2080 kg ha^{-1} respectively (Table 16). The potential was found to be marginally low in Karnataka (1750 kg ha^{-1}) while Rajasthan for which the weather data were available for only one predominant location (Kota) showed very low simulated potential rainfed yield of 1340 kg ha^{-1}.

Table 16. Rainfed potential yield of soybean and average crop season rainfall in different production zones, AEZs and states of India.

Zone/State	No. of location	Simulated yield (kg ha^{-1})				Crop season rainfall (mm)			
		Min	Max	Mean	CV	Min	Max	Mean	CV
Production Zone									
Primary	8	1340	2690	2050	21	680	1180	950	13
Secondary	9	1660	3260	2330	21	770	1140	1000	10
Tertiary	9	1150	3430	2120	30	420	1360	860	36
Others	8	290	2730	1850	48	300	750	590	25
AEZ									
5	6	1340	2670	2110	21	680	1020	880	12
6	8	1150	2570	1810	20	420	960	680	26
10	12	1450	3260	2250	21	950	1240	1030	10
State									
Madhya Pradesh	15	1450	3260	2200	18	750	1240	990	12
Maharashtra	7	1510	3060	2080	24	580	970	770	19
Rajasthan	1	1340	-	1340	-	-	-	680	-
Karnataka	3	1750	2200	1750	-	420	960	580	-

CV = Coefficient of variation (%).

In general, the simulation studies indicated that major soybean growing zones and states in the country have a rainfed yield potential of more than 2000 kg ha^{-1}, which is more than double compared to existing national productivity (less than 1000 kg ha^{-1}) of soybean. Moreover the relatively low productivity and its high variability in some of the zones appear to be so because of the low and highly variable rainfall received by these zones as compared to others (Table 16).

3.7 Yield Gaps

3.7.1 Yield gaps of selected locations

The magnitude of YG I and II in soybean are presented in Table 17. Across the locations, average yield gap I was 640 and ranged from 110 (Lam, Andhra Pradesh) to 1500 kg ha^{-1} (Pune, Maharashtra). The average YG II was 870 kg ha^{-1} and ranged from 170 (Jabalpur, Madhya Pradesh) to 1390 kg ha^{-1} (Dharwad, Karnataka). Considerably high values of coefficient of variation for YG I (59%) and YG II (34%) were recorded indicating different levels of these yield gaps across locations in India. The high variation in YG II across locations indicated the varying levels of adoption of technology and improved cultural practices among the average farmers at these locations. YG II was more than 700 kg ha^{-1} for all the locations except for Jabalpur. The extent of yield gaps particularly that of YG II (870 kg ha^{-1}) indicated that there is considerable scope to improve the productivity levels of soybean in India provided the reasons for these yield gaps are understood and proper interventions are made to abridge these gaps.

Table 17. Yield gaps of soybean at different AICRP locations across India.

	Yield gap (kg ha^{-1})							
	YG I				YG II			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone								
Sehore	0	1050	440	90	280	1340	830	48
Indore	0	720	180	146	40	1980	1030	60
Kota	70	1280	510	77	330	2300	740	77
Tertiary Zone								
Jabalpur	600	1360	790	40	20	330	170	93
Raipur	1	890	620	51	380	1560	870	49
Parbhani	220	1870	1160	46	440	1290	720	40
Dharwad	0	1160	560	65	1010	2030	1390	23
Pantnagar	0	1490	530	104	130	1570	1100	47
Others								
Pune	950	2180	1500	28	380	1430	990	39
Bangalore	0	1780	960	64	350	1400	790	41
Palampur	0	1030	490	89	140	1680	720	79
Lam	0	1140	110	386	380	1410	1130	36
Coimbatore	0	950	360	94		-	-	-
Ludhiana	100	1570	830	104		-	-	-
Mean	140	1320	640		350	1530	870	
CV[2]	205	32	59		74	32	34	

1 CV = Coefficient of variation (%) for mean yield gap of a location over years.
2 CV= Coefficient of variation (%) for mean yield gap over locations

Besides considerable spatial variability, a high degree of temporal variation in these yield gaps was also observed (Table 17). Depending on the location, coefficient of variation for year-to-year variability in YG I and YG II ranged from 28 to 386% and 23 to 93%, respectively. Large year-to-year variation in the yield gaps resulted in very narrow yield gaps in some years while in others the gaps were very wide at a given location. In general, it was observed that the yield gaps at given locations were narrow in those years in which the potential (experimental station) and achievable yields (on-farm) were low (Annexure II). In other words, these were the years when climatic conditions were unfavorable and particularly the rainfall received was much below the requirement of the crop.

3.7.2 Yield gaps of production zones

Across various crop production zones, YG I ranged from 130 to 380 and 290 to 740 kg ha^{-1} when estimated by using simulated and experiment station yields, respectively (Table 18). The magnitude of YG II was the maximum for primary production zone (850 kg ha^{-1}) followed by secondary (730 kg ha^{-1}) and in the zone designated as 'others' (690 kg ha^{-1}). As no on-farm data were available for any location in secondary zone, YG II could not be estimated.

Table 18. Yield gaps of soybean in different production zones of India.

	Primary	Secondary	Tertiary	Others
	(kg ha^{-1})			
Grain yield				
Simulated mean	2050	2330	2120	1850
Experimental mean	2220	1780	2480	2290
On-farm mean	1930	-	1740	1690
Districts' mean*	1070	1010	1010	1000
Yield gap				
Simulated – On-farm (YG I)	130	-	380	160
Experimental station – On-farm (YG I)	290	-	740	590
On-farm – District (YG II)	850	-	730	690

* Mean of all the districts for each soybean production zone (Table 10).

3.7.3 Yield gaps of agroecological zones

Among the agroecological zones, the YG I ranged from 0 to 870 and 340 to 670 kg ha^{-1} when estimated by using average simulated and experimental station yields, respectively (Table 19). The YG II was very wide for AEZ 5 (920 kg ha ha^{-1}) as compared to AEZ 6 (730 kg ha^{-1}) and AEZ 10 (410 kg ha^{-1}).

3.7.4 Yield gaps of major states

Across different states, the YG I ranged from 0 to 570 and 120 to 760 kg ha^{-1} as per the average simulated and experiment station yields, respectively (Table 20). YG II was wide in Karnataka (1200 kg ha^{-1}) followed by Maharashtra (820 kg ha^{-1}) Rajasthan (800 kg ha^{-1}) and Madhya Pradesh (620 kg ha^{-1}).

YG I is considered difficult to abridge because of environmental differences between on-farm and research station situations such as very small plot sizes with optimum homogeneity and the technical expertise available at research stations and theoretically optimum conditions created during

Table 19. Yield gaps of soybean in different agroecological zones of India.

	Semi-arid		Sub-humid
	5	6	10
	(kg ha^{-1})		
Grain yield			
Simulated mean	2110	1810	2250
Experimental mean	2340	2730	2040
On-farm mean	2000	2060	1380
Districts' mean	1080	1330	970
Yield gap			
Simulated – On-farm (YG I)	110	0	870
Experiment station – On-farm (YG I)	340	670	660
On-farm – District (YG II)	920	730	410

* Mean of all the districts for each AEZ (Table 11).

Table 20. Yield gap of soybean in major states of India.

	Madhya Pradesh	Maharashtra	Rajasthan	Karnataka
	(kg ha^{-1})			
Grain yield				
Simulated mean	2200	2080	1340	1750
Experimental mean	2080	2150	2340	2600
On-farm mean	1630	2030	1870	1840
Districts' mean*	1020	1210	1070	640
Yield gap				
Simulated – On-farm (YG I)	570	49	0	0
Experiment station – On-farm (YG I)	450	120	510	760
On-farm – District (YG II)	620	820	800	1200

* Mean of all the districts for each state (Table 12).

simulations. Though YG I cannot be abridged completely, it gives an indication of the upper limits of productivity that can be achieved in a given environment. If YG I is very narrow, it indicates the need to generate further technologies that can perform still better in a given environment.

On the other hand, YG II is manageable as it is mainly due to the differences in the management practices and input use. In case of soybean, on an average, this gap is 800–900 kg ha^{-1} and varies to a great extent among different major soybean regions such as AEZs and states of India. While the reasons for variation among different regions need to be understood, the narrowing of such a large gap can help in doubling the production of soybean in the country.

3.8 Water Balance of Selected Locations

Looking at the importance of rainfall and soil moisture availability for soybean production, the various aspects of water balance components observed during simulations at different locations across India are presented in Tables 21a & b. A considerable spatial and temporal variation in seasonal rainfall, surface

Table 21a. Long-term average water balance components (mm) of simulated soybean at selected locations across India.

	Rainfall				Surface runoff				Deep drainage			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Dhar	596	1492	906	24	75	648	255	56	0	317	84	116
Hoshangabad (Jamra)	572	1975	1175	26	123	901	400	47	3	635	263	57
(Saunther)	572	1967	1174	26	135	917	412	46	86	698	332	44
Indore (Kamliakheri)	449	1447	924	26	76	825	323	49	54	437	225	36
(Sarol)	449	1447	925	26	77	824	325	49	0	294	79	91
Kota	300	1475	683	39	24	656	212	69	0	183	39	145
Nagpur	553	1463	953	23	83	673	298	44	0	321	135	65
Rajgarh (Jamra)	423	1701	948	30	71	826	328	55	0	439	152	70
(Saunther)	423	1701	948	30	80	838	337	54	39	506	224	48
Shajapur (Sarol)	589	1751	952	25	77	842	320	55	0	447	113	87
(Saunther)	589	1751	952	25	78	844	321	55	46	554	218	47
Ujjain	454	1821	893	33	98	930	315	57	0	404	90	118
Secondary Zone												
Amravati	496	1151	767	26	41	453	212	54	0	50	9	196
Betul	574	1544	1092	22	138	691	367	42	0	306	120	78
Bhopal (Jamra)	462	1684	1014	27	72	761	337	48	0	455	191	61
(Saunther)	462	1684	1015	27	76	776	348	47	70	520	262	43
Guna (Jamra)	330	1743	961	32	69	963	353	57	0	237	122	65
(Saunther)	330	1748	961	32	72	969	361	56	0	306	192	45
Raisen	444	1575	1052	28	70	671	305	64	0	207	109	67
Ratlam	582	1851	1018	30	146	890	378	49	17	399	153	73
Vidisha	562	1627	950	25	90	680	245	65	0	444	150	72
Wardha	564	1568	970	23	87	719	293	48	0	333	125	78
Tertiary Zone												
Akola	278	1191	702	30	37	444	199	49	0	109	7	355
Belgaum	558	1557	956	23	97	742	308	39	0	288	108	80
Dharwad (Hogaluru)	41	776	422	39	0	170	60	74	0	0	0	0
(Achmatti)	41	776	423	39	0	177	71	63	0	47	2	512
Jhabua	293	1421	794	33	60	550	174	96	0	374	75	122
Jabalpur	592	1986	1241	24	124	1000	368	63	0	576	343	44
Nanded	309	1509	784	32	32	600	190	71	0	98	6	356
Parbhani	470	1548	832	36	69	500	209	61	0	425	68	178
Pantnagar	759	2915	1358	44	87	1202	385	76	74	1070	391	72
Others												
Bangalore	305	895	515	34	1	194	59	87	136	480	251	41
Coimbatore	183	455	296	34	7	56	25	59	0	0	0	0
Pune (Dholwad)	297	908	581	31	11	228	76	74	0	274	77	124
(Nimone)	329	908	588	29	60	399	169	56	0	113	18	199
Raipur	628	1636	1050	25	92	460	234	45	0	595	256	58
Delhi	190	1171	675	40	15	483	204	56	0	159	29	172
Hisar	18	957	416	59	0	604	147	114	0	0	0	0
Hyderabad (Deep)	466	1293	719	31	51	705	195	682	0	195	29	183
(Shallow)	466	1293	719	31	49	699	194	68	0	229	44	149
Ludhiana	217	1091	590	39	6	467	110	105	0	193	27	195
Nimuch	306	1467	747	32	27	686	232	64	0	433	85	108
Mean	418	1487	855		64	664	257		12	343	127	
CV[2]	40	29	28		61	38	41		242	63	83	

Table 21b. Long-term average water balance components (mm) of simulated soybean at selected locations across India.

Location	Evapo-transpiration				Extractable water*			
	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone								
Dhar	301	615	434	19	47	187	133	25
Hoshangabad (Jamra)	284	600	395	18	79	164	116	14
(Saunther)	254	579	382	19	18	87	49	28
Indore (Kamliakheri)	247	553	355	19	5	47	21	60
(Sarol)	284	558	381	16	36	185	142	22
Kota	118	488	323	25	8	221	109	58
Nagpur	289	471	395	11	97	156	126	15
Rajgarh (Jamra)	242	483	359	17	48	152	108	19
(Saunther)	238	470	344	18	22	80	43	51
Shajapur (Sarol)	255	522	373	19	79	182	145	16
(Saunther)	237	514	363	20	31	70	50	27
Ujjain	241	448	356	15	69	185	132	20
Secondary Zone								
Amravati	266	543	388	18	29	273	158	49
Betul	282	459	370	13	155	290	235	13
Bhopal (Jamra)	263	436	365	11	68	166	120	19
(Saunther)	244	424	355	12	18	88	51	34
Guna (Jamra)	238	512	381	19	18	156	105	24
(Saunther)	220	497	364	20	21	79	45	28
Raisen	355	660	535	16	19	151	103	27
Ratlam	226	449	338	18	113	195	149	16
Vidisha	281	563	447	22	41	156	109	20
Wardha	337	525	445	11	58	178	108	37
Tertiary Zone								
Akola	223	469	357	18	17	291	139	49
Belgaum	313	491	385	14	127	192	155	13
Dharwad (Hogaluru)	44	369	278	30	0	237	77	75
(Achmatti)	45	364	259	31	0	188	92	55
Jhabua	215	530	419	25	7	190	127	33
Jabalpur	275	461	393	15	111	169	138	9
Nanded	245	652	441	25	22	280	148	53
Parbhani	302	420	364	10	88	279	191	32
Pantnagar	429	518	478	6	35	208	105	42
Others								
Bangalore	259	391	326	10	52	154	96	31
Coimbatore	128	286	203	27	10	129	68	69
Pune (Dholwad)	249	400	346	11	30	130	82	39
(Nimone)	231	388	329	11	14	133	71	52
Raipur	350	454	396	7	94	220	163	19
Delhi	162	488	390	26	2	172	51	83
Hisar	20	386	256	40	0	56	14	115
Hyderabad (Deep)	313	448	393	9	15	203	103	57
(Shallow)	317	449	393	9	15	157	89	51
Ludhiana	207	557	406	21	1	151	47	79
Nimuch	181	476	327	20	25	152	103	29
Mean	243	479	371		42	170	105	
CV[2]	33	17	16		92	36	43	

In parenthesis are the soil series.
* Extractable water retained in the soil profile at harvest of soybean crop.
[1]CV = Coefficient of variation (%) for mean value of a location over years.
[2]CV = Coefficient of variation (%) for mean value over locations.

runoff and deep drainage was observed. The mean value over locations for these parameters was 855, 257 and 127 mm, respectively. The CV across locations was 28, 41 and 83% for rainfall, surface runoff and deep drainage, respectively (Table 21a). The estimated runoff across the locations ranged from 8 to 38% of the total seasonal rainfall received. Hence, there is a great scope at many locations for harnessing excess water and its efficient use in soybean growing regions. Evapo-transpiration (ET), which has strong positive association with total biomass and yield, also exhibited a considerable variability across locations as well as over years at a given location (Table 21b).

Among different production zones, the mean rainfall (995 mm), evapo-transpiration (396 mm) and runoff (327 mm) were the highest for secondary zone followed by primary and tertiary zones, respectively (Table 22). Among the major soybean growing AEZs, the mean rainfall (1020 mm), runoff (337 mm) and the ET (390 mm) were highest for AEZ 10 (Table 23). Among the states, the mean values for these parameters were highest for Madhya Pradesh (990, 327 and 382 mm, respectively) as compared to other states (Table 24). The variation in the mean rainfall and the PET partly explains the variations observed in the potential rainfed yields of soybean among various zones/states.

Table 22. Water balance components (mm) of soybean in different production zones of India.

	Primary		Secondary		Tertiary	
Water balance component	Mean	Range	Mean	Range	Mean	Range
Rainfall	953	683–1175	995	767–1144	835	422–1358
Evapo-transpiration	371	323–434	396	338–535	375	259–478
Surface runoff	320	212–412	327	212–396	218	60–385
Deep drainage	163	39–332	154	9–267	111	0–391

Table 23. Water balance components (mm) of soybean in different agroecological zones of India.

	Rainfall		Runoff		Drainage		Evapo-transpiration	
AEZ	Mean	Range	Mean	Range	Mean	Range	Mean	Range
5	878	683–1018	283	174–378	106	39–225	372	323–434
6	680	422–956	173	60–308	38	0–108	347	259–441
10	1020	948–1241	337	245–412	191	109–343	390	344–535

Table 24. Water balance components (mm) of soybean in major states of India.

	Rainfall		Runoff		Drainage		Evapotranspiration	
State	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Karnataka	558	422–956	103	59–308	144	0–251	317	259–385
Maharashtra	772	581–970	206	76–298	56	6.46–135	383	329–445
Madhya Pradesh	990	746–1241	327	174–412	175	75–343	382	327–535
Rajasthan	683	-	212	-	39	-	323	-

3.9 Major Constraints and Opportunities for Abridging Yield Gaps

Several biotic, abiotic and socioeconomic constraints to soybean productivity in India have been identified (Joshi and Bhatia 2003, Bhatnagar and Joshi 2004, Singh et al. 2002). These constraints are:

- Undependable weather in terms of onset of rainy season and amount of rainfall and its distribution during the soybean growing period.
- Land degradation in the form of soil erosion, waterlogging and nutrient depletion.
- Inefficient use of natural resources, particularly rainfall.
- Inappropriate soil and water management practices.
- Imbalance in use of chemical fertilizers and biofertilizers.
- Infestation by weeds, pests and diseases.
- Lack of region-specific high yielding and tolerant varieties to various abiotic and biotic stresses.
- Low adoption of improved varieties of variable duration and unavailability of quality seeds.
- Inadequate use of improved farm equipment for various field operations such as sowing and harvesting.
- Inaccessibility to knowledge and inputs of improved technologies and low adoption of scientific crop production practices.
- Meager credit facilities to small farmers for appropriate investments.

Perhaps among all the above factors, unpredictable nature of rains in terms of total rainfall and its onset and distribution, is the predominant constraint to soybean. This constraint was evident when the average simulated rainfed yield of locations and district average yield (excluding Kota and Pune due to considerable soybean area under irrigation) were plotted against the average crop season rainfall (Table 15). Both the simulated and district average yield showed a significant and positive curvilinear relationship (R^2 = 0.41 and 0.49, respectively) with average crop season rainfall (Figs. 5 and 6). The spread of yield data around the fitted regression line indicates the effect of rainfall distribution on the yield of soybean in addition to other yield limiting factors. However, the simulated yields increased

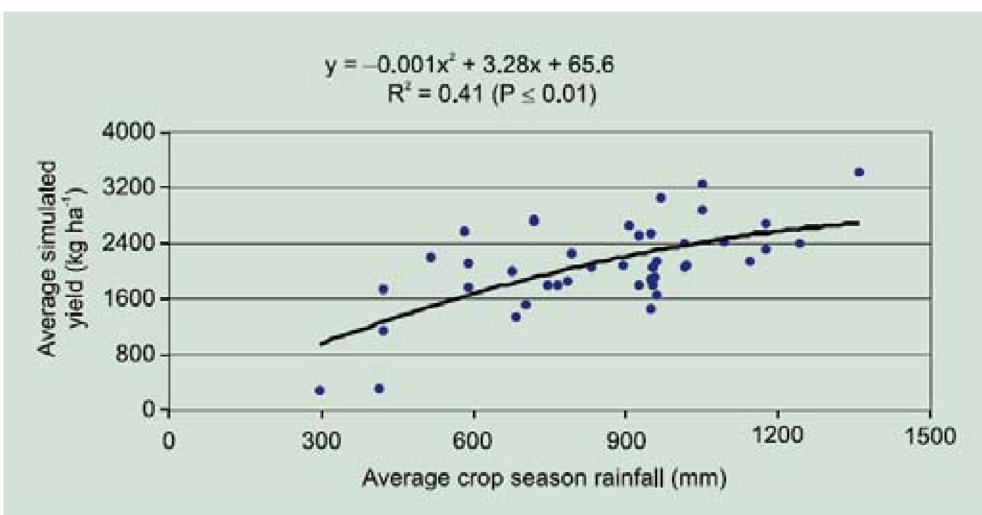

Figure 5. Relationship between average simulated rainfed yield and average crop season rainfall at selected locations across India (n = 43).

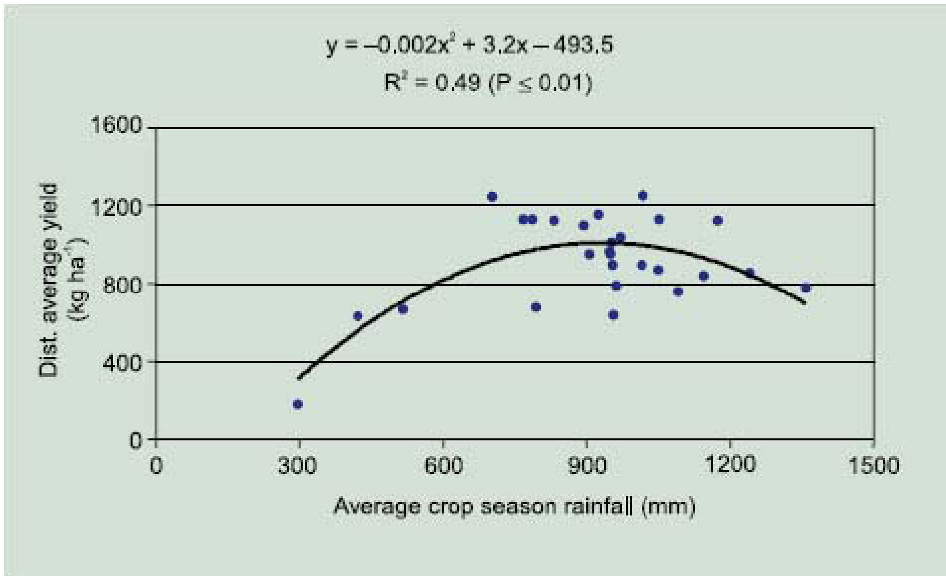

Figure 6. Relationship between district average yield and average crop season rainfall at selected locations across India (n = 27).

linearly at a faster rate up to ~900 mm of rainfall after which the rate of increase slowed down. As against this, the district average yield also increased in a curvilinear manner with the increase in the average crop season rainfall, but the rate of increase and the linearity of response occurred only up to ~650 mm. Between ~650 and ~900 mm, the district average yields gradually leveled off and further increase in the average crop season rainfall beyond 900 mm, resulted in a negative impact as the district yield showed a sharp decline (Fig. 6). The negative impact of rainfall beyond 950 mm in case of district yields could be due to poor drainage of water and resultant waterlogging conditions in the farmers' fields.

It was observed that the YG I and II (Section 3.7) were narrow during the years when climate was not favorable. To confirm this phenomenon, the differences between simulated yield and average district yield (Table 15), which reflect the total YG of these locations, were plotted against the crop season rainfall and a significant positive relationship (R^2 = 0.37) was observed (Fig. 7). As in the case of simulated and district average yields, the relationship was again curvilinear but the pattern was just opposite. The total yield gap decreased in a curvilinear manner with the decrease in rainfall. A major decline started with the decrease in rainfall up to ~700 mm and when it decreased below ~600 mm it gradually leveled off. The relationship clearly indicated that yield gaps across locations were of higher magnitude when available soil moisture was optimal due to higher rainfall regime; while at locations with low average rainfall (sub-optimal availability of soil moisture) the yield gaps were narrow.

The above relationships indicate that optimum use of nutrients and improved management practices are the main factors responsible for higher yields in simulation (and also at experimental station and on-farm level). As these factors strongly interact with climate and particularly with the availability of soil moisture, the positive impact of these factors is maximum when enough soil moisture is available in the soil. The flattening of the district yields above seasonal rainfall of ~650 mm indicates the lack of optimal use of nutrients and poor adoption of improved technology by the average farmer. On the other hand, under sub-optimal soil moisture conditions due to low rainfall in a given environment, the impact of these factors are reduced considerably. Under such a situation, the yield at a given location

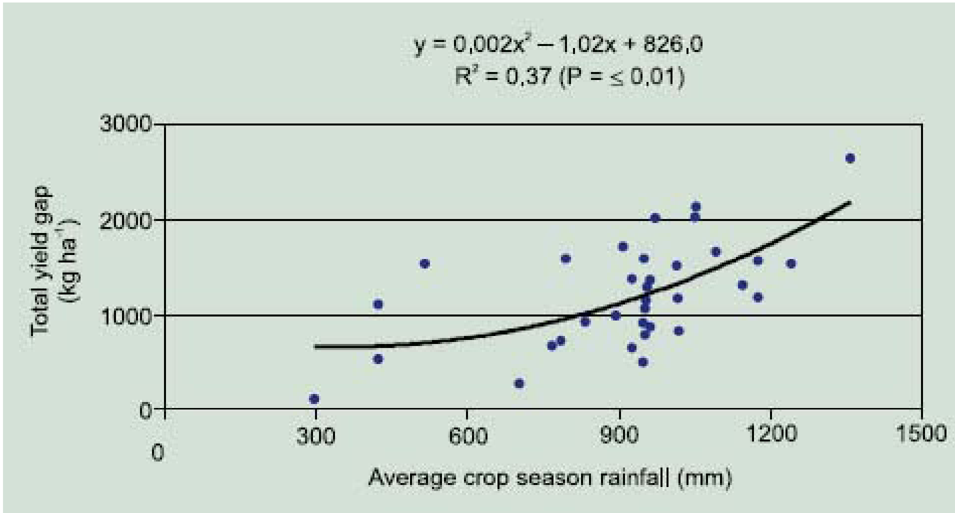

Figure 7. Relationship between total yield gap (difference between average simulated rainfed and district average yields) and average crop season rainfall at selected locations across India (n = 34).

is mostly governed by the environmental factors at all the technology levels (simulated, experimental station, on-farm and average farmer's management) and yields obtained at all the levels do not vary considerably and resultant yield gaps are also low/negligible (Fig. 7). Thus low rainfall environments warrant the development of high yielding drought resistance varieties with better water use efficiency. Adoption of proven technologies such as improved watershed management along with improved land surface management (raised-and-sunken beds, ridge-and-furrow system, broadbed-and-furrow system, etc) and water harvesting can help in more water availability during stress periods. Thus efficient use of water and nutrients could lead to improvement in productivity of soybean in the country.

Due to high degree of sensitivity to photoperiod, planting time is another important factor, which determines soybean productivity (Board 1985, Bhatia et al. 1999). Planting of rainfed crops in India depends on the onset of monsoon, which has been erratic over the years. In the present study, most locations showed a negative association of planting time with yield simulated for a number of years indicating that delayed planting has a negative impact on the soybean yield realized by the farmers. When the average planting time was plotted against average simulated yields across the locations (Fig. 8), a significant curvilinear relationship was observed (R^2 = 0.34). The optimum yield was observed at the locations when the average planting date was about 15th June (165 Julian day). Planting of soybean before or after this date resulted in decline in yield. However, rate of decrease in yield was much steeper when planting was delayed. This clearly indicates that, the sowing time available for obtaining optimum yield in soybean is limited. The planting of soybean at its optimum time was however, not possible in many years due to erratic nature of monsoon arrival resulting in sub-optimum yields in major soybean growing regions.

It is reported that the majority of varieties released in India are highly sensitive to photoperiod (Bhatia et al. 2003). Development of varieties, which are insensitive/less sensitive to photoperiods and hence, adapted to a wider range of planting dates could further help in realizing the optimum yields of soybean in India.

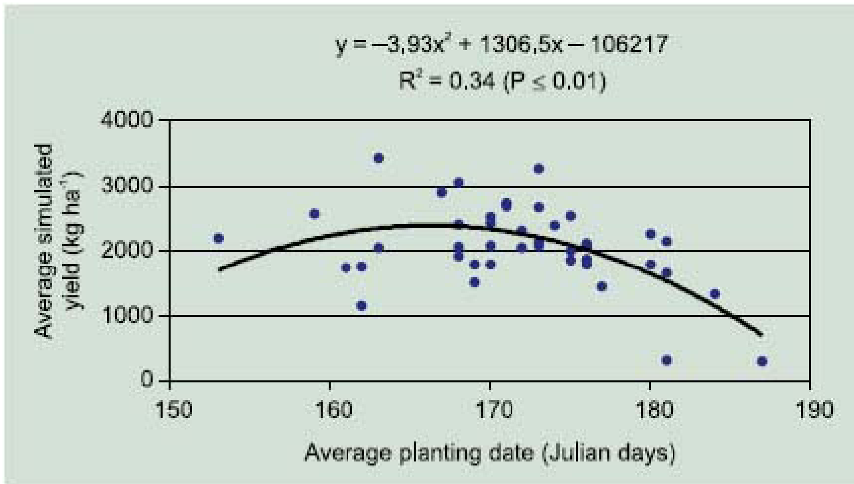

Figure 8. Relationship between average simulated rainfed yield and average planting time at selected locations across India (n = 43).

3.10 Summary

Soybean has established itself as an important oilseed crop in the rainfed agroecosystem of Central peninsular India. Besides being a cash crop for the resource-poor farmers, it significantly meets the edible oil need of the country. It is currently cultivated in about six million hectares. The productivity of soybean, however, continues to be about one t ha^{-1}, which is much below its potential. There are several biophysical, technical and socioeconomic constraints, which limit the productivity of soybean in India. In order to mitigate these limitations, it is essential to have an assessment of production potential of the environment in relation to achievable and current level of productivity as well as the availability of the natural resources. Therefore, the study was undertaken: a) to analyze the soybean area in terms of intensity of distribution in different districts (production zones), agroecological zones (AEZs) and states across India; b) to estimate the simulated water limited potential yield, achievable yield and current yield levels of average farmers in these regions; c) to quantify the extent of yield gap I and II; and d) to find out the possible reasons and ways to mitigate these yield gaps.

Using soybean simulation model, long-term potential yield and various water balance components were estimated for 34 locations representing different regions. To supplement the estimated simulated potential yields, last ten years yield data reported from experimental stations of All India Coordinated Project on Soybean were utilized. The achievable yields for locations across the country were taken from the trials conducted in farmers' fields with improved technology under FLDs. The district average yields were taken as the average farmers yields. Based on simulated, experiment station, achievable and average farmers yields, yield gap I and yield gap II were estimated.

Analysis indicated that the crop was concentrated in the states of Madhya Pradesh, Maharashtra, Rajasthan and Karnataka, and in AEZs 5 and 6 of semi-arid and 10 of sub-humid ecosystem. However, the area under soybean is rapidly spreading in some of the existing and other states with diverse agroecological conditions. Such a spread in area indicates the potential of soybean for much needed crop diversification in the country. Major soil groups in the soybean-growing region belong to Vertisols and Vertic Inceptisols. The average crop season rainfall varies from 300 to 1400 mm. This leads to a large variability in the production environment in terms of production potential and management of natural resources.

Depending upon the agroclimatic conditions, large spatial and temporal variation was observed in the average simulated potential yield, which ranged from 290 to 3430 kg ha^{-1} across locations. Similarly, the experimental station, on-farm and average farmers yields ranged from 1160 to 3580, 980 to 2130 and 600 to 1260 kg ha^{-1}, respectively. On an average there was 23 and 47% reduction in yield from experimental station to on-farm and from on-farm to an average farmer's yield. The average long term simulated potential yield across major production zones, AEZs and states ranged from 1850 to 2330, 1810 to 2250 and 1340 to 2200 kg ha^{-1}, respectively, indicating a much higher potential than what is realized by farmers at present. The YG I, the difference between potential and achievable yield, ranged from 130 **to** 380, 0 to 870 and 0 to 570 kg ha^{-1} in different production zones, AEZs and states across India, respectively. Though, YG I cannot be abridged in totality, it gives an indication of upper limits of achievable productivity in a given environment. The narrow YG I in some of the regions indicate the need to further refine the production technology and develop varieties that can perform still better in a given environment. On the other hand YG II, which is the difference between the achievable and average farmers yields, is manageable as it is mainly due to the difference in the management practices and extent of input use. In soybean, YG II ranged from 690 to 850, 410 to 920 and 620 to 1200 kg ha^{-1} across different production zones, AEZs and states of India, respectively. The extent of YG II and a high degree of spatial and temporal variability observed across locations and different regions indicate the potential to increase soybean productivity with improved management under rainfed situation.

The water balance analysis showed a high degree of runoff at some of the centers, which ranged from 8 to 38% of the total rainfall indicating the need not only to harvest and conserve this excess water for supplemental irrigation and/or recharging groundwater, but also to conserve fertile soil.

The average simulated yields, average farmers yields as well as total yield gap across different locations showed a significant and positive but curvilinear relationship with average crop season rainfall (R^2=0.41, 0.49 and 0.37, respectively). However, the rate of increase with increasing crop season rainfall (up to ~900 mm) was higher for simulated yield as compared to average farmers yield, which showed a linear increment only up to ~650 mm. Consequently, the yield gaps were of higher magnitude with higher amount of average seasonal rainfall across seasons/locations. The relationships indicate that sub-optimal water availability and resultant subdued expression of improved management practices (cultural and nutrient availability) are the major factors for lower potential yield in rainfed environments of many locations and regions. It also indicates that higher increase in average farmers yield with improved management practices would be possible in the years of good rainfall or with supplemental irrigations. It is concluded that further development of improved genotypes with better water use efficiency and adoption of improved practices can help in raising the potential productivity and in abridging the large yield gaps of soybean in a rainfed environment. The adoption of proven technologies such as effective watershed management, switching to planting on effective land configurations (broadbed-and-furrow, ridge-and-furrow systems) and water conserving cultural methods (residue recycling, mulching, etc) can help in efficient use of water and nutrients particularly in the seasons, locations and regions with sub-optimal water availability.

4. Yield Gap Analysis of Groundnut

4.1 Abstract

Groundnut (*Arachis hypogaea* L.) continues to be the major oilseed crop of India. With about seven million hectare under cultivation, the country has the largest area under groundnut in the world. However, its productivity has stagnated to less than one t ha^{-1}, which is far below the productivity levels achieved elsewhere and the actual potential (3 to 4 t ha^{-1}) of the crop. To workout a suitable strategy to improve the productivity levels of groundnut, it is imperative to assess the potential yield in the region of interest and the gap between the potential and actual yield obtained by the farmers. This analysis in turn also helps to know the major constraints causing these yield gaps for a given location or a region. In the present study, the long-term average rainfed potential yield and water balance of groundnut for 20 locations representing different regions across India, was estimated using CROPGRO-groundnut model. Based on long-term simulated potential yields, reported experiment station yields, on-farm yields and average farmers yield, yield gap I and yield gap II were estimated for different locations and regions across India. Depending upon the agroclimatic conditions, large spatial and temporal variations were observed in the average simulated rainfed potential yield, which ranged from 800 to 4460 kg ha^{-1} among locations across India. The average simulated rainfed potential yield across major production zones, AEZs and states of India ranged from 2320 to 3170, 790 to 3750 and 1200 to 3490 kg ha^{-1}, respectively.

Yield gap I, which is the difference between potential and achievable yield, ranged from 570 to 1410, 0 to 1290 and 660 to 1850 kg ha^{-1} across different soybean production zones, AEZs and states of India, respectively. The simulated yields and the extent of yield gap I clearly indicated a much higher yield potential of groundnut than currently being attained across many locations and regions of India. The yield gap II, which represents the difference between achievable and actual yield realized by the average farmer ranged from 0 to 670, 0 to 1390 and 460 to 820 kg ha^{-1} across different groundnut production zones, AEZs and states of India, respectively. The extent of yield gap II and a high degree of spatial and temporal variability observed in it across different locations/regions indicated substantial scope to increase groundnut productivity with improved management under rainfed situation. The water balance analysis showed a high amount of runoff at some of the locations, which ranged from 11 to 54% of the total rainfall, indicating the need to harvest and conserve this water to utilize it for supplemental irrigation or groundwater recharging. The average simulated yield as well as total yield gap across different locations showed a significant ($P \leq 0.01$) and positive but curvilinear relationship with average crop season rainfall ($R^2 = 0.63$ and 0.56, respectively). Both simulated yield and yield gap increased linearly with increasing crop season rainfall up to ~700 mm. These relationships demonstrate that groundnut productivity is limited in many regions/seasons by the availability of soil moisture and yield gaps are of high magnitude in the regions/seasons with higher seasonal rainfall. Therefore, the increase in average yield with improved management practices is likely to be of greater magnitude in good rainfall regions/seasons or with supplemental irrigations. Various constraints limiting groundnut yields across different regions have been identified and ways to abridge the large yield gaps are discussed.

4.2 Introduction

Groundnut plays an important role in the oil economy of the world. It is the world's 4th most important source of edible oil and 3rd most important source of vegetable protein. Groundnut seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%). The crop was introduced in India during 16th century (Reddy 1996). At present with about 5.95 M ha under cultivation, India has the largest area under groundnut in the world. Although the crop can be grown round the year, it is mainly grown in *kharif* (rainy) season. During *kharif* season, which accounts for more than 80% of the total groundnut production, the crop is largely grown as rainfed by a large number of small and marginal farmers of the country. Due to rainfed cultivation by resource-poor, small and marginal farmers, productivity has been exhibiting large year-to-year fluctuations (Reddy et al. 1992). Rest of the production comes from spring and summer season crops, which are largely irrigated. The crop occupies a prominent place in several cropping systems such as sequential, multiple and intercropping (Basu and Ghosh 1995). Though the share of groundnut in the total oilseeds production in India has been falling since 1950s, when it was 70% to the present level of about 30%, groundnut is still a major oilseed crop in India. Its production decides not only the price of groundnut oil in any year but also the prices of most other oils. About 80% of the groundnut produced in India goes for oil extraction, 10% as seed, 6% for edible use. Despite its long history of cultivation, its importance in oil economy of India and as an important source of livelihood for millions of small and marginal farmers, the productivity of the crop has remained very low.

In this section, we have estimated the potential rainfed yield of groundnut using both the experimental data and the data generated through simulation techniques and assessed the gaps between potential, achievable and average farmers yields across different locations/regions in India.

4.3 World Trends in Groundnut Production

Besides soybean, groundnut is also a major oilseed legume crop of the world. Though, the total production of groundnut in the world has continuously increased, the increase was of greater degree from 1980 onwards (Fig. 9). In 1980, the total groundnut production in the world was 16.9 million tons (M t), which has almost doubled to 33.3 M t by 2002 (Table 25). As against this, the increase in area since 1980 (18.4 M ha) till 2002 (24.1 M ha) has been just 35%. Hence, the major increase in the production of groundnut for the past two decades has come from the increase in productivity,

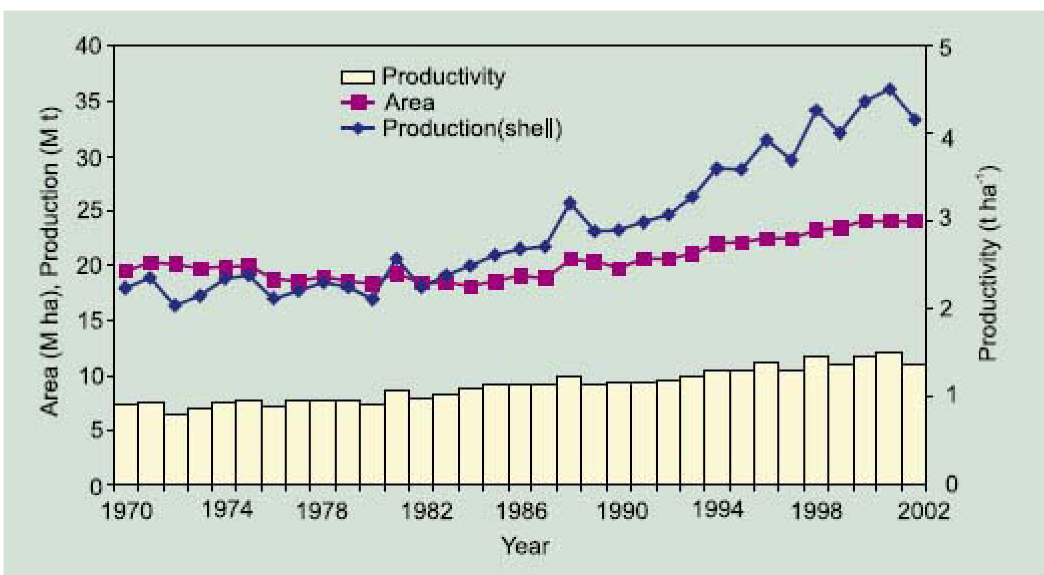

Figure 9. Trends in area, production and productivity of groundnut in world.
Source: FAOstat data, 2004.

Table 25. Global groundnut area, production and productivity during 2002–03.			
Country	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
India	5.95	4.36	730
China	4.95	14.90	3010
Nigeria	2.78	2.70	970
Sudan	1.90	1.27	670
Senegal	0.84	0.50	600
Indonesia	0.65	1.27	1960
Myanmar	0.57	0.72	1270
USA	0.52	1.51	2870
Chad	0.48	0.45	940
Congo	0.46	0.36	780
World	24.10	33.30	1380

Source: FAOstat data 2004.

which was 0.92 t ha^{-1} in 1980 and has reached to 1.4 t ha^{-1} in 2002. At present the crop is grown in nearly 100 countries around the world. The major groundnut producing countries are China, India, Nigeria, USA and Indonesia (Table 25). Nearly 96% of global area and 92% of global production of groundnut comes from the developing countries.

4.4 Groundnut Production in India

4.4.1 Area, production and productivity in the country

In India, groundnut is the major oilseed crop. During 2002 it accounted for about 29% of total area and production of oilseeds in the country. The trends in area, production and productivity of groundnut in India are presented in Figure 10. The area under groundnut remained stagnated to

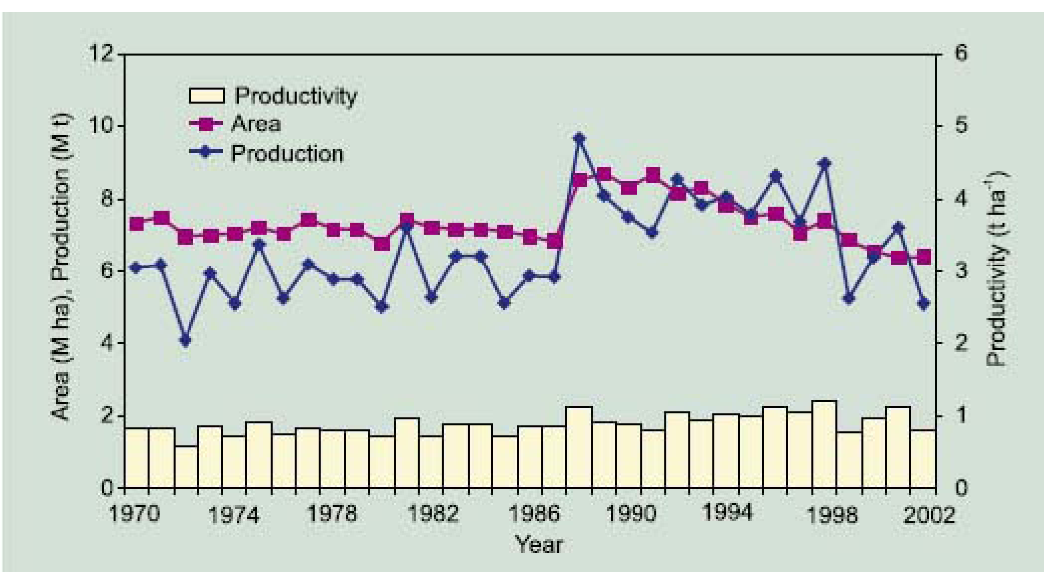

Figure 10. Trends in area, production and productivity of groundnut in India. Source: FAOstat data, 2004.

about 7 M ha from 1970–71 to 1987–88 after which it rose sharply to 8.7 M ha (M ha) in 1988–89. After the maximum area was achieved in 1988–89, a gradual decline has been observed and by the year 2002, the total area under groundnut has been just 5.95 M ha. The trends of total groundnut production are similar to that of the area except that it has shown large year-to-year fluctuations. The total groundnut production increased from an average of about 6 M t (1970–71 to 1987–88) to 9.68 M t in 1988–89, which is the maximum ever production recorded for groundnut in India. Thereafter, the groundnut production has gradually declined and in 2002 the total production was only 4.36 M t. The great fluctuation in the production has largely been due to year-to-year variations in productivity levels of groundnut. In the pre 1987 era, the yields ranged from 590 to 970 kg ha^{-1} while post 1987, it ranged from 730 to 1210 kg ha^{-1}. Thus, post 1987 era has seen some increase in the productivity of groundnut but the fluctuating nature has remained. Such large fluctuation in yield of groundnut has been attributed to a large extent to variability in rainfall in term of both amount and its distribution (Reddy et al. 1992).

To increase the production of oilseeds in the country and to achieve self-sufficiency, the Technology Mission on Oilseeds was launched in 1986. The sharp rise in area and production of groundnut in the post 1987 period was mainly due to the major efforts given under technology mission to groundnut production. Besides incentives to the farmers to takeup oilseeds production, the efforts also led to transfer of technology through large number of on-farm trials. However, the initial boost could not be sustained as the groundnut production continued to show great fluctuation in production, and between 1989–90 and 1998–99 the total production hovered between 7.1 and 9 M t. During subsequent four years (1999–00 to 2002–03), the weather conditions were unfavorable in the major groundnut growing regions, which resulted in sharp decline in both the area and production of the groundnut.

During 2002, India ranked first in terms of area under groundnut while in terms of total production it was next to China (Table 25). Average productivity of groundnut in India was 730 kg ha^{-1} in the year 2002 and maximum of 1210 kg ha^{-1} was observed in the year 1998 (Fig. 10). Both these productivity levels are much less than the average yield of China (3010 kg ha^{-1}), USA (2870 kg ha^{-1}) and Indonesia (1960 kg ha^{-1}). In India, groundnut is mainly grown during rainy season (85% area) while in some parts of the country it is also grown during postrainy (10% area) and summer season (5% area). Rainy season groundnut, which is widely grown all over India, is mostly rainfed; while postrainy and summer season crops are irrigated.

4.4.2 Area, production and productivity in crop production zones

Groundnut cultivation is spread over 273 districts across India covering 7.53 M ha with an average production of 8.63 M t (Table 26, Fig. 11). However, of the total area under cultivation, 13 districts contribute up to 50% of total area (primary zone) and 43 districts fall in secondary zone contributing up to another 35% of area under groundnut in the country. The rest 217 districts contribute only 15% to the total area under groundnut in the country, of which 90 districts have less than 1000 ha under cultivation. This clearly indicates a very high concentration of crop area in a few districts of the country. Only one district in Rayalaseema region of Andhra Pradesh (Anantapur) has 0.74 M ha and adjacent three more districts (Chittoor, Kurnool and Kadapa) together have 1.5 M ha area under groundnut. Similarly, four adjacent districts in Sourashtra region of Gujarat (Junagadh, Jamnagar, Amreli and Bhavnagar) together have 1.3 M ha of groundnut area. While such a pattern on the one hand needs to be analyzed in terms of differences in natural resources and socioeconomic infrastructure between high and low concentration districts. On the other hand, in a rainfed environment, it poses risks

Table 26. Area, production and productivity of groundnut in different production zones of India (1995–96 to 1997–98).

Production zone	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	Yield CV (%)
Primary	13	3.71	4.23	1140	28
Secondary	43	2.70	3.14	1160	33
Tertiary	127	1.09	1.24	1130	33
Others	90	0.02	0.02	960	51
Total	273	7.53	8.63	1150	37

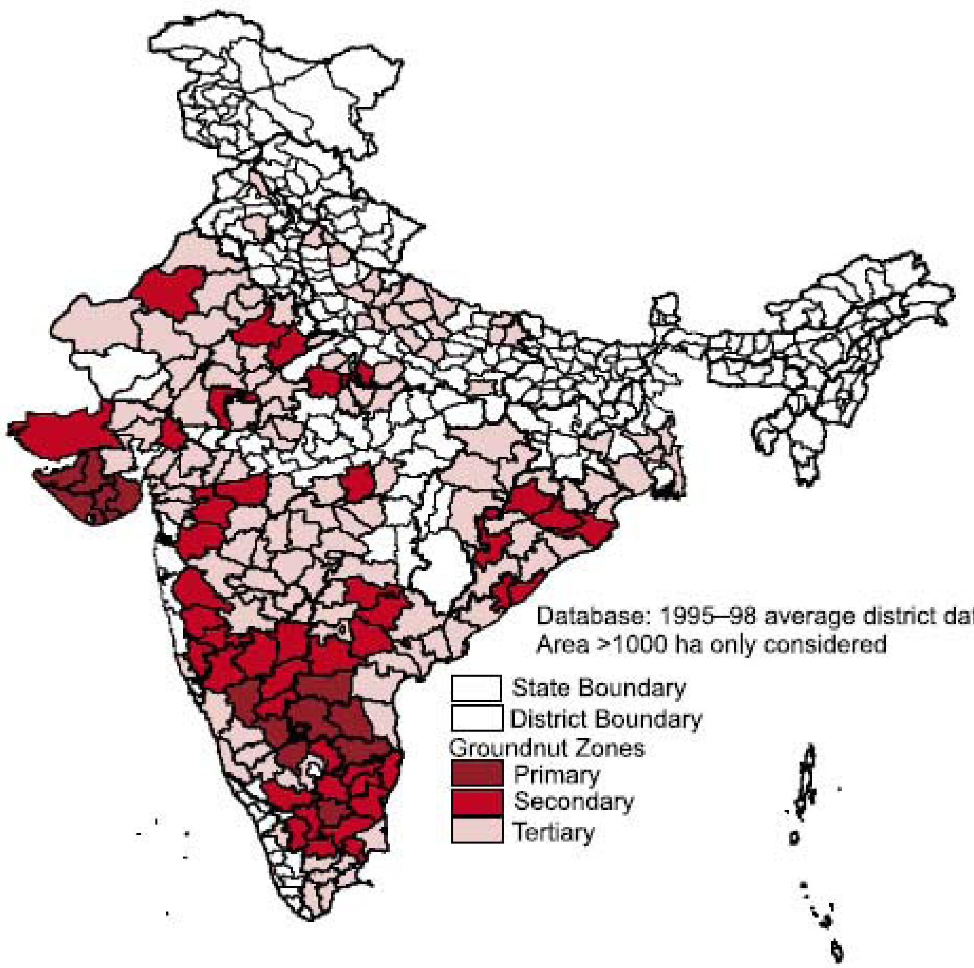

Figure 11. Primary, secondary and tertiary production zones of groundnut in India.

to both the planners at national level (planning for production, consumption and export/import of the commodity) and to the farmers who are totally dependent on the cultivation of only one crop. Adverse weather conditions in the small region of the country, where this crop is concentrated, could lead to a serious shortfall in the production at the national level as well as loss of livelihood for the concerned farmers.

The average yield and its coefficient variability among the districts of primary, secondary and tertiary zones did not differ significantly, which ranged from 1130 to 1160 kg ha^{-1} and 28 to 33%, respectively. However, relatively low average yield (960 kg ha^{-1}) and high CV (51%) was observed among the districts, which are grouped as "others".

4.4.3 Area, production and productivity in agroecological zones

Classification of groundnut area into different crop production zones gives an indication of the geographical area where the crop is most concentrated and where the intervention can lead to maximum gains in the production of crop. However, in each crop zone, districts may come from diverse ecological background and variability in their productivity may largely be governed by the variability in the climatic conditions of these districts. Based on uniformity in climate, soils, length of growing period (LGP) and physiography, the whole country have been divided into 20 agroecological zones (Sehgal et al. 1995). Therefore, an attempt was made to look into the spread of area, production and productivity of groundnut in these agroclimatic zones.

Semi-arid and arid ecosystems accounted for 63% and 28% of the total area under groundnut in the country, respectively (Table 27, Fig. 12). Further, the area under groundnut in India is equally distributed (about 1 M ha each) in AEZs 2 and 3 of arid ecosystem and among AEZs 4, 5, 6, 7 and 8 of semi-arid ecosystem. The agroecological zone 2, which comprises the western plain, Kutch and part of Kathiawar peninsula, is further divided into four sub regions (AESR) and the maximum area under groundnut in AEZ 2 is confined to AESR 2.4 (Bhuj, Jamnagar, northern part of Rajkot and Surendranagar districts of Gujarat). The AESR 2.4 is characterized by hot arid climate with an average annual precipitation of about 490 mm. The rainfall is highly variable from year-to-year (range 100–700 mm) and the probability of receiving more than 300 mm rainfall is <50%. The soils of sub-region are deep loamy saline and alkaline in nature and have low available water content. The LGP of the sub region is 60–90 days. The average productivity of groundnut for AEZ is 1190 kg ha^{-1} with a CV of 15%.

Table 27. Area, production and productivity of groundnut in different agroecological zones of India (1995–96 to 1997–98).

Ecosystem	AEZ	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Arid	2	21	0.97	1.16	1190	15
Arid	3	4	1.14	1.04	910	7
Semi-arid	4	51	0.38	0.40	1070	24
Semi-arid	5	23	1.09	1.52	1400	26
Semi-arid	6	28	1.09	1.03	940	39
Semi-arid	7	14	0.88	0.83	940	38
Semi-arid	8	27	1.36	1.99	1460	37
Sub-humid	9	23	0.04	0.03	750	42
Sub-humid	10	21	0.09	0.19	1140	29
Sub-humid	12	23	0.41	0.44	1070	19
Sub-humid	15	10	0.03	0.04	1370	31
Sub-humid	19	10	0.03	0.04	1380	46
Others	-	17	0.04	0.04	1030	71
Total	-	273	7.56	8.68	1150	40

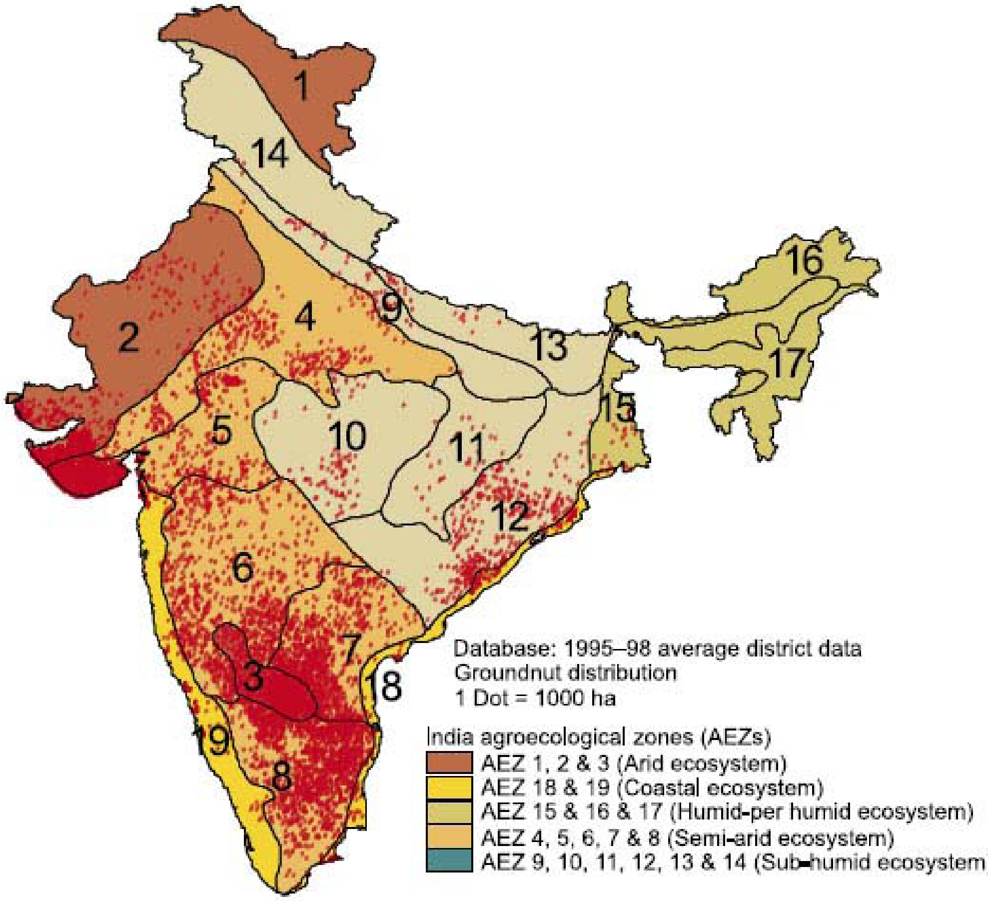

Figure 12. Distribution of groundnut in different agroecological zones of India.

AEZ 3 comprises parts of the Deccan plateau located in Karnataka (Bellary, southern parts of Bijapur, northern parts of Tumkur and Chitradurga districts) and Andhra Pradesh (Anantapur district) states and has hot arid climate. The mean annual precipitation is about 500 mm. This sub-region is situated in the rain shadow of southwest monsoon along the leeward side of Sahyadris. The total seasonal rainfall is 400 mm, which constitute 65% of the total annual rainfall. This AESR has deep loamy and clay mixed and black soils with low to medium available water content. LGP is intermediate and ranges from 60–90 days. Four districts (Anantapur, Chitradurga, Tumkur and Bellary) together contribute 1.14 M ha area of the groundnut in India. The average productivity of this region is 910 kg ha^{-1} with a very low CV of 7%.

Semi-arid ecosystems are characterized by seasonal rainfall, which has a CV of about 30%. The annual rainfall varies between 500 to 1000 mm. The LGP ranges from 90–150 days. The semi-arid ecosystems are further subdivided into semi-arid (dry) and semi-arid (moist) based on the duration of the availability of moisture. The AEZ 4 with a semi-arid (hot) climate has about 0.38 M ha under groundnut with an average productivity of 1070 kg ha^{-1}. The CV for average yield of this region is 24%. Most of this area is in the districts, which fall in the tertiary production zone and in those having less than 1000 ha under the crop. The groundnut area is spread in to all the AESRs of this zone, which include parts of the states of Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat and Haryana.

The AEZ 5 includes Central (Malwa) highlands, Gujarat plains and Kathiawar peninsular and is further sub-divided into three sub-regions viz, 5.1 (hot, dry, semi-arid), 5.2 and 5.3 (hot, moist, semi-arid). The major area under groundnut in this zone is in AESR 5.1 and concentrated in the districts of Junagadh, Amreli and Bhavnagar. Some of the groundnut areas in AEZ 5 is also spread in AESR 5.2 and 5.3 comprising the districts from Madhya Pradesh and Rajasthan. The climate of the region is hot semi-arid (dry), mean annual rainfall is 650 mm and the LGP is 90–120 days. The average productivity of groundnut in this region is 1400 kg ha^{-1} with a high CV of 26%.

The AEZ 6 includes Deccan plateau and covers most of Maharashtra, Karnataka and parts of Andhra Pradesh. The major groundnut area under AEZ 6 is distributed in AESR 6.1 and 6.4, which includes districts of northern Karnataka (Dharwad, Raichur, Bijapur and Belgaum) and southern and western Maharashtra (Satara, Kolhapur, Sangli, Pune, Jalgaon, etc). The climate is hot semi-arid (dry and wet), mean annual precipitation ranges from 750 to 1000 mm and LGP ranges from 90–120 (AESR 6.1) to 150–180 days (AESR 6.4). It has shallow and medium-deep black soils (Vertisols and Vertic inceptisols). The average productivity of groundnut is 940 kg ha^{-1} with a CV of 39%.

The agroecological zone 7 consists of Deccan plateau (Telangana) and eastern ghats in Andhra Pradesh. The major groundnut area in this zone is in AESR 7.1, which includes Rayalaseema region of Andhra Pradesh (districts of Kadapa and Kurnool) and some in AESR 7.2 comprising Telangana region of Andhra Pradesh (districts of Mahabubnagar, Warangal, Nalgonda, Karimnagar, etc). The climate of this ecological zone is hot semi-arid (dry) (AESR 7.1) and hot semi-arid (moist) (AESR 7.2). The mean annual precipitation is between 700–800 mm and the LGP is between 90–120 (AESR 7.1) and 120–150 days (AESR 7.2). The soils are red and black. The average productivity of this region is 940 kg ha^{-1} with a CV of 38%.

The AEZ 8 comprises of eastern ghats, Tamil Nadu uplands and Deccan plateau (Karnataka). The major groundnut area under AEZ 8 is in AESR 8.3 comprising of southern part of Deccan plateau encompassing southern part of Andhra Pradesh and North-Central parts of Tamil Nadu uplands. The districts in this region where groundnut is concentrated are Chittoor (Andhra Pradesh), Salem, Tiruvannamalai, South Arcot, Dharmapuri, etc (Tamil Nadu). The climate of this ecoregion is hot moist semi-arid and mean annual precipitation is about 850 mm. The major soils are red loamy and length of growing period is 90 to 150 days. The average productivity of groundnut in this region is 1460 kg ha^{-1}, which is the highest among all the agroecological zones. However, large variation exists in the productivity of the crop among the districts of this region (CV = 37%).

The distribution of groundnut across different agroecological regions and sub-regions clearly indicated that the majority of the areas face uncertain and scanty rainfall leading to prolonged spells of intermittent drought. This partly explains the year-to-year large fluctuations observed in the production and productivity of groundnut at national level. The high variability in average productivity within each agroecological zone indicates a high potential to increase the productivity levels of groundnut in India provided proper interventions are made.

4.4.4 Area, production and productivity in the major states

State being an administrative unit, the information on the extent of yield gaps and intervention required to fill these gaps can help the concerned states to take up required action. Therefore, an attempt has also made to estimate the existing yield gaps and constraints to production in major groundnut growing states of India. Among the states, Andhra Pradesh (2.1 M ha) and Gujarat

State	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Andhra Pradesh	22	2.06	1.99	970	32
Gujarat	19	1.90	2.55	1340	17
Karnataka	19	1.17	1.00	850	29
Tamil Nadu	20	0.90	1.46	1620	30
Maharashtra	29	0.54	0.64	1190	45
Rajasthan	26	0.29	0.32	1120	12
Orissa	13	0.26	0.29	1120	11
Madhya Pradesh	37	0.25	0.26	1010	25
Others	88	0.19	0.17	920	29
India	273	7.56	8.67	1150	40

Table 28. Area, production and productivity of groundnut in different states of India (1995–96 to 1997–98).

(1.9 M ha) together contribute 52% to the total groundnut area and production in the country (Table 28). Another 34% is contributed by Karnataka (1.17 M ha), Tamil Nadu (0.9 M ha) and Maharashtra (0.54 M ha). Rest of the area is scattered in the states of Rajasthan, Orissa, Madhya Pradesh and other parts of India. The productivity is higher than the national average (1150 kg ha^{-1}) in the states of Tamil Nadu (1620 kg ha^{-1}) and Gujarat (1340 kg ha^{-1}). The variation in yield among the districts of these states was very high for Maharashtra (45%), Andhra Pradesh (32%) and Tamil Nadu (30%) indicating a large scope to enhance the total production. Compared to the average figures for 1995–96 to 1997–98, the total area (7.6 M ha) and production (8.7 M t) of groundnut in India declined drastically in 2002 (Table 29) to 5.95 M ha and 4.36 M t, respectively. Similarly, productivity declined from 1150 to 730 kg ha^{-1}. This reduction has mainly been attributed to continuous unfavorable weather conditions in all the major groundnut areas of the country. There was a considerable reduction in area in all the major states except for Gujarat. On the other hand, a considerable reduction in the productivity levels was observed in all the states except for Tamil Nadu.

Table 29. Area, production and productivity of groundnut in different states of India during 2002–03.

State	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
Gujarat	2.03	1.09	540
Andhra Pradesh	1.47	0.82	560
Karnataka	0.84	0.55	650
Tamil Nadu	0.55	0.98	1780
Maharashtra	0.42	0.44	1040
Rajasthan	0.24	0.17	690
Madhya Pradesh	0.19	0.12	640
Uttar Pradesh	0.07	0.05	660
Orissa	0.06	0.05	870
Others	0.08	0.10	-
All India	5.95	4.36	730

Source: Ministry of Agriculture, Govt. of India, 2004.

4.5 Observed Rainfed Potential Yield of Groundnut

4.5.1 Observed experimental, on-farm and district yields

Experimental station, on-farm and district average yields of different locations of AICRPG in India are presented in Table 30. Across locations, depending on the rainfall, soil and other location specific factors, the mean experimental station and on-farm yields ranged from 1050 (Khargone, Madhya Pradesh) to 3620 (Dharwad, Karnataka) and 1130 (Jalgaon, Maharashtra) to 2460 kg ha^{-1} (Durgapura, Rajasthan), respectively. The district average yields for the corresponding years, for which experimental station

Table 30. Observed experimental station (Spanish type), on-farm and district average yields (kg ha^{-1}) of groundnut at different AICRP locations across India.

	Experimental station				On-farm				District Average[1]			
Location	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]
Primary Zone												
Junagadh	930	2820	1960	35	1020	2130	1530	26	340	1970	1030	60
Dharwad	2080	4960	3620	25	960	3050	1970	53	560	1080	830	20
Amreli	340	2710	1370	62	-		-	-	310	1830	850	69
Kadiri	680	3180	1840	46	-		-	-	380	1120	700	38
Secondary Zone												
Durgapura	1530	3130	2510	22	1140	3130	2460	32	690	1550	1000	34
Digraj	1450	3190	2290	29	1830	2350	2170	13	960	1460	1170	16
Chiplima	1310	3490	2170	37	1010	1920	1460	28	690	1490	1170	26
Vriddhachalam	1700	3500	2460	21	-	-	-	-	1490	2460	1880	21
Chintamani	1050	2610	1740	32	1230	1600	1380	12	480	1390	990	37
Raichur	1470	2810	2190	18	-	-	-	-	540	760	660	13
Jagtial	1220	2460	1840	25	1570	1730	1660	5	430	1450	1030	33
Khargone	670	1460	1050	25	-	-	-		520	830	690	15
Aliyarnagar	1860	3560	2720	25	-	-	-		1430	1740	1600	8
Palem	1130	2690	1830	39	-	-	-		510	880	750	20
Tertiary Zone												
Udaipur	2220	3460	2650	15	-	-	-	-	510	1060	720	38
Jalgaon	1020	2930	1710	44	840	1430	1130	18	560	1220	960	22
Hanumangarh	1270	3110	2170	31	-	-	-	-	690	1360	1060	23
Akola	940	2030	1320	25	-	-	-	-	620	1360	870	29
Latur	1000	2080	1490	26	-	-	-	-	450	770	580	21
Mainpuri	1040	2110	1510	26	-	-	-	-	660	1070	860	14
Others												
Jhargram	1780	3850	3000	23	-	-	-	-	860	1600	1150	22
Kanke	1220	2190	1610	24	-	-	-	-	900	1210	1090	9
Ludhiana	1170	1730	1530	17	-	-	-	-	830	1400	1090	26
Kayamkulam	1560	3970	2830	31	-	-	-	-	520	750	710	11
Mean	1280	2920	2060		1210	2160	1720		660	1320	980	
CV[3]	35	27	30		27	29	26		45	32	30	

- FLDs not conducted.
1 District yields are for the corresponding years for which experimental station data were collected (see Annexure IV).
2 CV = Coefficient of variation (%) for mean yield of a location over years.
3 CV = Coefficient of variation (%) for mean yield over locations.

yield were collected for each location ranged from 580 (Latur, Maharashtra) to 1880 (Vriddhachalam, Tamil Nadu). In general, experimental station and on-farm yields were considerably higher than district average yields at all the locations. When averaged over all the locations across India, the mean experimental station, on-farm and district average yields were 2060, 1720 and 980 kg ha^{-1}, respectively. Thus, there was on an average 17 and 43% reduction in yield from experimental station to on-farm and from on-farm to district level, respectively.

Minimum and maximum values and the CVs presented in Table 30 indicate the variability observed over the years in the yield of groundnut at each location. The temporal variability in yield was quite high and depending on the location, the CV in it ranged from 15 to 62%, 5 to 53% and 8 to 69% for experimental station, on-farm and district average yields, respectively (Table 30). Variation in yields over years at each location reflects the uncertainty of climatic factors in rainfed environment particularly that of rainfall leading to poor stability in the yield of groundnut crop over the years. Maximum yields are obtained when the climatic conditions including availability of soil moisture conditions are optimum and represent the full (water non-limiting) potential of the crop. Averaged over the locations, minimum experimental station yield (1280 kg ha^{-1}) was less than half of the maximum value (2920 kg ha^{-1}). While the average minimum yields in case of on-farm trials (1210 kg ha^{-1}) and district averages (660 kg ha^{-1}) were 44% and 50% less than the respective average maximum values. Similarly, large spatial variability existed in the magnitude of minimum and maximum groundnut yields obtained in experiment station, on-farm and district averages across the locations.

4.6 Simulated Rainfed Potential Yields

4.6.1 Potential yield at selected locations

Depending on the climatic conditions and soil type, large variation in simulated yield across locations and over the years at a given location was observed (Table 31). When averaged over all the sites across India, the mean simulated yield was 2640 kg ha^{-1} with a CV of 38% across these locations. The mean simulated yield of the locations ranged from 800 (Anantapur, Andhra Pradesh) to 4460 kg ha^{-1} (Patancheru). Large differences were observed in the minimum and maximum grain yields that were obtained over the years at each location. The high degree of temporal variability was evident as the CV for grain yield ranged from 17 to 124% among these locations. The maximum yield at each location was obtained in the season when rainfall was well distributed and the onset of monsoon was timely, which indicated the full yield potential (water non-limiting) of groundnut crop at the site. The maximum yield across locations ranged from 2340 (Surat, Gujarat) to 5850 kg ha^{-1} (Patancheru). The minimum yield at these sites was highly variable (0 to 2280 kg ha^{-1}) and at times the crop failed altogether in some of the years at some of the sites (Coimbatore and Thanjavur in Tamil Nadu). Rainfall played an important role in both the temporal and spatial variability in the rainfed simulated yields. The locations with low average rainfall (Anantapur, Coimbatore and Bijapur) also gave low simulated yields. As in the case of simulated yields, very high value of CV for rainfall was observed among the locations, which ranged from 16 to 51%. Besides rainfall, soil type also plays a critical role in crop production. It was evident when at the same location two different but predominant soils series were used for some of the sites, the minimum, maximum and mean yield obtained differed greatly.

Table 31. **Simulated yield, crop season rainfall, district average yield and total yield gap of groundnut at selected locations across India.**

Location	Simulated yield (kg ha^{-1}) Min	Max	Mean	CV[2]	Rainfall (mm) Min	Max	Mean	CV[2]	District yield[1] (kg ha^{-1})	Total YG (kg ha^{-1})
Primary Zone										
Dharwad (Achmatti)	110	4650	2380	52	130	800	460	32	850	1527
(Hogaluru)	80	4950	3110	47	130	800	460	31	850	2260
Anantapur	50	3950	800	124	120	760	320	46	910	0
Junagadh	60	5180	3010	53	140	1390	720	51	1870	1138
Kurnool (Vertisol)	510	4950	2200	62	350	1210	630	39	870	1328
(Alfisols)	620	5700	2700	55	350	1210	630	39	870	1826
Rajkot (Semla)	220	3050	1910	49	300	1080	610	38	1310	599
(Bhola)	230	4390	2430	55	300	1080	610	38	1310	1115
Secondary Zone										
Raichur	1000	4180	2420	48	400	860	600	26	640	1779
Jaipur	50	5180	3490	53	140	850	560	42	1180	2313
Pune (Otur)	1300	5760	4170	33	300	880	600	29	1440	2734
Pune (Nimone)	730	5130	3300	44	300	910	600	31	1440	1859
Jhansi	2060	5830	4000	30	510	1130	840	27	1010	2989
Bijapur	40	2590	1420	62	130	620	400	37	500	916
Warangal	2230	4100	3420	20	410	1350	770	38	920	2497
Jalgaon	1220	4940	3330	35	480	860	680	16	1040	2292
Akola	290	5600	3170	49	280	1170	690	29	660	2511
Patancheru	2280	5850	4460	24	400	1290	710	32	1060	3404
Kota	520	5120	2600	55	310	1010	660	29	960	1644
Coimbatore (Coimbatore)	0	2530	920	95	70	710	350	46	1350	0
(Palaturai)	0	3040	900	101	70	710	350	46	1350	0
Surat (Haldar)	1050	2340	1620	24	480	2220	1180	42	1510	108
(Kabilpura)	2020	3460	2550	19	480	2220	1180	42	1510	1036
(Sisodia)	1980	3250	2420	17	480	2220	1180	42	1510	913
Dhar	760	5480	3870	35	600	1490	880	27	730	3144
Jhabua	250	4710	2850	51	290	1410	790	45	680	2170
Thanjavur	0	4380	1790	76	60	870	500	42	1650	139
Mean	730	4450	2640		290	1150	660		1110	1564
CV[3]	107	24	38		54	39	35		32	65

In parentheses are the soil series.
1 District yields are average of 1995-96 to 1998-99.
2 CV = Coefficient of variation (%) for mean value of a location over years.
3 CV = Coefficient of variation (%) for mean value over locations.

4.6.2 Potential yield of production zones

Locations situated in different crop production zones, AEZs and states were grouped together. The minimum, maximum and average simulated yield and crop season rainfall among the locations in each group is presented in Table 32. Among the production zones, the highest mean simulated yield was observed in secondary zone (3170 kg ha^{-1}) followed by tertiary (2540 kg ha^{-1}) and primary zone (2320 kg ha^{-1}). Similarly, maximum yield among the locations was higher in tertiary and secondary zone (4460 and 4170 kg ha^{-1}, respectively) as compared to primary zone (3110 kg ha^{-1}). Hence, the

Table 32. Rainfed potential yield of groundnut and average crop season rainfall in different production zones, AEZ and states of India.

Zone/State	No. of locations	Simulated yield (kg ha^{-1})				Crop season rainfall (mm)			
		Min	Max	Mean	CV	Min	Max	Mean	CV
Production Zone									
Primary	8	800	3110	2320	32	320	720	550	23
Secondary	7	1420	4170	3170	30	400	840	620	23
Tertiary	12	900	4460	2540	43	340	1180	760	39
AEZ									
2	2	1910	2430	2170	-	-	-	610	-
3	1	-	-	790	-	-	-	320	-
4	2	3490	4000	3750	-	560	840	700	-
5	7	1620	3870	2700	25	660	1180	940	24
6	8	1420	4170	2910	28	400	690	560	19
7	4	2200	4460	3190	31	620	770	680	10
8	3	900	1790	1200	42	340	500	400	22
State									
Andhra Pradesh	5	800	4460	2720	50	320	770	600	29
Gujarat	6	1620	3010	2330	21	610	1180	910	32
Karnataka	4	1420	3110	2330	30	400	600	480	17
Maharashtra	4	3170	4170	3490	13	590	690	640	9
Tamil Nadu	3	900	1790	1200	42	340	500	400	22

CV = Coefficient of variation (%).

potential for groundnut is very high in secondary and tertiary zones as compared to primary zone, which has very high concentration of the area under groundnut in India. In case, proper incentives are given to the farmers in the secondary and tertiary zones, the area under groundnut can be increased and because of high yield potentials, the higher production of groundnut can be achieved. The CV of potential yield of locations within production zones ranged from 30 (secondary zone) to 43% (tertiary zone).

4.6.3 Potential yield of agroecological zones

Among the major AEZs, the lowest mean simulated yield was observed in AEZ 3 (790 kg ha^{-1}), followed by AEZ 8 (1200 kg ha^{-1}) and AEZ 2 (2170 kg ha^{-1}) (Table 32). The highest simulated yield was observed in AEZ 4 (3750 kg ha^{-1}) while in rest of the zones (AEZ 5, 6 and 7) the mean simulated yield ranged between 2700 and 3190 kg ha^{-1}. The CV of simulated yield among locations in these AEZs ranged from 25 to 42%.

4.6.4 Potential yield of major states

Among the major states covering groundnut area in India, the simulated potential rainfed yield was more than 2000 kg ha^{-1} (2330 to 3490 kg ha^{-1}) except for Tamil Nadu (1200 kg ha^{-1}) (Table 32). The states with lower mean rainfall had more variability in groundnut yield than the states with high mean rainfall.

In general, the simulation studies indicated that major groundnut growing zones and states in the country have a rainfed yield potential of more than 2000 kg ha^{-1}, which is more than double as compared to existing national productivity (less than 1000 kg ha^{-1}). Also the relatively low productivity and its high variability in some of the zones appear to be because of low and highly variable rainfall in these zones as compared to others. Therefore, if the facilities for supplementary irrigation are created, the productivity/production of groundnut can be tremendously increased and year-to-year variability can be minimized.

4.7 Yield Gaps

4.7.1 Yield gaps of selected locations

The magnitude of YG I and YG II in groundnut is presented in Table 33. Across locations, the average YG I was 510 kg ha^{-1} and ranged from 50 (Durgapura, Rajasthan) to 1660 kg ha^{-1} (Dharwad,

Table 33. Yield gaps of groundnut at different AICRP locations across India.

	Yield gap (kg ha^{-1})											
	YG I				YG II				Total YG			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Junagadh	10	1800	430	110	0	920	500	98	410	1850	930	66
Dharwad	140	2510	1660	80	400	2350	1140	77	990	4220	2800	36
Amreli	-	-	-	-	-	-	-	-	30	1410	520	103
Kadiri	-	-	-	-	-	-	-	-	270	2190	1140	57
Secondary Zone												
Durgapura	0	390	50	218	450	2060	1460	44	840	2060	1510	29
Digraj	0	810	130	98	740	1350	1000	33	80	2090	1130	57
Chiplima	420	1820	700	89	0	420	300	92	0	2230	1000	87
Vriddhachalam	-	-	-	-	-	-	-	-	60	1700	580	96
Chintamani	20	950	360	73	0	740	390	145	30	1780	750	80
Raichur	-	-	-	-	-	-	-	-	770	2250	1530	29
Jagtial	0	140	180	173	280	600	630	40	420	2000	810	78
Khargone	-	-	-	-	-	-	-	-	130	660	350	59
Aliyarnagar	-	-	-	-	-	-	-	-	390	1820	1120	52
Palem	-	-	-	-	-	-	-	-	280	1810	1080	67
Tertiary Zone												
Udaipur	-	-	-	-	-	-	-	-	1480	2960	1930	30
Jalgaon	80	1440	580	123	0	570	180	117	80	2020	760	98
Hanumangarh	-	-	-	-	-	-	-	-	310	1990	1110	61
Akola	-	-	-	-	-	-	-	-	60	1200	460	75
Latur	-	-	-	-	-	-	-	-	310	1570	910	52
Mainpuri	-	-	-	-	-	-	-	-	40	1090	650	63
Others												
Jhargram	-	-	-	-	-	-	-	-	920	2640	1850	42
Kanke	-	-	-	-	-	-	-	-	30	1040	510	70
Ludhiana	-	-	-	-	-	-	-	-	270	870	440	66
Kayamkulam	-	-	-	-	-	-	-	-	1030	2880	2120	39
Mean	80	1240	510		230	1130	700		390	1930	1080	
CV[2]	173	65	101		120	55	65		106	39	56	

1 CV = Coefficient of variation (%) for mean yield gap of a location over years.
2 CV = Coefficient of variation (%) for mean yield gap over locations.

Karnataka). The average YG II was 700 kg ha^{-1} and ranged from 180 (Jalgaon, Maharashtra) to 1460 kg ha^{-1} (Durgapura). The average total yield gap was 1080 kg ha^{-1} and ranged from 350 (Khargone, Madhya Pradesh) to 2800 kg ha^{-1} (Dharwad). Considerably high values of CV for YG I (101%), YG II (65%) and total YG (56%) were recorded indicating a large degree of variation in these yield gaps among different locations in India. The high variation in YG II across locations indicated the varying levels of adoption of technology and improved cultural practices among the average farmers at these locations. The high degree of yield gaps particularly that of YG II (700 kg ha^{-1}) and total yield gap (1080 kg ha^{-1}) indicated that there is a considerable scope to improve the productivity levels of groundnut in India, provided the reasons behind these gaps are understood and proper interventions are made. Besides considerable spatial variability, a high degree of temporal variation in these yield-gaps was also observed. Depending on the location, the CV for year-to-year variability in YG I, YG II and total YG ranged from 73 to 218%, 33 to 145% and 29 to 103%, respectively. Large year-to-year variation in the yield gaps resulted in very narrow YGs in some years while in others the gaps were very wide at a given location. In general, it was observed that the yield gaps at a given location were narrow in those years in which the potential (experiment station) and achievable (on-farm) yields were also quite low (Annexure IV). In other words, these were the years when climatic conditions were unfavorable and particularly the rainfall received was much below the requirement of the crop.

4.7.2 Yield gaps of production zones

The simulated rainfed potential yield was higher (2320 to 3170 kg ha^{-1}) as compared to the experimental yields (1810 to 2200 kg ha^{-1}) in all major crop production zones, indicating a high yield potential of groundnut in these zones. Across the crop production zones, YG I ranged from 570 to 1410 and 250 to 680 kg ha^{-1} when estimated using simulated and experiment station yields, respectively (Table 34). The yield gap II was more than 600 kg for the primary and secondary zones. In tertiary zone, for which the on-farm data was available only for one location (Jalgaon), there was no difference in the on-farm yields and the district average yields and hence, YG II was negligible.

Table 34. Yield gaps of groundnut in different production zones of India.

	Primary	Secondary	Tertiary
		(kg ha^{-1})	
Groundnut yield			
Simulated mean	2320	3170	2540
Experimental station mean	2200	2080	1810
On-farm mean	1750	1830	1130
Districts' mean*	1140	1160	1130
Yield gap			
Simulated – On-farm (YG I)	570	1340	1410
Experimental station – On-farm (YG I)	450	250	680
On-farm – District (YG II)	610	670	0

* Mean of all the districts for each groundnut production zone (Table 26).

4.7.3 Yield gaps of agroecological zones

Among the agroecological zones, no on-farm data was available for AEZ 2 and 3 and hence, YG I and YG II could not be estimated. Similarly, for AEZ 8, most of the area under groundnut falls in the state of Tamil Nadu where majority of the crop is irrigated and therefore would not represent true levels of yield gaps of a rainfed environment. In rest of the agroecological zones, where major groundnut area exists, the simulated yields were considerably higher than the reported experiment station yields (Table 35). Consequently, the YG I calculated as the difference between simulated potential and on-farm yields was very large (1160 to 1540 kg ha^{-1}) as compared to the difference between experiment station and on-farm yields (0 to 350 kg ha^{-1}). The YG II was highest in AEZ 4 (1390 kg ha^{-1}) followed by AEZ 6 (810 kg ha^{-1}), AEZ 7 (720 kg ha^{-1}) and AEZ 5 (120 kg ha^{-1}).

Table 35. Yield gaps of groundnut in different AEZs of India.

	Arid		Semi-arid				
	2	3	4	5	6	7	8
	(kg ha^{-1})						
Groundnut yield							
Simulated mean	2170	790	3750	2700	2910	3190	1200
Experimental station mean	2170	1840	2220	1460	2100	1840	2310
On-farm mean	-	-	2460	1530	1750	1660	1380
Districts' mean	1190	910	1070	1400	940	940	1460
Yield gap							
Simulated – On-farm (YG I)	-	-	1290	1180	1160	1540	0
Experimental station – On-farm (YG I)	-	-	0	0	350	180	930
On-farm – District (YG II)	-	-	1390	120	810	720	0

* Mean of all the districts for each AEZ (Table 27).

4.7.4 Yield gaps of major states

Among the states, the YG I ranged from 660 to 1850 and 60 to 850 kg ha^{-1} as per the average simulated and experiment station yields, respectively (Table 36). The YG II was maximum in Karnataka (820 kg ha^{-1}), followed by Andhra Pradesh (690), Maharashtra (460 kg ha^{-1}) and Gujarat (190 kg ha^{-1}).

Table 36. Yield gaps of groundnut in major states of India.

	Andhra Pradesh	Gujarat	Tamil Nadu	Karnataka	Maharashtra
	(kg ha^{-1})				
Groundnut yield					
Simulated mean	2720	2330	1200	2330	3490
Experimental station mean	1840	1660	2590	2520	1700
On-farm mean	1660	1530	-	1670	1650
Districts' mean	970	1340	1620	850	1190
Yield gap					
Simulated – On-farm (YG I)	1060	800	-	660	1850
Experimental station – On-farm (YG I)	180	140	-	850	60
On-farm – District (YG II)	690	190	-	820	460

* Mean of all the districts for each state (Table 28).

4.8 Water Balance of Selected Locations

Analyzing the importance of rainfall and soil moisture availability for groundnut production, the simulated water balance components of groundnut crop for different locations across India are presented in Tables 37a & b. A considerable spatial and temporal variation in seasonal rainfall, surface runoff, deep drainage and ET was observed. The average value over locations for these parameters was 663,197, 75 and 318 mm, respectively. The CV across locations was 35, 78, 102 and 18% for rainfall, surface runoff, deep drainage and ET, respectively (Table 37a and b). Hence, there is a great scope at many locations for harnessing the excess water and its efficient use as supplemental irrigation in groundnut-growing regions.

Table 37a. Long-term average water balance components (mm) of simulated groundnut at selected locations across India.

	Rainfall				Surface runoff				Deep drainage			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Dharwad (Achmatti)	132	800	463	32	7	201	79	62	0	47	2	450
(Hogaluru)	132	800	468	31	5	197	75	64	0	4	0	-
Anantapur	121	757	315	46	1	228	47	98	0	134	8	338
Junagadh	137	1392	723	51	5	555	225	72	0	387	98	142
Kurnool (Vertisol)	347	1211	627	39	40	489	136	8	0	207	34	179
(Alfisol)	347	1211	621	38	60	543	165	74	0	201	38	158
Rajkot (Semla)	295	1080	611	38	40	425	197	64	0	253	48	175
(Bhola)	195	1080	602	41	15	425	197	66	0	330	85	129
Secondary Zone												
Raichur	404	860	596	26	60	323	124	62	0	80	21	148
Jaipur	135	851	557	42	1	331	97	104	0	217	60	142
Pune (Otur)	297	881	595	29	22	251	96	65	0	218	57	139
(Nimone)	297	908	591	31	55	402	174	56	0	94	16	200
Jhansi	507	1129	843	27	86	509	262	49	0	256	76	109
Bijapur	128	621	402	37	8	172	87	67	0	29	2	400
Warangal	411	1350	766	38	35	397	201	62	0	449	126	114
Tertiary Zone												
Jalgaon	477	864	683	16	67	310	179	31	0	0	0	-
Akola	277	1173	692	29	37	453	198	46	0	108	5	420
Patancheru	398	1293	705	32	27	810	165	78	0	308	118	77
Kota	306	1011	662	29	24	449	197	52	0	143	37	135
Coimbatore (Coimbatore)	74	707	352	46	0	138	37	95	0	46	3	400
(Palaturai)	74	708	337	47	0	171	46	96	0	83	135	17
Surat ((Haldar)	484	2224	1176	42	140	1446	635	60	0	404	174	74
(Kabilpura)	484	2224	1175	42	96	1292	539	65	5	553	260	63
(Sisodia)	484	2224	1174	42	114	1344	573	63	0	503	230	67
Dhar	600	1492	878	27	52	589	235	60	53	476	190	62
Jhabua	294	1411	787	45	45	492	228	72	0	525	184	89
Thanjavur	62	868	496	42	1	313	112	79	0	155	19	221
Mean	293	1153	663		39	491	197		2	230	75	
CV[2]	54	39	35		97	71	78		475	74	102	

Table 37b. Long-term average water balance components (mm) of simulated groundnut at selected locations across India.

	Evapo-transpiration				Extractable soil water*			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone								
Dharwad (Achmatti)	114	383	300	21	2	189	84	58
(Hogaluru)	120	404	319	21	0	237	74	76
Anantapur	112	361	223	31	4	117	37	84
Junagadh	128	428	313	27	4	152	87	55
Kurnool (Vertisol)	269	453	348	14	15	184	109	51
(Alfisol)	265	442	355	14	8	129	63	56
Rajkot (Semla)	171	352	274	17	36	139	92	34
(Bhola)	168	387	290	18	12	69	33	55
Secondary Zone								
Raichur	265	444	342	15	32	172	108	44
Jaipur	133	417	338	27	1	143	62	69
Pune (Otur)	248	423	359	12	25	148	83	45
(Nimone)	233	398	338	13	9	128	63	65
Jhansi	321	507	431	12	24	123	74	42
Bijapur	119	335	258	24	1	188	54	100
Warangal	280	466	349	14	11	169	90	52
Tertiary Zone								
Jalgaon	311	459	381	11	60	229	124	40
Akola	232	517	375	18	8	294	114	61
Patancheru	288	440	377	10	19	97	45	51
Kota	118	493	335	23	22	220	93	56
Coimbatore (Coimbatore)	71	381	257	33	2	141	54	89
Coimbatore (Palaturai)	67	379	250	32	2	80	28	104
Surat (Haldar)	197	313	233	15	104	165	133	14
(Kabilpura)	207	310	246	13	85	174	129	21
(Sisodia)	210	311	242	13	99	168	130	15
Dhar	309	635	420	20	7	99	34	74
Jhabua	229	452	335	9	6	99	39	64
Thanjavur	53	426	307	26	1	136	58	79
Mean	194	419	318		22	155	77.6	
CV[2]	42	17	18		135	33	41.8	

In parenthesis are the soil series.
* Extractable water retained in the soil profile at harvest of groundnut crop.
1 CV = Coefficient of variation (%) for mean value of a location over years.
2 CV = Coefficient of variation (%) for mean value over locations.

4.9 Major Constraints and Opportunities for Abridging Yield Gaps

Several biotic, abiotic and socioeconomic constraints to groundnut productivity in India have been identified (Balaji et al. 2003, Basu 2003, Gadgil et al. 1996 and 2002, Reddy et al. 1992). These constraints are:

- Unpredictable weather in terms of onset of rainy season, amount of rainfall and its distribution during groundnut-growing period.

- Cultivation of the crop on marginal and sub-marginal lands under rainfed conditions subjected to frequent drought.
- Poor agronomic practices and low levels of input
- Use of low yielding and late maturing cultivars
- High infestation by insects, pests and diseases
- Inadequate availability of high quality seed of improved varieties
- Low levels of adoption of recommended technologies by the farmers

Perhaps among all the above factors, unpredictable nature of rains in terms of total rainfall and its onset and withdrawal is the predominant constraint to groundnut production and productivity in the country. This was evident when the average simulated rainfed yield was plotted against the average crop season rainfall at different locations (Table 31). The simulated yield showed a significant and positive curvilinear relationship with rainfall ($R^2 = 0.63$) (Fig. 13). The simulated yield increased in a curvilinear manner up to ~700 mm of rainfall. This clearly indicated that in most of the groundnut-growing regions where the average rainfall is below ~700 mm, the productivity levels are governed by the amount of rainfall received. When the district average yields of these locations were plotted against the average crop season rainfall, no significant association was observed (Fig. 14). This was mainly due to the fact that in some of these districts many farmers particularly in the low rainfall areas irrigate groundnut crop. Also, the average district yield pertains to both, rainy season and summer/postrainy season yields.

It was observed that YG I and II were narrow during the years when climate was not favorable (Section 4.7). In order to confirm this phenomenon, the differences between simulated and average district yields (Table 31), which reflects the total YG of these locations, were plotted against the crop duration rainfall and a significant and positive relationship ($R^2=0.56$) was observed (Fig. 15). As in the case of simulated yields, the relationship was again curvilinear. Total yield gap increased curvilinearly with the increase in rainfall up to 700 mm. Beyond 800 mm rainfall the yield gaps again narrowed. The relationship clearly indicated that yield gaps across locations were of higher magnitude when available soil moisture was optimum. As against this at locations with low levels of average rainfall and consequent sub-optimum soil moisture, the gaps were narrow.

The above relationships indicate that optimum use of nutrients and improved management practices are the main factors responsible for higher yields in simulation (and also at experiment station and on-farm level). As these factors strongly interact with climate and particularly with the availability of soil moisture, the positive impact of these factors is the maximum when enough soil moisture is available in the soil. Therefore, the maximum yields as well as yield gaps were observed at locations with about 700–800 mm of average rainfall. On the other hand, under sub-optimal soil moisture conditions due to low levels of rainfall in a given environment, the impact of these factors are considerably reduced. Under this situation, the yield of a given location is governed only by environmental factors at all the levels (simulated, experiment station, on-farm and average farmers) and yields obtained at all the levels do not vary significantly and resultant yield gaps are also low/negligible (Fig. 15). Therefore, to improve the productivity levels in areas/years where rainfall is not optimum, besides the development of more drought resistant varieties with better water use efficiency and higher yield potential under water limited conditions, the adaption of technologies which can help in the availability of soil moisture during stress period needs to be introduced. Technologies such as different land configurations (raised-and-sunken bed, ridge-and-furrow system, broadbed-and furrow system, etc) and watershed development can help in the more efficient use of water and applied nutrients resulting in improvements in productivity of groundnut in the country.

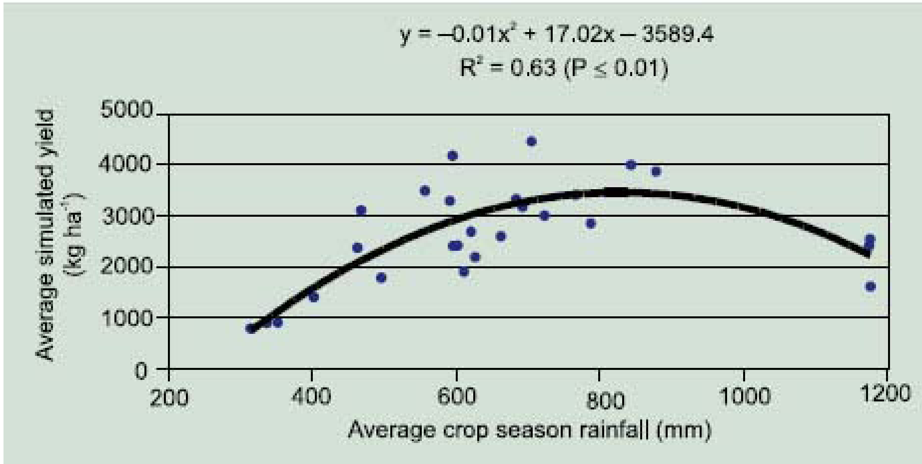

Figure 13. Relationship between average simulated rainfed yield and average crop season rainfall at selected locations across India (n=27).

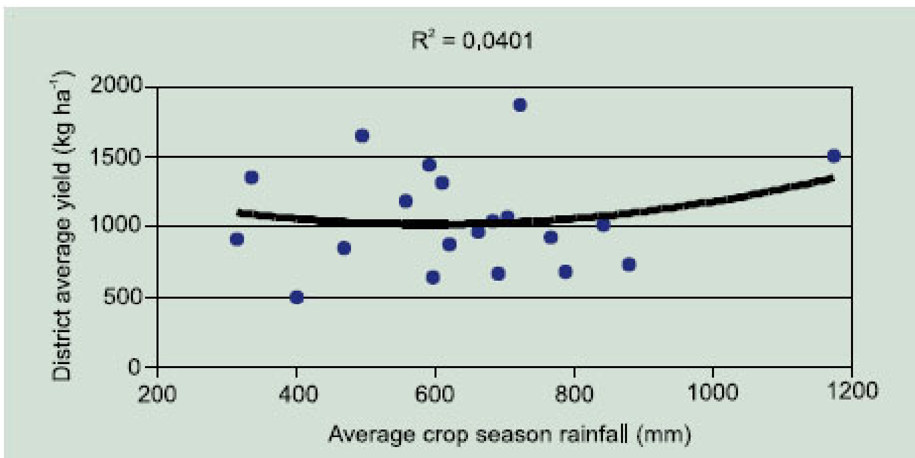

Figure 14. Relationship between district average yield and average crop season rainfall at selected locations across India (n= 20).

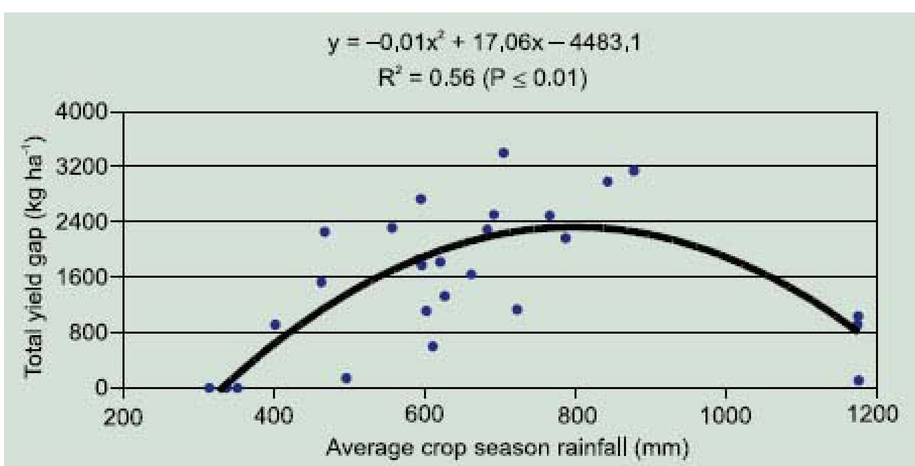

Figure 15. Relationship between total yield gap (difference between average simulated rainfed and district average yields) and average crop season rainfall at selected locations across India (n=27).

4.10 Summary

Groundnut continues to be an important oilseed crop in the rainfed agroecosystem of India. Besides being a cash crop for the resource poor farmers, it significantly supplements the edible oil requirements of the country. Current coverage of the crop is about seven M ha. The productivity of groundnut, however, continues to be strikingly low, ie, about one t ha^{-1} and is much below its potential. There are several biophysical, technical and socioeconomic constraints, which limit the productivity of groundnut in India. In order to mitigate these limitations, it is essential to assess the production potential of the environment in relation to achievable and current levels of production as well as the availability of the natural resources. Therefore, the study was undertaken: a) to analyze the groundnut area in terms of intensity of distribution in different districts (production zones), AEZs and states across India; b) to estimate the simulated water limited potential, achievable and current levels of average farmers yields in these regions; c) to quantify the extent of yield gap I and II; and d) to find out the possible reasons and ways to mitigate these yield gaps.

Using groundnut simulation model, long-term potential yield and various water balance components were estimated for 20 locations representing different regions. To supplement the estimated simulated potential yields, last ten years of yield data reported from experimental stations of AICRPG were utilized. The achievable yields for locations across the country were taken from the trials conducted in farmers' fields with improved production technology under FLDs. The district average yields were taken as the average farmers yields. Based on simulated, experiment station, achievable and average farmers yields, YG I and YG II were estimated.

Analysis indicated that the crop is concentrated in the states of Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu and Maharashtra, encompassing AEZs 2 and 3 of arid and 5 to 8 of semi-arid ecosystem. However, among the districts, the distribution of area is very uneven as out of 273 groundnut-growing districts, only 13 districts contribute 50% of the total area under the crop in India. The crop is grown in a wide range of major soil groups (Alfisols, Vertisols and Inceptisols). The average crop season rainfall varies from 350 to 1200 mm. This leads to a large variability in the production environments in terms of production potential and management of natural resources.

Depending on the agroclimatic conditions, large spatial and temporal variations were observed in the average simulated potential yield, which ranged from 800 to 4460 kg ha^{-1} across locations. Similarly, the reported experiment station, on-farm and average farmers yields ranged from 1050 to 3620, 1130 to 2460 and 580 to1880 kg ha^{-1}, respectively, across locations. On an average there was 17% reduction in yield from experimental station to on-farm and 43% reduction from on-farm to average farmers yield. The average long term simulated potential yield across major production zones, AEZs and states ranged from 2320 to 23170, 790 to 3750 and 1200 to 3490 kg ha^{-1}, respectively, indicating a large variability for the potential of groundnut in different regions across India. The simulated rainfed yields also indicated a much higher potential for groundnut productivity than what is realized at present. The YG I ranged from 570 to 1410, 0 to 1290 and 660 to 1850 kg ha^{-1} in different production zones, AEZs and states across India, respectively. Though, the yield gap I cannot be abridged completely, it gives an indication of upper limits of achievable productivity in a given environment. The narrow YG I in some of the regions indicate the need to further refine the production technology and develop varieties that can perform still better in a given environment. Existence of large variations in YG I in groundnut growing regions are indicative of under realization of varietal potentials. On the other hand YG II, is manageable as it is mainly due to the differences in the management practices and extent of input use. In groundnut,YG II ranged from 0 to 670, 0 to 1390 and 460 to 820 kg ha^{-1} across different production zones, AEZs and states of India, respectively. The extent of YG II and a high degree of spatial and temporal variability observed across locations and different regions indicate the potential to increase groundnut productivity with improved management under rainfed situation.

The water balance analysis showed a high degree of surface runoff at some of the centers, which ranged from 11 to 54% of the total crop season rainfall indicating the need not only to harvest and conserve this water for supplemental irrigation and/or recharging of the groundwater, but also to minimize the erosion of top fertile soil.

The average simulated yields as well as total yield gap across different locations showed a significant and positive but curvilinear relationship with average crop season rainfall (R^2 =0.63 and 0.56, respectively). Both simulated yield and yield gap increased linearly with increasing crop season rainfall up to ~700 mm. The relationships indicate that sub-optimal water availability and resultant subdued expression of improved management practices (cultural and nutrient management) are the major factors for lower potential yield in rainfed environments of many locations and regions. It also indicates that higher increase in average farmers yield with improved management practices would be possible in the regions/seasons of good rainfall or with supplemental irrigations. It is concluded that further development of improved genotypes with better water use efficiency and adoption of improved package of practices can help in raising the potential productivity and in abridging the large yield gaps of groundnut in a rainfed environment. The adaption of proven technologies such as effective watershed management, switching to planting on effective land configurations (BBF, ridge-and-furrow system) and water conserving cultural methods (residue recycling, mulching etc) can help in efficient use of water and nutrients particularly in the seasons, locations and regions with sub-optimal water availability.

5. Yield Gap Analysis of Pigeonpea

5.1 Abstract

Pigeonpea (C*ajanus cajan* (L.) Millsp.) is an important rainfed legume crop for millions of smallholder farmers in India and in many other countries of the tropical and subtropical regions of the world. In India, it is cultivated in about 3.4 M ha and contributes about 20% to the total pulses production of the country. However, its average productivity has remained strikingly low at about 0.5 to 0.7 t ha^{-1}. To work out a suitable strategy to improve the productivity of pigeonpea, it is imperative to assess the potential yield in the region of interest and gap between the potential and actual yield obtained by the average farmers. This analysis in turn also helps to know the major factors associated with these yield gaps for a given location or a region. In the present study, the long-term average rainfed potential yield and water balance components of medium-duration pigeonpea for 35 locations, representing different regions across India, were estimated using APSIM-pigeonpea model. Based on long-term simulated potential, reported experimental station, on-farm and average farmers yields, YG I and YG II were estimated for different locations as well as for different regions across India. Depending upon the agroclimatic conditions, large spatial and temporal variations were observed in the average simulated rainfed potential yield, which ranged from 300 to 2770 kg ha^{-1} among the locations across India.

The average simulated rainfed potential yield across major production zones, AEZs and states of India ranged from 1350 to 1530, 550 to 2220 and 830 to 1960 kg ha^{-1}, respectively. Yield gap I, which is the difference between potential and achievable yield, ranged from 30 to 230, 0 to 570 and 0 to 360 kg ha^{-1} across different production zones, AEZs and states, respectively. The yield gap II, which is the difference between achievable and actual yields realized by the average farmers ranged from 320 to 740, 330 to 1160 and 70 to 1190 kg ha^{-1} across different production zones, AEZs and states of India, respectively. The extent of yield gap II and high degree of spatial and temporal variability observed in it across locations/regions indicated that there is a substantial potential to increase pigeonpea productivity with improved management under rainfed situations. The water balance analysis showed a high surface runoff at some of the locations, which ranged from 10 to 41% of total rainfall indicating the need to harvest and conserve this water and use it for supplemental irrigation or recharging of groundwater. The average simulated yields, average farmers yields as well as total yield gaps across the locations showed a significant ($P \leq 0.01$) and positive association with average crop season rainfall (R^2=0.45, 0.18 and 0.14, respectively). The relationships demonstrate that pigeonpea productivity is limited in many regions / seasons by the availability of soil moisture and increase in average yield with improved management practices is likely to be of greater magnitude in good rainfall regions/seasons or with supplemental irrigations. Various constraints limiting pigeonpea yield across different regions were identified and ways to abridge the large yield gaps are discussed.

5.2 Introduction

Pigeonpea is the most versatile crop, cultivated in many countries of the tropical and subtropical regions of the world. Because of its capacity to tolerate drought and ability to utilize the residual moisture during dry season, it finds an important place in the rainfed farming system adopted by millions of smallholder farmers in many developing countries. The fast growing, deep extensive root system allows plants to grow and produce grain in very arid conditions and in drought years when no other crop can survive. Also, the slow above ground growth of pigeonpea plant during its early phase offers very little competition to other crops and allows productive intercropping with virtually any crop. Pigeonpea assimilates more nitrogen per unit of plant biomass than most other legumes and mobilizes soil bound phosphorus. This benefits both the pigeonpea and subsequent crops in rotation, thus contributing to increased productivity and soil amelioration (Ae et al. 1990; Sinha 1977).

Pigeonpea is used for food, feed and fuel. It has more diverse uses than any other pulse crop. As a *dhal* (dry, dehulled, split seed used for cooking), it is the principal source of dietary protein for more than a billion people, most of whom are vegetarian and poor. Its seed contains about 21% protein and is also rich in essential amino acids, carbohydrates, minerals and vitamin A and C (Saxena et al. 2002). Its green seeds are used for vegetable, crushed dry seeds as animal feed, green leaves as fodder, stems as fuel wood and to make huts and baskets and the plants are also used to culture the lac producing insects.

Pigeonpea as a low-input rainfed crop with all its characteristics that provide economic returns for each and every part of the plant, its cultivation, therefore, has a direct bearing on the socioeconomic and nutritional status of the subsistence farmers in many developing countries of the world. Strikingly low levels of productivity of pigeonpea in India (about 0.7 t ha^{-1}) and other developing countries, therefore, are cause of concern and require urgent attention.

In this section, we have estimated the potential rainfed yield of pigeonpea using both the experimental data and the data generated through simulation techniques and assessed the gaps between potential, achievable and average farmers yields across different locations/regions in India.

5.3 World Trends in Pigeonpea Production

A continuous rise in the global area and production of pigeonpea has been observed (Fig. 16). Its total area and production was 3 M ha and 2 M t in 1970, which rose to 4.26 M ha and 3.05 M t by 2002, respectively (Fig. 16 and Table 38). Its contribution to the total pulses production in the world is about 5%. However, its productivity has more or less remained unchanged to less than one t ha^{-1}. India alone contributes more than 80% of area and production of the pigeonpea in the world. Rest of the area is scattered in other South Asian (about 11%), African (7%), Caribbean and Southeast Asian countries.

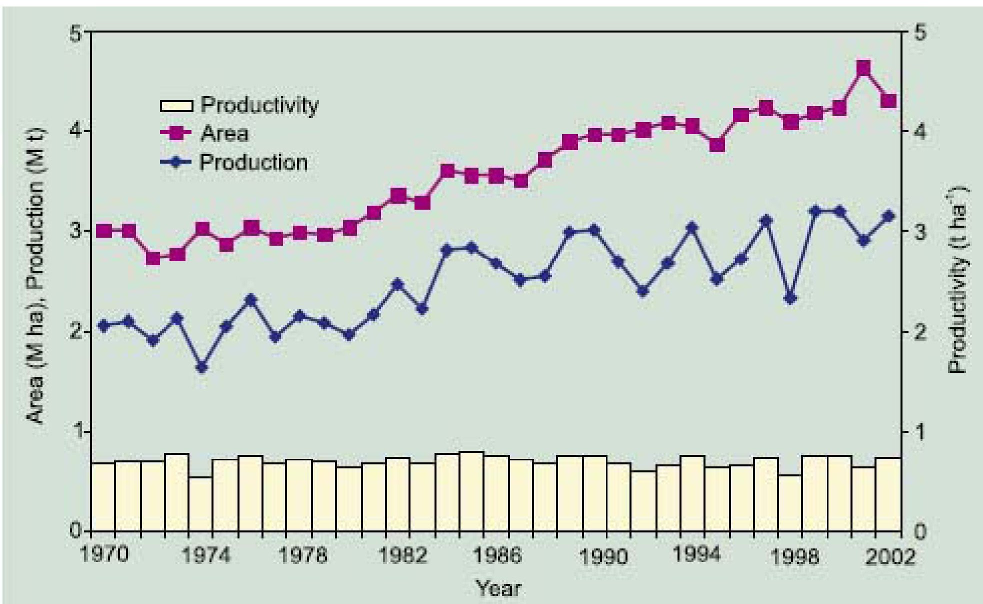

Figure 16. Trends in area, production and productivity of pigeonpea in the world.

Table 38. Global pigeonpea area, production and productivity during 2002–03.

Country	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
India	3.35	2.44	730
Myanmar	0.48	0.40	830
Kenya	0.15	0.06	370
Malawi	0.12	0.08	640
Uganda	0.08	0.08	1000
Tanzania	0.07	0.05	710
Nepal	0.03	0.03	890
Dominican Republic	0.01	0.01	1000
Haiti	0.01	0.00	400
World	4.26	3.05	720

Source: FAOstat data, 2004.

5.4 Pigeonpea Production in India

5.4.1 Area, production and productivity in the country

In India, pigeonpea is mainly grown as a rainy season crop and grown to maturity in the subsequent dry season (*rabi*) on stored soil water. It is grown in a wide range of cropping systems, which can be broadly divided into long season (long-duration), full season (medium-duration) and short season (short-duration) classes (Byth et al. 1981). Depending upon the agroecological situations and domestic needs, pigeonpea is grown as sole crop, mixed crop, intercrop, strip crop, alley crop or ratoon crop (Ali 1996). Over 90% of pigeonpea, mainly long-duration and medium-duration cultivars are grown in dryland areas as a mixed crop or intercropped with cereals (sorghum, maize and pearl millet), legumes (groundnut, soybean, urdbean, mungbean and cowpea) and commercial crops (cotton, castor and cassava).

Over the years, the area under pigeonpea in India has increased from about 2.6 M ha in 1970 to 3.35 M ha in 2002 (Fig. 17). However, during the same period, the total production has been fluctuating and ranged between 1.4 M t in 1973–74 to 2.5 M t in 1989–90. These fluctuations have mainly been due to variations observed in the productivity of pigeonpea crop, which ranged between a minimum of 0.5 t ha^{-1} in 1973–74 to the maximum of 0.8 t ha^{-1} in 1998–99. With 2.44 M t of production in the year 2002, pigeonpea contributes about 20% to the total pulse production in the country and is the second most important pulse crop next only to chickpea.

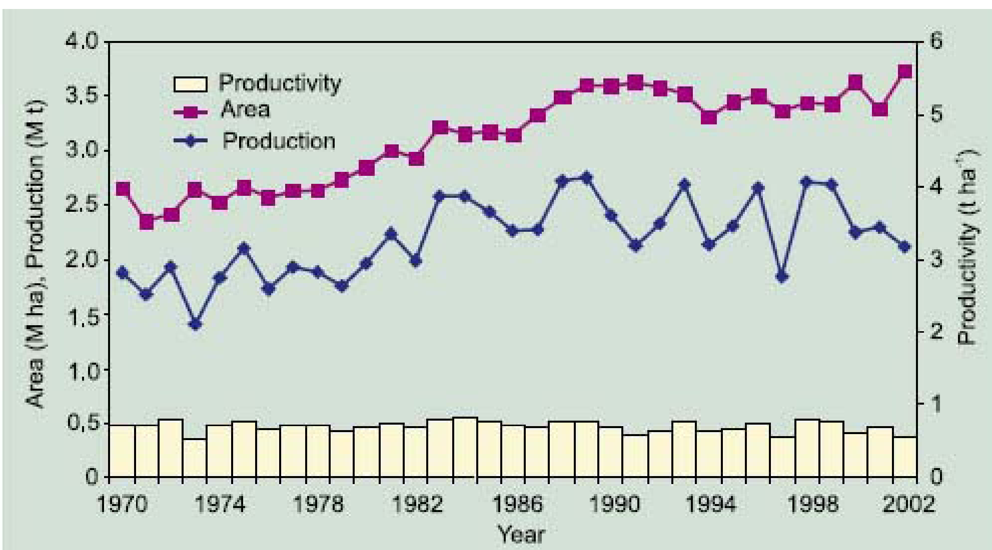

Figure 17. Trends in area, production and productivity of pigeonpea in India.
Source: FAOstat data, 2004.

5.4.2 Area, production and productivity in crop production zones

Pigeonpea cultivation is spread over 315 districts across India covering 3.36 M ha with an average production of 2.31 M t (Fig. 18, Table 39). However, only 26 districts (primary zone) contribute to 50% of the total area under pigeonpea in the country. Another 35% area is distributed in 74 districts (secondary zone). Rest 215 districts contribute to only 15% of the total area of which 87 districts have less than 1000 ha under pigeonpea cultivation. The distribution of pigeonpea area in such a large number of districts across India, each possessing a little proportion of the total area indicated the subsistence nature of pigeonpea farming, taken up mostly by poor farmers with very small holdings.

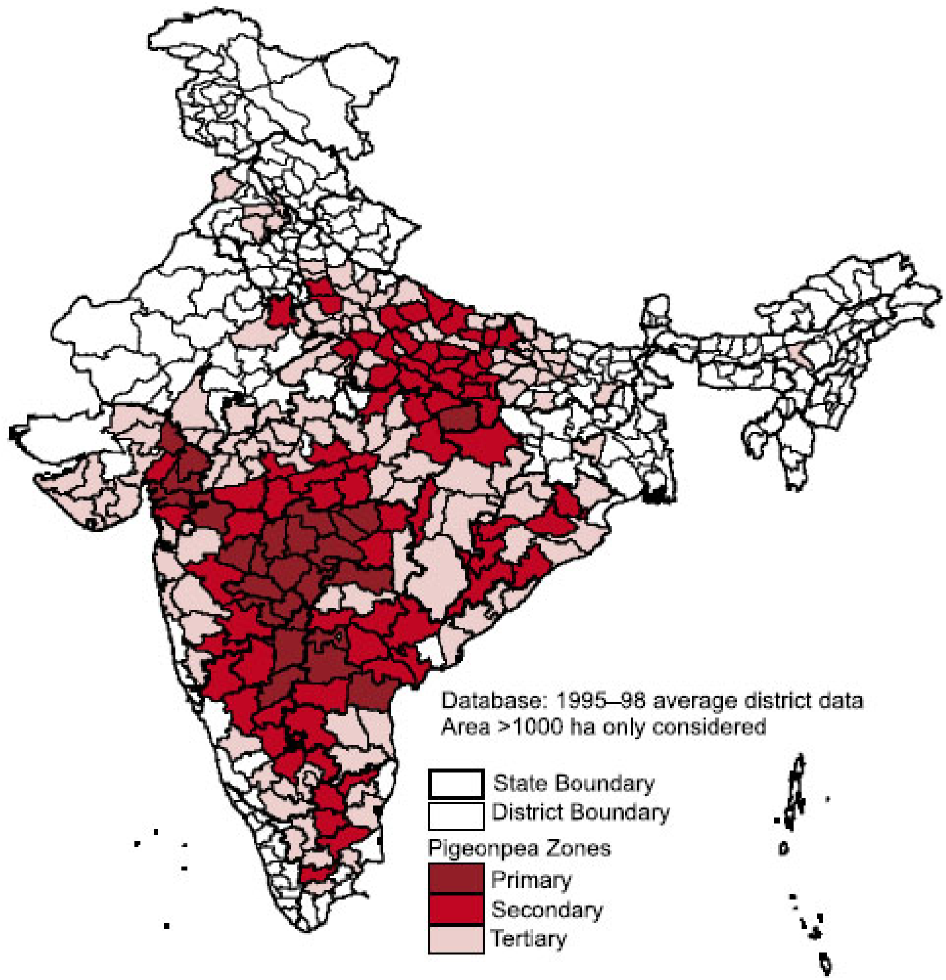

Figure 18. Primary, secondary and tertiary production zones of pigeonpea in India.

Table 39. Area, production and productivity of pigeonpea in different production zones of India (1995–96 to 1997–98).

Production Zone	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	Yield CV (%)
Primary	26	1.68	1.01	600	48
Secondary	74	1.19	0.91	760	55
Tertiary	128	0.47	0.37	800	43
Others	87	0.02	0.02	670	45
Total	315	3.36	2.31	690	48

The average productivity was considerably less (600 kg ha^{-1}) in primary zone as compared to secondary (760 kg ha^{-1}) and tertiary zone (800 kg ha^{-1}). The CV for the productivity among the districts ranged from 43 (tertiary zone) to 55% (secondary zone). The lower productivity levels, particularly in 23 districts of primary zone, which has the maximum area under the crop and high CV values among the districts in all the production zone offers a great scope to enhance the production levels of pigeonpea in the country.

5.4.3 Area, production and productivity in agroecological zones

Classification of pigeonpea area into different production zones gives an indication of the geographical area where the crop is most concentrated and where the intervention can lead to maximum gains in the production of crop. However, in each crop zone, districts may come from diverse ecological background and variability in their productivity may overwhelmingly be governed by the variability in the climatic conditions of these districts. Based on uniformity in climate, soils, etc, the whole country has been divided into 20 agroecological zones (Sehgal et al. 1995). Therefore, an attempt was made to look into the spread of area, production and productivity of pigeonpea in these agroecological zones.

The major pigeonpea area is confined to semi-arid ecosystem (71%) while sub-humid and arid ecosystems contribute 25 and 3% of the total area in the country, respectively (Fig. 19, Table 40).

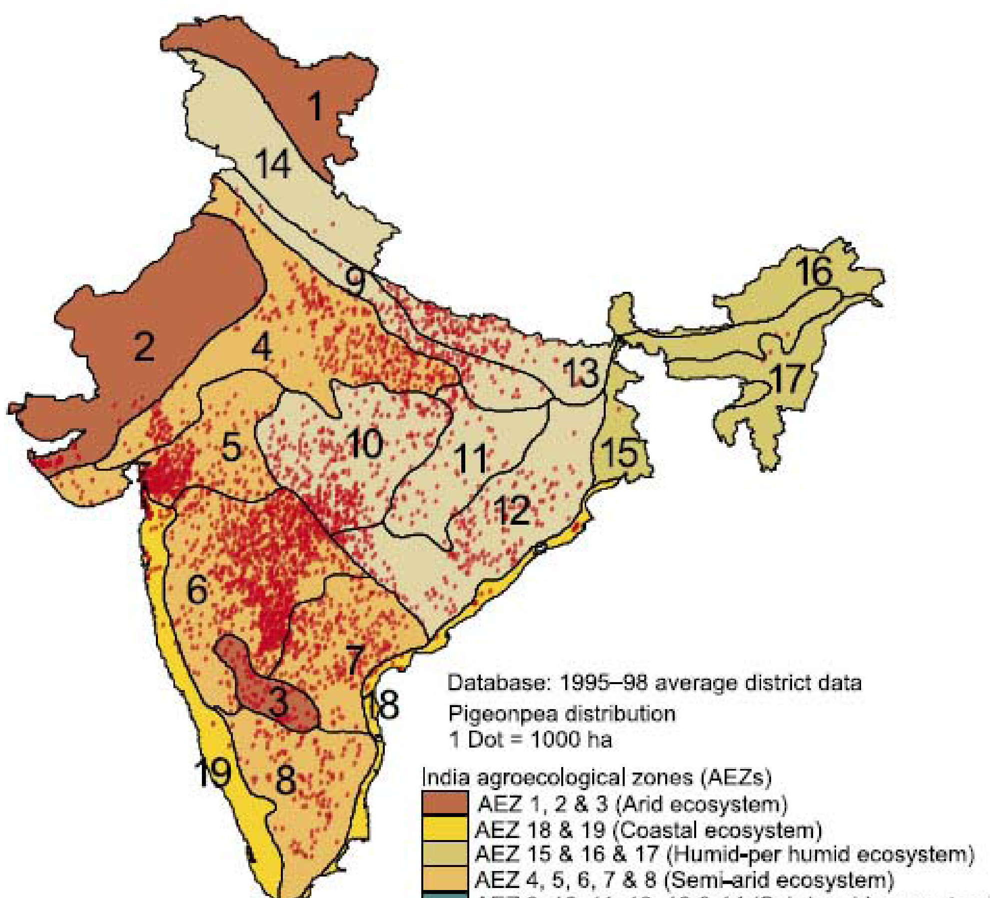

Figure 19. Distribution of pigeonpea in different agroecological zones of India.

Table 40. Area, production and productivity of pigeonpea in different AEZs of India (1995–96 to 1997–98).

Ecosystem	AEZ	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	Yield CV (%)
Arid	2	12	0.01	0.01	850	39
Arid	3	4	0.09	0.02	260	20
Semi-arid	4	52	0.37	0.43	1160	43
Semi-arid	5	24	0.39	0.32	820	30
Semi-arid	6	30	1.23	0.69	560	58
Semi-arid	7	15	0.27	0.10	360	47
Semi-arid	8	27	0.14	0.08	550	58
Sub-humid	9	27	0.12	0.11	930	32
Sub-humid	10	28	0.36	0.27	770	37
Sub-humid	11	8	0.06	0.06	910	25
Sub-humid	12	19	0.18	0.10	550	36
Sub-humid	13	20	0.10	0.09	880	36
Others	-	49	0.03	0.02	690	36
Total		315	3.36	2.31	690	48

Semi-arid ecologies in the tropics are characterized by seasonal rainfall, which is erratic and highly variable (CV of about 30%). Based on the duration of the availability of moisture, the semi-arid ecosystem is further subdivided into semi-arid (dry) and semi-arid (moist) ecosystems. In the dry semi-arid ecosystem, the LGP ranges between 90 to 120 days and the rainfall ranges from 500 to 750 mm, a situation suitable for sustaining a single crop. In the moist semi-arid ecosystem, LGP ranges between 120 and 150+ days. The rainfall varies from 750 to 1000 mm and soil moisture is sufficient for growing two crops either as sequential or intercropping system. Though, pigeonpea is cultivated in both the dry semi-arid and wet semi-arid ecoregions, the area is more concentrated in the former.

Within the semi-arid ecosystem, the major area is spread into AEZ 6 (1.23 M ha), which is 37% of the total area under pigeonpea in the country. This zone consists of Deccan plateau and is spread into Maharashtra, Karnataka and parts of Andhra Pradesh; climate is hot semi-arid having Vertic Inceptisols and Vertisols and LGP is 90 to 150 days. In this AEZ, the maximum area is spread in Maharashtra where 15 out of total 26 primary zone districts are located (Table 40). AEZs 4 and 5 of semi-arid ecosystem contribute 0.37 and 0.39 M ha area under pigeonpea. AEZ 5 comprises Central highlands and has Vertisols and Vertic Inceptisols; the climate is semi-arid (moist) and LGP varies from 90 to 150 days. AEZ 4 comprises northern plain and Central highlands ecoregion and is spread into parts of Gujarat, Rajasthan, Madhya Pradesh, Uttar Pradesh and Punjab. The climate is hot, semi-arid and has alluvium derived soils and the LGP is 90 to 150 days. The AEZs 7 and 8 together contribute about 0.414 M ha and area is spread in southern parts of the country (Andhra Pradesh, Karnataka and Tamil Nadu), having Alfisols, Vertisols and Vertic Inceptisols. In the sub-humid ecosystem, the maximum area (0.36 M ha) is spread in the AEZ 10. The zone consists of Central highlands (Malwa, Bundelkhand and eastern Satpura) and eastern Maharashtra plateau having Vertisols and Vertic Inceptisols. Climate is hot sub-humid (dry) and LGP varies from 120 to 180 days.

Across the AEZs, a large variation in the average yields was observed, which ranged from 260 kg ha^{-1} (AEZ 3) to 1160 kg ha^{-1} (AEZ 4). In AEZ 6, which has the maximum area under pigeonpea, the average productivity was only 560 kg ha^{-1}, which is much below the average productivity of many other AEZs as well as national average. Also the variation in the yield among the location in the AEZ 6 was the highest indicating a greater scope for improvement in productivity in this zone and total production at national level. In rest of the zones where there is a considerable area under pigeonpea, the variability in yield among the locations was also high (CV more than 30%).

The distribution of pigeonpea area into diverse agroecological zones, which are characterized by highly erratic rainfall, explains the large fluctuations observed in the total production of the crop in the country (Fig. 19). In a rainfed farming system, a high spatial and temporal variability in rainfall and other biophysical environment warrants a location specific understanding of the problems associated with poor productivity and technologies, which cater to the requirements of individual locations.

5.4.4 Area, production and productivity in the major states

State being an administrative unit, the information on the extent of yield gaps and intervention required to fill these gaps can help the concerned states to take required action. Therefore, an attempt has been made to estimate the existing yield gaps and constraints to production in major pigeonpea growing states of India. Among the states, Maharashtra has the largest area (1.03 M ha), which accounts for 31% of the total pigeonpea area in the country (Table 41). Five states, viz, Uttar Pradesh, Karnataka, Gujarat, Madhya Pradesh and Andhra Pradesh, each having an area of about 10 to 12%, together contribute to 60% of the total pigeonpea area in the country. Among these states, the highest average productivity was observed in Uttar Pradesh (1090 kg ha^{-1}) followed by Gujarat (880 kg ha^{-1}) and Madhya Pradesh (810 kg ha^{-1}). The average productivity was less in Maharashtra (610 kg ha^{-1}), Karnataka (410 kg ha^{-1}) and Andhra Pradesh (330 kg ha^{-1}) as compared to the national average (600 kg ha^{-1}). Except for Gujarat, the CV for average productivity among the districts of these states was very high (29 to 45%). No substantial change in the area, production and productivity of pigeonpea was observed in 2002 (Table 42) as compared to the average figures of 1995–96 to 1997–98 (Table 41).

Table 41. Area, production and productivity of pigeonpea in different states of India (1995–96 to 1997–98).

State	No. of districts	Area (M ha)	Production (M t)	Yield	
				(kg ha^{-1})	CV (%)
Maharashtra	28	1.03	0.62	610	35
Uttar Pradesh	63	0.47	0.51	1090	43
Karnataka	18	0.43	0.18	410	29
Gujarat	19	0.39	0.34	880	18
Madhya Pradesh	45	0.38	0.31	810	32
Andhra Pradesh	22	0.35	0.12	330	45
Orissa	13	0.14	0.08	570	28
Tamil Nadu	17	0.08	0.05	660	25
Bihar	21	0.04	0.06	1370	25
Rajasthan	21	0.04	0.03	770	40
Others	48	0.02	0.02	760	25
All India	315	3.36	2.31	690	49

Table 42. Area, production and productivity of pigeonpea in different states of India during 2002–03.

State	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
Maharashtra	1.06	0.78	730
Uttar Pradesh	0.33	0.30	910
Karnataka	0.51	0.24	470
Gujarat	0.31	0.20	630
Madhya Pradesh	0.27	0.17	640
Andhra Pradesh	0.43	0.15	350
Bihar	0.09	0.10	1060
Orissa	0.12	0.07	630
Jharkhand	0.05	0.07	1510
Tamil Nadu	0.05	0.03	640
Others	0.16	0.10	-
All India	3.38	2.21	650

Source: Ministry of Agriculture, India, 2004.

5.5 Observed Rainfed Potential Yield of Pigeonpea

5.5.1 Observed experimental, on-farm and district yields

For short- and medium-duration pigeonpea, experimental station data was available for 21 and 17 locations, respectively (Table 43). Across locations, depending upon rainfall, soil and other location specific factors, the mean experimental station yield for short- and medium-duration pigeonpea ranged from 730 (Vamban) to 2270 (Patancheru) and 910 (Vamban) to 2330 kg ha^{-1} (Madhira, Andhra Pradesh), respectively. The average on-farm yield across 13 locations for which data was available ranged from 620 (Vamban) to 1690 kg ha^{-1} (Badnapur, Maharashtra). As against this, the district average yields for the corresponding years for which experimental station and on-farm yields were collected for each location ranged from 130 (Patancheru) to 990 kg ha^{-1} (Faridkot, Punjab). In general, experimental station and on-farm yields were considerably higher than those of district average yields at all the locations. When averaged over all the locations across India, the mean experimental station yield for short- and medium-duration pigeonpea did not show any significant difference, which was 1500 and 1600 kg ha^{-1}, respectively. The average on-farm and district yields were 1250 and 620 kg ha^{-1}, respectively. Hence, on an average, there was about 20 and 50% reduction in average pigeonpea yields from experimental station to on-farm and from on-farm to district level, respectively.

Minimum and maximum values and the CV for each location presented in Table 43 indicated the variability observed over years in the yield of pigeonpea at each location. This temporal variability in yield was quite high and depending on the location, the CV ranged from 11 to 50% and 12 to 53% for short- and medium-duration pigeonpea, respectively. Similarly, the CV of average on-farm and district yields ranged from 11 to 43% and 5 to 50%, respectively. Variation in yield over years at each location reflects the uncertainty of climatic factors in rainfed environment particularly that of rainfall. The maximum yields are obtained when the climatic conditions including availability of soil moisture conditions are optimum and represent the full potential (water non-limiting) of the crop. Over the locations, the minimum experimental station yields for both the short- and medium-duration pigeonpea were just half of their respective average maximum yields. While the average minimum yields in case of on-farm trials (850 kg ha^{-1}) and district averages (410 kg ha^{-1}) were about 48% less than their respective average maximum values. Similarly, large spatial variability existed in

Table 43. Observed experimental station (short- and medium-duration), on-farm and district average yields (kg ha^{-1}) of pigeonpea at different AICRP locations across India.

	Experimental station															
	Short-duration				Medium-duration				On-farm				District Average[1]			
Location	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]
Primary Zone																
Badnapur	1100	2550	1690	28	870	2570	1830	27	1300	1990	1690	15	280	570	390	27
Gulbarga	590	3000	1580	50	820	1850	1350	28	460	1570	1180	29	250	610	450	25
Jalna	1110	1670	1410	15	1200	2580	1860	25	-	-	-	-	160	490	350	37
Parbhani	610	1800	1220	49	-	-	-	-	-	-	-	-	340	580	430	31
Bharuch	-	-	-	-	710	1900	1410	37	-	-	-	-	300	770	570	28
Vadodara	-	-	-	-	1090	2110	1770	26	-	-	-	-	360	860	670	35
Akola	-	-	-	-	-	-	-	-	860	1490	1150	21	780	870	800	5
Secondary Zone																
Rahuri	980	2440	2000	24	670	2980	1720	40	1160	2020	1480	19	260	730	500	26
Khargone	730	2580	1500	40	1280	2750	1740	32	790	1870	1410	32	320	660	540	19
Patancheru	2080	2690	2270	12	1440	1820	1640	12	-	-	-	-	90	190	130	50
Anand	910	1650	1260	25	-	-	-	-	-	-	-	-	460	1430	900	46
Berhampore	740	1160	950	18	820	1270	1000	24	-	-	-	-	500	750	600	22
Lam	-	-	-	-	900	1650	1380	24	-	-	-	-	390	710	540	23
Madhira	-	-	-	-	1820	2830	2330	21	-	-	-	-	450	540	500	8
Warangal	-	-	-	-	-	-	-	-	920	2000	1520	29	170	450	310	30
Tertiary Zone																
Bangalore	1150	1840	1440	20	520	2180	1400	37	930	1570	1180	27	410	680	610	4
SK Nagar	1190	2620	1730	32	-	-	-	-	990	1390	1280	13	340	950	720	26
Ludhiana	920	3320	1600	46	-	-	-	-	1130	1550	1350	11	540	890	760	13
Coimbatore	520	1910	1130	34	680	2390	1230	46	650	1160	840	23	380	870	630	25
Vamban	570	860	730	20	640	1460	910	41	510	780	620	15	140	490	360	42
Modipuram	1300	1690	1450	28	-	-	-	-	-	-	-	-	700	1290	980	25
Junagadh	-	-	-	-	1190	3380	2180	53	-	-	-	-	620	1000	870	20
Sehore	-	-	-	-	1120	2210	1860	20	910	2100	1510	33	460	870	700	20
Raipur	-	-	-	-	1300	1830	1610	17	490	1590	1060	43	270	710	530	31

Continued...

Table 43. *Continued.*

	Experimental station															
	Short-duration				Medium-duration				On-farm				District Average[1]			
Location	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]
Others																
Pantnagar	930	2230	1500	42	-	-	-	-	-	-	-	-	580	1000	730	19
Hisar	1340	2610	1720	24	-	-	-	-	-	-	-	-	220	1150	690	37
Sriganganagar	880	2130	1380	48	-	-	-	-	-	-	-	-	860	1000	950	9
New Delhi	1110	3330	1740	39	-	-	-	-	-	-	-	-	400	1160	690	35
Samba	1470	1910	1700	11	-	-	-	-	-	-	-	-	400	740	650	26
Faridkot	1020	2480	1550	40	-	-	-	-	-	-	-	-	900	1050	990	6
Mean	1010	2210	1500		1000	2220	1600		850	1620	1250		410	800	620	
CV[3]	36	29	23		33	26	26		31	23	24		50	34	34	

- Data (experimental station/on-farm) not available.
1 District average yields are for the corresponding years for which experimental station data was collected (Annexure VI & VII).
2 CV = Coefficient of variation (%) for mean yield of a location over years.
3 CV = Coefficient of variation (%) for mean yield over locations.

the magnitude of minimum and maximum pigeonpea yields obtained in experimental station, on-farm and district averages across the locations.

For long-duration pigeonpea data was available only for four locations (Table 44). The average experiment station yield of these locations was 2200 kg ha^{-1}, which ranged from 1750 (Dholi, Bihar) to 2610 kg ha^{-1} (Pusa, Bihar). The average maximum yield of these locations was 2960 kg ha^{-1}, which ranged from 1880 to 3490 kg ha^{-1}. The average minimum yield of these locations was 1470 kg ha^{-1}, which ranged from 1210 to 1780 ha^{-1}. The CV for the spatial variability (year-to-year) among these locations ranged from 8 to 35%. On-farm data for long-duration pigeonpea was not available. Mean of the district average yield for the locations was 1230 kg ha^{-1} with a minimum of 870 kg ha^{-1} and maximum of 1600 kg ha^{-1}.

Table 44. Observed experimental station (long-duration) and district average yield (kg ha^{-1}) of pigeonpea at different AICRP locations across India.

	Experimental station				District Average[1]			
	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]
Secondary Zone								
Varanasi	1210	3490	2190	35	800	1420	1140	16
Kanpur	1780	3070	2260	22	1000	2110	1630	28
Tertiary Zone								
Pusa	1310	3380	2610	27	750	1460	1090	20
Dholi	1580	1880	1750	8	920	1410	1050	23
Mean	1470	2960	2200		870	1600	1230	
CV[3]	18	25	16		13	21	22	

1 District yields are for the corresponding years for which experimental station data was collected (Annexure VIII).
2 CV = Coefficient of variation (%) for mean yield of a location over years
3 CV = Coefficient of variation (%) for mean yield over locations

5.6 Simulated Rainfed Potential Yields

5.6.1 Potential yield at selected locations

Depending on the climatic conditions and soil types, large variation in mean simulated yield across the locations (spatial) and also over the years at a given location (temporal) was observed (Table 45). When averaged over all the locations, the mean simulated yield was 1400 kg ha^{-1} with a CV of 38% across these locations. The mean simulated yield of the locations ranged from 300 (Hisar, Haryana) to 2770 kg ha^{-1} (Faizabad, Uttar Pradesh). Large differences were observed in the minimum and maximum grain yields that were obtained over years at each location. The high degree of temporal variability was evident as the CV for grain yield over number of years of simulation at each location ranged from 15 (Warangal, Andhra Pradesh) to 88% (Coimbatore). The maximum simulated yield at each location were obtained in those seasons when rainfall was well distributed and onset of monsoon was timely and indicated the full (water non-limiting) yield potential of pigeonpea crop at these sites. The maximum yield across locations ranged from 640 (Hisar, Haryana) to 3840 kg ha^{-1} (Faizabad, Uttar Pradesh). The minimum simulated yield at these locations was also highly variable (0 to 2010 kg ha^{-1}) and in some years the crop completely failed at some locations. The rainfall played an important role in both the temporal and spatial variability in the rainfed simulated yields. The locations, which

Table 45. Simulated grain yield (medium-duration), crop season rainfall, district average yield and total yield gap of pigeonpea at selected locations across India.

	Simulated yield (kg ha^{-1})				Rainfall (mm)				District	
Location	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	yield[1] (kg ha^{-1})	Yield gap (kg ha^{-1})
Primary Zone										
Akola	170	2570	1360	51	260	1130	680	32	910	450
Amravati	690	2420	1360	41	440	1130	750	26	900	460
Bharuch (Haldar)	340	1440	810	43	330	1090	680	52	640	170
(Sisodia)	700	1560	1050	29	370	1120	720	38	640	410
Gulbarga	270	2640	1570	32	280	1180	680	36	440	1130
Nagpur	670	2560	1320	40	440	1450	890	29	520	800
Nanded	220	2820	1600	47	250	1450	750	35	540	1060
Parbhani	60	3820	1890	36	420	1570	850	36	440	1450
Raichur	0	2000	1210	45	310	900	570	37	190	1020
Wardha	970	2230	1540	25	580	1580	940	24	700	840
Secondary Zone										
Anantapur	240	2180	1300	41	100	760	430	41	280	1020
Belgaum	1010	2650	1780	25	620	1620	960	24	240	1540
Bellary	30	1810	920	46	170	650	360	37	310	610
Bijapur	140	2090	1180	53	210	740	470	32	300	880
Dharwad	810	2610	1770	33	290	910	520	27	430	1350
Kurnool	530	2130	1220	37	220	1240	680	41	400	820
Patancheru	660	3460	1870	38	350	1260	730	30.	220	1650
Rahuri	0	2120	770	82	220	810	430	36	470	300
Warangal	1400	2240	1740	15	380	1470	870	35	300	1440
Betul	1140	3460	2280	24	660	1510	1100	21	640	1640
Kanpur	1430	2930	2080	23	590	1930	1160	39	170	1910
Raisen	370	1540	1040	33	580	1500	990	29	930	110
Varanasi	1430	2740	1970	19	600	1340	870	24	890	1080
Tertiary Zone										
Aduturai	0	2750	1710	37	470	1490	970	28	*	
Bangalore	0	3630	2320	50	270	1150	740	34	580	1740
Coimbatore (Coimbatore)	0	2130	960	88	270	750	500	35	590	370
(Palaturai)	0	1460	800	64	310	750	510	30	590	210
Jhabua	160	1630	1190	29	220	1340	630	44	530	660
Indore	890	3310	1880	30	360	1350	880	28	730	1150
Jhansi	510	1410	1030	33	390	1000	730	31	1040	0
Junagadh	0	1520	940	41	250	1290	680	43	890	50
Ludhiana	0	2700	1280	43	330	1170	640	25	710	570
Rajkot (Semla)	400	1450	760	41	250	880	510	44	900	0
(Bhola)	330	1300	580	49	250	880	540	42	900	0
Faizabad	2010	3840	2770	21	680	1220	890	15	1140	1630
Others										
Pantnagar	0	3120	1920	37	640	2450	1250	38	630	1290
Delhi	0	2300	1090	61	160	1120	660	38	*	-
Hisar	0	640	300	82	310	860	460	43	*	-
Mean	460	2350	1400		360	1210	730		636	810
CV[3]	111	33	38		43	30	29		49	66

In parentheses are the soil series.
* District Average yields are not available due to negligible area under pigeonpea.
1 District yields are average of 1995-96 to 1998-99.
2 Coefficient of variation (%) for mean value of a location over years.
3 Coefficient of variation (%) for mean value over locations.

received very low average rainfall (Hisar, Rajkot, Coimbatore, Rahuri, Bijapur, Bellary and Anantapur) gave very low average pigeonpea yield and had high temporal variability.

5.6.2 Potential yield of production zones

To find out the potential of pigeonpea crop in different crop production zones, AEZs and states, the locations situated in each region were grouped together. Based on long-term simulated average yield of each locations, the minimum, maximum and mean potential rainfed yield were calculated for each region and are presented in Table 46. Among the production zones, secondary zone showed a higher rainfed yield potential (1530 kg ha^{-1}) as compared to primary (1370 kg ha^{-1}) and tertiary production zone (1350 kg ha^{-1}). However, the maximum yield recorded in primary, secondary and tertiary zones was 1890, 2280 and 2770 kg ha^{-1}, respectively. The CV of mean potential yield was very high for tertiary zone (48%) followed by secondary (31%) and primary zone (20%).

5.6.3 Potential yield of agroecological zones

Among the agroecological zones, the maximum area under pigeonpea (71%) (Table 40) is in semi-arid ecosystem (AEZs 4 to 8). The average potential yield for this region ranged from 1170 to 1610 kg ha^{-1} (Table 46). In sub-humid ecosystem, AEZ 10 has significant area (10%) and the average rainfed

Table 46. Rainfed potential yield of pigeonpea in different production zones, AEZs and states of India.

Zone/State		No. of location	Simulated yield (kg ha^{-1}) Min	Max	Mean	CV	Crop season rainfall (mm) Min	Max	Mean	CV
Production Zone										
Primary		10	810	1890	1370	20	570	940	750	12
Secondary		13	770	2280	1530	31	360	1160	740	38
Tertiary		13	580	2770	1350	48	500	970	690	23
AEZ										
2	Arid	3	300	760	550	43	460	540	500	8
3	Arid	4	920	1300	1140	17	360	470	420	12
4	Semi-arid	4	1030	2080	1370	36	640	1160	800	30
5	Semi-arid	5	810	1880	1170	35	630	880	720	13
6	Semi-arid	9	770	1890	1480	24	430	960	690	24
7	Semi-arid	3	1220	1870	1610	21	680	870	760	13
8	Semi-arid	4	800	2320	1450	49	500	970	680	33
9	Sub-humid	4	1920	2770	2220	21	870	1250	1010	21
10	Sub-humid	4	1040	2280	1550	34	890	1100	980	9
State										
Maharashtra		7	1320	1890	1410	24	430	940	750	23
Karnataka		7	920	2320	1540	31	360	960	610	33
Andhra Pradesh		4	1220	1870	1530	21	930	870	680	27
Gujarat		5	580	1050	830	22	510	720	620	15
Madhya Pradesh		4	1040	2280	1600	36	630	1100	900	22
Uttar Pradesh		4	1030	2770	1960	37	730	1160	910	20
Tamil Nadu		3	800	1710	1160	42	500	970	660	

CV = Coefficient of variation (%)

potential of the crop was 1550 kg ha^{-1}. However, AEZ 9 having a marginal area under pigeonpea has shown a very high yield potential of 2220 kg ha^{-1}. In arid ecosystem, which has a negligible area under pigeonpea, the yield potential was very poor for AEZ 2 (550 kg ha^{-1}) and moderate for AEZ 3 (1140 kg ha^{-1}).

5.6.4 Potential yield of major states

Among the major states (Maharashtra, Karnataka, Andhra Pradesh and Madhya Pradesh) the average rainfed yield potential ranged between 1400 to 1600 kg ha^{-1} (Table 46). The average rainfed yield potential of pigeonpea in Gujarat (830 kg ha^{-1}) and Tamil Nadu (1160 kg ha^{-1}) was relatively low while Uttar Pradesh showed the maximum potential of 1960 kg ha^{-1}. In general, the simulation studies indicated that in major pigeonpea growing regions in India, the average rainfed potential is almost double as compared to the national average (690 kg ha^{-1}) and this indicates that there are ample opportunities for improving the production and productivity of pigeonpea crop in India.

5.7 Yield Gaps

5.7.1 Yield gap of selected locations

The magnitudes of YG I, II and total in pigeonpea are presented in Tables 47 to 49. Taking into account experimental station yield data of short-duration pigeonpea, the average yield gap I across the locations was 260 kg ha^{-1} and ranged from 0 (Badnapur, Maharashtra) to 520 kg ha^{-1} (Rahuri, Maharashtra) (Table 47). The average YG II was 700 kg ha^{-1} and ranged from 190 (Coimbatore) to 1300 kg ha^{-1} (Badnapur). The average total yield gap was 880 kg ha^{-1} and ranged from 360 (Anand, Gujarat) to 1500 kg ha^{-1} (Rahuri). Besides considerable spatial variability, a high degree of temporal variation in these yield gaps was observed. Depending on the location, CV for year-to-year variability in YG I, YG II and total YG ranged from 55 to 156, 25 to 153 and 14 to 145%, respectively.

Taking into account the experimental station yield data of medium-duration pigeonpea, the average yield gap I (Table 48) across the locations was 300 kg ha^{-1} with a range of 140 (Badnapur) to 550 kg ha^{-1} (Raipur, Chattisgarh). The average YG II was 720 kg ha^{-1}, which ranged from 210 (Coimbatore) to 1300 kg ha^{-1} (Badnapur). The average total yield gap was 1080 kg ha^{-1} with a range of 400 (Berhampore, Orissa) to 1840 kg ha^{-1} (Madhira). Besides the spatial variability, the extent of temporal variability in yield gaps was also very large and the coefficient of variation for temporal variation in yield gap I, II and total YG ranged from 95 to 187, 25 to 153 and 16 to 90%, respectively.

Experimental station yield data for late maturing pigeonpea was available only for four locations for which no on-farm yield data was available. Therefore, only total yield gaps could be calculated for these locations. The average total yield gap was 970 kg ha^{-1} and ranged from 630 (Kanpur, Uttar Pradesh) to 1510 kg ha^{-1} (Pusa) (Table 49).

High temporal and spatial variability in the yield gap clearly indicated that the extent of yield gap was dependent on climatic conditions. In general, in climatically bad years when even experiment station as well as on-farm yields were low the yield gaps were narrow (Annexures VI–VIII).

Table 47. Yield gaps of pigeonpea (short-duration) at different AICRP locations across India.

	Yield gap (kg ha^{-1})											
	YG I				YG II				Total YG			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Badnapur	0	150	0	156	740	1600	1300	26	740	2250	1310	39
Gulbarga	0	1430	400	147	200	1120	760	40	330	2390	1160	57
Parbhani	-	-	-	-	-	-	-	-	250	1460	790	77
Jalna	-	-	-	-	-	-	-	-	950	1360	1090	16
Akola	-	-	-	-	90	710	350	67	-	-	-	-
Secondary Zone												
Rahuri	190	1150	520	67	710	1440	980	25	460	2050	1500	36
Khargone	0	720	90	116	230	1210	880	52	110	2030	970	64
Patancheru	-	-	-	-	-	-	-	-	1940	2520	2080	14
Anand	-	-	-	-	-	-	-	-	170	860	360	93
Berhampore	-	-	-	-	-	-	-	-	10	600	410	55
Warangal	-	-	-	-	650	1640	1220	38	-	-	-	-
Tertiary Zone												
Bangalore	0	420	260	103	0	1160	570	66	490	1180	830	37
SK Nagar	70	1420	440	55	360	990	570	37	240	1900	1010	55
Ludhiana	80	1780	250	153	340	800	590	26	160	2520	840	88
Coimbatore	0	750	280	73	10	660	190	153	140	1400	470	79
Vamban	0	230	120	82	80	550	250	72	80	410	370	58
Modipuram	-	-	-	-	-	-	-	-	10	729	470	68
Others												
Pantnagar	-	-	-	-	-	-	-	-	210	1380	780	71
Hisar	-	-	-	-	-	-	-	-	440	1920	1020	46
Sriganganagar	-	-	-	-	-	-	-	-	20	1130	420	145
New Delhi	-	-	-	-	-	-	-	-	350	2490	1040	64
Samba	-	-	-	-	-	-	-	-	770	1390	1050	27
Faridkot	-	-	-	-	-	-	-	-	20	1590	560	129
Mean	40	890	260		320	1080	700		380	1600	880	
CV[2]	172	65	66		91	35	64		118	42	49	

1 CV = Coefficient of variation (%) for mean yield gap of a location over years
2 CV = Coefficient of variation (%) for mean yield gap over locations

5.7.2 Yield gaps of production zones

Both simulated and experimental station yields are indicative of the potential yield of a crop. It is generally expected that the simulated yield would be slightly higher than the experiment station yield as all the crop management conditions cannot be optimized under field conditions. However, in the present study, the average long-term rainfed simulated yields were less than the average experiment station yields (Tables 50 to 52) in different regions of India. The reasons for this could be: a) the varietal trials in AICRP are conducted in very small plots and yields are extrapolated to one hectare; b) the total number of years accounted for simulation was very high which could capture the climatic variability in a rainfed environment more than the experimental station for which data was available for limited years; c) non reporting of data from experimental station for the years when crop failed

Table 48. Yield gaps of pigeonpea (medium-duration) at different AICRP locations across India.

	Yield gap (kg ha^{-1})											
	YG I				YG II				Total YG			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Badnapur	0	380	140	132	740	1540	1300	26	590	2270	1440	40
Gulbarga	0	670	170	130	200	1120	730	44	570	1370	900	37
Jalna	-	-	-	-	-	-	-	-	1040	2090	1510	25
Bharuch	-	-	-	-	-	-	-	-	390	1250	830	54
Vadodara	-	-	-	-	-	-	-	-	740	1500	1100	29
Akola	-	-	-	-	90	710	350	67	-	-	-	-
Secondary Zone												
Rahuri	0	1560	250	141	710	1440	980	25	140	2460	1230	61
Khargone	0	1740	330	187	230	1310	870	52	660	2220	1200	46
Patancheru	-	-	-	-	-	-	-	-	1250	1730	1510	16
Lam	-	-	-	-	-	-	-	-	450	1150	840	36
Madhira	-	-	-	-	-	-	-	-	1330	2300	1840	26
Berhampore	-	-	-	-	-	-	-	-	60	770	400	90
Warangal	-	-	-	-	650	1640	1220	38	-	-	-	-
Tertiary Zone												
Sehore	0	1110	350	108	300	1570	810	62	300	1570	1160	38
Raipur	70	1200	550	121	180	970	530	63	770	1420	1080	29
Bangalore	100	830	220	95	0	1160	670	58	170	1660	890	58
Coimbatore	30	1740	390	120	7	660	210	153	60	1750	600	90
Vamban	70	800	290	109	80	550	260	54	160	1100	550	78
Junagadh	-	-	-	-	-	-	-	-	190	2510	1310	98
Mean	30	1110	300		290	1150	720		520	1710	1080	
CV[2]	132	44	42		98	36	58		77	30	35	

1 CV = Coefficient of variation (%) for mean yield gap of a location over years.
2 CV = Coefficient of variation (%) for mean yield gap over locations.

Table 49. Total yield gap of pigeonpea (long-duration) at different AICRP locations across India.

	Yield gap (kg ha^{-1})			
Location	Min	Max	Mean	CV[1]
Varanasi	20	2310	1060	68
Kanpur	160	1270	630	70
Pusa	380	2250	1510	42
Dholi	410	940	700	32
Mean	240	1690	970	-
CV[2]	11	54	59	-

1 CV = Coefficient of variation (%) for mean yield gap of a location over years
2 CV = Coefficient of variation (%) for mean yield gap over locations

Table 50. Yield gaps of pigeonpea (medium-duration) in different production zones of India.

	Primary	Secondary	Tertiary
		(kg ha^{-1})	
Grain yield			
Simulated mean	1370	1530	1350
Experimental station mean	1640	1630	1530
On-farm mean	1340	1470	1120
Districts' mean*	600	760	800
Yield gap			
Simulated – On-farm (YG I))	30	60	230
Expt. station – On-farm (YG I)	300	160	410
On-farm – District (YG II)	740	710	320

*Mean of all the districts for each pigeonpea production zone (Table 39).

Table 51. Yield gaps of pigeonpea (medium-duration) in different AEZs of India.

	Semi-arid				Sub-humid
	5	6	7	8	10
			(kg ha^{-1})		
Grain yield					
Simulated mean	1170	1480	1610	1450	1550
Experimental station mean	1770	1690	1780	1180	1860
On-farm mean	1400	1380	1520	880	1510
Districts' mean*	820	560	360	550	770
Yield gap					
Simulated – On-farm (YG I))	0	100	90	570	40
Expt. station – On-farm (YG I)	370	310	260	300	350
On-farm – District (YG II)	580	820	1160	330	740

*Mean of all the districts for each AEZ (Table 40).

Table 52. Yield gaps of pigeonpea (medium-duration) in major states of India.

	Maha-rashtra	Karnataka	Gujarat	Madhya Pradesh	Andhra Pradesh	Tamil Nadu
			(kg ha^{-1})			
Grain yield						
Simulated mean	1410	1540	830	1600	1530	1160
Experimental mean	1800	1370	1790	1800	1780	1070
On-farm mean	1440	1180	1280	1460	1520	730
Districts' mean*	610	410	880	810	330	660
Yield gap						
Simulated – On-farm (YG I)	0	360	0	140	10	430
Expt. station – On-farm (YG I)	360	190	510	340	260	340
On-farm – District (YG II)	830	770	400	650	1190	70

*Mean of all the districts for each state (Table 41) due to adverse weather conditions; and d) irrigations to the experiment station trials in case of severe drought in order to save the crop/trials. Therefore, for analyzing the average yield gaps for different regions, both experimental station and simulated rainfed yields (of medium-duration pigeonpea) were used.

Across various crop production zones, the YG I ranged from 30 to 230 and 160 to 410 kg ha^{-1} when estimated by using simulated and experimental station yields, respectively (Table 50). The YG II was the maximum for primary crop production zone (740 kg ha^{-1}) followed by secondary (710 kg ha^{-1}) and tertiary zones (320 kg ha^{-1}).

5.7.3 Yield gaps of agroecological zones

Among the agroecological zones, the YG I ranged from 0 to 570 kg ha^{-1} and 260 to 370 kg ha^{-1} when estimated by using average simulated and experimental station yields, respectively (Table 51). The YG II was very wide for AEZ 7 (1160 kg ha^{-1}) and AEZ 6 (820 kg ha^{-1}) as compared to AEZ 10 (740 kg ha^{-1}), AEZ 5 (580 kg ha^{-1}) and AEZ 8 (330 kg ha^{-1}).

5.7.4 Yield gaps of major states

Across different states, the YG I ranged from 0 to 430 and 190 to 510 kg ha^{-1} when estimated by using simulated and experiment station yield data, respectively (Table 52). The magnitude of YG II was highest in Andhra Pradesh (1190 kg ha^{-1}) followed by Maharashtra (830 kg ha^{-1}), Karnataka (770 kg ha^{-1}), Madhya Pradesh (650 kg ha^{-1}), Gujarat (400 kg ha^{-1}) and Tamil Nadu (70 kg ha^{-1}).

YG I is difficult to abridge as it is because of environmental differences between on-farm and research station situations or those assumed during simulations such as theoretically optimum conditions created during simulations and very small plot sizes with optimum homogeneity and the technical expertise at research stations. The variations observed among different regions for YG I thus, could be because of the above factors. Though YG I cannot be abridged completely, it gives an indication on the upper limits of productivity that can be achieved in a given environment. If the YG I is very narrow, it indicates the need to generate further technologies such as improved varieties that can perform better in a given environment.

On the other hand, YG II is manageable as it is mainly due to the differences in the management practices and input use. In case of pigeonpea on an average this gap is 700–800 kg ha^{-1} for the major pigeonpea growing regions such as primary and secondary production zones, AEZ 6 and states of Maharashtra, Karnataka, Andhra Pradesh and Madhya Pradesh. The narrowing of such a large gap can help in doubling the production of pigeonpea in the country.

5.8 Water Balance of Selected Locations

Looking at the limitations of rainfall and soil moisture availability for pigeonpea productivity, the various aspects of water balance components observed during simulations at different locations across India are presented in Tables 53a and 53b. A considerable spatial and temporal variation in seasonal rainfall, surface runoff, deep drainage, ET and extractable soil moisture at harvest was observed. The average value over locations for these parameters was 726, 189, 94, 487 and 21 mm, respectively. The CV across locations was 29, 47, 69, 18 and 90% for rainfall, surface runoff, deep drainage, ET and extractable water respectively. Hence, there is a large scope at many locations for harnessing the excess water and its efficient use in pigeonpea-growing regions.

Table 53a. Long-term average water balance components (mm) of simulated pigeonpea at selected locations across India.

Location	Rainfall				Surface runoff				Deep drainage			
	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Akola	258	1128	680	32	3	393	147	66	0	182	24	181
Amravati	441	1131	749	26	13	424	158	75	0	144	43	122
Bharuch (Haldar)	326	1091	677	52	66	476	277	106	0	167	44	18
(Sisodia)	372	1116	717	38	67	478	281	53	0	240	71	130
Gulbarga	278	1183	680	36	13	384	111	81	0	296	90	114
Nagpur	444	1452	886	28	55	666	238	57	14	410	175	59
Nanded	251	1451	746	35	4	509	144	87	0	170	23	212
Parbhani	419	1569	849	36	57	572	218	72	0	400	78	153
Raichur	314	900	567	37	14	279	90	97	0	220	63	139
Wardha	581	1581	940	24	93	736	270	54	2	332	148	63
Secondary Zone												
Anantapur	104	759	434	41	0	286	85	89	0	183	40	137
Belgaum	621	1616	963	24	140	820	321	48	0	313	123	69
Bellary	169	648	363	37	0	199	55	100	0	209	17	305
Bijapur	214	740	465	32	23	248	106	69	0	56	12	184
Dharwad	290	909	517	27	16	191	72	64	0	178	17	227
Kurnool	221	1237	680	41	12	575	202	78	0	244	43	156
Patancheru	354	1262	726	30	12	698	181	77	0	226	63	118
Rahuri	215	806	425	36	0	104	42	94	0	176	55	113
Warangal	383	1472	872	35	23	439	233	53	0	481	124	127
Betul	655	1510	1102	21	111	687	350	47	0	324	165	66
Kanpur	591	1934	1155	39	152	716	376	57	0	612	232	81
Raisen	575	1502	989	29	78	617	263	67	0	200	124	63
Varanasi	604	1344	873	23	104	594	228	60	12	327	167	62
Tertiary Zone												
Aduturai	472	1487	973	28	23	711	289	60	0	479	188	72
Bangalore	272	1146	742	34	10	415	144	80	0	411	127	96
Coimbatore (Coimbatore)	269	750	503	35	0	195	71	92	0	134	54	110
(Palathurai)	305	750	507	30	4	243	101	73	0	196	80	78
Jhabua	218	1335	633	44	19	462	126	121	0	431	100	109
Indore	361	1351	878	28	11	644	207	65	0	472	150	70
Jhansi	385	1004	727	31	91	425	248	45	0	214	65	115
Junagadh	245	1287	680	43	8	596	212	73	0	375	128	91
Ludhiana	332	1169	641	242	7	538	143	141	0	170	50	54
Rajkot (Semla)	247	882	509	44	13	383	153	79	0	257	52	154
(Bhola)	247	882	538	42	16	375	152	79	4	338	136	78
Faizabad	678	1218	889	15	124	391	221	31	74	235	146	35
Others												
Pantnagar	643	2448	1254	38	93	1062	387	69	26	791	267	74
Delhi	164	1119	659	38	0	474	188	67	0	179	44	128
Hisar	307	863	458	43	27	466	154	96	0	0	0	0
Mean	360	1216	726		39	486	189		3	286	94	
CV[2]	43	30	29		113	41	47		368	54	69	

In parenthesis are the soil series.
* Extractable water retained in the soil profile at harvest of pigeonpea crop.
1 CV = Coefficient of variation (%) for mean value of a location over years.
2 CV= Coefficient of variation (%) for mean value over locations.

Table 53b. Long-term average water balance components (mm) of simulated pigeonpea at selected locations across India.

Location	Evapo-transpiration				Extractable water*			
	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone								
Akola	281	720	541	20	5	104	52	42
Amravati	456	770	575	15	25	104	64	26
Bharuch (Haldar)	234	613	414	67	0	6	2	149
(Sisodia)	314	588	411	21	1	8	2	97
Gulbarga	290	618	509	17	19	169	53	65
Nagpur	406	659	532	14	0	54	4	277
Nanded	287	853	614	23	14	77	41	40
Parbhani	367	733	577	14	16	150	56	53
Raichur	361	627	478	15	1	20	8	93
Wardha	451	689	567	12	1	35	8	130
Secondary Zone								
Anantapur	146	524	364	25	4	78	15	131
Belgaum	426	665	549	13	7	42	20	62
Bellary	188	468	344	19	3	90	15	137
Bijapur	163	509	372	26	4	111	28	119
Dharwad	292	603	476	18	2	16	6	78
Kurnool	289	610	482	19	1	22	5	111
Patancheru	366	673	529	13	1	51	6	161
Rahuri	282	556	386	18	1	28	7	133
Warangal	408	679	551	14	6	105	23	140
Betul	461	736	617	12	14	83	45	41
Kanpur	415	759	577	21	4	86	45	78
Raisen	438	773	645	16	0	65	7	267
Varanasi	374	622	509	15	6	132	25	140
Tertiary Zone								
Aduturai	438	659	528	11	0	125	40	98
Bangalore	340	625	532	16	2	44	13	100
Coimbatore (Coimbatore)	308	549	436	17	1	111	38	130
(Palathurai)	276	420	347	12	0	64	21	127
Jhabua	234	544	465	18	1	22	3	130
Indore	391	694	565	15	1	51	8	165
Jhansi	264	530	453	19	0	35	5	214
Junagadh	305	539	423	15	2	27	6	103
Ludhiana	355	636	475	83	10	119	54	35
Rajkot (Semla)	250	528	375	22	1	8	4	53
(Bhola)	199	459	307	22	0	4	1	142
Faizabad	453	678	568	12	6	63	20	78
Others								
Pantnagar	517	709	626	9	1	103	45	83
Delhi	218	605	471	22	2	40	15	82
Hisar	272	457	357	16	1	5	3	49
Mean	326	622	487		4	65	21	
CV[2]	28	16	18		137	69	90	

In parenthesis are the soil series.
* Extractable water retained in the soil profile at harvest of pigeonpea crop.
1 CV = Coefficient of variation (%) for mean value of a location over years.
2 CV = Coefficient of variation (%) for mean value over locations.

5.9 Major Constraints and Opportunities for Abridging Yield Gaps

Several biotic, abiotic and socioeconomic constraints to pigeonpea productivity in India have been identified (Ali 1996; Kalamikar 2003; Chauhan et al. 1987; Shanower et al. 1999; Singh et al. 1999). These constraints are:

1. Unpredictable weather in terms of onset of rainy season, amount of rainfall and its distribution during pigeonpea growing period.
2. Cultivation of crop on marginal and sub-marginal lands under rainfed conditions subjected to frequent drought/waterlogging conditions.
3. Poor agronomic practices and low levels of input use.
4. Very high incidences of diseases such as sterility mosaic disease (SMD), wilt and *Phytophtora* blight.
5. Very high incidences of insects such as flower- and pod-feeding *Lepidoptera*, pod-sucking *Hemiptera*, and seed-feeding *Diptera* and *Hymenoptera*.
6. Non-availability of quality seeds of appropriate varieties
7. Poor adoption of improved technology.

Perhaps among all the above factors, unpredictable nature of rains in terms of its onset, amount and distribution is the predominant constraint to pigeonpea production grown on marginal lands. This was evident when the average simulated yield was plotted against the average crop season rainfall at different locations (Table 45). The simulated yield showed a significant and positive but slightly curvilinear relationship with rainfall (R^2 = 0.45, P ≤ 0.01) (Fig. 20). The simulated yield increased linearly up to ~800 mm of rainfall after which there was a slight reduction in the rate of increase in the yield.

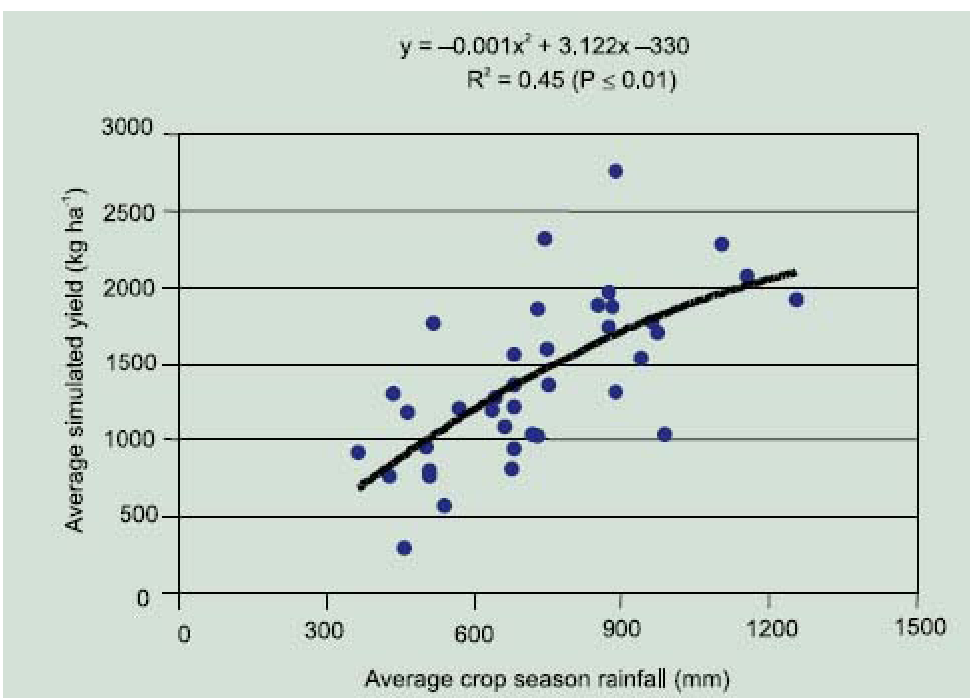

Figure 20. Relationship between average simulated rainfed yield of medium-duration pigeonpea and average crop season rainfall at selected locations across India (n=38).

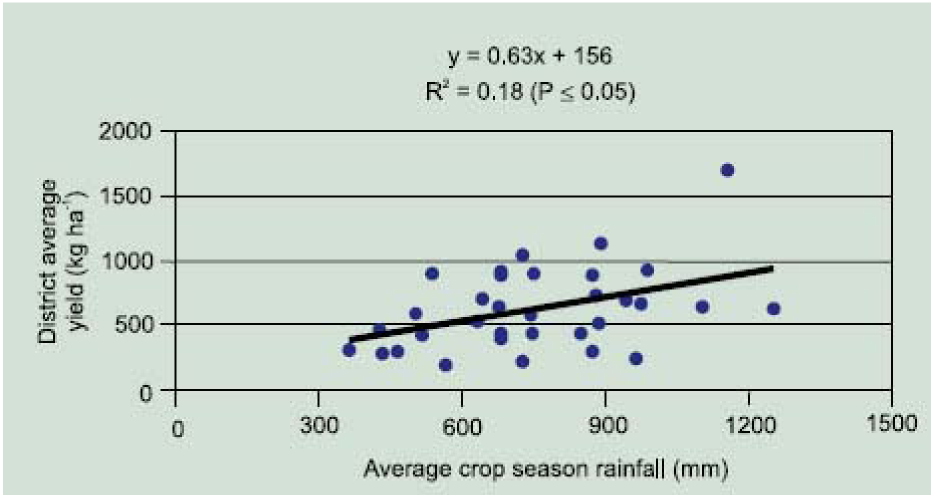

Figure 21. Relationship between district average yield and average crop season rainfall at selected locations across India (n=33).

Similarly the district average yields of these locations (except Delhi and Hisar for which district average yields were not available) also showed a significant and positive relationship (R^2 = 0.18, P ≤ 0.05) with average crop season rainfall (Fig. 21) but the relationship was not as strong as was observed for simulated yield. The relationship clearly indicated the dependence of pigeonpea yield on the seasonal rainfall, which often varies widely from year-to-year at a given site.

When the differences between simulated yield and average district yield (which reflect the total YG) of these locations were plotted against the crop season rainfall, a significant and positive relationship (R^2 = 0.14*, P ≤ 0.05) was observed (Fig. 22). The total yield gap increased linearly as the seasonal rainfall increased up to ~800 mm after which there was a little decline in the rate of increase in the total YG. The relationship clearly indicated that the extent of yield gaps across locations was dependent on the amount of rainfall received and hence availability of soil moisture.

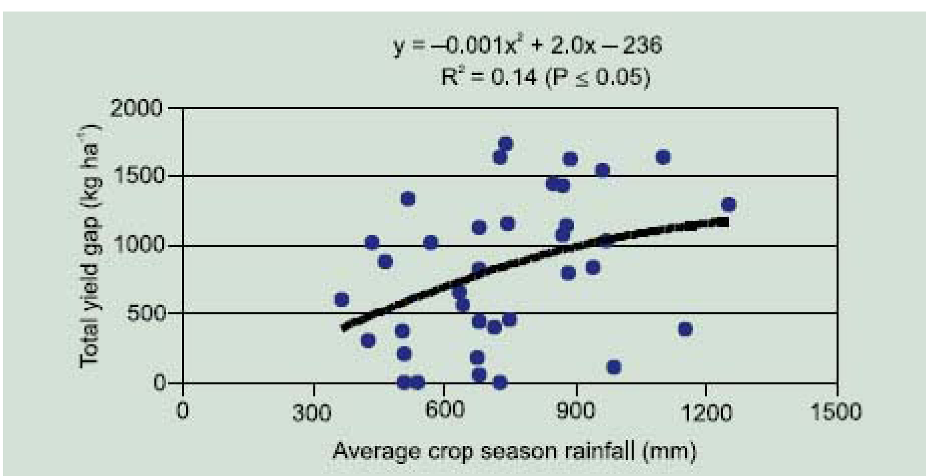

Figure 22. Relationship between total yield gap (difference between average simulated and district average yield) and crop season rainfall observed at selected locations across India (n=36).

The above relationships indicate that optimum use of nutrients and improved management practices are the main factors responsible for higher yields during simulation (and also at experimental station and on-farm level). As these factors strongly interact with climate and particularly with the availability of soil moisture, the positive impact of these factors is the maximum when enough soil moisture is available in the soil. On the other hand, under sub-optimal soil moisture conditions due to low levels of rainfall in a given environment, the impact of these factors are reduced greatly. Under this situation, the yield of a given location is governed only by environmental factors at all the levels (simulated, experiment station, on-farm and average farmers) and yields obtained at all the levels do not vary considerably and resultant yield gaps are also low/negligible. Therefore, in order to improve the productivity of pigeonpea in rainfed environment, an integrated approach including development of drought resistant varieties with better water use efficiency, improved input use and adoption of improved technology is needed. The adoption of proven technologies such as effective watershed management, switching to planting on effective land configurations (BBF, ridges-and-furrow) and water conserving cultural methods (residue recycling, mulching, etc) can help in efficient use of water and nutrients particularly in the seasons, locations and regions with sub-optimal water availability.

5.10 Summary

Pigeonpea is an important rainfed legume crop for millions of smallholder farmers in India and many other countries of the tropical and subtropical region of the world. In India, it is cultivated on about 3.4 M ha and contributes to about 20% of the total pulse production of the country. However, its average productivity has remained strikingly low at about 0.5 to 0.7 t ha^{-1}. There are several biophysical, technical and socioeconomic constraints, which limit the productivity of pigeonpea in India. In order to mitigate these limitations, it is essential to assess the production potential of the environment in relation to achievable and current levels of production as well as the availability of the natural resources. Therefore, the study was undertaken: a) to analyze the pigeonpea area in terms of intensity of distribution in different districts (production zones), AEZs and states across India, b) to estimate the water limited potential, achievable and current levels of average farmers yields in these regions, c) to quantify the extent of YG I and II and d) to find out the possible reasons and ways to reduce these yield gaps.

Using pigeonpea model provided in APSIM, long-term potential yield of a medium-duration pigeonpea and its water balance components were simulated for 35 locations representing different regions across India. To supplement the simulated potential yields, last ten years yield data reported from experimental stations of AICRP on pigeonpea were utilized. The achievable yields of locations across the country were taken from the Front Line Demonstrations conducted in farmers' fields with improved production technology. The district average yields were taken as the average farmers yields. Based on simulated, experimental station, achievable and average farmers yields, YG I and YG II were estimated.

Analysis indicated that the crop is concentrated in the states of Maharashtra, Karnataka, Uttar Pradesh, Gujarat, Madhya Pradesh and Andhra Pradesh, encompassing AEZs 4 to 8 of semi-arid and 9 to 12 of sub-humid ecosystem. However, out of 315 pigeonpea growing districts, only 26 districts contribute to 50% of the total area under the crop in India. The crop is grown in a wide range of soils covering major soil orders (Vertisols, Inceptisols and Alfisols). The average crop season rainfall varies from 400 to 1200 mm. This leads to a large variability in the production environment in terms of production potential and management of natural resources.

Depending upon the agroclimatic conditions, large spatial and temporal variations were observed in simulated potential yield. Among locations the average simulated potential yield ranged from 300 to 2770 kg ha^{-1} across India. Similarly, the reported experimental station, on-farm and an average farmer's yield ranged from 910 to 2330, 620 to 1690 and 130 to 990 kg ha^{-1}, respectively. The average long-term simulated potential yield across major production zones, AEZs and states ranged from 1350 to 1530, 550 to 2220 and 830 to 1960 kg ha^{-1}, respectively indicating a large variability for the potential of pigeonpea in different regions across India. Yield gap I, ranged from 30 to 230, 0 to 570 and 0 to 360 kg ha^{-1} across different production zones, AEZs and states, respectively. Though the YG I cannot be abridged completely, it gives an indication of the upper limits of achievable yields in a given environment. The narrow YG I in some of the regions indicate the need to further refine the production technology and develop varieties that can perform better in a given environment. On the other hand, in YG II, is manageable as it is mainly due to the differences in the management practices and extent of input use. In pigeonpea, YG II ranged from 320 to 740, 330 to 1160 and 70 to 1190 kg ha^{-1} across different production zones, AEZs and states of India, respectively. The extent of YG II and a high degree of spatial and temporal variability observed across locations and different regions indicate the potential to increase pigeonpea productivity with improved management under rainfed situations.

The water balance analysis showed a high degree of runoff at some of the locations, which ranged from 10 to 41% of total rainfall indicating the need to harvest and conserve this excess water and utilize it for supplemental irrigation/recharging of groundwater and to minimize the erosion of fertile top soil.

The average simulated yield, average farmers yield and total yield gap across locations showed a significant and positive association with average crop season rainfall (R^2=0.45, 0.18 and 0.14, respectively). The relationships indicate that sub-optimal water availability and resultant subdued expression of improved management practices (cultural and nutrient management) are the major factors for lower potential yield in rainfed environments of many locations and regions. It also indicates that higher increase in average farmers yield with improved management practices would be possible in the regions/seasons of good rainfall or with supplemental irrigations. It is concluded that further development of improved genotypes with better water use efficiency and adoption of improved package of practices can help in raising the potential productivity and in bridging the large yield gaps of pigeonpea in a rainfed environment. The adoption of proven technologies such as effective watershed management, switching to planting on effective land configurations (broadbed-and-furrow, ridge-and-furrow systems etc) and water conserving cultural methods (residue recycling, mulching, etc) can help in efficient use of water and nutrients particularly in the seasons, locations and regions with sub-optimal water availability.

6. Yield Gap Analysis of Chickpea

6.1 Abstract

Chickpea (C*icer arietinum* L.) with an area of more than six million ha is the most important pulse crop of India. It is mainly grown on receding soil moisture regime during postrainy season as a rainfed crop. Despite its long history of cultivation and being an important crop for small and marginal farmers, its productivity has remained very low and more or less stagnated to about 800 kg ha^{-1}. In order to workout a suitable strategy to improve the productivity levels of this crop, it is imperative

to assess the potential yield in the region of interest and gap between the potential and actual yield obtained by average farmers. This analysis in turn will help to know the major factors associated with these yield gaps for a given location or a region. As soybean-chickpea sequential system is the predominant cropping system, the long-term rainfed potential yield and water balance of chickpea for 30 locations, representing different regions across India, were simulated using CROPGRO/soybean and chickpea models in sequence. Based on long-term simulated potential, reported experimental station, on-farm and average farmers yields of chickpea, YG I and YG II were estimated for different locations and regions across India. The average simulated rainfed yield of chickpea was 1130 kg ha^{-1}, which ranged from 490 to 2030 kg ha^{-1} among the locations across India. However, at 24 out of 30 locations, chickpea crop failed in 3 to 90% of the years due to moisture stress, indicating great uncertainty involved in chickpea production in a rainfed environment. The application of pre-sowing irrigation to chickpea is a common practice particularly in the Central and peninsular India where chickpea-soybean has in recent years become a predominant cropping system. The experimental data of rainfed trials conducted under AICRP on chickpea also followed the same practice. Therefore, simulations were also carried out with a provision of pre-sowing irrigation in case the soil moisture at the time of chickpea planting was below 40% of the extractable moisture in the top 30 cm layer of the soil. The average simulated rainfed (with pre-sowing irrigation) potential yield was 1610 kg ha^{-1} and ranged from 910 to 2480 kg ha^{-1} among the locations across India. Hence, on an average 30% increase in the simulated yield was observed with the application of pre-sowing irrigation without any failure of the crop.

The average simulated rainfed (with pre-sowing irrigation) potential yield across major production zones, AEZs and states of India ranged from 1010 to 1900, 830 to 2050 and 1250 to 2120 kg ha^{-1}, respectively. Yield gap I, which is the differences between potential and achievable yield, ranged from 0 to 260, 0 to 580 and 0 to 1100 kg ha^{-1} across different chickpea production zones, AEZs and states of India, respectively. The yield gap II, ranged from 610 to 890, 530 to 920 and 560 to 1020 kg ha^{-1} across different chickpea production zones, AEZs and states of India, respectively. The extent of YG II and a high degree of spatial and temporal variability observed in it across different locations/regions indicated that there is a substantial potential to increase chickpea productivity with improved management under rainfed situation. The water balance analysis showed a high degree of runoff during preceding rainy season crop (soybean) at some of the locations, which ranged from 11 to 37% of the total rainfall indicating the need to harvest and conserve this lost water to utilize for supplemental irrigation to chickpea crop.

As a postrainy season crop, chickpea receives scarce rainfall during the cropping season, which ranges from 24 to 170 mm across these locations. A significant and positive association ($R^2 = 0.31$, $P \leq 0.01$) was observed between simulated yields and average crop season rainfall across the locations. Similarly, the total yield gap was also significantly and positively associated with crop season rainfall ($R^2 = 0.42$, $P \leq 0.01$). The relationships demonstrate that chickpea productivity is limited in many regions/seasons by the availability of soil moisture and yield gaps are of higher magnitude in the regions/seasons where the availability of soil moisture is higher. Therefore, the increase in average yield with improved management practices is likely to be greater in situations with higher soil moisture availability or with supplemental irrigations. Various constraints limiting chickpea productivity across different regions were identified and ways to abridge yield gaps are discussed.

6.2 Introduction

Chickpea is the third most important food legume and second most important pulse crop of the world. It is traditionally grown in many parts of the world in a wide range of agroclimatic environments. Chickpea is grown mostly as a rainfed, postrainy season, winter crop in subtropical south Asia, parts of Africa and Australia. It is a spring season crop in the Temperate and Mediterranean types of climate.

Chickpea has considerable importance as food, feed and fodder (Singh 1997). As a human food, chickpea is a valuable source of protein, particularly in developing countries where majority of the population depend on the low priced food for meeting their dietary requirements.

In low input traditional production systems chickpea has been a preferred crop because of its minimal dependence on monetary inputs of N and P-containing fertilizers, irrigation and agrochemicals in general. Being a legume crop, chickpea also helps in improving the physical, chemical and biological environment of soil. Hence, it has an important role in sustaining soil fertility particularly in drylands (Jodha and Subba Rao 1987).

Despite its long history of cultivation (Singh 1987), the productivity of chickpea has remained very low (about 800 kg ha^{-1}). It is a valuable source of protein for poor population and a source of livelihood for the small and marginal farmers in India and other developing countries and, therefore, its low production is a cause of concern and requires urgent attention.

In this section, the potential rainfed yield of chickpea has been estimated based on experimental data and the data generated through simulation techniques. The gaps between potential, achievable and average farmers yields for different locations/regions in India has also been assessed.

6.3 World Trends in Chickpea Production

Chickpea is presently cultivated in about 44 countries across the globe (FAOstat, 2002). However, despite its rise in popularity and wide range of adaptability, the crop area and productivity has not substantially increased in the past 30 years (Fig. 23). In fact, the total area during this period has

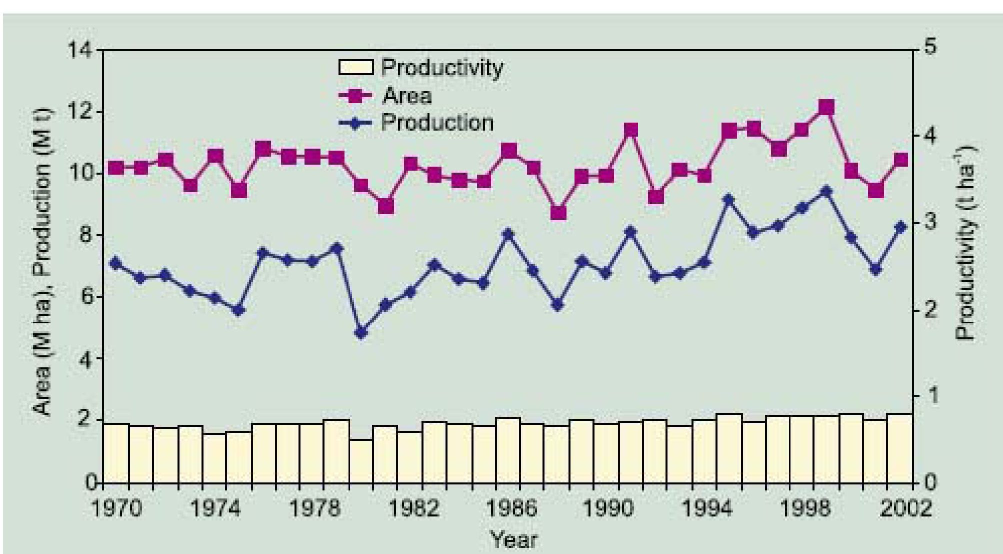

Figure 23. Trends in area, production and productivity of chickpea in the world.

been fluctuating largely between 8.73 and 12.16 M ha along with fluctuations in production between 4.85 to 9.42 M t. The average productivity of the crop has remained below 1 t ha^{-1} and ranged from 0.5 to 0.8 t ha^{-1}.

In 2002, chickpea was cultivated on about 10.48 M ha in the world, with an average annual production of 8.26 M t (Table 54). Its average productivity was 790 kg ha^{-1}. The distribution of chickpea area and production in the world is quite uneven. Indian subcontinent alone accounts for almost 90% of the world's crop area. Beside India, which alone accounts for more than 65% of world production, the crop is also grown in Pakistan, Iran, Turkey, Syria, Myanmar, Bangladesh and Nepal in Asia. In Africa, which accounts for about 6% of the world's production, the crop is mainly grown in Ethiopia, Algeria, Malawi, Sudan, Tanzania and Tunisia. The North and Central America produce 5% of the total chickpea of the world, major chickpea growing countries are Canada and Mexico. In Europe, chickpea is mainly grown in Spain and Portugal. Chickpea is also grown in Oceania in Australia. Except for Mexico (1590 kg ha^{-1}) and Canada (1020 kg ha^{-1}) the productivity levels are less than 1000 kg ha^{-1} in all the major chickpea growing countries of the world.

6.4 Chickpea Production in India

6.4.1 Area, production and productivity in the country

India is the largest producer of chickpea in the world. It accounts for 61% of the total area and 66% of total production in the world. In India chickpea represents 32% (6.42 M ha) of total pulse area and 49% (5.47 M t) of total pulse production. Almost 70% of the Indian chickpea farmers are subsistence farmers with less than two hectares of land holding.

Among the pulses, chickpea is the main source of dietary protein for a large population in India, which is largely vegetarian and poor. Due to continuous rise in the population and stagnant growth in terms of both area and production, the per capita availability of chickpea has declined tremendously from 219 g day^{-1} in 1970 to 10 g day^{-1} in 2002–03. In 1970 chickpea was cultivated in 7.89 M ha with a production of 5.2 M t and both showed a negative trend till 1991–92 (5.58 M ha and 4.12 M t, respectively) (Fig. 24). Due to greater emphasis laid on pulses production in the country through the Technology Mission on Oilseeds and Pulses (TMOP) launched in 1990, the trends were

Table 54. Global chickpea area, production and productivity during 2002–2003.

Country	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
India	6.42	5.47	850
Pakistan	0.93	0.36	390
Iran	0.75	0.29	390
Turkey	0.67	0.65	970
Australia	0.20	0.14	680
Ethiopia	0.20	0.18	920
Myanmar	0.19	0.19	990
Canada	0.15	0.16	1020
Mexico	0.15	0.24	1590
Syria	0.10	0.09	870
World	10.48	8.26	790

Source : FAOstat data, 2004.

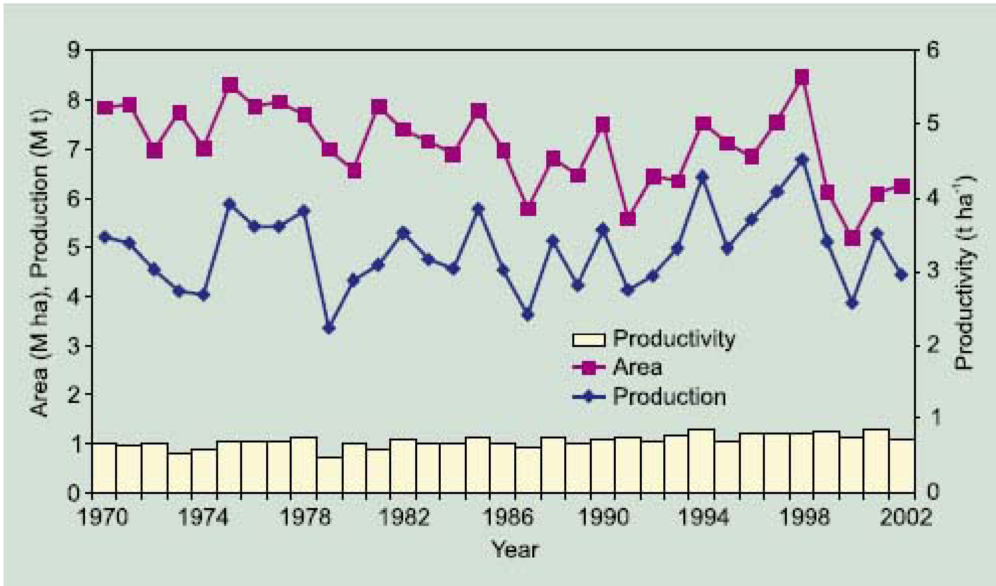

Figure 24. Trends in area, production and productivity of chickpea in India.

reversed and both the area and production increased to 8.47 M ha and 6.8 M t, respectively by the year 1998–99. The productivity of the crop during this period has been fluctuating and has shown an increase from 660 kg ha^{-1} in 1970 to 850 kg ha^{-1} in 2001–02. However, since the highest ever area and production figures achieved in 1998–99 the crop has again seen a rapid decline largely due to unfavorable weather conditions.

6.4.2 Area, production and productivity in crop production zones

Chickpea cultivation is spread in 322 districts across India on 7.28 M ha, with an average production of 5.79 M t (Table 55, Fig. 25). However, among the large number of these districts, only 30 core districts contribute 50% of the total chickpea area in the country (primary zone). Another 35% of the total area is contributed by 58 districts, which fall in the secondary zone. Remaining 234 districts contribute only 15% of the total area. Of which, 101 districts have less than 1000 ha area under chickpea cultivation. The average chickpea yield of primary zone is 840 kg ha^{-1}, which progressively decreases to 670 kg ha^{-1} in the districts classified as 'others'. Along with the decreasing trend in average yield, an increasing trend in the CV for average yield from primary zone to the rest of the country was observed.

Table 55. Area, production and productivity of chickpea in different production zones of India (1995–96 to 1997–98).

Production zone	No. of Districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Primary	30	3.65	3.06	840	17
Secondary	58	2.55	1.94	760	32
Tertiary	133	1.05	0.77	730	35
Others	101	0.03	0.02	670	58
Total	322	7.28	5.79	800	41

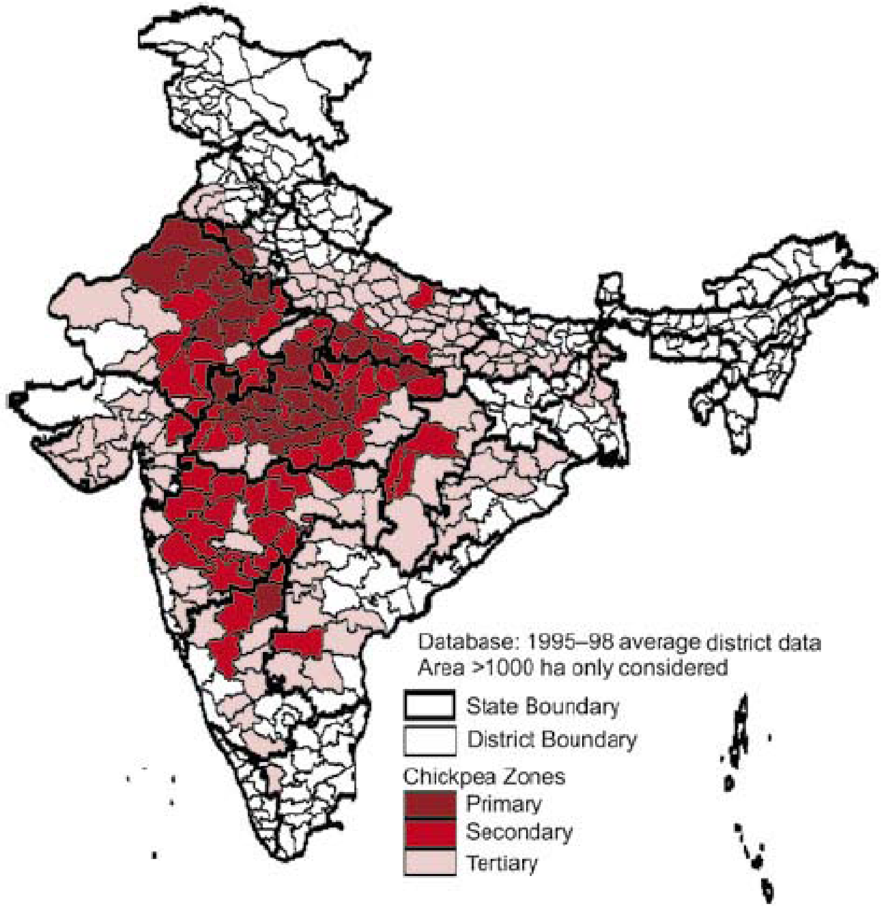

Figure 25. Primary, secondary and tertiary production zones of chickpea in India.

6.4.3 Area, production and productivity in agroecological zones

Classification of chickpea area into different crop production zones gives an indication of the geographical area where the crop is most concentrated and where the interventions can lead to maximum gains in the production of the crop. However, in each crop zone, districts may come from diverse ecological background and variability in their productivity may largely be governed by the variability in the climatic conditions of these districts. Based on uniformity in climate, soils, LGP and physiography the whole country has been divided into 20 agroecological zones (AEZs) (Sehgal et al. 1995). Therefore, an attempt was made to look into the spread of area, production and productivity of chickpea in these agroecological zones (Table 56, Fig. 26). For this, districts falling in their respective AEZs were grouped together and total area, production and average productivity of each agroecological zone was calculated.

On an average, semi-arid ecosystem, with an area of 3.57 M ha accounts for 49% of the total chickpea cultivation in the country (Table 56). Another 2.19 and 1.44 M ha of chickpea is cultivated in sub-humid and arid ecosystems accounting for 30 and 20% of total area under the crop, respectively. The semi-arid ecosystem is characterized by seasonal rainfall, which has a CV of about 30%. The annual rainfall varies between 500 to 1000 mm and LGP ranges from 90 to 180 days.

Table 56. Area, production and productivity of chickpea in different agroecological zones of India (1995–96 to 1997–98).

Ecosystem	AEZ	No. of districts	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Arid	2	21	1.44	1.05	730	16
Semi-arid	4	61	1.66	1.55	930	38
Semi-arid	5	21	0.77	0.68	880	25
Semi-arid	6	30	1.02	0.56	550	31
Semi-arid	7	10	0.10	0.07	720	75
Semi-arid	8	17	0.02	0.01	470	25
Sub-humid	9	32	0.13	0.11	860	20
Sub-humid	10	27	1.70	1.49	880	32
Sub-humid	12	20	0.23	0.12	530	37
Sub-humid	13	18	0.10	0.07	730	25
Sub-humid	15	10	0.03	0.02	860	40
Others	-	55	0.07	0.04	630	59
Total	-	322	7.28	5.79	800	41

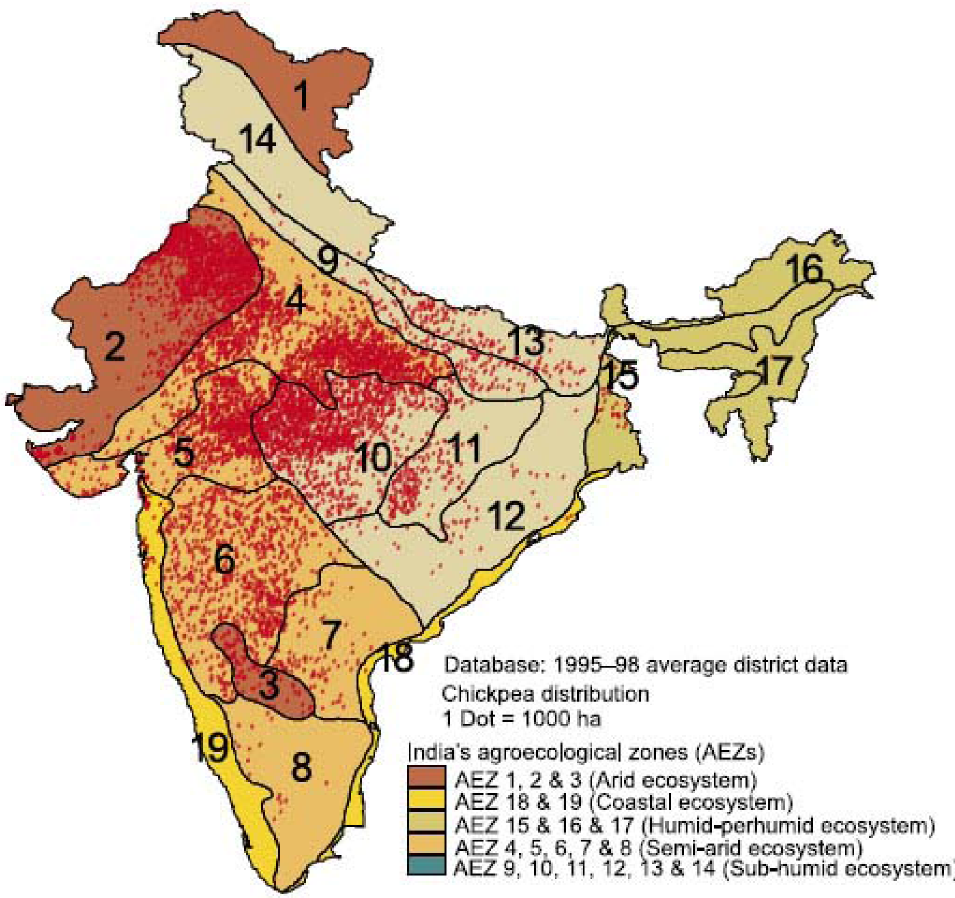

Figure 26. Distribution of chickpea in different agroecological zones of India.

Table 57. Area, production and productivity of chickpea in different states of India (1995–96 to 1997–98).

State	Area (M ha)	Production (M t)	Yield (kg ha^{-1})	CV (%)
Madhya Pradesh	2.60	2.30	880	29
Rajasthan	1.87	1.50	800	16
Uttar Pradesh	0.92	0.77	830	18
Maharashtra	0.77	0.43	560	20
Haryana	0.35	0.31	870	78
Karnataka	0.33	0.15	460	10
Gujarat	0.13	0.11	790	32
Andhra Pradesh	0.13	0.09	680	73
Bihar	0.09	0.08	940	17
Orissa	0.03	0.02	520	30
West Bengal	0.03	0.03	890	24
Others	0.03	0.02	770	51
All India	7.28	5.79	800	41

Within semi-arid ecosystem, the main agroecological zones where chickpea is an important crop are 4 (1.66 M ha), 5 (0.77 M ha) and 6 (1.02 M ha) while some area is also spread in zone 7 (0.1 M ha) and 8 (0.02 M ha). The major soil types of semi-arid ecosystem where chickpea is cultivated include Vertisols, Vertic Inceptisols and Entisols. A great extent of variability in the productivity of chickpea among the AEZs of semi-arid ecosystem was observed. The maximum yield was observed in AEZ 4 (930 kg ha^{-1}), which is also the highest yield level among all the AEZ where chickpea is cultivated. Similarly, the AEZs 6 (550 kg ha^{-1}) and 8 (470 kg ha^{-1}) had very low productivity levels.

In sub-humid ecosystem, chickpea area is concentrated in AEZ 10 (1.70 M ha). The zone consists of Central highlands (Malwa, Bundelkhand and eastern Satpura) and eastern Maharashtra plateau having Vertisols and Vertic Inceptisols. Climate is sub-humid (dry) and LGP varies from 120 to 180 days. The average productivity of the AEZ 10 was found to be 880 kg ha^{-1}, which is next to the yield levels observed in AEZ 4 of semi-arid ecosystem. In AEZ 10, 5 and 6, soybean has established itself as a major rainy season crop and soybean-chickpea sequential system has become a major cropping system in the rainfed areas.

In the AEZ 2 of hot arid ecosystem, the major area under chickpea is confined to the agroecological sub-region (AESR) 2.3, which includes parts of western Rajasthan and southwest Haryana and Punjab. The sub-region is characterized by a hot, arid climate with mean annual precipitation of 400 mm, which is highly uncertain. It has deep loamy desert soils with low water holding capacity. The LGP is 60–90 days. The average productively of this region is 730 kg ha^{-1}. However, in this ecosystem, cultivation of chickpea, which is a postrainy season crop is possible only with supplemental irrigation.

6.4.4 Area, production and productivity in the major states

State being an administrative unit, the information on the extent of yield gaps and intervention required to fill these gaps can help the concerned states to take required action. Therefore, an attempt was also made to analyze the distribution of chickpea area and its productivity in different states of India. With an area of about 2.6 M ha and production of 2.30 M t, Madhya Pradesh alone contributes 36 and 40% of total area and production of chickpea in the country (Table 57). The soybean-chickpea cropping system has become a well-established and profitable cropping system in rainfed area of this state. Rajasthan with 1.87 M ha and 1.50 M t of production contributes to 26% of the total chickpea area in the country. Another 23% area of the crop is spread into Uttar Pradesh and Maharashtra. Rest 15% area is spread in many other states across India. Among the major chickpea growing states, the average productivity is better than the national average (800 kg ha^{-1}) in Madhya Pradesh (880 kg ha^{-1}), Uttar Pradesh (830 kg ha^{-1}) and Haryana (870 kg ha^{-1}). On the other hand, the average productivity is much below the national average in the states of Karnataka (460 kg ha^{-1}), Maharashtra (560 kg ha^{-1}) and Andhra Pradesh (680 kg ha^{-1}).

Table 58. Area, production and productivity of chickpea in different states of India during 2002–03.

State	Area (M ha)	Production (M t)	Yield (kg ha^{-1})
Madhya Pradesh	2.25	1.62	720
Uttar Pradesh	0.87	0.78	890
Maharashtra	0.80	0.45	560
Andhra Pradesh	0.39	0.38	980
Rajasthan	0.45	0.34	760
Karnataka	0.48	0.26	540
Chattisgarh	0.16	0.09	620
Bihar	0.07	0.07	960
Haryana	0.06	0.04	750
West Bengal	0.05	0.04	780
Gujarat	0.06	0.03	500
Orissa	0.02	0.01	570
All India	5.67	4.13	730

Source: Ministry of Agriculture, India, 2004.

Compared to the average figures for 1995–96 to 1997–98, the total area (7.28 M ha) and production (5.79 M t) of chickpea in India declined drastically in 2002–03 (Table 58) to 5.67 M ha and 4.13 M t, respectively. Similarly, productivity declined from 800 to 730 kg ha^{-1}. The reduction in area and production has mainly been attributed to continuous unfavorable weather conditions particularly bad monsoon in all the major chickpea growing areas of the country. There was a considerable reduction in area of Rajasthan, Haryana and Gujarat while in Uttar Pradesh and Madhya Pradesh the decline was marginal. In contrast, most of the southern states showed an increase in chickpea cultivation in 2002–03 as compared to the average figures of 1995–96 to 1997–98.

6.5 Observed Rainfed Potential Yield of Chickpea

6.5.1 Observed experimental, on–farm and district yields

Average and range of experimental station and on-farm yields over years across different locations of AICRP on chickpea in India are presented in Table 59. Across locations, depending on the weather, soil and other location-specific factors, the experimental station and on-farm (FLD) yields ranged from 1050 kg ha^{-1} (Coimbatore) to 2620 kg ha^{-1} (Bathinda, Punjab) and 880 kg ha^{-1} (Bangalore, Karnataka) to 2180 kg ha^{-1} (New Delhi), respectively. The district average yields for the corresponding years for which experimental station yields were collected for each location ranged from 510 (Dharwad, Karnataka) to 1140 kg ha^{-1} (Junagadh, Gujarat). In general, experimental station and

Table 59. Observed experimental station, on-farm and district average yields (kg ha^{-1}) of chickpea at different AICRP locations across India.

	Experimental station				On-farm				District Average[1]			
Location	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]	Min	Max	Mean	CV[2]
Primary Zone												
Sehore	1240	2780	1990	24	1240	1880	1630	15	740	1040	950	11
Durgapura	1440	2420	1940	18	1130	1990	1610	21	590	1080	780	19
Sriganganagar	1130	3840	2410	46	1020	1740	1440	19	490	770	660	16
Gulbarga	760	2210	1310	35	610	1500	1150	24	390	650	550	14
Diggi	990	3640	2120	49	-	-	-	-	440	930	670	25
Hisar	-	-	-	-	1130	1550	1372	11	510	1010	760	24
Secondary Zone												
Bharari	1480	2270	1930	15	1480	1930	1780	11	720	1100	870	14
Dharwad	1080	2110	1670	29	-	-	-	-	200	650	510	41
Jabalpur	1650	2860	2130	22	-	-	-	-	560	1220	880	29
Kota	1720	2750	2160	25	-	-	-	-	630	840	720	15
Bhopal	-	-	-	-	1440	1520	1480	2	940	990	970	3
Rahuri	-	-	-	-	1770	2140	1920	7	460	900	630	23
Akola	-	-	-	-	1010	1860	1400	24	360	800	590	27
Tertiary Zone												
Raipur	800	1600	1360	24	600	1400	1200	23	570	910	680	20
Badnapur	1150	1770	1460	16	1150	1700	1430	14	310	680	550	25
Lam	-	-	-	-	1240	2240	1740	24	570	1230	1120	36
Bawal	1220	1920	1520	21	-	-	-	-	950	1130	1030	7
Bathinda	1460	3320	2620	39	-	-	-	-	740	880	829	10
Faridkot	1400	3270	2230	38	-	-	-	-	500	1000	760	30
Berhampore	1290	1620	1450	12	-	-	-	-	860	990	910	8
Arnej	830	1900	1310	30	-	-	-	-	330	690	490	28
Coimbatore	760	1880	1050	45	-	-	-	-	550	740	680	13
Faizabad	-	-	-	-	1530	2000	1750	12	440	960	750	27
Varanasi	-	-	-	-	840	2250	1630	33	730	1340	930	23
Kanpur	-	-	-	-	1400	2070	1722	16	800	1350	1110	18
Junagadh	-	-	-	-	1190	1670	1410	15	830	1480	1140	25
Others												
New Delhi	2130	2910	2520	14	1940	2500	2180	11	783	810	790	1
Bangalore	530	1830	1060	36	460	1830	880	49	400	740	570	18
Samba	910	2730	1640	46	770	1050	910	16	770	810	790	1
Warangal	950	2210	1660	39	-	-	-	-	720	1230	940	28
Dholi	780	2200	1530	34	-	-	-	-	660	1090	900	21
Pantnagar	-	-	-	-	840	2250	1560	37	700	960	880	12
Ludhiana	-	-	-	-	1390	2260	1800	16	790	970	890	7
Mean	1170	2460	1780		1150	1870	1520		610	970	800	
CV[3]	33	27	26		33	19	21		32	22	23	

- Data (experimental station/on-farm yields) not available
1 District yields are for the corresponding years for which experimental station data was collected (Annexure X).
2 CV = Coefficient of variation (%) for mean yield of a location over years.
3 CV = Coefficient of variation (%) for mean yield over locations.

on-farm yields were considerably higher than district average yields at majority of the locations. When averaged over all the locations across India, the mean experimental station, on-farm and district average yields were 1780, 1520 and 800 kg ha^{-1}, respectively. Thus, there was on an average 14 and 48% reduction in yield from experimental station to on-farm (FLD) and from on-farm (FLD) to district level, respectively.

Minimum and maximum values and the CV for each location presented in Table 59 indicate the variability observed over years in the yield of chickpea crop at each location. Large variations in yields over years were observed and depending on the location, the CV ranged from 12 to 49, 2 to 49 and 1 to 41% for experimental station, on-farm and district average yields, respectively. Large variations in yield over years at many of these locations reflect the uncertainty of climatic factors in rainfed environment particularly that of soil moisture availability leading to poor stability in the yield of chickpea crop over the years. Over all the locations, average minimum experimental station yield (1170 kg ha^{-1}) was less than half of the average maximum value (2460 kg ha^{-1}). Similarly, across the locations, there was 39 and 37% difference in the average minimum and maximum on-farm and district average yields, respectively (Table 59).

6.5.2 Simulated potential yields

6.5.2.1 Simulated rainfed yields at selected locations: Depending on the climatic conditions and soil type, large variation in mean simulated yield across the locations and also over the years at a given location was observed (Table 60). When averaged over all the locations across India, the mean simulated yield was 1130 kg ha^{-1} with a CV of 32% across locations. The mean simulated yield ranged from 490 (Guna, Madhya Pradesh) to 2030 kg ha^{-1} (Parbhani, Maharashtra). Large differences were observed in the minimum and maximum grain yields that were obtained over years at each location. The high degree of temporal variability was evident as the CV for average grain yield ranged from 42 to 102% among locations. The average maximum yield across locations was 2470 kg ha^{-1} and ranged from 1090 to 4300 kg ha^{-1} indicating a good potential of chickpea provided good weather conditions prevail. On the other hand, during long-term simulations, rainfed chickpea crop failed in some of the seasons at many locations due to inadequate availability of soil moisture. Out of 26 locations, only five locations (Sagar, Vidisha, Bhopal, Dharwad and Belgaum) did not show failure of chickpea crop. At rest of the locations, the crop failure ranged from 3 to 36% of the years the simulations were carried out. Some of the location in north (Hisar, Ludhiana, Delhi and Durgapura) the failure of rainfed crop was almost 75 to 90% (data not shown).

The failure of crop in many seasons and large temporal variation in yield among the locations indicated the uncertainty of chickpea cultivation in a rainfed environment due to inadequate availability of soil moisture after the harvest of rainy season crop. In black soils, which have high water-holding capacity, the early withdrawal of monsoon in many years led to very low moisture content in the upper (15–20 cm) layers of soils while moisture at lower layers may have been adequate. This condition resulted in poor germination and crop failure. In order to ensure adequate soil moisture, the traditional practice was to keep the land fallow and conserve soil moisture in the rainy season. However, due to the fast spread of soybean cultivation, largely in the fallow land, in Central and peninsular India, soybean-chickpea has emerged as a predominant cropping system. The cropping system is more remunerative but the availability of soil moisture at the time of chickpea planting becomes a critical limitation in many seasons. Application of pre-sowing irrigation (*Paleva*) to chickpea in the years when there is not enough moisture in the upper layers of soil has thus become very common in major chickpea-growing regions of the country.

Table 60. **Simulated rainfed grain yield, crop season rainfall, district average yield and total yield gap of chickpea at selected locations across India.**

Location	Simulated yield (kg ha^{-1}) Min	Max	Mean	CV[2]	Crop season rainfall (mm) Min	Max	Mean	CV[2]	Crop failure (%)	District yield[1] (kg ha^{-1})	Total yield gap (kg ha^{-1})
Primary Zone											
Guna	0	1170	490	83	0	160	40	124	25	1010	0
Hoshangabad	0	1710	840	55	0	170	60	80	5	1020	0
Raisen	0	1090	620	63	10	240	80	74	6	900	0
Rajgarh	0	1450	760	50	0	230	60	107	4	970	0
Sagar	170	2210	1070	56	0	220	80	85	0	750	320
Shajapur	0	2800	930	89	0	200	70	153	36	1010	0
Ujjain	0	2210	1010	66	0	140	50	99	22	960	50
Vidisha	60	1370	620	50	0	180	40	102	0	1050	0
Secondary Zone											
Akola	0	2570	1220	71	0	190	60	97	19	620	600
Amravati	0	2990	1260	81	0	200	80	75	17	640	620
Betul	0	2620	1240	61	0	220	90	75	14	450	790
Bhopal	180	2800	1020	62	0	330	60	110	0	910	110
Dhar	0	1840	930	79	0	140	50	40	35	790	140
Dharwad	0	4300	1960	66	10	330	170	50	4	480	1480
Indore	0	2370	1250	51	0	120	60	79	14	790	460
Jhabua	0	2820	1150	62	0	90	20	96	21	650	500
Jabalpur	0	3710	1240	102	0	180	40	127	33	650	590
Kota	0	2250	790	90	0	660	70	224	5	880	0
Nagpur	0	2700	1080	63	0	380	100	94	7	490	590
Nanded	0	2190	1430	50	0	360	70	101	7	400	1030
Parbhani	0	3550	2030	43	0	330	100	82	10	480	1550
Ratlam	0	2420	1220	64	0	170	40	111	23	910	310
Wardha	0	2440	1160	57	20	160	80	56	12	430	730
Tertiary Zone											
Belgaum	240	2100	1240	46	40	240	110	50	0	470	770
Hyderabad	0	2980	1110	58	10	390	130	82	3	330	780
Raipur	0	3600	1610	42	0	190	70	72	4	600	1010
Mean	30	2470	1130		0	240	70			720	480
CV[3]	261	32	32		258	50	44			32	96

1 District yields are average of 1995-96 to 1998-99.
2 CV = Coefficient of variation (%) for mean value of a location over years.
3 CV = Coefficient of variation (%) for mean value over locations.

6.5.2.2 Simulated yield with pre-sowing irrigation at selected locations: To assess the potential of the crop with adequate soil moisture at the time of planting, simulations were carried out with the provision of pre-sowing irrigation in case the soil moisture in the top 30 cm soil layer was below 40% of its extractable moisture capacity. The simulated minimum, maximum and mean grain yield of chickpea with pre-sowing irrigation for all the locations (including Durgapura, Delhi and Ludhiana, where the crop failure was more than 75% without pre-sowing irrigation) are presented in Table 61. When averaged over all the locations across India, the simulated grain yield of chickpea with pre-sowing irrigation was 1610 kg ha^{-1} with a CV of 29% across locations. The mean simulated grain yield among the locations ranged from 910 (Durgapura, Rajasthan) to

Table 61. Simulated grain yield (with pre-sowing irrigation), district average yield and total yield gap of chickpea at selected locations across India.

Location	Simulated yield (kg ha^{-1}) Min	Max	Mean	CV[2]	District yield[1] (kg ha^{-1})	Yield gap (kg ha^{-1})
Primary Zone						
Durgapura	230	1590	910	49	960	0
Guna	660	1280	1000	16	1010	0
Hoshangabad	690	2420	1480	25	1020	460
Raisen	660	1720	1050	24	900	150
Rajgarh	710	2150	1220	25	970	250
Sagar	1330	3150	1910	29	750	1160
Shajapur	920	3620	1550	36	1010	540
Ujjain	740	3340	1590	39	960	630
Vidisha	570	1770	1000	30	1050	0
Secondary Zone						
Akola	780	2490	1880	24	620	1260
Amravati	800	3320	2150	26	640	1510
Betul	1020	2950	1970	23	450	1520
Bhopal	860	3110	1630	36	910	720
Dhar	1110	2890	1790	25	790	1000
Dharwad	200	4550	2360	54	480	1880
Indore	660	3010	1850	31	790	1060
Jhabua	320	3550	1680	36	650	1030
Jabalpur	1510	3820	2480	25	650	1830
Kota	850	2900	1580	38	880	700
Nagpur	760	2750	1560	29	490	1070
Nanded	230	2410	1660	37	400	1260
Parbhani	1740	3480	2360	15	480	1880
Ratlam	1480	3540	2020	24	910	1110
Wardha	870	2490	1550	33	430	1120
Tertiary Zone						
Belgaum	1500	2570	1880	19	470	1410
Hyderabad	150	2970	1220	48	330	890
Raipur	1200	3600	1840	32	600	1240
Others						
Ludhiana	140	2170	1120	52	1000	120
Pantnagar	0	2370	1440	46	840	600
Delhi	60	1180	470	62	*	-
Mean	760	2770	1610		740	910
CV[3]	62	28	29		31	62

1 District yields are average of 1995-96 to 1998-99
* District Average yields are not available due to negligible area under chickpea
2 CV = Coefficient of variation (%) for mean yield of a location over years
3 CV = Coefficient of variation (%) for mean yield over locations

2480 kg ha^{-1} (Jabalpur, Madhya Pradesh). The average maximum yield ranged from 1280 (Guna, Madhya Pradesh) to 4550 kg ha^{-1} (Dharwad, Karnataka) with an average value of 2770 kg ha^{-1} across these locations. Similarly, the average minimum yield observed across these locations was 760 kg ha^{-1} and ranged from zero (Pantnagar, Uttaranchal) to 1730 kg ha^{-1} (Jabalpur). Hence, the application of pre-sowing irrigation resulted on an average 30% and 11% increase in the average and maximum yield of these locations, as compared to simulated yields without pre-sowing irrigation (Table 60), respectively. However, the increase in average minimum yield with pre-sowing irrigation was much higher and increased from a mere 30 kg ha^{-1} (Table 60) to 760 kg ha^{-1} (Table 61). Also, pre-sowing irrigation resulted in reduced temporal variability in average simulated yields across years at all the locations when compared to the average simulated yields without pre-sowing irrigation.

6.6 Simulated Rainfed Potential Yields

Both simulated and experiment station yields are indicative of the potential yield of a crop. Therefore, to find out the potential of chickpea crop across different geographical regions, the locations for which simulations were carried out with pre-sowing irrigation and locations for which experimental station yield data was available were grouped as per their production zones, AEZs and states. The minimum, maximum and average simulated yield among the location in each geographical region is presented in Table 62. It is generally expected that the simulated yield would be slightly higher than the experiment station yield as all the crop management conditions cannot be optimized under field conditions. However, in the present study, the average long-term simulated rainfed yields were less than the average experiment station yields (Table 62) in different crop production zones. The reasons for this could be a) the varietal trials in AICRP are conducted on very small plots and yields are extrapolated for per hectare; b) the total number of years accounted for simulation was very high

Table 62. Rainfed potential yield (with pre-sowing irrigation) of chickpea in different crop production zones, AEZs and states of India.

	Simulated yield (kg ha^{-1})					Experimental yield (kg ha^{-1})				
Zone/State	No. of locations	Min	Max	Mean	CV (%)	No. of locations	Min	Max	Mean	CV (%)
Production Zone										
Primary	9	910	1910	1300	26	5	1310	2410	1950	21
Secondary	15	1550	2480	1900	16	4	1670	2160	1970	11
Tertiary	3	1220	1880	1650	23	8	1050	2620	1630	32
Others	3	470	1440	1010	49	5	1060	2520	1680	31
AEZ										
2	-	-	-	-	-	3	1520	2620	2180	27
4	3	470	1120	830	40	6	1310	2520	2000	20
5	6	1580	2020	1750	10	1	-	-	2160	-
6	6	1660	2360	2050	14	3	1310	1670	1480	12
10	12	1000	2480	1540	29	2	1990	2130	2060	-
State										
Madhya Pradesh	14	1000	2480	1620	26	2	1990	2130	2060	-
Maharashtra	6	1550	2360	1860	18	1	-	-	1460	-
Rajasthan	2	910	1580	1250	-	4	1940	2410	2160	9
Karnataka	2	1880	2360	2120	-	3	1060	1670	1350	23

CV = Coefficient of variation (%)

which could capture the climatic variability more than the experiment station for which data was available for limited years; c) non reporting of data from experiment station for the years when crop failed due to adverse weather conditions; and d) possibility of life-saving irrigations to the experiment station trials in addition to the pre-sowing irrigation in case of severe drought.

6.6.1 Potential yield of production zones

The primary production zone which accounts for 50% of the total chickpea area in the country, the average simulated and experimental station yields were 1300 and 1950 kg ha^{-1}, respectively. The maximum simulated and experimental yields observed among the locations of this zone were 1910 and 2410, respectively. Secondary zone, which accounts for another 35% of the total chickpea area in the country, the simulated and experimental yields were 1900 and 1970 kg ha^{-1}, respectively. The maximum simulated and experimental yield observed among the locations of secondary zone was 2480 and 2160 kg ha^{-1}, respectively. The potential of tertiary zone and the zone designated as 'others', which account for rest of the 15% of total area of chickpea in the country, was about 1650 kg ha^{-1} and 1010 kg ha^{-1}, respectively (Table 62).

6.6.2 Potential yield of agroecological zones

The major rainfed area under chickpea is spread in Central and peninsular India comprising of AEZs 5 and 6 of semi-arid ecosystem and AEZ 10 of sub-humid ecosystem. The rainfed chickpea is possible in this region mainly due to black soils, which have high available water holding capacity (AWHC). The average simulated yields of AEZ 5, 6 and 10 was 1750, 2050 and 1540 kg ha^{-1}. The maximum simulated yield among the locations in each of these zones was 2020, 2360 and 2480 kg ha^{-1}, respectively. The average experimental yields were somewhat higher than average simulated yields in AEZ 5 (2160 kg ha^{-1}) and 10 (2060 kg ha^{-1}) while lower in AEZ 6 (1480 kg ha^{-1}). Substantial area under chickpea is also spread in the AEZ 2 of arid ecosystem and AEZ 4 of semi-arid ecosystem which is spread in the states of Rajasthan, Punjab, Haryana and Uttar Pradesh. Large area in this zone is irrigated. Cultivation of chickpea crop without irrigation in these zones is difficult because of low rainfall and predominantly light soils with low to medium AWHC. This was evident when the simulations were carried out for the locations falling in these zones. Chickpea crop failed in more than 90% years in AEZ 2 (Hisar) and for more than 75% of the years in AEZ 4 at the locations such as (Delhi and Ludhiana) when simulations were carried out for rainfed chickpea. With pre-sowing irrigation though the failure of the crop was reduced still the yields were very poor for AEZ 2. The average reported experimental yield of AEZ 2 and 4 was 2180 and 2000 kg ha^{-1}. On the other hand, the simulated yield for AEZ 4 was 830 kg ha^{-1}, which is even less than the average district yields of the zone (930 kg ha^{-1}), indicating that the area under the zone is to some extent irrigated.

6.6.3 Potential yield of states

Among the states, the major rainfed area under chickpea in India is spread in Madhya Pradesh, Maharashtra and Karnataka. The average simulated yields of these states were 1620, 1860 and 2120 kg ha^{-1}, respectively. The average experimental station yields for these states were 2060, 1460 and 1350 kg ha^{-1}, respectively. The other states, which possess substantial area under chickpea, are Rajasthan and Uttar Pradesh where crop is grown with supplemental irrigation.

It is evident from the simulated as well as experimental station yields that in general the potential of rainfed chickpea in major geographical regions is between 1500 to 2000 kg ha^{-1} which is substantially higher than the present national average of about 800 kg ha^{-1}.

Table 63. Yield gaps of chickpea at different AICRP locations across India.

	Yield gap (kg ha^{-1})											
	YG I				YG II				Total YG			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Sehore	0	1190	360	132	510	1000	680	27	360	1750	1040	42
Durgapura	30	1210	330	135	510	1090	830	31	850	1720	1160	28
Sriganganagar	0	2400	970	110	260	1150	780	42	450	3290	1750	66
Gulbarga	0	710	150	107	10	940	600	50	240	1650	750	59
Diggi	-	-	-	-	-	-	-	-	400	3200	1450	71
Hisar	-	-	-	-	120	1050	620	55	-	-	-	-
Secondary Zone												
Bharari	0	450	150	120	380	1110	910	33	380	1260	1070	32
Dharwad	-	-	-	-	-	-	-	-	430	1910	1160	56
Jabalpur	-	-	-	-	-	-	-	-	430	2120	1250	51
Kota	-	-	-	-	-	-	-	-	880	2120	1440	43
Bhopal	-	-	-	-	460	540	510	8	-	-	-	-
Rahuri	-	-	-	-	1020	1550	1290	14	-	-	-	-
Akola	-	-	-	-	370	1290	800	42	-	-	-	-
Tertiary Zone												
Raipur	0	490	160	96	30	770	520	53	230	950	680	41
Badnapur	0	180	40	245	640	1290	870	28	640	1470	910	34
Lam	-	-	-	-	120	1480	630	82	-	-	-	-
Bawal	-	-	-	-	-	-	-	-	200	790	490	54
Bathinda	-	-	-	-	-	-	-	-	590	2440	1800	58
Faridkot	-	-	-	-	-	-	-	-	400	2770	1470	71
Berhampore	-	-	-	-	-	-	-	-	290	740	540	42
Arnej	-	-	-	-	-	-	-	-	150	1370	830	55
Coimbatore	-	-	-	-	-	-	-	-	20	1140	370	120
Faizabad	-	-	-	-	820	1260	1000	18	-	-	-	-
Varanasi	-	-	-	-	110	1410	700	67	-	-	-	-
Kanpur	-	-	-	-	250	870	610	42	-	-	-	-
Junagadh	-	-	-	-	70	620	270	76	-	-	-	-
Others												
Delhi	0	920	340	116	1140	1720	1390	17	1410	2100	1720	20
Bangalore	0	480	180	109	30	1100	310	120	30	1100	490	66
Samba	150	1700	730	100	0	230	130	108	120	1920	860	87
Warangal	-	-	-	-	-	-	-	-	240	1340	720	79
Dholi	-	-	-	-	-	-	-	-	30	1200	620	67
Pantnagar	-	-	-	-	140	1340	680	73	-	-	-	-
Ludhiana	-	-	-	-	600	1310	910	29	-	-	-	-
Mean	20	970	340	-	360	1100	720	-	410	1740	1030	-
CV[2]	263	70	86	-	93	32	42	-	80	41	43	-

1 CV = Coefficient of variation (%) for mean yield gap of a location over the years
2 CV = Coefficient of variation (%) for mean yield gap over locations

6.7 Yield Gaps

6.7.1 Yield gaps of selected locations

The magnitude of YG I and II in chickpea is presented in Table 63. Across locations, the average YG I was 340 kg ha^{-1} and ranged from 40 (Badnapur) to 970 kg ha^{-1} (Sriganganagar, Rajasthan). The average YG II was 720 kg ha^{-1} and ranged from 130 (Samba, Jammu and Kashmir) to 1390 kg ha^{-1} (Delhi). The average total yield gap was 1030 kg ha^{-1} and ranged from 370 (Coimbatore) to 1800 kg ha^{-1} (Bathinda, Punjab). Considerably high values of CV for YG I (86%), YG II (42%) and total YG (43%) were recorded indicating large degree of variation in these yield gaps among different locations in India. The high variation in YG II across locations indicated the varying levels of adaption of technology and improved cultural practices among the average farmers at these locations. The high degree of yield gaps particularly that of YG II (720 kg ha^{-1}) and total YG (1030 kg ha^{-1}) indicated that there is a considerable scope to improve the productivity levels of chickpea in India, provided the reasons behind these yield gaps are understood and proper interventions are made. Besides considerable spatial variability, a high degree of temporal variation in these yield gaps were also observed. Depending on the location, CV for year-to-year variability in YG I, YG II and total YG ranged from 96 to 245, 8 to 120 and 20 to 120%, respectively. Large year-to-year variation in the yield gaps resulted in very narrow yield gaps in some years while in others the gaps were very wide at a given location. In general, it was observed that the yield gaps at a given location were narrow in those years in which potential (experimental station) and achievable (on-farm) yields were also quite low (Annexure X). In other words, these were the years when climatic conditions were unfavorable particularly when the availability of soil moisture was much below the requirement of the crop.

6.7.2 Yield gaps of production zones

Across various production zones, the YG I ranged from 0 to 260 and 80 to 510 kg ha^{-1} when estimated by using simulated and experimental station yields respectively (Table 64). The extent of YG II was the maximum for secondary production zone (890 kg ha^{-1}) followed by tertiary (820 kg ha^{-1}) others (800 kg ha^{-1}) and primary production zone (610 kg ha^{-1}).

Table 64. Yield gaps of chickpea in different production zones of India.

	Primary	Secondary	Tertiary	Others
	(kg ha^{-1})			
Grain yield				
Simulated mean	1300	1900	1650	1010
Experimental mean	1950	1970	1630	1680
On-farm mean	1440	1640	1550	1470
Districts' mean*	830	750	730	670
Yield gap				
Simulated – On-farm (YG I)	0	260	100	0
Experimental station – On-farm (YG I)	510	330	80	210
On-farm – District (YG II)	610	890	820	800

* Mean of all the districts for each chickpea production zone (Table 55).

6.7.3 Yield gaps of agroecological zones

Among the agroecological zones, the YG I ranged from 0 to 580 and 10 to 780 kg ha^{-1} when estimated based on average simulated and experimental station yields, respectively (Table 65). The YG II was very high for AEZ 6 (920 kg ha^{-1}) followed by AEZs 4 (890 kg ha^{-1}), 10 (680 kg ha^{-1}), 2 (670 kg ha^{-1}) and 5 (530 kg ha^{-1}).

6.7.4 Yield gaps of major states

Across different states of India, the YG I ranged from 0 to 1100 and 0 to 640 kg ha^{-1} when estimated based on simulated and experimental station yields, respectively (Table 66). The magnitude of YG II was very high for Maharashtra (1020 kg ha^{-1}) followed by Uttar Pradesh (860 kg ha^{-1}), Rajasthan (720 kg ha^{-1}), Madhya Pradesh (680 kg ha^{-1}) and Karnataka (560 kg ha^{-1}).

Table 65. Yield gaps in chickpea in different AEZs of India.

	Arid	Semi-arid			Sub-humid
	2	4	5	6	10
	(kg ha^{-1})				
Grain yield					
Simulated mean	-	830	1750	2050	1540
Experimental mean	2180	2000	2160	1480	2060
On-farm mean	1400	1820	1410	1470	1560
Districts' mean*	730	930	880	550	880
Yield gap					
Simulated – On-farm (YG I)	-	0	340	580	0
Experimental station – On-farm (YG I)	780	180	750	10	500
On-farm – District (YG II)	670	890	530	920	680

* Mean of all the districts for each agroecological zone (Table 56).

Table 66. Yield gaps of chickpea in major states of India.

	Madhya Pradesh	Maharashtra	Uttar Pradesh	Rajasthan	Karnataka
	(kg ha^{-1})				
Grain yield					
Simulated mean	1620	1860	-	1250	2120
Experimental mean	2060	1460	1930	2160	1350
On-farm mean	1560	1580	1690	1520	1020
Districts' mean*	880	560	830	800	460
Yield gap					
Simulated – On-farm (YG I)	60	280	-	0	1100
Experimental station – On-farm (YG I)	500	0	240	640	330
On-farm – District (YG II)	680	1020	860	720	560

* Mean of all the districts for each state (Table 57).

Yield gap I is considered to be difficult to abridge as it is because of environmental differences such as theoretically optimum conditions created during simulations and very small plot sizes with optimum homogeneity and the technical expertise at research stations. The variations observed among different regions for YG I thus, could be because of the above factors. Though, YG I cannot be abridged totally, it gives an indication of the upper limits of productivity that can be achieved in a given environment. If the YG I is very narrow, it indicates the need to generate further technologies such as improved varieties that can perform still better in a given environment.

On the other hand, YG II is manageable as it is mainly due to the differences in the management practices and input use. In case of chickpea, on an average this gap ranged from 600 to 1000 kg ha^{-1} for the major production zones, AEZs and states of India. The narrowing of such a large gap can help in a substantial increase in the total production of chickpea in the country.

6.8 Water Balance of Selected Locations

6.8.1 Water balance components of rainfed chickpea crop

Chickpea is grown as a postrainy season crop and consequently very little rain is received during the crop duration. Average rainfall across locations during chickpea season was 72 mm and a wide variability ranging from 24 to 166 mm across locations was observed (Table 67a). Besides spatial variability in the average rainfall, a large year-to-year variation was observed in the amount of rainfall received at each location as CV values for the average rainfall ranged from 40 to 224% across locations. Surface runoff and deep drainage were negligible with an average value of 11 and 5 mm, respectively (Table 67a). Chickpea being a winter crop, the evaporative demands are generally low. Large spatial and temporal variability in simulated evapo-transpiration among the locations is attributed to the amount of rainfall received during the chickpea growing season and the differences in crop duration at different locations (Table 67b).

6.8.2 Water balance components of soybean preceding chickpea crop

As a postrainy season crop in a rainfed environment, the crop establishment of chickpea and its productivity is dependent on the stored soil moisture at the harvest of the rainy season crop. Therefore, the soil water balance of the preceding crop/season becomes more important for the chickpea. In recent years, soybean-chickpea has emerged as a predominant cropping system of rainfed areas of Central and peninsular India. Therefore, in the present study, simulations were carried out for a sequential cropping system where chickpea is preceded by soybean. A considerable spatial and temporal variation in seasonal rainfall, surface runoff, deep drainage, ET and extractable soil water at the end of the soybean crop was observed among the locations (Tables 68a and 68b). The average rainfall of these locations was 889 mm and ranged from 390 to 1328 mm with a CV of 23%. The CV for the average rainfall received over the simulated years ranged from 23 to 42%. The average runoff during the *kharif* season was 265 mm and ranged from 44 to 407 mm among these locations. On an average, water lost through runoff was 30% of the average rainfall received and ranged from 11 to 37% among the locations. Similarly, the average value for the deep drainage was 174 mm, which ranged from 4 to 420 mm among these locations. The average amount of potential ET was 390 mm and ranged from 274 to 546 mm across these locations. At the time of harvest of soybean, the average amount of extractable water in the soil profile was 142 mm and ranged from 48 to 246 mm. The poor amount of average extractable water at the time of harvesting of soybean crop and a large temporal

Table 67a. Long-term water balance components (mm) of simulated rainfed chickpea at selected locations across India.

	Rainfall				Surface runoff				Deep drainage			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Durgapura	13	151	54	88	0	22	3	204	0	18	2	298
Guna	0	164	43	124	0	17	2	183	0	19	2	310
Hoshangabad	0	174	56	82	0	72	11	197	0	16	1	286
Raisen	8	238	79	74	0	130	11	291	0	0	0	0
Rajgarh	1	229	58	107	0	120	12	221	0	23	3	230
Sagar	0	215	78	85	0	108	13	183	0	51	4	252
Shajapur	0	200	72	153	0	540	27	398	0	204	10	415
Ujjain	0	144	46	99	0	57	8	157	0	38	3	355
Vidisha	0	177	40	102	0	76	4	362	0	39	2	497
Secondary Zone												
Akola	0	194	59	97	0	84	13	175	0	48	4	277
Amravati	0	202	75	75	0	50	11	127	0	27	2	424
Betul	0	220	93	75	0	91	20	124	0	34	7	162
Bhopal	0	326	60	110	0	70	9	180	0	84	4	362
Dhar	0	135	50	40	0	57	7	208	0	43	3	303
Dharwad	7	333	166	50	0	123	28	105	0	50	7	211
Indore	0	116	55	55	0	38	8	134	0	30	5	191
Jhabua	0	87	24	96	0	26	2	284	0	0	0	0
Jabalpur	1	177	44	127	0	38	4	222	0	17	1	458
Kota	0	663	66	224	0	212	15	312	0	162	8	447
Nagpur	2	375	99	94	0	74	15	131	0	63	9	167
Nanded	0	355	73	101	0	110	11	215	0	102	10	233
Parbhani	0	325	98	82	0	97	12	189	0	125	16	195
Ratlam	0	167	43	111	0	249	18	278	0	186	11	342
Wardha	22	162	77	56	0	41	11	124	0	43	4	276
Tertiary Zone												
Belgaum	38	241	110	50	0	53	14	118	0	44	7	180
Hyderabad	8	390	126	82	0	142	25	143	0	137	12	258
Raipur	0	189	71	72	0	28	4	147	0	70	10	191
Others												
Ludhiana[1]	3	256	115	53	0	58	5	248	0	7	0	480
Pantnagar	0	398	96	109	0	57	11	128	0	4	0	326
Delhi	0	204	27	178	0	22	4	157	0	0	0	0
Mean	3	240	72		0	95	11		0	56	5	
CV[2]	238	48	43		0	104	62		0	99	87	

variability in it points toward the limitations imposed by soil moisture availability for the cultivation of rainfed chickpea at most of the locations in India. However, the water balance data of soybean season indicates a great scope of harnessing the rainwater lost through runoff, which can be utilized for subsequent chickpea crop.

6.9 Major Constraints and Opportunities for Abridging Yield Gaps

Several biotic, abiotic and socioeconomic constraints to chickpea productivity in India have been identified and reported (Khanna-Chopra and Sinha 1987, Ali and Shiv Kumar 2001). High temperature

Table 67b. Water balance components (mm) of simulated rainfed chickpea at various benchmark locations in India.

	Evapo-transpiration				Extractable water*			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone								
Durgapura	99	216	147	25	11	26	18	24
Guna	56	197	143	21	21	61	30	30
Hoshangabad	98	204	151	15	29	85	36	33
Raisen	120	260	190	21	24	51	34	23
Rajgarh	112	188	144	14	22	58	34	28
Sagar	97	185	148	16	33	111	48	35
Shajapur	67	304	161	27	32	74	43	26
Ujjain	80	224	152	27	32	74	44	22
Vidisha	41	183	144	20	19	62	28	28
Secondary Zone								
Akola	77	182	133	20	38	205	154	18
Amravati	86	212	143	23	76	197	158	15
Betul	62	249	171	23	140	182	151	8
Bhopal	94	284	156	23	21	71	37	32
Dhar	125	220	164	15	38	58	47	12
Dharwad	54	300	203	28	7	71	53	27
Indore	76	215	156	22	34	72	48	22
Jhabua	54	186	140	23	33	85	47	19
Jabalpur	157	272	206	15	35	89	46	23
Kota	86	307	146	34	36	103	63	24
Nagpur	58	200	136	23	43	75	54	15
Nanded	35	201	138	33	68	197	154	15
Parbhani	118	244	180	21	106	179	130	12
Ratlam	86	278	156	23	40	72	51	16
Wardha	115	241	179	18	14	39	23	29
Tertiary Zone								
Belgaum	127	227	162	17	69	98	78	11
Hyderabad	61	268	175	25	17	47	26	27
Raipur	147	269	194	15	21	40	28	17
Others								
Ludhiana[1]	98	301	191	30	20	37	24	20
Pantnagar	12	282	203	33	10	82	20	83
Delhi	61	198	128	28	12	36	19	24
Mean	85	237	161		37	88	58	
CV[2]	39	17	14		80	59	77	

* Extractable water retained in the soil profile at harvest of chickpea crop.
1 CV = Coefficient of variation (%) for mean value of a location over years.
2 CV = Coefficient of variation (%) for mean value over locations.

and drought are the major constraints to chickpea in a rainfed environment. Inadequate soil moisture at the time of planting often results in poor germination and poor crop stand. Among the biotic factors, diseases such as *Fusarium* wilt, *Aschochyta* blight and *botrytis* gray mold are widespread in major chickpea growing regions. Chickpea pod borer (*Helicoverpa armigera* Hübner) is the most

Table 68a. Long-term average water balance components (mm) of simulated soybean preceding chickpea crop at selected locations across India.

	Rainfall				Surface runoff				Deep drainage			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone												
Durgapura	241	835	582	33	4	330	103	96	0	275	102	99
Guna	322	1726	942	33	65	909	315	61	14	336	197	48
Hoshangabad	518	1967	1162	27	125	903	400	47	84	711	326	46
Raisen	416	1566	1045	28	69	683	315	62	0	245	126	58
Rajgarh	407	1699	933	30	97	825	328	52	46	509	197	56
Sagar	441	1991	1136	31	89	890	407	50	52	662	321	46
Shajapur	104	1751	912	31	19	840	308	57	0	514	176	63
Ujjain	454	1817	885	33	100	929	315	57	0	489	143	79
Vidisha	562	1627	934	27	90	680	247	66	0	510	199	58
Secondary Zone												
Akola	278	1178	692	30	37	441	199	49	0	257	74	93
Amravati	488	1144	765	26	87	457	222	50	0	280	98	96
Betul	555	1544	1078	23	143	690	366	42	87	400	272	35
Bhopal	441	1684	1004	28	72	761	338	48	86	519	246	46
Dhar	592	1492	897	25	75	646	254	55	20	422	146	68
Dharwad	130	737	390	35	5	163	44	71	0	57	4	323
Indore	435	1445	914	27	78	824	323	49	0	328	130	59
Jhabua	293	1421	786	33	65	549	177	93	0	455	128	85
Jabalpur	590	1986	1236	24	124	999	368	63	79	667	420	37
Jabalpur	590	1989	1247	24	114	970	355	65	76	617	400	39
Kota	60	1011	624	38	0	449	185	60	0	256	88	107
Nagpur	553	1463	942	23	88	673	297	44	28	415	199	48
Nanded	601	1509	767	33	35	602	189	71	0	256	67	112
Parbhani	470	1533	824	40	70	503	221	63	1	565	177	96
Ratlam	582	1847	1011	30	146	893	376	49	72	474	220	52
Wardha	555	1561	963	24	87	718	293	48	0	351	151	65
Tertiary Zone												
Belgaum	549	1549	944	24	97	738	307	46	38	377	191	51
Hyderabad	443	1269	686	33	52	713	191	70	0	208	47	144
Raipur	622	1600	1045	26	93	461	242	46	31	612	296	51
Others												
Ludhiana	166	1091	580	41	0	467	111	105	0	210	49	131
Pantnagar	731	2494	1328	37	86	953	334	65	82	971	394	59
Delhi	190	1171	659	42	15	485	202	57	0	258	42	152
Mean	426	1524	889		70	672	265		24	418	174	
CV[2]	41	23	23		56	30	33		138	45	60	

widespread insect causing a severe yield erosion of chickpea in India. Weeds are another biotic factor, which limit the productivity of chickpea in India. Lack of adoption of improved technology, low input, use of marginal lands, unfavorable market fluctuations, inadequate procurement mechanism and lack of liberal credit policy are some of the socioeconomic factors which limit the productivity of chickpea in the country.

In rainfed environment where chickpea is grown on residual moisture, the availability of soil moisture to chickpea is influenced by both the quantum and distribution of rains in the rainy season as well as

Table 68b. Long-term average water balance components (mm) of simulated soybean preceding chickpea crop at selected locations across India.

	Evapo-transpiration				Extractable water*			
Location	Min	Max	Mean	CV[1]	Min	Max	Mean	CV[1]
Primary Zone								
Durgapura	261	462	364	20	44	146	82	42
Guna	234	513	390	19	72	156	107	18
Hoshangabad	282	592	396	18	82	164	115	15
Raisen	370	666	546	15	81	176	128	18
Rajgarh	250	460	360	17	69	171	109	19
Sagar	248	512	360	16	78	162	119	18
Shajapur	55	512	361	25	103	186	147	15
Ujjain	260	445	357	14	88	185	134	18
Vidisha	291	566	442	21	78	156	111	16
Secondary Zone								
Akola	229	462	352	18	75	291	232	18
Amravati	300	515	390	14	115	277	228	18
Betul	287	450	368	11	218	286	245	7
Bhopal	287	438	364	11	82	185	120	18
Dhar	308	602	435	18	100	187	138	18
Dharwad	138	357	274	19	30	240	121	52
Indore	270	559	384	15	64	191	142	20
Jhabua	231	504	412	22	65	190	140	19
Jabalpur	309	466	413	12	146	226	182	12
Kota	55	491	302	31	97	221	143	22
Nagpur	290	468	391	10	96	162	126	16
Nanded	235	611	426	24	134	290	242	17
Parbhani	273	405	328	11	201	280	246	10
Ratlam	230	445	344	16	107	195	147	17
Wardha	349	534	453	12	57	178	107	38
Tertiary Zone								
Belgaum	323	507	387	14	126	191	155	13
Hyderabad	311	434	386	7	50	186	117	38
Raipur	345	435	392	6	96	199	157	21
Others								
Ludhiana	215	627	444	21	11	150	48	150
Pantnagar	436	521	477	5	48	207	112	37
Delhi	167	556	407	26	17	170	59	68
Mean	261	503	390		88	200	142	
CV[2]	31	14	13		52	22	36	

* Extractable water retained in the soil profile at harvest of soybean crop.
1 CV = Coefficient of variation (%) for mean value of a location over years
2 CV = Coefficient of variation (%) for mean value over locations

in the postrainy season. In case there are late season rains in the months of September and October, it helps in availability of enough soil moisture in the soil profile that can be utilized by the subsequent chickpea crop. However, this is not the case in most of the years in majority of the chickpea-growing regions of the country and early withdrawal of monsoon in many years coupled with high temperature and high evaporative demands, for the chickpea crop are not suitable. The importance of rains during

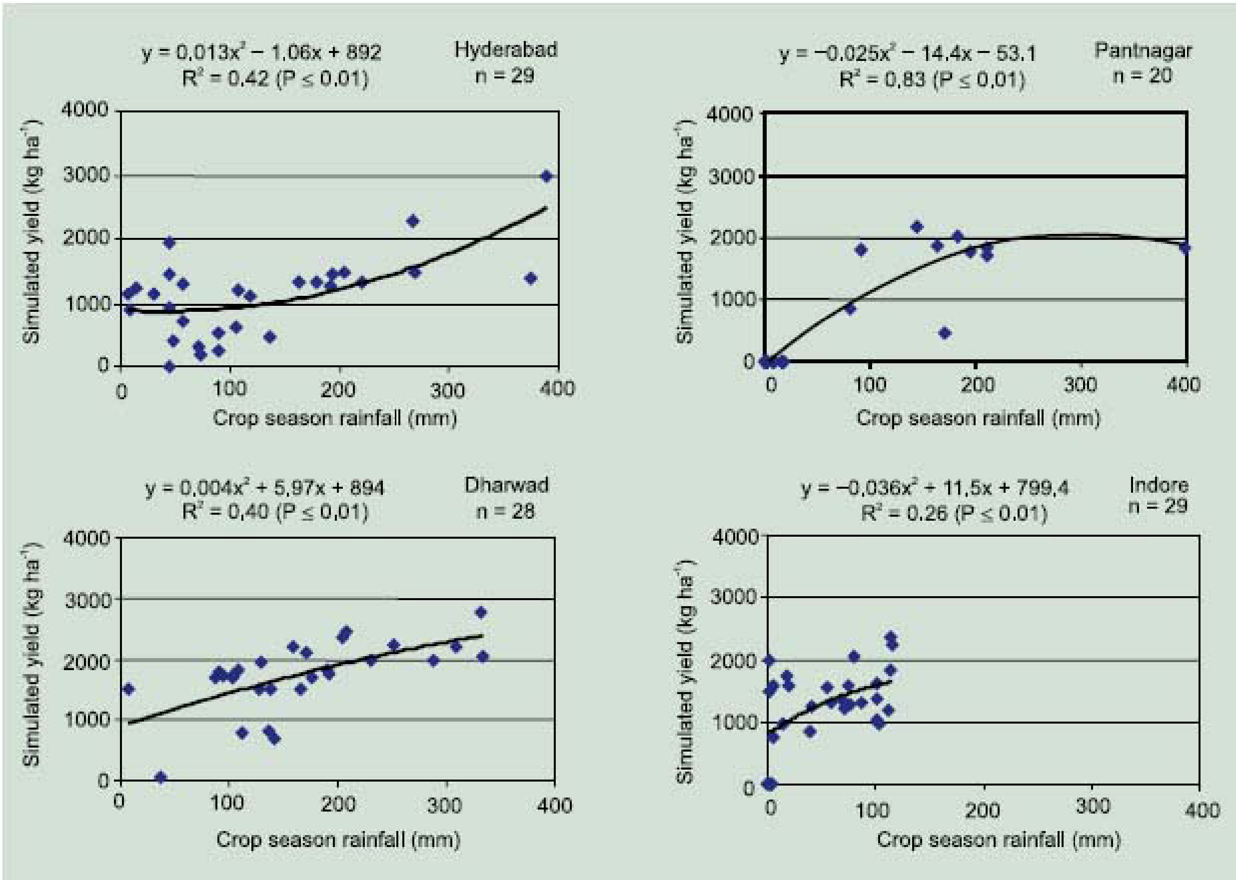

Figure 27. Relationship between simulated rainfed yield and crop season rainfall over years at different locations across India.

the crop season was evident across the locations when the average simulated yield over the years was plotted against the corresponding crop season rainfall. At majority of locations, the association was significant and positive, indicating a great influence of crop season rainfall on the productivity levels of the chickpea at these locations. The R^2 values for the association between simulated rainfed yields and crop season rainfall for the four diverse locations across India shown in Figure 27 ranged from 0.26 to 0.83 indicating a varying degree of influence of crop season rainfall on chickpea yield at these locations. The crop season rainfall varies widely from year-to-year at a given site resulting in great instability in the yields.

Similarly, when the long-term average simulated rainfed yield obtained across the locations was plotted against the respective long-term average crop season rainfall (Table 60), a significant and positive relationship was observed indicating an increase in the average simulated yield with increasing amount of rainfall across locations in India (Fig. 28). However, when district average yields were plotted against the average rainfall of the respective locations, a reverse relationship was observed (Fig. 29). The district yields were significantly higher at locations where the average crop season rainfalls were low and declined as the average rainfall increased. Such a pattern of chickpea yield in relation to average crop season rainfall is indicative of the fact that chickpea crop in majority of these locations receives protective irrigations particularly at the locations where crop season rainfall is very low or negligible.

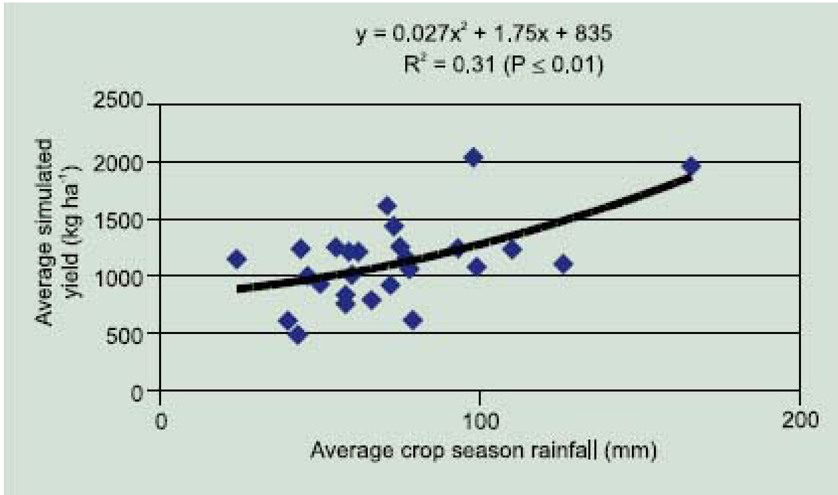

Figure 28. Relationship between average simulated rainfed yield and average crop season rainfall at selected locations across India (n= 26).

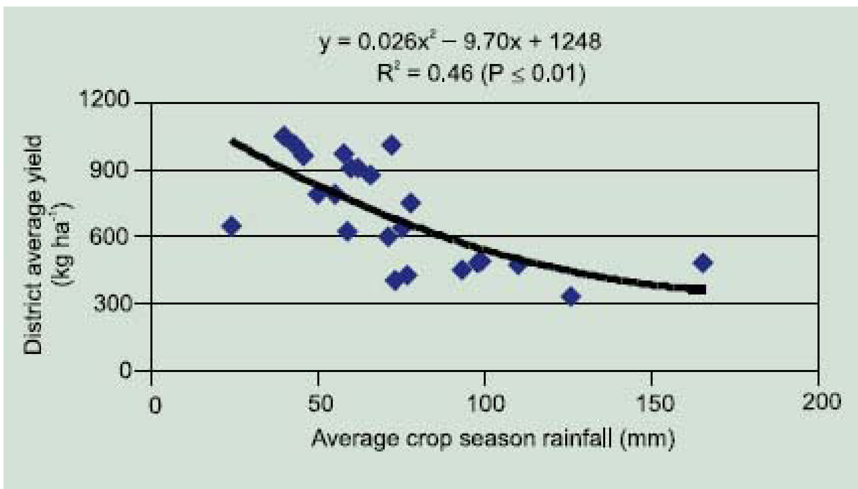

Figure 29. Relationship between district average yield and average crop season rainfall at selected locations across India (n = 26).

When the difference between simulated yield and district yield (Table 60) (which reflects the total YG) were plotted against the crop season rainfall, a significant and positive relationship ($R^2 = 0.42$, $P \leq 0.01$) was observed (Fig. 30). The total yield gap increased with the increasing average crop season rainfall indicating that yield gaps across locations were of higher magnitude when availability of soil moisture was higher.

This relationship indicates the importance of input use and improved management practices. The optimum use of nutrients and improved management practices are the main factors responsible for higher simulated yields (and also at experimental station and on-farm level). As these crop management factors strongly interact with climate and particularly with the availability of soil moisture, the positive impact of these factors is the maximum when enough moisture is available in the soil. On the other hand, under sub-optimal soil moisture conditions due to low levels of rainfall in a given environment, the impact of these factors are reduced drastically. Under this situation, the yield of a given location

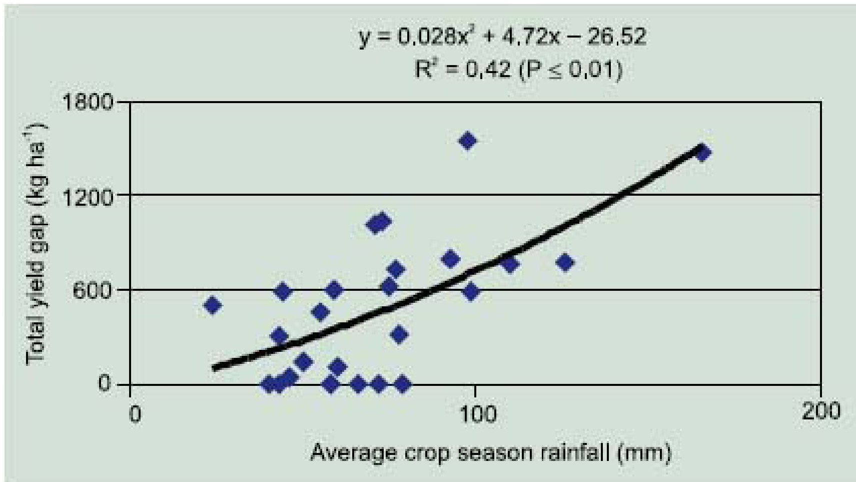

Figure 30. Relationship between total yield gap (difference between average simulated rainfed and district average yield) and average crop season rainfall at selected locations across India (n = 26).

is governed only by environmental factors at all the levels (simulated, experiment station, on-farm and average farmers) and yields obtained at all the levels do not vary considerably and resultant yield gaps are also low/negligible. Therefore, in order to improve the productivity of chickpea in rainfed environment, an integrated approach including development of drought tolerant varieties with better water use efficiency, improved input use, and adoption of improved technology is needed. Adoption of proven technologies such as effective watershed management, switching to planting on effective land configurations (broadbed-and-furrow, ridge-and-furrow, etc) and water conserving cultural methods (residue recycling, mulching, etc) can help in efficient use of water and nutrients particularly in the seasons, locations and regions with sub-optimal water availability. Use of high yielding early maturing soybean varieties can substantially help subsequent chickpea crop by leaving positive water balance in the soil profile.

6.10 Summary

Chickpea has been the most important legume crop grown traditionally in the rainfed agroecosystem by millions of small and marginal farmers in India. Presently, it is cultivated in about 6.4 million ha and contributes to about 49% of the total pulse production of the country. However, its average productivity has remained strikingly low and ranged between 0.5 to 0.9 t ha^{-1}. There are several biophysical, technical and socioeconomic constraints, which limit the productivity of chickpea in India. In order to mitigate these limitations, it is essential to assess the production potential of the environment in relation to achievable and current levels of production as well as the availability of natural resources. Therefore, the study was undertaken mainly a) to analyze the chickpea growing area in terms of intensity of distribution of the crop in different districts (production zones), AEZs and states across India, b) to estimate the water limited potential, achievable and current levels of average farmers yield in these regions, c) to quantify the extent of YG I and II, and d) to find out the possible reasons and ways to mitigate these yield gaps.

The crop was traditionally grown as a fallow-chickpea cropping sequence. With the introduction of soybean, soybean-chickpea cropping sequence has emerged as an important and predominant cropping system. Therefore, rainfed potential yield and water balance of chickpea for 30 locations representing different regions across India were simulated using CROPGRO soybean and chickpea models in sequence. To supplement the simulated potential yields, the last ten years experimental stations yield data reported by the All India Coordinated Research Project on chickpea were utilized. The achievable yields for locations across the country were taken from the trials conducted in farmers' fields with improved production technology under FLDs. The district average yields were taken as the average farmers yields. Based on simulated, experimental station, achievable and average farmers yields, yield gap I and yield gap II were estimated.

Analysis indicated that the crop is concentrated in the states of Madhya Pradesh, Rajasthan, Uttar Pradesh, Maharashtra, Andhra Pradesh and Karnataka encompassing AEZ 2 of arid ecosystem, AEZs 4 to 6 of semi-arid and AEZ 10 of sub-humid ecosystem. However, out of 322 chickpea growing districts, only 30 districts contribute 50% of the total area under the crop in India. Major soils of the chickpea-growing region are Vertisols and Vertic Inceptisols. The crop is mainly grown on the residual moisture during the postrainy season. The average seasonal rainfall varies from 400 to 1300 mm and the rainfall during the chickpea crop growth period is very meager and ranges from 24 to 166 mm. Also a large temporal and spatial variability exists in the rainfall received during both the rainy and postrainy seasons. This leads to a large variability in the production environments in terms of their production potential and management of natural resources.

Depending upon the agroclimatic conditions, large spatial and temporal variations were observed in average simulated potential yield, which ranged from 490 to 2030 kg ha^{-1} among locations with an average value of 1130 kg ha^{-1}. However, during long-term simulations of rainfed chickpea, the crop failed in some of the seasons at most locations. The crop failure across locations ranged from 3 to 90% of years indicating great uncertainty in chickpea production in the country. The application of pre-sowing irrigation to chickpea is a common practice particularly in the Central and peninsular India where soybean followed by chickpea has become a predominant cropping system in recent years. The experimental data of rainfed trials conducted under AICRP on chickpea also followed the same practice. Therefore, simulations were also carried out with the provision of pre-sowing irrigation in case the soil moisture at the time of chickpea planting was below 40% of the extractable capacity in the top 30 cm layer of the soil. The average simulated rainfed potential yield (with pre-sowing irrigation) was 1610 kg ha^{-1} and ranged from 910 to 2480 kg ha^{-1} among locations across India. Hence, on an average 30% increase in the simulated yield with the application of pre-sowing irrigation was observed and the increase was largely associated with non-failure of the crop. The reported experimental station, on-farm and average farmers yields across the locations ranged from 1050 to 2620, 880 to 2180 and 510 to 1140 kg ha^{-1}, respectively. On an average, there was 14 and 48% reduction in yield from experimental station to on-farm and from on-farm to average farmers yield respectively. The average simulated rainfed potential yield (with pre-sowing irrigation) across major production zones, AEZs and states of India ranged from 1010 to 1900, 830 to 2050 and 1250 to 2120 kg ha^{-1}, respectively indicating a large variability for the potential of chickpea in different regions across India.

Yield gap I, ranged from 0 to 260, 0 to 580 and 0 to 1100 kg ha^{-1} across different production zones, AEZs and states, respectively. Though the YG I cannot be abridged completely, it gives an indication of upper limits of achievable yields in a given environment. The narrow YG I in some of the regions indicate the need to further refine the production technology and develop varieties that can perform better in a given environment. On the other hand, YG II, is manageable as it is mainly due to the differences in the management practices and extent of input use. In chickpea, YG II ranged from 610 to 890, 530 to 920 and 560 to 1020 kg ha^{-1} across different production zones, AEZs and states of

India, respectively. The extent of YG II and a high degree of spatial and temporal variability observed across locations and different regions indicate the potential to increase the chickpea productivity with improved management under rainfed situations.

The water balance analysis showed a high degree of runoff during preceding rainy season crop (soybean) at many locations, which ranged from 11 to 37% of the total rainfall indicating the need to harvest and conserve this lost water and utilize for supplemental irrigation to subsequent chickpea crop and/or recharging of groundwater and also to minimize the erosion of fertile soil. As a postrainy season crop, chickpea receives very little rains during the crop season, which ranged from 24 to 166 mm across these locations. A significant and positive association (R^2 = 0.31, $P \leq 0.01$) was observed between simulated rainfed yields and average crop season rainfall over the locations, indicating the importance of this meager rainfall received during chickpea cropping period. Similarly, the total yield gap was also found to be significantly and positively associated with crop season rainfall (R^2 =0.42, $P \leq 0.01$). The relationships demonstrate that chickpea productivity is limited in many regions/ seasons by the availability of soil moisture and yield gaps are of larger magnitude in the regions/seasons where the availability of soil moisture is higher. Therefore, increase in average yield with improved management practices is likely to be of a greater magnitude in good rainfall regions/seasons or with supplemental irrigations.

It is concluded that further development of improved genotypes with better water use efficiency and adopting improved package of practices can help in raising the potential productivity and in abridging the yield gaps of chickpea in a rainfed environment. The adoption of proven technologies such as effective watershed management, switching to planting on effective land configurations (broadbed-and-furrow, ridge-and-furrow, minimum tillage, etc) and water conserving cultural methods (residue recycling, mulching, etc) can help in efficient use of water and nutrients particularly in the seasons, locations and regions with sub-optimal water availability.

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Annexures

Annexure I. Planting and harvesting dates and total dry matter (kg ha^{-1}) of simulated soybean at selected locations across India.

	Planting date				Harvest date				Total dry matter			
Location	Early	Late	Mean	CV	Early	Late	Mean	CV	Min	Max	Mean	CV
Primary Zone												
Dhar	1 Jun	12 Jul	21 Jun	7	28 Sep	21 Oct	10 Oct	2	1292	7047	4402	32
Hoshangabad (Jamra)	1 Jun	8 Jul	20 Jun	5	30 Sep	16 Oct	8 Oct	2	3245	6615	4429	16
(Saunther)	1 Jun	8 Jul	19 Jun	5	29 Sep	17 Oct	7 Oct	2	2518	5268	3817	19
Indore (Sarol)	4 Jun	17 Jul	18 Jun	5	30 Sep	25 Oct	7 Oct	2	1486	5456	4154	26
(Kamliakheri)	4 Jun	17 Jul	18 Jun	5	30 Sep	28 Oct	7 Oct	2	831	5060	3067	37
Kota	5 Jun	27 Jul	2 Jul	7	6 Oct	4 Nov	17 Oct	2	594	6404	2529	61
Nagpur	4 Jun	6 Jul	20 Jun	5	26 Sep	14 Oct	6 Sep	2	1418	4610	3263	22
Rajgarh (Jamra)	7 Jun	15 Jul	24 Jun	7	3 Oct	21 Oct	11 Oct	2	1063	5082	3330	32
(Saunther)	8 Jun	15 Jul	25 Jun	6	4 Oct	21 Oct	11 Oct	1	696	4380	2569	37
Shajapur (Sarol)	6 Jun	23 Jul	24 Jun	8	2 Oct	27 Oct	10 Oct	2	1372	5596	3489	36
(Saunther)	6 Jun	23 Jul	24 Jun	8	2 Oct	28 Oct	11 Oct	2	1069	5316	3018	42
Ujjain	4 Jun	22 Jul	21 Jun	7	1 Oct	1 Nov	9 Oct	2	1183	5032	3500	32
Secondary Zone												
Amravati	4 Jun	9 Jul	17 Jun	6	29 Sep	17 Oct	5 Oct	2	1047	4721	2938	37
Betul	1 Jun	2 Jul	18 Jun	4	28 Sep	13 Oct	6 Oct	1	1729	5188	3908	20
Bhopal (Jamra)	1 Jun	4 Jul	16 Jun	5	27 Sep	13 Oct	6 Oct	2	2440	5307	4124	20
(Saunther)	1 Jun	4 Jul	16 Jun	5	28 Sep	13 Oct	6 Oct	1	1539	4879	3463	27
Guna (Jamra)	8 Jun	21 Jul	29 Jun	6	5 Oct	22 Oct	12 Oct	2	1233	5791	3882	36
(Saunther)	8 Jun	21 Jul	29 Jun	6	5 Oct	22 Oct	12 Oct	6	797	5044	3057	46
Raisen	1 Jun	7 Jul	21 Jun	4	2 Oct	17 Oct	9 Oct	1	1836	7917	5627	29
Ratlam	1 Jun	28 Jul	18 Jun	8	29 Sep	2 Nov	8 Oct	2	873	5724	3575	37
Sagar	1 Jun	14 Jul	21 Jun	7	2 Oct	25 Oct	12 Oct	2	2124	5362	3882	27
Vidisha	1 Jun	15 Jul	23 Jun	7	3 Oct	21 Oct	12 Oct	2	2327	6600	4306	22
Wardha	1 Jun	11 Jul	16 Jun	6	26 Sep	17 Oct	4 Oct	2	3340	6455	5137	18
Tertiary Zone												
Akola	1 Jun	9 Jul	17 Jun	7	25 Sep	19 Oct	6 Oct	2	203	4391	2408	52
Belgaum	1 Jun	11 Jul	16 Jun	6	20 Sep	14 Oct	28 Sep	2	1437	4232	3012	29
Dharwad (Hogaluru)	1 Jun	16 Jul	9 Jun	8	20 Sep	24 Oct	28 Sep	3	0	4612	2757	48
(Achmatti)	1 Jun	16 Jul	10 Jun	8	19 Sep	25 Oct	28 Sep	3	0	3778	1773	64
Jhabua	1 Jun	19 Jul	28 Jun	7	28 Sep	30 Oct	12 Oct	3	634	5110	3616	33
Jabalpur	7 Jun	7 Jul	22 Jun	4	3 Oct	15 Oct	9 Oct	1	2309	4784	3896	16
Nanded	1 Jun	25 Jul	23 Jun	8	24 Sep	28 Oct	8 Oct	3	592	6218	2876	58
Parbhani	1 Jun	25 Jun	11 Jun	5	22 Sep	12 Oct	30 Sep	2	1829	5034	3271	26
Pantnagar	1 Jun	25 Jun	11 Jun	6	5 Oct	16 Oct	10 Oct	1	5718	7265	6348	8
Raipur	1 Jun	4 Jul	15 Jun	5	25 Sep	14 Oct	3 Oct	1	4105	5342	4785	8
Others												
Bangalore	1 Jun	6 Jun	1 Jun	1	14 Sep	25 Sep	19 Sep	1	1593	491	3283	32
Coimbatore	20 May	27 Aug	5 Jul	22	31 Aug	30 Nov	12 Oct	13	63	792	436	57
Pune (Dholwad)	1 Jun	28 Jun	7 Jun	5	20 Sep	10 Oct	26 Sep	2	2160	5559	4254	24
(Nimone)	1 Jun	28 Jun	10 Jun	5	22 Sep	13 Oct	28 Sep	2	636	5177	2922	
Delhi	13 Jun	18 Jul	23 Jun	5	10 Oct	29 Oct	17 Oct	2	164	6544	4040	44

Continued...

Annexure I. *Continued.*

	Planting date				Harvest date				Total dry matter			
Location	Early	Late	Mean	CV	Early	Late	Mean	CV	Min	Max	Mean	CV
Hisar	15 Jun	9 Jul	29 Jun	4	16 Oct	28 Oct	21 Oct	1	0	3631	1243	53
Hyderabad (Deep)	2 Jun	11 Jul	19 Jun	5	23 Sep	17 Oct	3 Oct	2	1879	5269	4300	87
(Shallow)	2 Jun	11 Jul	19 Jun	5	23 Sep	17 Oct	3 Oct	2	1939	5235	4300	20
Ludhiana	15 Jun	25 Jul	24 Jun	7	14 Oct	8 Nov	19 Oct	2	424	7808	4508	20
Nimuch	3 Jun	27 Jul	28 Jun	8	3 Oct	28 Oct	13 Oct	2	439	5115	3216	37

In parenthesis are the soil series. CV = Coefficient of variation (%)

Annexure II. Experimental station, on-farm (FLD with improved technology) and district average yields and yield gaps of soybean during 1994 to 2003 at different AICRP locations across India.

Attribute		Yield (kg ha^{-1})												
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*	Mean	SD	CV
Location: Sehore, Madhya Pradesh										**23.20°N**		**Zone: Primary**		
Expt. Station	Max	3139	2963	3153	2585	2639	1588	1477	2222	#	2757	2503	622.2	24.9
	Mean	2861	2720	2978	2509	2414	1432	1379	2071	1341	2592	2230	568.0	25.4
FLD (Imp.),	Mean	1980	2380	1928	2392	1519	1362	1348	1668	1341	1956	1787	403.0	22.5
District Average		819	1042	911	1120	955	1086	895	1013	769	991	960	113.0	11.8
State Average		889	1011	946	1149	1011	1068	767	840	652	1019	935	149.7	16.0
YG I		**881**	**340**	**1050**	**117**	**895**	**70**	**31**	**403**	**0**	**636**	**442**	**397.9**	**90.0**
YG II		**1161**	**1338**	**1017**	**1272**	**564**	**276**	**453**	**655**	**572**	**965**	**827**	**370.2**	**44.7**
YG Total		**2042**	**1678**	**2067**	**1389**	**1459**	**346**	**484**	**1058**	**572**	**1601**	**1270**	**629.1**	**49.5**
Location: Indore, Madhya Pradesh										**22.72°N**		**Zone: Primary**		
Expt. Station	Max	2534	3576	2503	2512	1750	2570	1927	3497	#	2874	2638	614.1	23.3
	Mean	2463	3166	2251	2367	1494	2332	1780	3231	1387	2635	2311	625.0	27.0
FLD (Imp.),	Mean	NA	2450	1712	2302	1304	2293	@	2963	1387	2612	2128	596.9	28.1
District Average		921	1106	1072	1161	1263	1486	1031	979	875	1096	1099	177.1	16.1
State Average		889	1011	946	1149	1011	1068	767	840	652	1019	935	149.7	16.0
YG I		**-**	**716**	**539**	**65**	**190**	**39**	**-**	**268**	**0**	**23**	**183**	**265.7**	**145.5**
YG II		**-**	**1344**	**640**	**1141**	**41**	**807**	**-**	**1984**	**512**	**1516**	**1029**	**620.8**	**60.3**
YG Total		**1542**	**2060**	**1179**	**1206**	**231**	**846**	**749**	**2252**	**512**	**1539**	**1212**	**651.3**	**53.8**
Location: Jabalpur, Madhya Pradesh										**23.17°N**		**Zone: Tertiary**		
Expt. Station	Max	1029	3333	2304	2634	2716	3094	1901	1210	1852	2914	2299	783.3	34.1
	Mean	942	2041	1877	1759	1922	2718	1385	980	1654	2405	1768	565.7	32.0
FLD (Imp.),	Mean	@	1440	NA	910	720	@	770	@	960	1050	975	258.2	26.5
District Average		695	1114	977	747	576	955	748	932	500	850	809	191.4	23.6
State Average		889	1011	946	1149	1011	1068	767	840	652	1019	935	149.7	16.0
YG I		**-**	**601**	**-**	**849**	**1202**	**-**	**615**	**-**	**694**	**1355**	**793**	**320.3**	**40.4**
YG II		**-**	**326**	**-**	**163**	**144**	**-**	**22**	**-**	**460**	**200**	**166**	**153.3**	**92.6**
YG Total		**247**	**927**	**900**	**1012**	**1346**	**1763**	**637**	**48**	**1154**	**1555**	**959**	**541.2**	**56.4**
Location: Amlaha, (Sehore) Madhya Pradesh										**23.12°N**		**Zone: Primary**		
Expt. Station	Max	NA	NA	NA	3086	NA	1439	1111	1891	2099	3704	2222	991.5	44.6
	Mean	NA	NA	NA	3002	NA	1324	1070	1719	1947	3053	2019	838.4	41.5
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	1120	NA	1086	895	1013	769	991	979	129.4	13.2
State Average		NA	NA	NA	1149	NA	1068	767	840	652	1019	916	192.7	21.0
YG Total		**-**	**-**	**-**	**1882**	**-**	**238**	**175**	**706**	**1178**	**2062**	**1040**	**809.4**	**77.8**
Location: Raipur, Chattisgarh										**21.23°N**		**Zone: Tertiary**		
Expt. Station	Max	1852	2708	3021	2472	1923	2581	2746	2592	3461	2501	2586	470.7	18.2
	Mean	1831	2597	2778	2306	1738	2461	2594	2008	3216	2411	2394	448.8	18.7
FLD (Imp.),	Mean	NA	1860	1884	1623	1431	NA	1990	1201	NA	2410	1771	395.7	22.3
District Average		1000	1109	940	1091	778	1068	714	821	668	846	904	160.7	17.8
State Average		889	1011	946	1149	1011	1068	543	821	668	846	895	184.8	20.6
YG I		**-**	**737**	**894**	**683**	**307**	**-**	**604**	**807**	**-**	**1**	**623**	**315.0**	**50.6**
YG II		**-**	**751**	**944**	**532**	**653**	**-**	**1276**	**380**	**-**	**1564**	**868**	**421.8**	**48.6**
YG Total		**831**	**1488**	**1838**	**1215**	**960**	**1393**	**1880**	**1187**	**2548**	**1565**	**1490**	**504.4**	**33.8**
Location: Amravati, Maharashtra										**20.93°N**		**Zone: Secondary**		
Expt. Station	Max	1889	1274	1933	2304	NA	2388	NA	1563	1564	2543	1932	451.4	23.4
	Mean	1721	1100	1669	2036	-	2222	-	1501	1501	2459	1776	440.2	24.8

Continued...

Annexure II. *Continued.*

Attribute		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*	Mean	SD	CV
		Yield (kg ha^{-1})												
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		957	961	1068	1026	-	764	-	1447	887	1256	1046	215.7	20.6
State Average		938	1131	1287	988	-	1392	-	1254	903	1253	1143	181.6	15.9
YG Total		**764**	**139**	**601**	**1010**	**-**	**1458**	**-**	**54**	**614**	**1203**	**731**	**488.5**	**66.9**
					Location: Jalna, Maharashtra					**19.83 °N**			**Zone: Tertiary**	
Expt. Station	Max	NA	NA	NA	NA	4029	2376	2443	2716	2556	2870	2832	613.7	21.7
	Mean	NA	NA	NA	NA	3155	2191	2368	2313	2438	2626	2515	344.9	13.7
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	NA	1511	1273	489	1053	718	1450	1082	410.1	37.9
State Average		NA	NA	NA	NA	1395	1392	1109	1254	903	1253	1218	187.2	15.4
YG Total		**-**	**-**	**-**	**-**	**1644**	**918**	**1879**	**1260**	**1720**	**1176**	**1433**	**370.8**	**25.9**
					Location: Parbhani, Maharashtra					**19.13 °N**			**Zone: Tertiary**	
Expt. Station	Max	3426	3531	3519	3793	3981	3562	3086	2778	3704	2296	3368	509.5	15.1
	Mean	3263	3224	3380	3482	3847	3281	2844	2584	3346	2064	3132	506.9	16.2
FLD (Imp.),	Mean	1790	1850	2223	1656	1973	2227	1921	2115	2148	1845	1975	196.1	9.9
District Average		1353	1154	1269	1083	944	1774	1154	1610	862	1356	1256	282.2	22.5
State Average		938	1131	1287	988	1395	1392	1109	1254	903	1253	1165	179.7	15.4
YG I		**1473**	**1374**	**1157**	**1826**	**1874**	**1054**	**923**	**469**	**1198**	**219**	**1157**	**530.1**	**45.8**
YG II		**437**	**696**	**954**	**573**	**1029**	**453**	**767**	**505**	**1286**	**489**	**719**	**287.9**	**40.0**
YG Total		**1910**	**2070**	**2111**	**2399**	**2903**	**1507**	**1690**	**974**	**2484**	**708**	**1876**	**678.2**	**36.2**
					Location: Nagpur, Maharashtra					**21.15 °N**			**Zone: Primary**	
Expt. Station	Max	2375	2144	3562	2086	2835	2822	2590	1844	2160	3118	2554	533.8	20.9
	Mean	1783	1914	3510	1183	2254	2557	2122	1653	2022	2483	2148	625.9	29.1
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		789	956	1007	720	926	944	784	937	900	1187	915	132.0	14.4
State Average		938	1131	1287	988	1395	1392	1109	1254	903	1253	1165	179.7	15.4
YG Total		**994**	**958**	**2503**	**463**	**1328**	**1613**	**1338**	**716**	**1122**	**1296**	**1233**	**556.4**	**45.1**
					Location: Pune, Maharashtra					**18.53 °N**			**Zone: Others**	
Expt. Station	Max	4032	4372	3481	4038	4176	4436	3654	3757	3195	3201	3834	449.9	11.7
	Mean	3897	4281	3273	3926	3902	3688	3414	3548	2807	3092	3583	445.4	12.4
FLD (Imp.),	Mean	2060	2100	2041	2001	2610	2375	2119	1683	1860	1996	2085	256.2	12.3
District Average		714	667	1200	1400	1250	2000	857	1184	714	1000	1099	407.4	37.1
State Average		938	1131	1287	988	1395	1392	1109	1254	903	1253	1165	179.7	15.4
YG I		**1837**	**2181**	**1232**	**1925**	**1292**	**1313**	**1295**	**1865**	**947**	**1096**	**1498**	**415.2**	**27.7**
YG II		**1346**	**1433**	**841**	**601**	**1360**	**375**	**1262**	**499**	**1146**	**996**	**986**	**387.4**	**39.3**
YG Total		**3183**	**3614**	**2073**	**2526**	**2652**	**1688**	**2557**	**2364**	**2093**	**2092**	**2484**	**570.0**	**22.9**
					Location: Kota, Rajasthan					**25.18 °N**			**Zone: Primary**	
Expt. Station	Max	3746	2031	3151	3147	2247	1899	2317	2641	1900	2270	2535	623.1	24.6
	Mean	3598	1939	2428	3092	2168	1751	2150	2530	1817	2286	2376	580.0	24.4
FLD (Imp.),	Mean	3500	1870	1875	1813	1942	1591	1500	1954	868	1743	1866	658.9	35.3
District Average		1196	1079	1210	1483	1424	1153	950	1116	513	1104	1123	266.3	23.7

Continued...

Annexure II. *Continued.*

Attribute		Yield (kg ha^{-1})												
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*	Mean	SD	CV
State Average		1098	937	975	1265	1316	1221	692	1091	504	1057	1016	254.5	25.1
YG I		**98**	**69**	**553**	**1279**	**226**	**160**	**650**	**576**	**949**	**543**	**510**	**391.3**	**76.7**
YG II		**2304**	**791**	**665**	**330**	**518**	**438**	**550**	**838**	**355**	**639**	**743**	**574.2**	**77.3**
YG Total		**2402**	**860**	**1218**	**1609**	**744**	**598**	**1200**	**1414**	**1304**	**1182**	**1253**	**508.4**	**40.6**
Location: Dharwad, Karnataka										**15.47 °N**			**Zone: Tertiary**	
Expt. Station	Max	3547	2746	#	2555	3290	2404	1920	2626	NA	NA	2727	545.4	20.0
	Mean	3136	2541	2808	2477	2958	2289	2531	2547	NA	NA	2661	280.8	10.6
FLD (Imp.),	Mean	1980	1950	2808	2210	2325	NA	1953	1928	1687	NA	2105	342.8	16.3
District Average		402	491	781	683	1089	911	550	857	678	NA	716	218.1	30.5
State Average		893	490	781	683	1077	915	894	857	878	NA	824	175.8	21.3
YG I		**1156**	**591**	**0**	**267**	**633**	**-**	**578**	**619**	**-**	**-**	**556**	**356.9**	**64.2**
YG II		**1578**	**1459**	**2027**	**1527**	**1236**	**-**	**1403**	**1071**	**1009**	**-**	**1389**	**323.1**	**23.3**
YG Total		**2734**	**2050**	**2027**	**1794**	**1869**	**1378**	**1981**	**1690**	**-**	**-**	**1945**	**388.5**	**20.0**
Location: Bangalore, Karnataka										**12.97 °N**			**Zone: Others**	
Expt. Station	Max	#	#	2870	2860	3293	3465	2886	3292	3216	2666	3069	282.2	9.2
	Mean	2030	1350	2628	2412	2751	3242	2765	2998	2933	2347	2546	546.7	21.5
FLD (Imp.),	Mean	2030	1350	1623	1804	1485	1465	1456	1558	-	1473	1583	211.2	13.3
District Average		632	486	776	683	1133	915	894	857	678	900	795	183.2	23.0
State Average		893	490	781	683	1077	915	894	857	678	900	817	164.3	20.1
YG I		**0**	**0**	**1005**	**608**	**1266**	**1777**	**1309**	**1440**	**-**	**874**	**963**	**620.1**	**64.4**
YG II		**1398**	**864**	**847**	**1121**	**352**	**550**	**562**	**701**	**-**	**573**	**787**	**324.5**	**41.3**
YG Total		**1398**	**864**	**1852**	**1729**	**1618**	**2327**	**1871**	**2141**	**2255**	**1447**	**1750**	**445.4**	**25.4**
Location: Almora, Uttaranchal										**29.77 °N**			**Zone: Others**	
Expt. Station	Max	1941	2058	2098	2469	2572	2490	2206	1251	2025	3852	2296	663.4	28.9
	Mean	1755	1873	1966	2008	2387	2202	2008	1187	1961	3212	2056	512.9	25.0
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA			
District Average		1075	775	476	500	500	778	623	NA	NA	NA	675	217.6	32.2
State Average		1074	781	759	989	416	778	623	NA	NA	NA	774	218.9	28.3
YG Total		**680**	**1098**	**1490**	**1508**	**1887**	**1424**	**1385**	**-**	**-**	**-**	**1380**	**376.9**	**27.3**
Location: Kangra, Himachal Pradesh										**32.17 °N**			**Zone: Others**	
Expt. Station	Max	NA	NA	3734	1806	NA	NA	NA	NA	2936	3630	3027	887.4	29.3
	Mean	NA	NA	3414	1478	NA	NA	NA	NA	2273	3113	2569	873.3	34.0
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	500	400	333	1833	1667	1667	NA	NA	1067	722.8	67.8
State Average		NA	NA	500	400	333	1833	1667	1667	NA	NA	1067	722.8	67.8
YG Total		**-**	**-**	**2914**	**1078**	**-**	**-**	**-**	**-**	**-**	**-**	**1503**	**1298.0**	**86.4**
Location: Palampur, (Kangra) Himachal Pradesh										**32.11 °N**			**Zone: Others**	
Expt. Station	Max			#	#	#	2661	2536	2252	2742	2361	2450	235.0	9.6
	Mean	NA	2040	2175	2024	1744	2346	2232	1954	2531	2083	2125	229.3	10.8
FLD (Imp.),	Mean	790	1810	2175	2024	1744	@	@	1805	1501	1211	1633	451.4	27.6
District Average		375	500	500	400	333	1833	1667	1667	NA	NA	909	677.5	74.5
State Average		375	500	500	400	333	1833	1667	1667	NA	NA	909	677.5	74.5

Continued...

Annexure II. *Continued.*

Attribute		Yield (kg ha^{-1})												
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*	Mean	SD	CV
YG I		**-**	**230**	**0**	**0**	**0**	**-**	**-**	**149**	**1030**	**872**	**493**	**438.2**	**88.9**
YG II		**415**	**1310**	**1675**	**1624**	**1411**	**-**	**-**	**138**	**1501**	**1211**	**723**	**571.3**	**79.0**
YG Total		**-**	**1540**	**1675**	**1624**	**1411**	**513**	**565**	**287**	**-**	**-**	**1216**	**603.8**	**49.7**
					Location: Delhi					**28.58 °N**			**Zone: Others**	
Expt. Station	Max	NA	2933	3840	1360	NA	4267	2456	2702	2080	1867	2688	981.4	36.5
	Mean	NA	2490	3669	1145	NA	4151	1639	2444	1689	1437	2333	1084.8	46.5
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
					Location: Hisar, Haryana					**29.17 °N**			**Zone: Others**	
Expt. Station	Max	2995	NA		3028	NA	3062	NA	2315	1865	897	NA	2360	863.7
	Mean	2416	NA		3017	NA	2726	NA	1836	1638	760	NA	2065	824.9
FLD (Imp.),	Mean	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	-	-
District Average		NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	-	-
State Average		NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	-	-
					Location: Ludhiana, Punjab					**30.93 °N**			**Zone: Others**	
Expt. Station	Max	NA	NA	1778	2379	1851	2617	3634	3415	1696	3395	2596	799.0	30.8
Mean		NA	NA	1592	1994	1247	2156	3433	2883	1696	2802	2225	748.2	33.6
FLD (Imp.),	Mean	1390	1450	1493	1312	NA	NA	1384	NA	1511	1230	1396	100.3	7.2
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
YG I		**-**	**-**	**99**	**682**	**-**	**-**	**2049**	**185**	**1572**	**830**	**861.8**	**103.9**	
					Location: Pantnagar (Nainital), Uttaranchal					**29.05 °N**			**Zone: Tertiary**	
Expt. Station	Max	3272	2468	1435	2561	2191	2778	1852	3951	2407	3086	2600	721.5	27.7
	Mean	3047	2468	1343	2206	2030	2432	1852	3716	2407	2691	2419	652.2	27.0
FLD (Imp.),	Mean	2010	2440	577	2059	1949	1841	1852	2228	2387	1582	1893	530.5	28.0
District Average		1506	1033	451	487	655	778	638	NA	NA	NA	793	369.6	46.6
State Average		1074	781	759	989	416	778	638	NA	NA	NA	776	217.2	28.0
YG I		**1037**	**28**	**766**	**147**	**81**	**591**	**0**	**1488**	**20**	**1109**	**527**	**548.8**	**104.2**
YG II		**504**	**1407**	**126**	**1572**	**1294**	**1063**	**1214**	**-**	**-**	**-**	**1100**	**521.9**	**47.4**
YG Total		**1541**	**1435**	**892**	**1719**	**1375**	**1654**	**1214**	**-**	**-**	**-**	**1627**	**283.0**	**17.4**
					Location: Berhampore (Murshidabad), West Bengal					**24.10 °N**			**Zone: Others**	
Expt. Station	Max	NA	3327	NA	NA	NA	NA	NA	3251	2486	2593	2914	436.0	15.0
	Mean	NA	2817	NA	NA	NA	NA	NA	2936	2433	2208	2599	337.4	13.0
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	565	516	750	625	571	600	600	NA	NA	604	73.1	12.1
State Average		NA	565	516	750	625	571	600	600	NA	NA	604	73.1	12.1
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1995**	**-**	**-**
					Location: Ranchi, Jharkhand					**23.38 °N**			**Zone: Others**	
Expt. Station	Max	3136	2099	2017	2914	3193	3506	2798	2839	3291	2222	2802	522.8	18.7
	Mean	2709	2009	1934	2800	2494	3131	2610	2419	2924	2209	2524	390.1	15.5
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-

Continued...

Annexure II. *Continued.*

Attribute		Yield ($kg\ ha^{-1}$) 1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*	Mean	SD	CV
				Location: Lam (Guntur), Andhra Pradesh						**16.40 °N**		**Zone: Others**		
Expt. Station	Max	#	2074	#	#	3111	2791	1817	2315	NA	#	2422	526.7	21.7
	Mean	1810	1909	2218	2353	2977	2344	1675	2076	NA	2008	2152	386.1	17.9
FLD (Imp),	Mean	1810	1360	2218	2353	1836	NA	NA	1928	2800	2008	2039	427.2	21.0
District Average		323	984	1053	948	971	939	1009	1015	NA	NA	905	238.2	26.3
State Average		323	984	1053	948	971	939	1009	1015	-	NA	905	238.2	26.3
YG I		**0**	**549**	**0**	**0**	**1141**	**-**	**-**	**148**	**-**	**0**	**113**	**436.5**	**385.7**
YG II		**1487**	**376**	**1165**	**1405**	**865**	**-**	**-**	**913**	**-**	**-**	**1134**	**408.9**	**36.1**
YG Total		**1487**	**925**	**1165**	**1405**	**2006**	**1405**	**666**	**1061**	**-**	**-**	**1247**	**407.7**	**32.7**
				Location: Coimbatore, Tamil Nadu						**11.00 °N**		**Zone: Others**		
Expt. Station	Max	#	1621	1425	2049	2519	1482	1819	2617	1859	1609	1889	431.5	22.8
	Mean	1890	1572	1323	1891	2276	1438	1603	2400	1700	1609	1770	347.9	19.7
FLD (Imp.),	Mean	1890	1370	1177	1198	NA	NA	1222	1448	1438	1581	1416	238.4	16.8
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
YG I		**0**	**202**	**146**	**693**	**-**	**-**	**381**	**952**	**262**	**28**	**355**	**333.0**	**93.9**
				Location: Imphal, Manipur						**24.83 °N**		**Zone: Others**		
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	1155	428	2154	1246	866.6	69.6
	Mean	NA	NA	NA	NA	NA	NA	NA	1022	400	2051	1158	833.7	72.0
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-

*District and state average yield data for 2003 are provisional, SD = Standard deviation, CV = Coefficient of variation (%), NA = Data (Experimental station, FLD, District and state average yield) not available,
= Experimental station yield less than FLD yield, @ = FLD yield less than district yield.

Annexure III. Planting and harvesting dates, and total dry matter (kg ha^{-1}) of simulated groundnut at selected locations across India.

Location	Planting date				Harvest date				Total dry matter			
	Early	Late	Mean	CV	Early	Late	Mean	CV	Min	Max	Mean	CV
Primary Zone												
Dharwad (Achmatti)	31 May	1 Aug	11Jun	10	22 Sep	23 Nov	6 Oct	6	271	7791	4414	47
(Hogaluru)	31 May	1 Aug	12 Jun	10	22 Sep	22 Nov	7 Oct	6	447	8764	6091	37
Anantapur	31 May	11 Aug	12 Jun	12	8 Sep	22 Nov	28 Sep	8	412	7307	2519	68
Junagadh	12 Jun	20 Jul	28 Jun	8	24 Sep	6 Nov	14 Oct	5	205	9544	6189	45
Kurnool (Vertisol)	31 May	12 Jul	14 Jun	9	17 Sep	31 Oct	2 Oct	5	1945	8834	5056	45
(Alfisol)	31 May	12 Jul	13 Jun	8	16 Sep	1 Nov	1 Oct	5	2787	10922	6841	34
Rajkot (Semla)	15 Jun	5 Jul	22 Jun	4	1 Oct	21 Oct	7 Oct	2	730	6284	4165	41
(Bhola)	15 Jun	6 Jul	22 Jun	4	29 Sep	21 Oct	7 Oct	3	1151	8368	5460	40
Secondary Zone												
Raichur	31 May	21 Aug	24 Jun	17	28 Dec	14 Dec	15 Oct	10	2520	7921	5136	39
Jaipur	31 May	29 Jul	23 Jun	10	18 Sep	17 Nov	12 Oct	6	716	10728	7568	45
Pune (Otur)	31 May	28 Jun	9 Jun	5	15 Sep	18 Oct	27 Sep	3	3579	10197	7736	25
(Nimone)	31 May	28 Jun	10 Jun	5	15 Sep	17 Oct	28 Sep	3	2554	9237	6377	33
Jhansi	5 Jun	14 Jul	28 Jun	7	21 Sep	4 Nov	15 Oct	5	5234	10611	8783	19
Bijapur	31 May	13 Jul	11 Jun	9	11 Sep	6 Nov	28 Sep	6	306	6967	4192	49
Warangal	31 May	30 Jun	16 Jun	5	17 Sep	23 Oct	4 Oct	4	5262	8826	7912	14
Tertiary Zone												
Jalgaon	1 Jun	13 Jul	18 Jun	6	18 Sep	2 Nov	6 Oct	4	2797	9509	6543	30
Akola	31 May	9 Jul	17 Jun	7	18 Sep	26 Oct	4 Oct	4	1169	10391	6288	41
Medak	31 May	5 Jul	13 Jun	5	16 Sep	30 Oct	2 Oct	4	6236	10673	8856	14
Kota	8 Jun	27 Jul	3 Jul	7	27 Sep	11 Nov	19 Oct	4	1740	10410	5802	42
Coimbatore (Coimbatore)	1 Jun	27 Aug	9 Jul	16	13 Sep	20 Dec	29 Oct	11	0	5775	2759	69
(Palaturai)	2 Jun	27 Aug	6 Jul	13	14 Sep	20 Dec	26 Oct	10	0	7612	3475	66
Surat (Haldar)	31 May	2 Jul	18 Jun	6	15 Sep	19 Oct	3 Oct	4	3243	6395	4423	22
(Kabilpura)	31 May	2 Jul	17 Jun	5	15 Sep	19 Oct	3 Oct	4	4106	7262	5314	19
(Sidodia)	31 May	1 Jul	17 Jun	5	15 Sep	17 Oct	3 Oct	3	3787	6969	4963	18
Dhar	31 May	12 Jul	21 Jun	8	17 Sep	16 Nov	8 Oct	6	3316	10238	8130	25
Jhabua	31 May	19 Jul	21 Jun	9	17 Sep	16 Nov	8 Oct	6	2479	9369	6836	33
Thanjavur	30 Jun	9 Aug	10 Jul	7	12 Oct	24 Nov	27 Oct	4	0	9126	5065	52

In parenthesis are the soil series. CV = Coefficient of variation (%)

Annexure IV. Experimental station (Spanish type), on-farm (FLD with improved technology) and district average yields and yield gaps of groundnut during 1993 to 2002 at different AICRP locations across India.

Attribute		Pod yield (kg ha^{-1})											
		1993	1994	1995	1996	1998	1999	2000	2001	2002*	Mean	SD	CV
				Location: Amreli, Gujarat				**21.62 °N**			**Zone: Primary**		
Expt. Station	Max	570	NA	2074	3746	1572	848	NA	2901	778	1784	1196	67.1
	Mean	340	NA	1673	2708	1414	761	NA	2073	617	1369	854	62.4
Irrigation		0	NA	0	0	0	0	NA	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		314	-	535	1297	1141	311	-	1828	508	848	582	68.7
State Average		330	-	540	1335	1328	393	-	1412	508	835	495	59.3
YG Total		**26**	**-**	**1138**	**1411**	**273**	**450**	**-**	**245**	**109**	**522**	**537**	**102.9**
				Location: Junagadh, Gujarat				**21.52 °N**			**Zone: Primary**		
Expt. Station	Max	1099	NA	1757	2431	4658	1519	2911	NA	2675	2436	1177	48.3
	Mean	933	NA	1550	2172	2541	1340	2816	NA	2353	1958	692	35.4
Irrigation		1	NA	0	0	0	1	0	NA	0	-	-	-
FLD (Imp.),	Mean	NA	NA	1542	1790	2132	1236	1021	NA	1429	1525	396	26.0
District Average		343	-	930	1761	1974	658	1021	-	508	1028	622	60.5
State Average		330	-	540	1335	1328	393	395	-	508	690	444	64.4
YG I		**-**	**-**	**8**	**382**	**409**	**104**	**1795**	**-**	**924**	**433**	**665**	**110.2**
YG II		**-**	**-**	**612**	**29**	**158**	**578**	**0**	**-**	**921**	**497**	**375**	**97.9**
YG Total		**590**	**-**	**620**	**411**	**567**	**682**	**1795**	**-**	**1845**	**930**	**614**	**66.0**
				Location: Udaipur, Rajasthan				**24.58 °N**			**Zone: Secondary**		
Expt. Station	Max	NA	4066	NA	2373	3588	2894	3534	3233	2666	3193	588	18.4
	Mean	NA	3461	NA	2215	2472	2547	2790	2676	2390	2650	404	15.2
Irrigation		NA	0	NA	0	0	1	0	1	1	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	505	-	733	824	1061	260	1000	687	724	278	38.4
State Average		-	790	-	1113	1091	965	924	1226	687	971	189	19.5
YG Total		**-**	**2956**	**-**	**1482**	**1648**	**1486**	**2530**	**1676**	**1703**	**1926**	**578**	**30.0**
				Location: Hanumangarh, Rajasthan				**29.62 °N**			**Zone: Secondary**		
Expt. Station	Max	3648	2400	3089	1500	1556	3037	2797	2363	1667	2451	761	31.1
	Mean	3107	2116	2755	1426	1556	2897	2245	2144	1270	2168	661	30.5
Irrigation		4	3	0	0	0	4	0	4	3	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1358	1136	762	1113	1333	966	924	1226	687	1056	238	22.6
State Average		728	790	762	1113	1091	965	924	1226	687	921	192	20.9
YG Total		**1749**	**980**	**1993**	**313**	**223**	**1931**	**1321**	**918**	**583**	**1112**	**676**	**60.8**
				Location: Durgapura (Jaipur), Rajasthan				**26.9 °N**			**Zone: Secondary**		
Expt. Station	Max	NA	#	2517	2871	#	NA	#	NA	1736	2375	581	24.5
	Mean	NA	2573	2367	2502	2949	NA	3131	NA	1528	2508	560	22.3
Irrigation		NA	3	0	0	0	NA	0	NA	0	-	-	-
FLD (Imp.),	Mean	NA	2573	NA	2496	2949	NA	3131	NA	1138	2457	783	31.8
District Average		-	702	812	1181	1553	-	1074	-	687	1001	336	33.6
State Average		-	790	762	1113	1091	-	924	-	687	895	178	19.9
YG I		**-**	**0**	**-**	**6**	**0**	**-**	**0**	**-**	**390**	**51**	**174**	**218.9**
YG II		**-**	**1871**	**-**	**1315**	**1396**	**-**	**2057**	**-**	**451**	**1456**	**624**	**44.0**
YG Total		**-**	**1871**	**1555**	**1321**	**1396**	**-**	**2057**	**-**	**841**	**1507**	**431**	**28.6**

Continued...

Annexure IV. *Continued.*

Attribute		Pod yield (kg ha^{-1})											
		1993	1994	1995	1996	1998	1999	2000	2001	2002*	Mean	SD	CV
				Location: Akola, Maharashtra				**20.7 °N**			**Zone: Tertiary**		
Expt. Station	Max	2225	1564	1076	1482	1179	1714	1311	1421	1111	1454	359	24.7
	Mean	2029	1235	942	1273	1086	1627	1165	1421	1111	1321	332	25.1
Irrigation		0	0	0	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		826	723	756	619	750	1167	640	1357	958	866	250	28.9
State Average		1167	1043	1128	1313	1217	1059	959	1147	958	1110	118	10.6
YG Total		**1203**	**512**	**186**	**654**	**336**	**460**	**525**	**64**	**153**	**455**	**342**	**75.3**
				Location: Jalgaon, Maharashtra				**21.05 °N**			**Zone: Tertiary**		
Expt. Station	Max	2795	1328	3316	3328	1351	1325	1675	1320	1458	1988	889	44.7
	Mean	2192	1338	2876	2926	1315	1020	1293	1320	1118	1711	751	43.9
Irrigation		0	0	0	0	0	0	0	1	1	-	-	-
FLD (Imp.),	Mean	NA	1221	1432	1327	1167	936	835	1164	977	1132	203	17.9
District Average		1046	1217	862	1149	1143	936	558	732	958	956	214	22.4
State Average		1167	1043	1128	1313	1217	1059	959	1147	958	1110	118	10.6
YG I		**-**	**117**	**1444**	**1599**	**148**	**84**	**458**	**156**	**141**	**578**	**631**	**121.8**
YG II		**-**	**4**	**570**	**178**	**24**	**0**	**277**	**432**	**19**	**177**	**220**	**116.8**
YG Total		**1146**	**121**	**2014**	**1777**	**172**	**84**	**735**	**588**	**160**	**755**	**738**	**97.7**
				Location: Digraj (Sangli), Maharashtra				**16.87°N**			**Zone: Secondary**		
Expt. Station	Max	2135	3288	3490	3496	1799	3241	2199	#	2049	2712	727	26.8
	Mean	1953	2643	3191	3038	1445	2778	1748	2316	1513	2292	658	28.7
Irrigation		1	1	0	0	0	2	0	2	0	-	-	-
FLD (Imp.),	Mean	NA	1830	NA	NA	NA	2348	NA	2316	NA	2165	290	13.4
District Average		1050	1093	1104	1392	1368	1000	1080	1463	958	1168	188	16.1
State Average		1167	1043	1128	1313	1217	1059	959	1147	958	1110	118	10.6
YG I		**-**	**813**	**-**	**-**	**-**	**430**	**-**	**0**	**-**	**127**	**407**	**98.2**
YG II		**-**	**737**	**-**	**-**	**-**	**1348**	**-**	**853**	**-**	**997**	**324**	**33.1**
YG Total		**903**	**1550**	**2087**	**1646**	**76.6**	**1778**	**668**	**853**	**-**	**1124**	**676**	**56.5**
				Location: Latur, Maharashtra				**18.4°N**			**Zone: Tertiary**		
Expt. Station	Max	1782	2855	1215	1549	2066	1562	1498	NA	NA	1790	538	30.1
	Mean	1298	2075	1001	1354	1959	1443	1299	NA	NA	1490	386	25.9
Irrigation		0	0	0	0	0	0	0	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		608	505	695	772	446	543	479	-	-	578	120	20.7
State Average		1167	1043	1128	1313	1217	1059	959	-	-	1127	118	10.5
YG Total		**690**	**1570**	**306**	**582**	**1513**	**900**	**820**	**-**	**-**	**912**	**470**	**51.6**
				Location: Khargone, Madhya Pradesh				**21.82 °N**			**Zone: Secondary**		
Expt. Station	Max	1852	831	1233	1024	1532	1330	839	1267	1314	1247	326	26.1
	Mean	1464	665	1225	959	1358	990	741	998	1002	1045	264	25.3
Irrigation		0	0	0	0	0	0	0	2	1	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		800	517	760	830	727	611	616	759	622	694	106	15.2

Continued...

Annexure IV. *Continued.*

Attribute		Pod yield (kg ha^{-1})											
		1993	1994	1995	1996	1998	1999	2000	2001	2002*	Mean	SD	CV
State Average		993	816	1031	992	1065	992	1059	853	975	975	92.1	9.4
YG Total		**664**	**148**	**465**	**129**	**631**	**379**	**125**	**239**	**380**	**351**	**208**	**59.1**
		Location: Jhargram (Midnapur), West Bengal						**22.45 °N**			**Zone: Others**		
Expt. Station	Max	NA	2050	3063	2800	4346	2807	3519	4045	4001	3329	783	23.5
	Mean	NA	1781	2749	2534	3657	2647	3246	3851	3569	3004	700	23.3
Irrigation		NA	0	0	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	860	1206	1253	1030	1604	1351	1000	929	1154	248	21.5
State Average		-	1124	1399	1282	1349	1343	1471	1000	929	1237	197	15.9
YG Total		**-**	**921**	**1543**	**1281**	**2627**	**1043**	**1895**	**2851**	**2640**	**1850**	**771**	**41.7**
		Location: Chiplima (Sambalpur), Orissa						**21.9 °N**			**Zone: Secondary**		
Expt. Station	Max	1648	3837	2818	1592	2025	3006	2518	1273	3354	2452	876	35.7
	Mean	1637	3489	2363	1308	1678	2725	2263	1131	2918	2168	791	36.5
Irrigation		1	0	0	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	1671	1918	1010	1256	NA	NA	NA	NA	1464	408	27.8
District Average		1489	1396	1494	1306	1256	1145	738	985	688	1166	304	26.0
State Average		1139	1126	1013	816	864	914	794	985	688	927	153	16.5
YG I		**-**	**1818**	**445**	**-**	**422**	**-**	**-**	**-**	**-**	**704**	**799**	**89.3**
YG II		**-**	**275**	**424**	**-**	**0**	**-**	**-**	**-**	**-**	**297**	**215**	**92.3**
YG Total		**148**	**2093**	**869**	**2**	**422**	**1580**	**1525**	**146**	**2230**	**1002**	**875**	**87.3**
		Location: Kanke, (Ranchi), Jharkhand						**23.43°N**			**Zone: Others**		
Expt. Station	Max	NA	1632	1427	1489	2525	1675	2379	1537	1897	1820	417	22.9
	Mean	NA	1484	1312	1215	2193	1675	2134	1260	1577	1606	379	23.6
Irrigation		NA	0	0	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	1000	902	1186	1170	1207	1093	1093	1093	1093	102	9.3
State Average		-	1000	902	1186	1170	1207	1093	1093	1093	1093	102	9.3
YG Total		**-**	**484**	**410**	**29**	**1023**	**468**	**1041**	**167**	**484**	**513**	**360**	**70.2**
		Location: Aliyar Nagar (Coimbatore), Tamil Nadu						**11.0°N**			**Zone: Secondary**		
Expt. Station	Max	2188	NA	NA	4311	3241	3520	3068	3762	2199	3184	785	24.6
	Mean	1862	NA	NA	3559	2720	3186	2512	3313	1889	2720	676	24.9
Irrigation		0	NA	NA	0	0	0	0	8	8	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1468	-	-	1741	1734	1659	1594	1562	1430	1598	122	7.6
State Average		1603	-	-	1595	1829	1659	1942	1724	1430	1683	168	10.0
YG Total		**394**	**-**	**-**	**1818**	**986**	**1527**	**918**	**1751**	**459**	**1122**	**588**	**52.4**
		Location: Vriddhachalam (Cuddalore), Tamil Nadu						**11.5°N**			**Zone: Secondary**		
Expt. Station	Max	2914	1854	2708	2367	2942	3860	2613	2703	NA	2745	569	20.7
	Mean	2340	1697	2484	2163	2572	3504	2613	2324	NA	2462	511	20.8
Irrigation		0	0	0	0	0	0	0	0	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1489	1631	1681	1494	2456	1800	2443	2074	-	1884	396	21.0
State Average		1603	1604	1629	1595	1829	1659	1942	1724	-	1698	127	7.5
YG Total		**851**	**66**	**803**	**669**	**116**	**1704**	**170**	**250**	**-**	**579**	**554**	**95.8**

Continued...

Annexure IV. *Continued.*

Attribute		Pod yield (kg ha^{-1}) 1993	1994	1995	1996	1998	1999	2000	2001	2002*	Mean	SD	CV
Location: Chintamani (Kolar), Karnataka								**13.4 °N**			**Zone: Secondary**		
Expt. Station	Max	1811	1172	2940	1418	3113	1927	2203	2199	1348	2015	679	33.7
	Mean	1510	1051	2551	1351	2605	1799	1913	1686	1204	1741	549	31.5
Irrigation		0	0	0	0	0	0	0	0	1	-	-	-
FLD (Imp.),	Mean	NA	NA	1600	1330	NA	1225	1365	NA	NA	1380	158	11.5
District Average		1297	953	1386	1324	823	483	1365	702	563	989	363	36.7
State Average		964	791	955	893	969	686	1017	702	563	838	159	18.9
YG I		**-**	**-**	**951**	**21**	**-**	**574**	**548**	**-**	**-**	**361**	**382**	**73.0**
YG II		**-**	**-**	**214**	**6**	**-**	**742**	**0**	**-**	**-**	**391**	**349**	**145.2**
YG Total		**213**	**98**	**1165**	**27**	**1782**	**1316**	**548**	**984**	**641**	**753**	**602**	**80.0**
Location: Raichur, Karnataka								**16.2 °N**			**Zone: Secondary**		
Expt. Station	Max	2438	2926	2292	1622	NA	2694	NA	2766	3270	2573	527	20.5
	Mean	2210	2167	2117	1471	NA	2190	NA	2351	2811	2188	395	18.0
Irrigation		2	2	0	0	NA	0	NA	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		758	635	716	697	-	539	-	702	563	659	82.1	12.5
State Average		964	791	955	893	-	686	-	702	563	793	152	19.1
YG Total		**1452**	**1532**	**1401**	**774**	**-**	**1651**	**-**	**1649**	**2248**	**1530**	**436**	**28.5**
Location: Dharwad, Karnataka								**15.47 °N**			**Zone: Primary**		
Expt. Station	Max	3816	4514	3866	5249	3457	5191	2266	3356	3912	3959	936	23.6
	Mean	3669	4097	3248	4837	3063	4959	2075	3188	3472	3623	905	25.0
Irrigation		0	0	0	0	0	0	0	1	0	-	-	-
FLD (Imp.),	Mean	NA	1886	NA	NA	NA	NA	NA	3050	958	1965	1048	53.3
District Average		889	764	997	874	1011	735	1082	702	563	846	169	20.4
State Average		964	791	955	893	969	686	1017	702	563	872	129	15.0
YG I		**-**	**2211**	**-**	**-**	**-**	**-**	**-**	**138**	**2514**	**1658**	**1293**	**79.8**
YG II		**-**	**1122**	**-**	**-**	**-**	**-**	**-**	**2348**	**395**	**1118**	**987**	**76.6**
YG Total		**2780**	**3333**	**2251**	**3963**	**2052**	**4224**	**993**	**2486**	**2909**	**2777**	**993**	**35.8**
Location: Jagtial (Karimnagar), Andhra Pradesh								**18.8 °N**			**Zone: Secondary**		
Expt. Station	Max	1861	#	#	2329	3611	NA	NA	1374	3063	2448	900	36.8
	Mean	1643	1565	1685	1865	2458	NA	NA	1221	2422	1837	455	24.8
Irrigation		0	0	0	0	0	NA	NA	0	0	-	-	-
FLD (Imp.),	Mean	NA	1565	1685	1725	NA	NA	NA	NA	NA	1658	83.3	5.0
District Average		1208	1196	1087	1450	1100	-	-	739	427	1030	340	33.0
State Average		1082	816	1183	931	1082	-	-	739	427	894	259	29.0
YG I		**-**	**0**	**0**	**140**	**-**	**-**	**-**	**-**	**-**	**179**	**80.8**	**173.2**
YG II		**-**	**369**	**598**	**275**	**-**	**-**	**-**	**-**	**-**	**629**	**166**	**40.1**
YG Total		**435**	**369**	**598**	**415**	**1358**	**-**	**-**	**482**	**1995**	**807**	**626**	**77.5**
Location: Kadiri (Anantapur), Andhra Pradesh								**14.12 °N**			**Zone: Primary**		
Expt. Station	Max	1904	1097	3385	2089	2456	766	3088	1224	2191	2022	887	43.9
	Mean	1753	1016	3176	1874	2265	681	2839	1011	1939	1839	843	45.9
Irrigation		0	0	0	0	0	1	0	1	-	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		739	427	988	555	904	383	1116	739	427	698	267	38.3
State Average		1082	816	1183	931	1082	607	1144	739	427	890	262	29.4
YG Total		**1014**	**589**	**2188**	**1319**	**1361**	**298**	**1723**	**272**	**1512**	**1142**	**656**	**57.4**

Continued...

Annexure IV. *Continued.*

Attribute		Pod yield (kg ha^{-1}) 1993	1994	1995	1996	1998	1999	2000	2001	2002*	Mean	SD	CV
		Location: Palem (Mahabubnagar), Andhra Pradesh						**16.73 °N**			**Zone: Secondary**		
Expt. Station	Max	1152	1353	2840	1778	2628	2619	NA	NA	NA	2062	728	35.3
	Mean	1152	1129	2691	1339	2492	2193	NA	NA	NA	1833	708	38.6
Irrigation		4	1	0	0	0	1	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		869	629	883	855	756	509	-	-	-	750	152	20.3
State Average		1082	816	1183	931	1082	607	-	-	-	950	212	22.3
YG Total		**283**	**500**	**1808**	**484**	**1736**	**1684**	**-**	**-**	**-**	**1083**	**728**	**67.3**
		Location: Kayamkulam (Alappuzha), Kerala						**9.18 °N**			**Zone: Others**		
Expt. Station	Max	NA	3625	2609	4540	2086	3571	3333	5135	1778	3335	1155	34.6
	Mean	NA	3413	2158	3965	1868	3262	2744	3634	1556	2825	884	31.3
Irrigation		NA	0	0	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	734	692	746	700	739	754	750	524	705	76.6	10.9
State Average		-	734	692	746	700	739	754	750	524	705	76.6	10.9
YG Total		**-**	**2679**	**1466**	**3219**	**1168**	**2523**	**1990**	**2884**	**1032**	**2120**	**828**	**39.1**
		Location: Ludhiana, Punjab						**30.9 °N**			**Zone: Others**		
Expt. Station	Max	1476	2372	NA	2045	2124	NA	NA	NA	NA	2004	379	18.9
	Mean	1171	1516	NA	1728	1706	NA	NA	NA	NA	1530	258	16.8
Irrigation		2	4	NA	0	0	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		875	1250	-	1400	833	-	-	-	-	1090	279	25.6
State Average		900	1000	-	1000	833	-	-	-	-	933	81.8	8.8
YG Total		**296**	**266**	**-**	**328**	**873**	**-**	**-**	**-**	**-**	**441**	**289**	**65.6**
		Location: Mainpuri, Uttar Pradesh						**27.23 °N**			**Zone: Tertiary**		
Expt. Station	Max	3125	3241	3009	1678	1042	1522	1586	1759	1806	2085	812	38.9
	Mean	1921	1921	2107	1539	1042	1114	1363	1167	1424	1511	390	25.8
Irrigation		2	2	0	0	0	2	0	2	3	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1065	827	782	925	1000	844	833	840	662	864	119	13.8
State Average		861	736	722	934	649	825	835	853	662	786	97.9	12.5
YG Total		856	1094	1325	614	42	270	530	327	762	647	410	63.3

*District and state average yield data for 2002 are provisional, SD = Standard deviation, CV = Coefficient of variation (%), NA = Data (Experimental station, FLD) not available, # = Experimental station yield less than FLD yield.

Annexure V. Planting and harvesting dates and total dry matter (kg ha^{-1}) of simulated pigeonpea at selected locations across India.

Location	Planting date				Maturity date				Total dry matter			
	Early	Late	Mean	CV	Early	Late	Mean	CV	Min	Max	Mean	CV
Primary Zone												
Akola	01 Jun	09 Jul	16 Jun	6	07 Dec	11 Jan	23 Dec	3	1182	13778	7026	48
Amravati	05 Jun	10 Jul	16 Jun	6	04 Dec	29 Dec	16 Dec	2	4161	12882	7770	33
Bharuch (Haldar)	11 Jun	15 Jul	24 Jun	2	06 Dec	30 Dec	16 Dec	44	2445	8651	5251	45
(Sisodia)	05 Jun	15 Jul	20 Jun	8	07 Dec	30 Dec	14 Dec	2	3826	9124	6449	31
Gulbarga	01 Jun	15 Aug	17 Jun	11	04 Dec	23 Jan	19 Dec	4	1593	12771	8779	33
Kurnool	01 Jun	24 Jul	25 Jun	10	27 Nov	30 Dec	13 Dec	3	3359	13550	7617	37
Nagpur	03 Jun	21 Jul	28 Jun	6	16 Dec	14 Jan	30 Dec	3	3918	11474	7393	30
Nanded	01 Jun	26 Jul	22 Jun	8	09 Dec	23 Jan	29 Dec	3	1550	12370	8040	39
Parbhani	01 Jun	10 Jul	14 Jun	6	07 Dec	04 Feb	28 Dec	4	219	15728	8862	31
Raichur	01 Jun	08 Aug	02 Jul	14	03 Dec	19 Jan	26 Dec	4	0	12369	6802	48
Wardha	06 Jun	15 Jul	20 Jun	6	11 Dec	07 Jan	24 Dec	2	5506	12249	8558	23
Secondary Zone												
Anantapur	01 Jun	29 Aug	02 Jul	15	25 Nov	01 Feb	21 Dec	6	1372	13094	7613	41
Belgaum	05 Jun	12 Jul	17 Jun	5	11 Dec	09 Jan	24 Dec	2	5789	11756	8875	21
Bellary	01 Jun	29 Aug	30 Jun	18	03 Dec	19 Feb	01 Jan	7	195	8919	4927	42
Bijapur	01 Jun	06 Aug	20 Jun	13	29 Nov	25 Jan	24 Dec	5	930	10827	6187	49
Dharwad	01 Jun	18 Jul	18 Jun	9	23 Dec	04 Feb	10 Jan	3	4023	12342	8458	29
Kurnool	01 Jun	24 Jul	25 Jun	10	27 Nov	30 Dec	13 Dec	3	3359	13550	7617	37
Patancheru	01 Jun	23 Jul	23 Jun	7	19 Dec	31 Jan	05 Jan	3	4673	14364	9910	25
Rahuri	01 Jun	13 Jul	16 Jun	9	11 Dec	29 Jan	11 Jan	4	0	10951	3918	75
Warangal	07 Jun	01 Jul	17 Jun	4	29 Nov	24 Dec	11 Dec	2	6900	12138	10259	17
Betul	31 May	27 Jun	16 Jun	4	05 Jan	31 Jan	18 Jan	33	4760	13952	9291	23
Kanpur	13 Jun	25 Jul	08 Jul	9	30 Jan	09 Mar	19 Feb	3	5900	12756	8909	26
Raisen	11 Jun	17 Jul	27 Jun	5	23 Jan	11 Feb	03 Feb	1	2373	10938	7249	35
Varanasi	06 Jun	02 Aug	02 Jul	9	22 Dec	08 Feb	12 Jan	4	5302	13231	8872	26
Tertiary Zone												
Aduturai	03 Jun	18 Aug	05 Jul	12	27 Dec	07 Mar	25 Jan	5	6904	16120	11072	19
Bangalore	01 Jun	24 Aug	23 Jun	16	15 Jan	06 Mar	02 Feb	50	0	14680	9513	50
Coimbatore (Coimbatore)	04 Jun	28 Aug	07 Jul	15	23 Dec	04 Feb	04 Jan	4	0	12791	5651	88
(Palaturai)	03 Jun	28 Aug	10 Jul	14	03 Dec	04 Feb	01 Jan	6	0	8788	4668	64
Jhabua	03 Jun	21 Jul	05 Jul	7	03 Dec	30 Jan	04 Jan	3	1150	10076	6090	31
Indore	07 Jun	25 Jul	22 Jun	8	03 Dec	15 Feb	02 Jan	5	5862	13294	9674	21
Jhansi	09 Jun	14 Aug	08 Jul	12	06 Jan	15 Mar	13 Feb	56	2166	8771	5623	35
Junagadh	10 Jun	17 Aug	08 Jul	10	10 Dec	27 Jan	27 Dec	4	0	7869	4912	42
Ludhiana	04 Jun	27 Jul	26 Jun	15	24 Jan	11 Apr	09 Mar	16	0	12507	6509	42
Rajkot (Semla)	17 Jun	26 Jul	27 Jun	6	10 Dec	10 Jan	19 Dec	3	2276	8504	4411	41
(Bhola)	12 Jun	05 Jul	23 Jun	4	05 Dec	19 Dec	12 Dec	1	2415	7580	3860	41
Faizabad	01 Jun	07 Jul	16 Jun	6	16 Dec	22 Jan	04 Jan	3	9996	16842	12273	17
Others												
Pantnagar	01 Jun	06 Jul	17 Jun	7	16 Jan	15 Mar	09 Feb	4	0	13563	10250	29
Delhi	04 Jun	28 Jul	27 Jun	8	16 Jan	10 Mar	14 Feb	31	0	11988	5580	63
Hisar	05 Jun	23 Jul	04 Jul	8	11 Feb	19 Mar	06 Mar	19	0	4087	1935	79

In parenthesis are the soil series. CV = Coefficient of variation (%)

Annexure VI. Experimental station (short-duration), on-farm (FLD with improved technology) and district average yields and yield gaps of pigeonpea during 1991 to 2002 at different AICRP locations across India.

Attribute		Yield (kg ha^{-1})														
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
Location: Rahuri (Ahmed Nagar), Maharashtra											**19.38 °N**			**Zone: Secondary**		
Expt. Station	Max	2714	NA	2103	1181	NA	2524	NA	2810	2638	2582	2179	1636	2263	549	24
	Mean	2314	NA	2047	984	NA	2287	NA	2270	2437	2345	1788	1512	1998	485	24
Irrigation		4	NA	1	2	NA	2	NA	1	1	1	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1448	2024	1157	1424	1722	1199	1497	1326	1475	284	19
District Average		262	-	727	524	420	589	333	526	474	492	634	498	498	130	26
State Average		360	-	724	492	595	682	353	804	834	602	757	733	631	168	27
YG I		**-**	**-**	**-**	**-**	**-**	**263**	**-**	**846**	**715**	**1146**	**291**	**186**	**524**	**387**	**67**
YG II		**-**	**-**	**-**	**-**	**1028**	**1435**	**824**	**898**	**1248**	**707**	**863**	**828**	**976**	**246**	**25**
YG Total		**2052**	**1320**	**460**	**-**	**1698**	**-**	**1743**	**1963**	**1853**	**1154**	**1014**	**1500**	**525**	**36**	
Location: Badnapur (Jalna), Maharashtra											**19.38 °N**			**Zone: Primary**		
Expt. Station	Max	1405	NA	2971	1142	NA	#	NA	#	#	#	1852	2360	1946	737	38
	Mean	1159	NA	2552	1102	NA	1538	NA	1302	1779	1946	1752	2108	1693	474	28
Irrigation		1	NA	0	0	NA	0	NA	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	1538	NA	1302	1779	1946	1603	1986	1692	262	15
District Average		278	-	301	318	-	492	-	565	470	402	278	388	388	104	27
State Average		360	-	724	492	-	682	-	804	834	602	757	733	665	155	23
YG I		**-**	**-**	**-**	**-**	**-**	**0**	**-**	**0**	**0**	**0**	**149**	**121**	**1**	**70**	**156**
YG II		**-**	**-**	**-**	**-**	**-**	**1046**	**-**	**737**	**1309**	**1544**	**1325**	**1598**	**1304**	**323**	**26**
YG Total		**881**	**-**	**2251**	**784**	**-**	**1046**	**-**	**737**	**1309**	**1544**	**1474**	**1720**	**1305**	**507**	**40**
Location: Jalna, Maharashtra											**19.83 °N**			**Zone: Primary**		
Expt. Station	Max	2083	NA	2009	NA	NA	NA	1500	NA	2176	1435	NA	NA	1841	346	19
	Mean	1357	NA	1665	NA	NA	NA	1107	NA	1579	1354	NA	NA	1412	219	15
Irrigation		0	NA	0	NA	NA	NA	0	NA	0	0	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		278	-	301	-	-	-	158	-	470	402	-	-	322	120	37
State Average		360	-	724	-	-	-	353	-	834	602	-	-	575	215	37
YG Total		**1079**	**1364**	**-**	**-**	**-**	**949**	**-**	**1109**	**952**	**-**	**-**	**1090**	**169**	**16**	
Location: Parbhani, Maharashtra											**19.13 °N**			**Zone: Primary**		
Expt. Station	Max	708	NA	1375	1890	NA	NA	NA	NA	NA	NA	NA	NA	1324	593	45
	Mean	611	NA	1237	1801	NA	NA	NA	NA	NA	NA	NA	NA	1216	595	49
Irrigation		0	NA	0	0	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		358	-	576	344	-	-	-	-	-	-	-	-	426	130	31
State Average		360	-	724	492	-	-	-	-	-	-	-	-	525	184	35
YG Total		**253**	**-**	**662**	**1457**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**791**	**613**	**77**
Location: Akola, Maharashtra											**20.50 °N**			**Zone: Primary**		
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	1297	1036	NA	NA	855	1487	1079	1151	245	21
District Average		-	-	-	-	-	867	790	-	-	765	777	800	800	40	5
State Average		-	-	-	-	-	682	353	-	-	602	757	733	625	163	26
YG II		**-**	**-**	**-**	**-**	**-**	**430**	**246**	**-**	**-**	**90**	**710**	**279**	**351**	**234**	**67**
Location: Pantnagar (U.S. Nagar), Uttaranchal											**29.05 °N**			**Zone: Others**		
Expt. Station	Max	2552	NA	NA	NA	NA	1413	932	939	2414	1809	NA	2527	1798	721	40
	Mean	2129	NA	NA	NA	NA	984	932	807	2105	1335	NA	2231	1503	631	42

Continued...

Annexure VI. *Continued.*

Attribute		Yield (kg ha^{-1}) 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
Irrigation		0	NA	NA	NA	NA	0	0	0	0	0	NA	-	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1000	-	-	-	-	727	583	600	728	728	-	728	728	136	19
State Average		845	-	-	-	-	710	641	597	749	-	708	708	97	14	
YG Total		**1129**	**-**	**-**	**-**	**-**	**257**	**349**	**207**	**1377**	**607**	**-**	**1503**	**776**	**551**	**71**
		Location: Khargone, Madhya Pradesh									**21.82 °N**			**Zone: Secondary**		
Expt. Station	Max	1264	NA	1618	721	NA	1462	3981	1308	2757	#	1709	#	1853	1035	56
	Mean	1125	NA	1346	729	NA	1162	2530	1069	2584	1489	1473	1469	1498	605	40
Irrigation		0	0	0	0	0	0	0	0	0	0	1	2	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	1869	1489	792	1469	1405	448	32
District Average		471	-	663	618	-	598	527	523	557	318	564	453	529	98	19
State Average		698	-	963	817	-	852	710	920	987	665	837	643	809	125	15
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**715**	**0**	**681**	**0**	**93**	**403**	**116**
YG II		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1312**	**1171**	**228**	**1016**	**876**	**485**	**52**
YG Total		**655**	**-**	**684**	**111**	**-**	**564**	**2003**	**546**	**2027**	**1171**	**909**	**1016**	**968**	**623**	**64**
		Location: Patancheru (Medak), Andhra Pradesh									**17.53 °N**			**Zone: Secondary**		
Expt. Station	Max	2520	NA	3050	2474	NA	2623	NA	NA	NA	NA	NA	NA	2667	263	10
	Mean	2134	NA	2687	2083	NA	2155	NA	NA	NA	NA	NA	NA	2265	283	12
Irrigation		2	NA	2	0	NA	2	NA	NA	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		192	-	166	91	-	273	-	-	-	-	-	-	181	75	42
State Average		352	-	340	330	-	385	-	-	-	-	-	-	343	28	8
YG Total		**1942**	**-**	**2521**	**1992**	**-**	**1882**	**-**	**-**	**-**	**-**	**-**	**-**	**2084**	**295**	**14**
		Location: Gulbarga, Karnataka									**17.33 °N**			**Zone: Primary**		
Expt. Station	Max	1500	NA	NA	NA	NA	NA	826	2651	3114	#	1426	#	1903	946	50
	Mean	1347	NA	NA	NA	NA	NA	585	2178	2999	1472	1426	1060	1581	788	50
Irrigation		0	NA	NA	NA	NA	NA	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1095	1200	457	1181	1574	1472	1420	1060	1182	347	29
District Average		232	-	-	-	541	533	253	478	614	452	303	426	426	135	32
State Average		358	-	-	-	476	502	234	466	581	441	303	420	420	106	25
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**128**	**996**	**1425**	**0**	**6**	**0**	**399**	**625**	**147**
YG II		**-**	**-**	**-**	**-**	**554**	**667**	**204**	**703**	**960**	**1020**	**1117**	**634**	**757**	**295**	**40**
YG Total		**1115**	**-**	**-**	**-**	**-**	**-**	**332**	**1700**	**2385**	**1020**	**1123**	**634**	**1155**	**680**	**57**
		Location: Bangalore, Karnataka									**12.97 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	NA	2154	#	1619	1495	1756	350	20
	Mean	NA	NA	NA	NA	NA	NA	NA	NA	1841	1150	1395	1355	1435	291	20
Irrigation		NA	NA	NA	NA	NA	NA	NA	NA	0	0	0	1	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	1062	679	1569	1486	1150	1347	933	1175	316	27
District Average		-	-	-	-	-	537	679	410	658	658	658	658	608	85	14
State Average		-	-	-	-	-	502	234	466	581	441	303	420	421	118	28
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**356**	**0**	**48**	**422**	**260**	**213**	**103**
YG II		**-**	**-**	**-**	**-**	**-**	**525**	**0**	**1159**	**828**	**492**	**689**	**275**	**567**	**376**	**66**
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1183**	**492**	**737**	**697**	**827**	**291**	**37**

Continued...

Annexure VI. *Continued.*

Attribute		Yield (kg ha^{-1})														
Attribute		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
					Location: S.K. Nagar (Banaskantha), Gujarat						**24.25 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	NA	1604	NA	2113	1560	1487	2693	1910	2246	3059	2084	566	27
	Mean	NA	NA	NA	1305	NA	1840	1214	1188	2398	1402	1858	2619	1728	550	32
Irrigation		NA	NA	NA	2	NA	0	0	0	1	4	2	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1362	1441	NA	NA	1387	1331	985	1202	1284	167	13
District Average		-	-	-	632	717	938	718	952	812	337	624	716	716	185	26
State Average		-	-	-	639	728	952	749	952	812	337	563	717	717	192	27
YG I		**-**	**-**	**-**	**-**	**-**	**399**	**1214**	**1188**	**1011**	**71**	**874**	**1417**	**444**	**483**	**55**
YG II		**-**	**-**	**-**	**-**	**645**	**503**	**-**	**-**	**575**	**994**	**361**	**486**	**568**	**218**	**37**
YG Total		**-**	**-**	**-**	**673**	**-**	**902**	**496**	**236**	**1586**	**1065**	**1234**	**1903**	**1012**	**557**	**55**
					Location: Anand (Kheda), Gujarat						**22.57 °N**			**Zone: Secondary**		
Expt. Station	Max	1374	NA	1645	NA	NA	1237	1053	NA	NA	NA	NA	NA	1327	249	19
	Mean	1322	NA	1645	NA	NA	1153	907	NA	NA	NA	NA	NA	1257	310	25
Irrigation		0	NA	0	NA	NA	0	0	NA	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		462	-	1428	-	-	979	722	-	-	-	-	-	898	412	46
State Average		604	-	892	-	-	952	749	-	-	-	-	-	799	156	19
YG Total		**860**	**-**	**217**	**-**	**-**	**174**	**185**	**-**	**-**	**-**	**-**	**-**	**359**	**335**	**93**
					Location: Hisar, Haryana						**29.17 °N**			**Zone: Others**		
Expt. Station	Max	2159	NA	1481	1746	NA	1786	NA	NA	2068	1640	1794	2751	1928	397	21
	Mean	1744	NA	1344	1556	NA	1587	NA	NA	1929	1539	1418	2614	1716	406	24
Irrigation		1	NA	1	1	NA	1	NA	NA	0	1	0	1	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		592	-	635	223	-	1145	-	-	798	768	693	693	693	255	37
State Average		1023	-	1052	954	-	1145	-	-	798	768	768	768	957	148	15
YG Total		**1152**	**-**	**709**	**1334**	**-**	**442**	**-**	**-**	**1131**	**771**	**725**	**1921**	**1023**	**466**	**46**
					Location: Sriganganagar, Rajasthan						**29.17 °N**			**Zone: Others**		
Expt. Station	Max	1667	NA	2838	NA	NA	NA	880	NA	NA	NA	NA	NA	1795	985	55
	Mean	1119	NA	2130	NA	NA	NA	880	NA	NA	NA	NA	NA	1376	663	48
Irrigation		2	NA	2	NA	NA	NA	2	NA	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1000	-	1000	-	-	-	857	-	-	-	-	-	952	82	9
State Average		248	-	358	-	-	-	791	-	-	-	-	-	466	287	62
YG Total		**119**	**-**	**1130**	**-**	**-**	**-**	**23**	**-**	**-**	**-**	**-**	**-**	**424**	**613**	**145**
					Location: Ludhiana, Punjab						**30.93 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	1302	1520	NA	1127	2074	1469	1481	NA	1530	3630	1767	800	45
	Mean	NA	NA	1064	1458	NA	919	1732	1469	1481	NA	1348	3321	1599	741	46
Irrigation		NA	NA	4	1	NA	0	2	1	4	NA	3	5	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1133	NA	1419	1336	1400	NA	1261	1545	1349	142	11
District Average		-	-	858	892	789	759	746	538	739	-	696	797	757	102	13
State Average		-	-	895	1048	878	845	798	609	837	-	844	844	844	113	13
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**313**	**133**	**81**	**-**	**88**	**1776**	**250**	**732**	**153**
YG II		**-**	**-**	**-**	**-**	**344**	**-**	**673**	**798**	**661**	**-**	**565**	**748**	**592**	**162**	**26**
YG Total		**-**	**-**	**207**	**566**	**-**	**160**	**986**	**931**	**742**	**-**	**652**	**2524**	**842**	**742**	**88**

Continued...

Annexure VI. *Continued.*

Attribute		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
		Yield (kg ha^{-1})														
						Location: Faridkot, Punjab					**30.67 °N**			**Zone: Others**		
Expt. Station	Max	2066	NA	2813	1406	NA	NA	NA	NA	NA	NA	1202	1015	1700	738	43
	Mean	1875	NA	2483	1250	NA	NA	NA	NA	NA	NA	1109	1015	1546	622	40
Irrigation		2	NA	2	1	NA	NA	NA	NA	NA	NA	1	6	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		992	-	895	1048	-	-	-	-	-	-	1000	1000	987	56	6
State Average		992	-	895	1048	-	-	-	-	-	-	998	998	986	56	6
YG Total		**883**	**-**	**1588**	**202**	**-**	**-**	**-**	**-**	**-**	**-**	**109**	**15**	**559**	**669**	**120**
						Location: New Delhi, Delhi					**28.58 °N**			**Zone: Others**		
Expt. Station	Max	1825	NA	1345	2500	NA	1688	2402	1174	1269	1720	3519	2449	1989	728	37
	Mean	1384	NA	1083	1870	NA	1513	2090	1113	1218	1540	3334	2200	1735	684	39
Irrigation		2	NA	2	1	NA	1	-	-	-	-	1	1	1	1	60
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		717	-	731	731	-	400	400	400	702	1159	849	849	694	242	35
YG Total		**667**	**-**	**352**	**1139**	**-**	**1113**	**1690**	**713**	**516**	**381**	**2485**	**1351**	**1041**	**671**	**64**
						Location: Samba, Jammu and Kashmir					**32.57 °N**			**Zone: Others**		
Expt. Station	Max	NA	NA	NA	NA	NA	2142	NA	NA	1527	NA	2130	1759	1890	300	16
	Mean	NA	NA	NA	NA	NA	1794	NA	NA	1472	NA	1907	1624	1699	191	11
Irrigation		NA	NA	NA	NA	NA	-	NA	NA	-	NA	-	-	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
State Average		-	-	-	-	-	400	-	-	702	-	743	743	647	166	26
YG Total		**-**	**-**	**-**	**-**	**-**	**1394**	**-**	**-**	**770**	**-**	**1164**	**881**	**1052**	**282**	**27**
						Location: Coimbatore, Tamil Nadu					**11.00 °N**			**Zone: Tertiary**		
Expt. Station	Max	1081	NA	517	1126	NA	1222	2216	2222	#	1032	1503	989	1323	569	43
	Mean	1000	NA	517	1037	NA	1222	1905	1560	934	927	1225	920	1125	384	34
Irrigation		-	NA	5	6	NA	6	5	5	5	4	4	4	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	1160	913	934	740	668	647	844	197	23
District Average		423	-	375	826	-	834	505	870	667	710	658	640	651	172	26
State Average		546	-	452	820	-	703	504	644	667	710	658	634	634	108	17
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**745**	**648**	**0**	**187**	**557**	**274**	**281**	**292**	**73**
YG II		**-**	**-**	**-**	**-**	**-**	**-**	**655**	**43**	**267**	**30**	**10**	**7**	**193**	**258**	**153**
YG Total		**578**	**142**	**211**	**388**	**1400**	**690**	**267**	**217**	**567**	**280**	**474**	**374**	**79**		
						Location: Vamban (Pudukkottai), Tamil Nadu					**10.50 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	#	NA	690	902	954	849	140	16
	Mean	NA	NA	NA	NA	NA	NA	NA	570	NA	650	856	859	734	146	20
Irrigation		NA	NA	NA	NA	NA	NA	NA	-	NA	5	1	4	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	513	778	570	-	565	625	659	618	93	15
District Average		-	-	-	-	-	139	225	486	-	452	452	452	368	147	40
State Average		-	-	-	-	-	703	504	644	-	710	658	644	644	74	12
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0**	**-**	**85**	**231**	**200**	**115**	**106**	**83**
YG II		**-**	**-**	**-**	**-**	**-**	**374**	**553**	**84**	**-**	**113**	**173**	**207**	**251**	**180**	**72**
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**84**	**-**	**198**	**404**	**407**	**366**	**160**	**58**

Continued...

Annexure VI. *Continued.*

Attribute		Yield (kg ha^{-1})														
Attribute		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
				Location: Berhampore (Ganjam), Orissa							**19.32 °N**		**Zone: Secondary**			
Expt. Station	Max	1378	NA	1015	NA	NA	1157	NA	952	NA	1426	1264	964	1165	196	17
	Mean	1156	NA	776	NA	NA	1088	NA	791	NA	1088	1032	742	954	176	18
Irrigation		-	NA	-	NA	NA	-	NA	-	NA	-	-	-	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		704	-	762	-	-	558	194	-	503	555	570	549	182	33	
State Average		704	-	762	-	-	558	589	194	-	503	555	552	552	169	31
YG Total		**452**	**-**	**14**	**-**	**-**	**530**	**-**	**597**	**-**	**585**	**477**	**172**	**404**	**224**	**55**
				Location: Modipuram (Meerut), Uttar Pradesh							**28.98 °N**		**Zone: Tertiary**			
Expt. Station	Max	1900	NA	1488	1300	NA	NA	2407	NA	NA	NA	NA	NA	1774	491	28
	Mean	1692	NA	1374	1300	NA	NA	1432	NA	NA	NA	NA	NA	1450	170	12
Irrigation		3	NA	0	2	NA	NA	0	NA	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1022	-	891	1286	-	-	703	-	-	-	-	-	976	245	25
State Average		1074	-	1035	1077	-	-	1034	-	-	-	-	-	1055	24	2
YG Total		**670**	**-**	**483**	**14**	**-**	**-**	**729**	**-**	**-**	**-**	**-**	**474**	**324**	**68**	

*District and state average yield data for 2002 are provisional, SD = Standard deviation, CV = Coefficient of variation (%), NA = Data (Experimental station, FLD) not available, # =Experimental station yield less than FLD yield.

Annexure VII. Experimental station (medium-duration), on-farm (FLD with improved technology) and district average yields, and yield gaps of pigeonpea at different AICRP locations across India.

Attribute		Yield (kg ha[-1])														
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
Location: Rahuri (Ahmed Nagar), Maharashtra											**19.38 °N**			**Zone: Secondary**		
Expt. Station	Max	2206	NA	1190	667	NA	#	NA	3390	2220	1802	1675	NA	1879	866	46
	Mean	1868	NA	1108	667	NA	2024	NA	2982	1960	1628	1544	NA	1723	685	40
Irrigation		4	NA	2	2	NA	2	NA	1	1	0	0	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1448	2024	1157	1424	1722	1199	1497	1326	1475	284	19
District Average		262	-	727	524	420	589	333	526	474	492	634	498	498	130	26
State Average		360	-	724	492	595	682	353	804	834	602	757	733	631	168	27
YG I		**-**	**-**	**-**	**-**	**-**	**0**	**-**	**1558**	**238**	**430**	**47**	**-**	**248**	**640**	**141**
YG II		**-**	**-**	**-**	**-**	**1028**	**1435**	**824**	**898**	**1248**	**707**	**863**	**828**	**976**	**246**	**25**
YG Total		**1605**	**-**	**381**	**143**	**-**	**1435**	**-**	**2455**	**1486**	**1136**	**910**	**-**	**1225**	**732**	**61**
Location: Badnapur (Jalna), Maharashtra											**19.38 °N**			**Zone: Primary**		
Expt. Station	Max	986	NA	2571	2275	NA	#	NA	1488	#	#	1984	2155	1910	577	30
	Mean	872	NA	2571	2203	NA	1538	NA	1437	1779	1946	1984	2155	1832	499	27
Irrigation		0	NA	0	0	NA	0	NA	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	1538	NA	1302	1779	1946	1603	1986	1692	262	15
District Average		278	301	318	492	-	565	470	402	278	388	388	104	27		
State Average		360	724	492	595	682	-	804	834	602	757	733	658	148	22	
YG I		**-**	**-**	**-**	**-**	**-**	**0**	**-**	**135**	**0**	**0**	**381**	**169**	**139**	**151**	**132**
YG II		**-**	**-**	**-**	**-**	**-**	**1046**	**-**	**737**	**1309**	**1544**	**1325**	**-**	**1304**	**310**	**26**
YG Total		**594**	**-**	**2270**	**1885**	**-**	**1046**	**-**	**872**	**1309**	**1544**	**1706**	**-**	**1444**	**557**	**40**
Location: Jalna, Maharashtra											**19.83 °N**			**Zone: Primary**		
Expt. Station	Max	2018	NA	2304	NA	NA	2733	1525	NA	1921	1921	NA	NA	2070	410	20
	Mean	1644	NA	2133	NA	NA	2577	1200	NA	1757	1831	NA	NA	1857	465	25
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
Irrigation		0	NA	0	NA	NA	0	0	NA	0	0	NA	NA	-	-	-
District Average		278	-	301	-	-	492	158	-	470	402	-	-	350	128	37
State Average		360	-	724	-	-	682	353	-	834	602	-	-	593	198	33
YG Total		**1366**	**-**	**1832**	**-**	**-**	**2085**	**1042**	**-**	**1287**	**1429**	**-**	**-**	**1507**	**382**	**25**
Location: Khargone, Madhya Pradesh											**21.82 °N**			**Zone: Secondary**		
Expt. Station	Max	NA	NA	1670	1832	NA	1685	1833	2985	1976	#	2670	1605	2032	512	25
	Mean	NA	NA	1518	1279	NA	1281	1381	2745	1941	1489	2530	1489	1739	548	32
Irrigation		NA	NA	0	0	NA	0	0	0	0	0	1	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	1869	1489	792	1469	1405	448	32
District Average		-	-	663	618	-	598	527	523	557	318	564	453	536	102	19
State Average		-	-	963	817	-	852	710	920	987	665	837	643	822	126	15
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**72**	**0**	**1738**	**20**	**334**	**854**	**187**
YG II		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1312**	**1171**	**228**	**1016**	**869**	**485**	**52**
YG Total		**-**	**-**	**856**	**661**	**-**	**683**	**853**	**2222**	**1384**	**1171**	**1966**	**1036**	**1204**	**558**	**46**

Continued...

Annexure VII. *Continued.*

Attribute		Yield (kg ha^{-1})														
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
Location: Sehore, Madhya Pradesh 23.20 °N														**Zone: Tertiary**		
Expt. Station	Max	NA	NA	1895	1226	NA	2190	NA	2135	1892	#	2123	2335	1971	365	18
	Mean	NA	NA	1758	1120	NA	2014	NA	2076	1508	2035	2123	2212	1856	373	20
Irrigation		NA	NA	0	0	NA	0	NA	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1354	906	966	1319	NA	2035	2100	1871	1507	496	33
District Average		-	-	863	821	693	607	560	874	662	464	633	792	697	137	20
State Average		-	-	963	817	777	852	710	920	987	665	837	643	817	120	13
YG I		-	-	-	-	-	1108	758	-	0	23	341	349	481	108	
YG II		**-**	**-**	**-**	**-**	**661**	**299**	**405**	**445**	**-**	**1571**	**1467**	**1079**	**810**	**525**	**62**
YG Total			**895**	**299**	**1407**	**1203**	**846**	**1571**	**1490**	**1420**	**1159**	**434**	**38**			
Location: Raipur, Chattisgarh											**21.23 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	2014	1570	1938	NA	NA	1841	237	13
	Mean	NA	NA	NA	NA	NA	NA	NA	1830	1298	1688	NA	NA	1605	275	17
Irrigation		NA	NA	NA	NA	NA	NA	NA	0	0	0	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1278	NA	701	1590	1230	488	NA	NA	1057	451	43
District Average		-	-	-	-	707	-	524	617	529	269	-	-	529	164	31
State Average		-	-	-	-	959	-	768	1049	-	430	-	-	802	274	34
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**240**	**69**	**1199**	**-**	**-**	**548**	**609**	**121**
YG II		**-**	**-**	**-**	**-**	**571**	**-**	**177**	**973**	**701**	**219**	**-**	**-**	**528**	**335**	**63**
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1213**	**769**	**1419**	**-**	**-**	**1076**	**332**	**29**
Location: Patancheru (Medak), Andhra Pradesh											**17.53 °N**			**Zone: Secondary**		
Expt. Station	Max	1558	NA	1825	2164	NA	NA	NA	NA	NA	NA	NA	NA	1849	304	16
	Mean	1440	NA	1651	1816	NA	NA	NA	NA	NA	NA	NA	NA	1636	188	12
Irrigation		0	NA	0	0	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		192	56	166	91	-	-	-	-	-	-	-	-	126	63	50
State Average		352	238	340	330	-	-	-	-	-	-	-	-	315	52	17
YG Total		**1248**	**-**	**1485**	**1725**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1510**	**239**	**16**
Location: Warangal, Andhra Pradesh											**18.00 °N**			**Zone: Secondary**		
FLD (Imp.),	Mean	NA	NA	NA	1029	923	NA	2004	1721	1905	1234	1844	1523	448	29	
District Average		0	0	0	429	286	273	167	364	211	290	449	291	307	93	30
State Average		-	-	-	330	308	385	179	432	358	427	449	449	359	88	25
YG II		**-**	**-**	**-**	**-**	**743**	**650**	**-**	**1640**	**1510**	**1615**	**785**	**1553**	**1216**	**460**	**38**
Location: Lam, (Guntur), Andhra Pradesh											**16.40 °N**			**Zone: Secondary**		
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	1775	2080	1690	1042	1383	1594	396	25
	Mean	NA	NA	NA	NA	NA	NA	NA	1623	1650	1531	896	1173	1375	328	24
Irrigation		NA	NA	NA	NA	NA	NA	NA	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	-	-	-	-	-	709	580	386	449	558	536	125	23
State Average		-	-	-	-	-	-	-	432	358	427	449	449	417	40	10
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**914**	**1070**	**1145**	**447**	**615**	**838**	**298**	**36**

Continued...

Annexure VII. *Continued.*

Attribute		Yield (kg ha^{-1})														
		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
Location: Madhira, (Khammam), Andhra Pradesh											**17.25 °N**		**Zone: Secondary**			
Expt. Station	Max	2344	NA	NA	NA	NA	NA	NA	NA	NA	2916	2480	3400	2785	477	17
	Mean	1816	NA	NA	NA	NA	NA	NA	NA	NA	2834	1994	2678	2331	501	21
Irrigation		0	NA	NA	NA	NA	NA	NA	NA	NA	0	2	2	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		485	-	-	-	-	-	-	-	-	538	449	511	496	38	8
State Average		352	-	-	-	-	-	-	-	-	427	449	449	409	51	12
YG Total		**1332**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2296**	**1545**	**2167**	**1835**	**469**	**26**
Location: Gulbarga, Karnataka											**17.33 °N**		**Zone: Primary**			
Expt. Station	Max	NA	NA	NA	1128	NA	NA	956	1924	1619	#	1572	#	1440	392	27
	Mean	NA	NA	NA	1047	NA	NA	820	1850	1619	1472	1572	1060	1348	375	28
Irrigation		NA	NA	NA	0	NA	NA	0	0	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	1095	1200	457	1181	1574	1472	1420	1060	1182	347	29
District Average		-	-	-	466	541	533	253	478	614	441	303	450	453	114	25
State Average		-	-	-	395	476	502	234	466	581	441	303	303	425	112	26
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**363**	**669**	**45**	**0**	**152**	**0**	**166**	**265**	**130**
YG II		**-**	**-**	**-**	**-**	**-**	**-**	**204**	**703**	**960**	**1031**	**1117**	**610**	**729**	**339**	**44**
YG Total		**-**	**-**	**-**	**580**	**-**	**-**	**567**	**1372**	**1005**	**1031**	**1269**	**610**	**895**	**337**	**37**
Location: Bangalore, Karnataka											**12.97 °N**		**Zone: Tertiary**			
Expt. Station	Max	NA	NA	790	1593	NA	NA	1137	1870	1630	1370	2332	1977	1587	489	31
	Mean	NA	NA	515	1531	NA	NA	850	1666	1630	1261	2175	1529	1395	516	37
Irrigation		NA	NA	0	0	NA	NA	0	0	0	0	0	1	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	1062	679	1569	1486	1150	1347	933	1175	316	27
District Average		-	-	353	424	-	537	679	410	658	511	511	511	510	108	21
State Average		-	-	430	395	-	502	234	466	581	441	303	303	419	110	26
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**171**	**98**	**145**	**112**	**829**	**596**	**220**	**310**	**95**
YG II		**-**	**-**	**-**	**-**	**-**	**525**	**0**	**1159**	**828**	**639**	**836**	**422**	**664**	**368**	**58**
YG Total		**-**	**-**	**162**	**1107**	**-**	**-**	**171**	**1256**	**972**	**750**	**1664**	**1018**	**884**	**517**	**58**
Location: Junagadh, Gujarat											**21.32 °N**		**Zone: Tertiary**			
Expt. Station	Max	1203	NA	1410	NA	NA	NA	NA	NA	NA	NA	3151	4909	2668	1731	65
	Mean	1203	NA	1190	NA	NA	NA	NA	NA	NA	NA	2963	3382	2184	1154	53
Irrigation		0	NA	0	NA	NA	NA	NA	NA	NA	NA	3	3	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		1000	-	1000	-	-	-	-	-	-	-	624	870	874	177	20
State Average		604	-	892	-	-	-	-	-	-	-	563	683	686	179	26
YG Total		**203**	**-**	**190**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2339**	**2512**	**1311**	**1289**	**98**
Location: Bharuch, Gujarat											**21.70 °N**		**Zone: Primary**			
Expt. Station	Max	NA	NA	NA	NA	NA	1458	1214	NA	2028	946	2579	2135	1727	621	36
	Mean	NA	NA	NA	NA	NA	1153	994	NA	1901	713	1859	1807	1405	515	37
Irrigation		NA	NA	NA	NA	NA	0	0	NA	0	0	0	0	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	-	-	-	766	520	-	662	295	611	571	571	159	28
State Average		-	-	-	-	-	952	749	-	812	337	563	683	683	238	35
YG Total		**-**	**-**	**-**	**-**	**-**	**386**	**474**	**-**	**1239**	**418**	**1248**	**1236**	**834**	**447**	**54**

Continued...

Annexure VII. *Continued.*

Attribute		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
		Yield (kg ha^{-1})														
					Location: Vadodara, Gujarat						**22.30 °N**		**Zone: Primary**			
Expt. Station	Max	2335	NA	NA	NA	NA	NA	NA	2291	2041	1169	NA	NA	1959	542	28
	Mean	2111	NA	NA	NA	NA	NA	NA	2045	1825	1093	NA	NA	1769	467	26
Irrigation		2	NA	NA	NA	NA	NA	NA	0	2	0	NA	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		613	-	-	-	-	-	-	857	833	358	-	-	665	232	35
State Average		604	-	-	-	-	-	-	952	812	337	-	-	676	268	40
YG Total		**1498**	**-**	**-**	**-**	**-**	**-**	**-**	**1188**	**992**	**735**	**-**	**-**	**1103**	**322**	**29**
					Location: Coimbatore, Tamil Nadu						**11.00 °N**		**Zone: Tertiary**			
Expt. Station	Max	1164	NA	775	1790	NA	NA	NA	1354	1549	1155	1296	3333	1552	779	50
	Mean	826	NA	676	1622	NA	NA	NA	1189	1407	771	992	2388	1234	569	46
Irrigation		0	NA	5	0	NA	NA	NA	5	5	4	4	3	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	1160	913	934	740	668	647	844	197	23
District Average		423	375	826	-	-	505	870	667	710	658	642	631	169	25	
State Average		546	452	820	-	-	504	644	667	710	658	625	625	119	17	
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**277**	**473**	**30**	**324**	**1742**	**390**	**674**	**119**
YG II		**-**	**-**	**-**	**-**	**-**	**-**	**655**	**43**	**267**	**30**	**10**	**5**	**213**	**258**	**153**
YG Total		**403**	**-**	**301**	**795**	**-**	**-**	**-**	**319**	**740**	**61**	**334**	**1746**	**603**	**526**	**90**
					Location: Vamban (Pudukkottai), Tamil Nadu						**10.50 °N**		**Zone: Tertiary**			
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	644	NA	782	1065	2116	1152	666	58
	Mean	NA	NA	NA	NA	NA	NA	NA	644	NA	731	807	1456	909	370	41
Irrigation		NA	NA	NA	NA	NA	NA	NA	3	NA	0	2	4	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	513	778	570	NA	565	625	659	618	93	15
District Average		-	-	-	-	594	139	225	486	-	361	361	361	361	151	42
State Average		-	-	-	-	734	703	504	644	-	710	658	625	659	83	13
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**74**	**-**	**166**	**182**	**797**	**291**	**332**	**109**
YG II		**-**	**-**	**-**	**-**	**-**	**374**	**553**	**84**	**-**	**204**	**264**	**298**	**257**	**159**	**54**
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**158**	**-**	**370**	**446**	**1095**	**548**	**404**	**78**
					Location: Berhampore (Ganjam), Orissa						**19.32 °N**		**Zone: Secondary**			
Expt. Station	Max	NA	NA	1048	NA	NA	NA	NA	NA	NA	1856	1033	NA	1312	471	36
	Mean	NA	NA	815	NA	NA	NA	NA	NA	NA	1271	909	NA	998	241	24
Irrigation		NA	NA	0	NA	NA	NA	NA	NA	NA	0	0	NA	-	-	-
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	751	-	-	-	-	-	-	503	555	-	603	131	22
State Average		-	-	762	-	-	-	-	-	-	503	555	-	607	137	23
YG Total		**-**	**-**	**64**	**-**	**-**	**-**	**-**	**-**	**-**	**768**	**354**	**-**	**395**	**354**	**90**

*District and state average yield data for 2002 are provisional, SD = Standard deviation, CV = Coefficient of variation (%), NA = Data (Experimental station, FLD) not available, # = Experimental station yield less than FLD yield.

Annexure VIII. Experimental station (long-duration) and district average yields and yield gap of pigeonpea during 1990–99 at different AICRP locations across India.

Attribute		Grain yield (kg ha^{-1})											SD	CV
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Mean		
				Location: Varanasi, Uttar Pradesh					**25.33 °N**			**Zone: Secondary**		
Expt. Station	Max	1249	NA	2709	2303	NA	2103	1659	2076	3686	3062	2356	779	33
	Mean	1208	NA	2595	2194	NA	1839	1625	1628	3491	2963	2193	772	35
Irrigation		0	NA	0	0	NA	0	0	0	0	0	-	-	-
District Average		1189	-	1117	1254	-	798	996	1145	1179	1424	1138	183	16
State Average		1237	-	1034	1035	-	1015	1141	1034	1167	1281	1118	104	9
YG Total		**19**	**-**	**1478**	**940**	**-**	**1041**	**629**	**483**	**2312**	**1539**	**1055**	**716**	**68**
				Location: Kanpur, Uttar Pradesh					**26.40 °N**			**Zone: Secondary**		
Expt. Station	Max	NA	NA	1988	1929	NA	NA	2407	3361	2569	2695	2492	525	21
	Mean	NA	NA	1831	1779	NA	NA	2052	3074	2192	2650	2263	505	22
Irrigation		NA	NA	2	1	NA	NA	1	0	1	0	1	-	-
District Average		-	-	999	1132	-	-	1895	1807	1861	2111	1634	454	28
State Average		-	-	1034	1035	-	-	1141	1034	1167	1281	1115	100	9
YG Total		**-**	**-**	**832**	**647**	**-**	**-**	**157**	**1267**	**331**	**539**	**629**	**392**	**62**
				Location: Pusa, (Samastipur), Bihar					**25.98 °N**			**Zone: Tertiary**		
Expt. Station	Max	3571	NA	2688	2369	NA	1520	3905	3905	NA	2898	2979	881	30
	Mean	3299	NA	2564	2271	NA	1312	3379	2867	NA	2541	2605	700	27
Irrigation		0	NA	0	0	NA	0	0	0	NA	0	-	-	-
District Average		1463	-	1214	1060	-	936	1133	750	-	1093	1093	222	20
State Average		1463	-	1214	1060	-	936	1133	1299	-	1186	1184	169	14
YG Total		**1836**	**-**	**1350**	**1211**	**-**	**376**	**2246**	**2117**	**-**	**1448**	**1512**	**635**	**42**
				Location: Dholi (Mujaffarpur), Bihar					**25.85 °N**			**Zone: Tertiary**		
Expt. Station	Max	1798	NA	1623	NA	NA	2100	NA	2016	NA	NA	1884	216	11
	Mean	1727	NA	1576	NA	NA	1880	NA	1821	NA	NA	1751	132	8
Irrigation		0	NA	0	NA	NA	0	NA	0	NA	NA	-	-	-
District Average		939	-	924	-	-	936	-	1409	-	-	1052	238	23
State Average		1463	-	1214	-	-	936	-	1299	-	-	1228	220	18
YG Total		**788**	**-**	**652**	**-**	**-**	**944**	**-**	**412**	**-**	**-**	**699**	**226**	**32**

*District and state average yield data for 2002 are provisional, SD = Standard deviation, CV = Coefficient of variation (%), NA = Data (Experimental station) not available.

Annexure IX. Planting and harvesting dates and total dry matter (kg ha^{-1}) of simulated rainfed chickpea (with pre-sowing irrigation) at selected locations across India.

	Planting date				Harvest date				Total dry matter			
Location	Early	Late	Mean	CV	Early	Late	Mean	CV	Min	Max	Mean	CV
Primary Zone												
Durgapura	09 Oct	11 Nov	01 Nov	3	21 Jan	05 Mar	25 Feb	24	1105	4421	2584	38
Guna	12 Oct	29 Oct	18 Oct	2	25 Jan	21 Feb	05 Feb	17	1271	2874	2225	18
Hoshangabad	09 Oct	20 Oct	13 Oct	1	16 Jan	17 Feb	23 Jan	28	1374	4465	3028	22
Raisen	10 Oct	25 Oct	16 Oct	1	08 Feb	23 Feb	15 Feb	9	1558	3480	2406	24
Rajgarh	09 Oct	27 Oct	17 Oct	1	20 Jan	15 Feb	03 Feb	20	1463	4153	2669	23
Sagar	09 Oct	31 Oct	15 Oct	2	17 Jan	19 Feb	28 Jan	30	2488	5202	3491	21
Shajapur	09 Oct	27 Oct	15 Oct	2	24 Jan	27 Feb	08 Feb	24	1673	6245	3109	31
Ujjain	09 Oct	08 Nov	15 Oct	2	25 Jan	03 Mar	08 Feb	23	1314	6153	3113	37
Vidisha	10 Oct	28 Oct	18 Oct	2	30 Jan	18 Feb	09 Feb	12	839	3689	2318	29
Secondary Zone												
Akola	09 Oct	26 Oct	13 Oct	2	17 Jan	10 Feb	24 Jan	24	1249	4349	3099	25
Amravati	09 Oct	24 Oct	12 Oct	2	10 Jan	02 Feb	18 Jan	32	1227	5441	3474	25
Betul	09 Oct	17 Oct	12 Oct	1	22 Jan	12 Feb	29 Jan	20	1479	4534	3393	22
Bhopal	09 Oct	20 Oct	13 Oct	1	18 Jan	11 Feb	29 Jan	23	1840	5859	3199	31
Dhar	09 Oct	27 Oct	17 Oct	2	15 Jan	16 Feb	30 Jan	28	1866	5308	3494	23
Dharwad	09 Oct	01 Nov	11 Oct	2	06 Jan	05 Feb	16 Jan	39	541	7741	4430	44
Indore	09 Oct	01 Nov	13 Oct	2	16 Jan	18 Feb	28 Jan	26	1156	5175	3508	27
Jhabua	09 Oct	05 Nov	17 Oct	2	19 Jan	27 Feb	29 Jan	24	630	5990	3318	34
Jabalpur	10 Oct	23 Oct	15 Oct	1	23 Jan	11 Feb	01 Feb	13	3319	7123	4866	21
Kota	09 Oct	01 Nov	20 Oct	2	15 Jan	17 Feb	06 Feb	22	1507	5070	3013	34
Nagpur	09 Oct	21 Oct	12 Oct	1	13 Jan	01 Feb	22 Jan	24	1144	4408	2689	26
Nanded	09 Oct	25 Oct	13 Oct	2	14 Jan	07 Feb	24 Jan	27	310	4152	2817	39
Parbhani	09 Oct	19 Oct	10 Oct	1	17 Jan	05 Feb	25 Jan	20	2893	6228	4113	19
Ratlam	09 Oct	29 Oct	14 Oct	2	19 Jan	12 Feb	26 Jan	24	2410	6176	3812	20
Wardha	09 Oct	24 Oct	11 Oct	1	07 Jan	26 Jan	15 Jan	33	1957	5334	3622	28
Tertiary Zone												
Belgaum	09 Oct	21 Oct	10 Oct	1	13 Jan	22 Jan	17 Jan	17	2454	4170	3066	18
Hyderabad	09 Oct	18 Oct	10 Oct	1	07 Jan	21 Jan	13 Jan	31	308	5448	2876	41
Raipur	09 Oct	21 Oct	11 Oct	1	13 Jan	03 Feb	22 Jan	28	2943	6476	4232	20
Others												
Ludhiana	01 Nov	15 Nov	07 Nov	1	23 Mar	27 Apr	07 Apr	9	449	4639	2776	48
Pantnagar	28 Oct	06 Nov	31 Oct	1	08 Mar	02 Apr	23 Mar	8	0	5702	3641	41
Delhi	29 Oct	20 Nov	06 Nov	2	08 Mar	01 Apr	18 Mar	8	372	2973	1294	54

CV = Coefficient of variation (%)

Annexure X. Experimental station (rainfed trials), on-farm (FLD with improved technology) and district average yields and yields gaps of chickpea at different AICRP locations across India.

Attribute		Grain yield (kg ha^{-1})												
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
				Location: Sehore, Madhya Pradesh					**23.20 °N**		**Zone: Primary**			
Expt. Station	Max	2222	2083	#	2881	2722	#	2347	1632	2291	2317	2312	381	16
	Mean	1996	2055	1244	2777	2545	1705	2241	1361	1872	2064	1986	477	24
FLD (Imp.),	Mean	NA	NA	1244	1592	NA	1705	1719	NA	NA	1880	1628	238	15
District Average		825	1037	737	1032	1022	964	979	1000	1020	877	949	102	11
State Average		834	907	747	913	945	924	986	819	989	931	900	77	9
YG I		**-**	**-**	**0**	**1185**	**-**	**0**	**522**	**-**	**-**	**184**	**358**	**499**	**132**
YG II		**-**	**-**	**508**	**560**	**-**	**741**	**740**	**-**	**-**	**1003**	**679**	**195**	**27**
YG Total		**1170**	**1018**	**507**	**1745**	**1523**	**741**	**1262**	**361**	**852**	**1187**	**1037**	**433**	**42**
				Location: Bhopal, Madhya Pradesh					**23.27 °N**		**Zone: Secondary**			
FLD (Imp.),	Mean	NA	NA	NA	NA	1500	1440	1470	NA	1520	NA	1482	35	2
District Average		-	-	-	-	994	984	936	-	978	-	973	26	3
State Average		-	-	-	-	945	924	986	-	989	-	961	32	3
YG II		**-**	**-**	**-**	**-**	**506**	**456**	**534**	**-**	**542**	**-**	**509**	**39**	**8**
				Location: Jabalpur, Madhya Pradesh					**23.17 °N**		**Zone: Secondary**			
Expt. Station	Max	NA	NA	NA	2441	2570	2392	2381	3090	NA	NA	2575	298	12
	Mean	NA	NA	NA	1916	1940	2294	1645	2858	NA	NA	2131	467	22
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	-	1017	564	862	1215	734	-	-	879	251	29
State Average		-	-	-	913	945	924	986	819	-	-	917	62	7
YG Total		**-**	**-**	**-**	**899**	**1376**	**1432**	**430**	**2124**	**-**	**-**	**1252**	**634**	**51**
				Location: Raipur, Chattisgarh					**21.23 °N**		**Zone: Tertiary**			
Expt. Station	Max	NA	NA	1694	NA	NA	903	#	NA	1684	1493	1444	372	26
	Mean	NA	NA	1544	NA	NA	799	1369	NA	1600	1493	1361	326	24
FLD (Imp.),	Mean	NA	NA	1369	1323	1044	604	1369	1364	1115	1400	1198	274	23
District Average		-	-	598	640	568	571	638	615	907	892	679	139	20
State Average		-	-	747	913	945	924	986	819	907	892	892	75	8
YG I		**-**	**-**	**176**	**-**	**-**	**194**	**1**	**-**	**485**	**93**	**163**	**182**	**96**
YG II		**-**	**-**	**770**	**683**	**476**	**34**	**731**	**749**	**208**	**508**	**520**	**273**	**53**
YG Total		**-**	**-**	**946**	**-**	**-**	**228**	**731**	**-**	**693**	**601**	**683**	**263**	**41**
				Location: Durgapura (Jaipur), Rajasthan					**26.91 °N**		**Zone: Primary**			
Expt. Station	Max	NA	NA	NA	NA	1979	2500	2701	1708	2395	2013	2216	375	17
	Mean	NA	NA	NA	NA	1837	2420	2215	1444	1930	1784	1938	343	18
FLD (Imp.),	Mean	NA	NA	1286	1895	1809	1214	1985	1131	1845	1683	1606	341	21
District Average		-	-	675	1077	901	700	751	590	759	758	776	150	19
State Average		-	-	673	705	869	737	695	590	759	758	723	80	11
YG I		**-**	**-**	**-**	**-**	**28**	**1206**	**230**	**313**	**85**	**101**	**332**	**443**	**135**
YG II		**-**	**-**	**611**	**818**	**908**	**514**	**1234**	**541**	**1086**	**925**	**830**	**261**	**31**
YG Total		**-**	**-**	**-**	**-**	**936**	**1720**	**1464**	**854**	**1171**	**1026**	**1162**	**335**	**28**
				Location: Sriganganagar, Rajasthan					**29.17 °N**		**Zone: Primary**			
Expt. Station	Max	NA	NA	NA	NA	3594	#	4236	2222	1231	NA	2821	1352	48
	Mean	NA	NA	NA	NA	3267	1742	3840	2055	1126	NA	2406	1118	46
FLD (Imp.),	Mean	NA	NA	1558	1611	1672	1742	1437	1427	1025	1018	1436	277	19

Continued...

Annexure X. *Continued.*

Attribute		Grain yield (kg ha^{-1})												
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
District Average		-	-	675	494	751	591	551	770	673	758	658	103	16
State Average		-	-	673	705	869	737	695	590	759	758	723	80	11
YG I		**-**	**-**	**-**	**-**	**1595**	**0**	**2403**	**628**	**101**	**-**	**970**	**1031**	**109**
YG II		**-**	**-**	**883**	**1117**	**921**	**1151**	**886**	**657**	**352**	**260**	**778**	**330**	**42**
YG Total		**-**	**-**	**-**	**-**	**2515**	**1151**	**3289**	**1285**	**453**	**-**	**1748**	**1141**	**66**
					Location: Diggi (Tonk), Rajasthan				**26.37 °N**			**Zone: Primary**		
Expt. Station	Max	1715	3923	NA	3923	1847	2917	1430	1138	NA	NA	2413	1170	48
	Mean	1622	3638	NA	3388	1586	2354	1286	993	NA	NA	2124	1038	49
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		502	441	-	926	740	793	695	590	-	-	669	170	25
State Average		612	864	-	705	869	737	695	590	-	-	725	110	15
YG Total		**1120**	**3198**	**-**	**2462**	**846**	**1561**	**591**	**403**	**-**	**-**	**1454**	**1033**	**71**
					Location: Kota, Rajasthan				**25.18 °N**			**Zone: Secondary**		
Expt. Station	Max	2981	NA	2055	NA	NA	1771	NA	NA	NA	NA	2269	633	28
	Mean	2749	NA	2014	NA	NA	1715	NA	NA	NA	NA	2159	532	25
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		634	-	673	-	-	838	-	-	-	-	715	108	15
State Average		612	-	673	-	-	737	-	-	-	-	674	63	9
YG Total		**2115**	**-**	**1341**	**-**	**-**	**877**	**-**	**-**	**-**	**-**	**1444**	**625**	**43**
					Location: Bharari (Jhansi), Uttar Pradesh				**27.45 °N**			**Zone: Secondary**		
Expt. Station	Max	1806	NA	NA	#	2347	2188	#	2420	2385	2458	2267	245	11
	Mean	1669	NA	NA	1861	2162	2038	1475	1776	2220	2273	1934	285	15
FLD (Imp.),	Mean	NA	NA	1926	1861	1717	NA	1475	NA	1932	NA	1782	192	11
District Average		720	-	821	901	899	697	1096	855	960	874	869	120	14
State Average		919	-	674	930	847	872	948	844	960	874	874	86	10
YG I		**-**	**-**	**-**	**0**	**445**	**-**	**0**	**-**	**288**	**-**	**152**	**221**	**121**
YG II		**-**	**-**	**1105**	**960**	**818**	**-**	**379**	**-**	**972**	**-**	**913**	**280**	**33**
YG Total		**949**	**-**	**-**	**960**	**1263**	**1341**	**379**	**921**	**1260**	**1399**	**1065**	**334**	**32**
					Location: Faizabad, Uttar Pradesh				**26.75 °N**			**Zone: Tertiary**		
FLD (Imp.),	Mean	NA	NA	1705	1915	1530	1590	NA	NA	2000	NA	1748	204	12
District Average		-	-	442	887	699	772	-	-	960	-	752	201	27
State Average		-	-	674	930	847	872	-	-	960	-	857	112	13
YG II		**-**	**-**	**1263**	**1028**	**831**	**818**	**-**	**-**	**1040**	**-**	**996**	**182**	**18**
					Location: Kanpur, Uttar Pradesh				**26.43 °N**			**Zone: Tertiary**		
FLD (Imp.),	Mean	NA	NA	1645	2068	1396	NA	1904	1673	1400	1966	1722	268	16
District Average		-	-	798	1203	1141	-	1296	1349	887	1112	1112	204	18
State Average		-	-	674	930	847	-	948	844	960	874	867	107	12
YG II		**-**	**-**	**847**	**865**	**254**	**-**	**608**	**324**	**513**	**854**	**609**	**258**	**42**
					Location: Varanasi, Uttar Pradesh				**25.33 °N**			**Zone: Tertiary**		
FLD (Imp.),	Mean	NA	NA	840	1988	1166	NA	1554	2251	NA	1990	1632	546	33
District Average		-	-	726	1343	806	-	948	844	-	933	933	217	23
State Average		-	-	674	930	847	-	948	844	-	874	849	108	13
YG II		**-**	**-**	**114**	**645**	**360**	**-**	**606**	**1407**	**-**	**1057**	**698**	**469**	**67**

Continued...

Annexure X. *Continued.*

Attribute		Grain yield (kg ha^{-1})												
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
Location: Pantnagar, Uttaranchal									**29.05 °N**		**Zone: Others**			
FLD (Imp.),	Mean	NA	NA	840	1988	1166	NA	1554	2251	NA	NA	1560	578	37
District Average		-	-	702	963	863	-	948	909	-	-	877	105	12
State Average		-	-	674	930	847	-	948	909	-	-	862	112	13
YG II		**-**	**-**	**138**	**1025**	**304**	**-**	**606**	**1342**	**-**	**-**	**683**	**500**	**73**
Location: Badnapur (Jalna), Maharashtra									**19.38 °N**		**Zone: Tertiary**			
Expt. Station	Max	1566	NA	#	1982	#	#	NA	#	#	1774	294	17	
	Mean	1393	NA	1148	1773	1267	1379	NA	1700	1584	1463	230	16	
FLD (Imp.),	Mean	NA	NA	1148	1314	1594	1267	1379	NA	1700	1584	1427	202	14
District Average		684	-	510	531	308	522	619	-	501	759	554	136	25
State Average		725	-	524	665	407	621	644	-	595	563	593	97	16
YG I		**-**	**-**	**0**	**-**	**179**	**0**	**0**	**-**	**0**	**0**	**37**	**73**	**245**
YG II		**-**	**-**	**638**	**783**	**1286**	**745**	**760**	**-**	**1199**	**825**	**872**	**248**	**28**
YG Total		**709**	**-**	**638**	**-**	**1465**	**745**	**760**	**-**	**1199**	**825**	**909**	**306**	**34**
Location: Akola, Maharashtra									**20.50 °N**		**Zone: Secondary**			
FLD (Imp.),	Mean	NA	NA	1245	1430	1159	1862	1788	1645	1005	1032	1396	338	24
District Average		-	-	528	800	395	684	749	355	574	664	594	161	27
State Average		-	-	524	665	407	621	644	519	595	563	567	84	15
YG II		**-**	**-**	**717**	**630**	**764**	**1178**	**1039**	**1290**	**431**	**368**	**802**	**338**	**42**
Location: Rahuri, Maharashtra									**19.38 °N**		**Zone: Secondary**			
FLD (Imp.),	Mean	NA	NA	2143	NA	1766	1891	1772	1981	1924	1932	1916	129	7
District Average		-	-	595	-	463	683	626	497	900	645	630	143	23
State Average		-	-	524	-	407	621	644	519	595	563	553	80	14
YG II		**-**	**-**	**1549**	**-**	**1302**	**1207**	**1146**	**1484**	**1024**	**1287**	**1286**	**184**	**14**
Location: Gulbarga, Karnataka									**17.33 °N**		**Zone: Primary**			
Expt. Station	Max	NA	NA	1033	1514	911	#	#	#	1777	2326	1512	575	38
	Mean	NA	NA	847	1514	755	1055	1313	1229	1526	2206	1306	460	35
FLD (Imp.),	Mean	NA	NA	608	1316	NA	1055	1193	1229	1182	1498	1154	277	24
District Average		-	-	602	575	386	547	516	648	606	554	554	79	14
State Average		-	-	483	557	341	670	549	648	606	545	550	112	20
YG I		**-**	**-**	**239**	**198**	**-**	**0**	**120**	**0**	**343**	**708**	**151**	**245**	**107**
YG II		**-**	**-**	**6**	**740**	**-**	**508**	**677**	**581**	**576**	**944**	**600**	**289**	**50**
YG Total		**-**	**-**	**244**	**939**	**369**	**508**	**797**	**581**	**920**	**1652**	**751**	**442**	**59**
Location: Dharwad, Karnataka									**15.47 °N**		**Zone: Secondary**			
Expt. Station	Max	NA	NA	NA	NA	NA	2514	2625	1222	NA	1750	2028	663	33
	Mean	NA	NA	NA	NA	NA	2108	2032	1082	NA	1461	1671	487	29
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
Dist. Average		-	-	-	-	-	203	556	648	-	622	507	206	41
State Average		-	-	-	-	-	670	549	648	-	545	603	64	10
Yield Gap		**-**	**-**	**-**	**-**	**-**	**1905**	**1476**	**434**	**-**	**839**	**1164**	**654**	**56**

Continued...

Annexure X. *Continued.*

Attribute		Grain yield (kg ha^{-1})												
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
				Location: Bangalore, Karnataka					**12.97 °N**		**Zone: Others**			
Expt. Station	Max	NA	1009	1173	#	534	#	1388	#	1185	1072	1060	288	27
	Mean	NA	935	1131	1040	534	1834	1388	674	957	1018	1057	382	36
FLD (Imp.),	Mean	NA	NA	654	1040	464	1834	975	674	798	597	880	431	49
District Average		-	500	467	571	400	737	643	648	606	572	572	103	18
State Average		-	502	483	557	341	670	549	648	606	545	545	105	19
YG I		**-**	**-**	**477**	**0**	**70**	**0**	**413**	**0**	**159**	**422**	**177**	**210**	**109**
YG II		**-**	**-**	**187**	**469**	**64**	**1097**	**332**	**26**	**192**	**25**	**308**	**358**	**120**
YG Total		**-**	**435**	**665**	**469**	**134**	**1097**	**745**	**26**	**351**	**446**	**485**	**322**	**66**
				Location: Warangal, Andhra Pradesh					**18.00 °N**		**Zone: Others**			
Expt. Station	Max	NA	NA	NA	NA	NA	NA	NA	1054	1816	2365	1745	658	38
	Mean	NA	NA	NA	NA	NA	NA	NA	953	1816	2214	1661	645	39
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	-	-	-	-	-	718	1234	871	941	265	28
State Average		-	-	-	-	-	-	-	1139	1234	1187	1187	67	6
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**235**	**582**	**1343**	**720**	**567**	**79**
				Location: Lam (Guntur), Andhra Pradesh					**16.42 °N**		**Zone: Tertiary**			
FLD (Imp.),	Mean	NA	NA	1412	2236	2057	NA	1235	NA	1761	NA	1740	421	24
District Average		-	-	986	1671	574	-	1112	-	1234	-	1115	398	36
State Average		-	-	630	853	383	-	583	-	1234	-	737	324	44
YG II		**-**	**-**	**426**	**565**	**1483**	**-**	**123**	**-**	**527**	**-**	**625**	**510**	**82**
				Location: Dholi (Mujaffarpur), Bihar					**26.16 °N**		**Zone: Others**			
Expt. Station	Max	1463	1783	NA	NA	864	1853	NA	NA	NA	2350	1663	548	33
	Mean	1350	1656	NA	NA	778	1640	NA	NA	NA	2200	1525	519	34
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		658	1019	-	-	750	1091	-	-	-	1000	904	188	21
State Average		1064	1104	-	-	750	1091	-	-	-	1000	1002	169	17
YG Total		**692**	**637**	**-**	**-**	**28**	**549**	**-**	**-**	**-**	**1200**	**621**	**418**	**67**
				Location: Bawal (Rewari) Haryana					**28.08 °N**		**Zone: Tertiary**			
Expt. Station	Max	NA	NA	NA	NA	NA	NA	1666	2152	1673	1222	1678	380	23
	Mean	NA	NA	NA	NA	NA	NA	1312	1920	1623	1222	1519	318	21
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	-	-	-	-	952	1129	1000	1027	1027	75	7
State Average		-	-	-	-	-	-	580	640	855	777	713	145	21
YG Total		**-**	**-**	**-**	**-**	**-**	**-**	**360**	**791**	**623**	**195**	**492**	**266**	**54**
				Location: Hisar, Haryana					**29.17 °N**		**Zone: Primary**			
FLD (Imp.),	Mean	NA	NA	1126	1354	NA	NA	1522	1554	1306	1370	1372	156	11
District Average		-	-	1011	800	-	-	580	509	854	777	755	184	24
State Average		-	-	1011	800	-	-	580	640	855	777	777	172	22
YG II		**-**	**-**	**115**	**554**	**-**	**-**	**942**	**1045**	**452**	**593**	**617**	**339**	**55**
				Location: Arnej (Ahmedabad), Gujarat					**22.58 °N**		**Zone: Tertiary**			
Expt. Station	Max	NA	NA	NA	NA	1514	2082	1424	NA	1673	1048	1548	377	24
	Mean	NA	NA	NA	NA	1262	1900	1149	NA	1418	831	1312	393	30
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-

Continued...

Annexure X. *Continued.*

Attribute		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
		Grain yield (kg ha⁻¹)												
District Average		-	-	-	-	500	528	385	-	330	686	486	138	28
State Average		-	-	-	-	801	877	512	-	554	686	686	180	26
YG Total		**-**	**-**	**-**	**-**	**762**	**1372**	**764**	**-**	**1088**	**145**	**826**	**458**	**55**
				Location: Junagadh, Gujarat					**21.32 °N**			**Zone: Tertiary**		
FLD (Imp.),	Mean	NA	NA	1232	1194	1602	1671	NA	1215	1525	NA	1406	216	15
District Average		-	-	1026	1120	1481	1478	-	833	908	-	1141	280	25
State Average		-	-	608	700	801	877	-	529	554	-	678	140	21
YG II		**-**	**-**	**206**	**74**	**121**	**193**	**-**	**382**	**617**	**-**	**265**	**202**	**76**
				Location: Bathinda, Punjab								**Zone: Tertiary**		
Expt. Station	Max	NA	NA	3611	1791	NA	3333	NA	NA	NA	NA	2912	980	34
	Mean	NA	NA	3316	1460	NA	3097	NA	NA	NA	NA	2624	1014	39
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	881	869	-	736	-	-	-	-	829	81	10
State Average		-	-	892	917	-	788	-	-	-	-	866	68	8
YG Total		**-**	**-**	**2435**	**591**	**-**	**2361**	**-**	**-**	**-**	**-**	**1796**	**1044**	**58**
				Location: Ludhiana, Punjab								**Zone: Others**		
FLD (Imp.),	Mean	NA	NA	1728	1694	1578	1391	1782	2261	2200	1727	1795	296	16
District Average		-	-	891	917	824	788	968	948	889	889	889	60	7
State Average		-	-	892	917	827	788	968	948	-	-	890	70	8
YG II		**-**	**-**	**837**	**777**	**754**	**603**	**814**	**1313**	**1311**	**838**	**906**	**262**	**29**
				Location: Faridkot, Punjab					**30.67 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	1944	2083	3542	3437	1589	NA	NA	NA	2519	905	36
	Mean	NA	NA	1621	1884	2965	3271	1400	NA	NA	NA	2228	837	38
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	979	707	601	500	1000	-	-	-	757	224	30
State Average		-	-	892	917	827	788	968	-	-	-	878	72	8
YG Total		**-**	**-**	**642**	**1177**	**2364**	**2771**	**400**	**-**	**-**	**-**	**1471**	**1050**	**71**
				Location: Berhampore (Murshidabad), West Bengal					**24.10 °N**			**Zone: Tertiary**		
Expt. Station	Max	NA	NA	NA	NA	1764	1899	1832	NA	NA	NA	1832	68	4
	Mean	NA	NA	NA	NA	1285	1620	1453	NA	NA	NA	1453	167	12
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		-	-	-	-	993	877	861	-	-	-	910	72	8
State Average		-	-	-	-	667	815	827	-	-	-	770	89	12
YG Total		**-**	**-**	**-**	**-**	**292**	**743**	**592**	**-**	**-**	**-**	**542**	**230**	**42**
				Location: Samba (Jammu), Jammu and Kashmir					**32.57 °N**			**Zone: Others**		
Expt. Station	Max	NA	NA	NA	2476	949	1111	3090	NA	2474	1147	1875	913	49
	Mean	NA	NA	NA	2043	949	907	2729	NA	2068	1147	1640	747	46
FLD (Imp.),	Mean	NA	NA	NA	771	797	NA	1033	NA	@	1053	914	150	16
District Average		-	-	-	771	778	783	806	-	785	785	785	12	1
State Average		-	-	-	771	778	783	806	-	785	785	785	12	1
YG I		**-**	**-**	**-**	**1272**	**152**	**-**	**1695**	**-**	**-**	**94**	**727**	**805**	**100**
YG II		**-**	**-**	**-**	**0**	**19**	**-**	**227**	**-**	**-**	**268**	**129**	**139**	**108**
YG Total		**-**	**-**	**-**	**1272**	**171**	**124**	**1923**	**-**	**1283**	**362**	**856**	**741**	**87**

Continued...

Annexure X. *Continued.*

Attribute		Grain yield (kg ha^{-1})												
		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*	Mean	SD	CV
				Location: New Delhi					**28.58 °N**			**Zone: Others**		
Expt. Station	Max	NA	NA	NA	NA	NA	2576	2929	3165	#	#	2890	296	10
	Mean	NA	NA	NA	NA	NA	2197	2858	2906	2500	2130	2518	361	14
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	1943	2146	2500	2130	2180	233	11
District Average		-	-	-	-	-	783	806	803	785	794	794	10	1
State Average		-	-	-	-	-	783	806	803	785	794	794	12	2
YG I		**-**	**-**	**-**	**-**	**-**	**-**	**915**	**760**	**0**	**0**	**338**	**488**	**116**
YG II		**-**	**-**	**-**	**-**	**-**	**-**	**1137**	**1343**	**1715**	**1336**	**1386**	**241**	**17**
YG Total		**-**	**-**	**-**	**-**	**-**	**1414**	**2052**	**2103**	**1715**	**1336**	**1724**	**353**	**20**
				Location: Coimbatore, Tamil Nadu					**11.00 °N**			**Zone: Tertiary**		
Expt. Station	Max	1054	2812	755	NA	NA	966	873	NA	NA	NA	1292	857	66
	Mean	848	1879	755	NA	NA	966	803	NA	NA	NA	1050	470	45
FLD (Imp.),	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-	-	-
District Average		553	739	740	-	-	740	628	-	-	-	680	86	13
State Average		553	553	701	-	-	624	628	-	-	-	612	62	10
YG Total		**295**	**1140**	**15**	**-**	**-**	**226**	**175**	**-**	**-**	**-**	**370**	**442**	**120**

*District and state average yield data for 2002 are provisional, SD = Standard deviation, CV = Coefficient of variation (%), NA = Data (Experimental station, FLD) not available, # = Experimental station yield less than FLD yield, @ = FLD yield less than district yield.

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