Potential Productivity and Yield Gap of Selected Crops in the Rainfed Regions of India, Thailand, and Vietnam

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Executive summary

Before any improvements to crop management practices are made, it is useful to know the potential yield of the crop in the region of interest, and the gap between the potential yield and the actual yield obtained by the growers. This analysis helps to know the major factors causing the difference between the actual and the attainable yield for a given site. Under the Asian Development Bank (ADB)-supported project on integrated watershed management we carried out such analysis for selected crops predominantly grown in the regions where the project is operational. We used CROPGRO-soybean model to determine the yield potential (water-limited yields) and yield gap of soybean crop for several locations in India. For northeastern Thailand and northern Vietnam we compared the experimental yields obtained at the research farms with the farmers' current crop yields in the region to estimate the yield gaps.

For the eleven selected sites in India, the potential yield of soybean ranged from 1249 to 3050 kg ha^{-1} whereas the observed yields ranged from 570 to 1120 kg ha^{-1} giving yield gaps ranging from 235 to 1955 kg ha^{-1} (19–65% of potential yield). For northeastern Thailand the yield gaps ranged from 1370 to 2320 kg ha^{-1} (38–65%) in paddy rice, 175 to 270 kg ha^{-1} (11–18%) in upland rice, 1210 to 3180 kg ha^{-1} (25–67%) in maize, 625 to 940 kg ha^{-1} (32–49%) in soybean, and 190 to 570 kg ha^{-1} (11–33%) in groundnut. In northern Vietnam the farmers were able to harvest almost two-third of the potential yield of maize; however, in groundnut and soybean the yield gap was wider and ranged from 40% to 60% of potential yield.

Various constraints limiting the crop yields in these regions have been highlighted. It is suggested that location-specific integrated approaches would be needed to bridge the yield gap of the predominant crops grown in the target regions.

Introduction

Assessment of potential yield and the yield gap between potential and actual yield is essential before any investment for improving crop production for a location is made. Potential yield is determined by solar radiation, temperature, photoperiod, atmospheric concentration of carbon dioxide, and genotype characteristics assuming water, nutrients, pests, and diseases are not limiting crop growth. This is also called water non-limiting potential yield. Under rainfed situation where the water supply for crop production is not fully under the control of the grower, water-limiting yield may be considered as the maximum attainable yield for yield gap analysis assuming other factors are not limiting crop production. However, there may be season-to-season variability in potential yield caused by weather variability, particularly rainfall. Once the yield gap between water-limiting yield and actual yield is determined, then the relative contribution of other major constraints and limitations causing yield gap can be assessed in order to focus on the priority research or crop management needs to bridge the yield gap.

Water-limiting potential yield for a site could be determined by growing crops without any growth constraints, except water availability. Alternatively, crop simulation models could be used to estimate the potential yields provided the required soils and climatic input data for the site are available for model execution. For the ADB-supported watershed project we have estimated the potential yields and yield gaps of selected crops grown in India, Thailand, and Vietnam. In these countries land degradation caused by water erosion, soil fertility depletion, and waterlogging are the major constraints limiting crop yields and sustainability on relatively high water-holding capacity soils. The production problems are further amplified by the existence of biotic and socioeconomic constraints in these regions. The crops selected were soybean for India; rice, maize, soybean, groundnut, and sunflower for northeastern Thailand; and maize, groundnut, and soybean for northern Vietnam. As the soils and climatic data were available for India, CROPGRO-soybean model was used to estimate potential yields of soybean. For northeastern Thailand and northern Vietnam experimental yields obtained at the research stations were taken as the potential yields and compared with the on-farm actual yields to determine the yield gap. This report presents the current productivity levels, potential yields, and the yield gap of the selected crops for the regions where the ADB-supported watershed management project is in operation. Suggestions have also been made for bridging the yield gap through crop management and conservation and use of natural resources of the target regions.

Section 1: Productivity and yield gap of soybean in India

India ranks third after Argentina and Brazil to have registered a phenomenal growth in the production of soybean. Soybean cultivation in India has steadily increased. It was a minor crop during the early 1970s but at present, it occupies third place in the oilseed production in India. The area under soybean in India has rapidly increased from 0.03 million ha in 1970 to 2.6 million ha in 1990 and to 5.6 million ha in 1997 (Directorate of Economics and Statistics, Government of India 1970–92, Directorate of Economics and Statistics 1993–2000).

Increased soybean production is mainly driven by increased area sown to the crop. In 1998, the soybean production was 5.2 million t. While the progress in soybean production is most impressive, these growth figures belie the fact that the productivity continues to remain low and major steps are required to enhance production by increasing productivity rather than increasing area under the crop. The average soybean productivity for India has hovered around 1 t ha^{-1} during 1983–2000 (Fig. 1.1).

The study of long-term growth trend does not indicate any appreciable contribution towards productivity gains by improved agricultural technologies in soybean cultivation except the maintenance of yield. Despite the release of short-duration and high-yielding varieties in recent years, there is no evidence of yield increase in the state of Madhya Pradesh, which is the heartland of soybean production in India. Thus, it can be averred that the growth in production is primarily led by an increased area sown under the crop.

Major soybean-producing states of India

In India, soybean crop is primarily cultivated in the states of Madhya Pradesh, Rajasthan, Maharashtra, and Uttar Pradesh. Figure 1.2 shows the distribution of the crop in two epochs: 1985 and 1997. Efforts to grow soybean in the submountane plains of India commenced in the early 1960s. The crop was promising in Madhya Pradesh, Maharashtra, and Uttar Pradesh but not in Gujarat. Currently Madhya Pradesh accounts for nearly 87% of the area under the crop in the country and contributes about 83% of the total national production. In Uttar Pradesh, the area under soybean increased until mid-1980s, but a sharp decline was noted in 1987. This is clearly seen in comparing the area distribution pattern maps for 1985 and 1997. As in Gujarat, the crop did not hold ground initially in Maharashtra as well. However, by 1990, Maharashtra regained the position of the second largest soybean producing state in India.

Classification of soybean-producing districts

The soybean area distribution presented in Figure 1.2 reveals a selective, concentrated adaptation of the crop in India. This is more clearly evident in the area and production data of 1997 which show that only 14 districts in Madhya Pradesh account for 61% of the national area under the crop and contribute as much as 75% to the total national soybean production. Such a development pattern raises an important question: How are these (high spread) districts different in terms of their natural resource endowments and socioeconomic infrastructure compared to the other districts that show a low spread of soybean crop? The resources could be defined in terms of regional soil type, annual or seasonal rainfall, irrigation facilities, use of fertilizers, adoption of high-yielding varieties, cropping patterns, location of soybean processing industries, etc. To provide an answer to the above question, it is necessary to identify those factors of production that render some districts as high density soybean producers and some as low density producers. Based on soybean productivity levels and contribution of soybean area in the districts to their gross cropped area (GCA) and to total soybean area in India, we grouped soybean-producing districts of India into three zones: primary, secondary, and tertiary. For this purpose the available data of the last three seasons (1994/95, 1995/96, and 1996/97) were used. A district was considered primary if it had at least 15% of GCA under soybean, at least 1% of total soybean area in the country, and soybean productivity levels more than the national average (0.95 t ha^{-1}). The districts meeting all the three conditions in any one season were grouped under the primary zone. After separating the primary districts, the secondary districts were identified from the remaining districts. The secondary zone constituted those districts which had at least 5% of GCA under soybean, at least 0.5% of total soybean area in the country, and soybean productivity levels more than 0.5 t ha^{-1}. The remaining districts which grew soybean but did not fall in the above two categories were grouped under the tertiary zone. The map of these zones was overlayed on the map of agroecological zones (AEZs) of India (Sehgal et al. 1995). The AEZs of interest from soybean production point of view are AEZs 4, 5, 6, 9, 10, 11, 12, and 14 (Fig. 1.3).

Soybean area, production, and productivity in different zones

Soybean area, production, and productivity of primary, secondary, and tertiary zones during the 1996/97 cropping season are presented in Table 1.1. Twenty four of the soybean-producing districts are included in the primary zone. The primary zone is located predominantly in Madhya

Table 1.1. Soybean area, production, and productivity in primary, secondary, and tertiary zones of India during 1996/97.

	Area ('000 ha)			Production ('000 t)			Productivity (t ha^{-1})		
Zones[1]	Total	SD[2]	CV[3]	Total	SD	CV	Average	SD	CV
Primary (24)	4233	86	2	4216	79	2	1.04	0.2	19
Secondary (27)	996	21	2	987	29	3	0.96	0.5	48
Tertiary (37)	158	4	2	166	4	3	0.95	0.4	40

1. Figures in parentheses represent number of districts.
2. SD = standard deviation.
3. CV = coefficient of variation (expressed in %).

Pradesh and also in two districts in Maharashtra (Nagpur and Wardha) and three districts in Rajasthan (Chittorgarh, Jhalawar, and Kota) (Table 1.2). Primary production zone corresponds to the AEZs 5 and 10. AEZ 5 constitutes central highlands having Vertic Inceptisols and Vertisols; 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 semi-arid (dry and moist) and length of growing season varies from 120 to 180 days.

Table 1.2. Area and production of soybean in the primary soybean production zone of India during 1996/97.

District	Area ('000 ha)	Production ('000 t)	Productivity (t ha^{-1})	Gross cropped area (GCA) ('000 ha)	Soybean area (% of GCA)
Bhopal	65.2	63.3	0.97	210.0	31.0
Chhindwara	130.1	148.4	1.14	594.0	21.9
Guna	126.4	103.5	0.82	734.0	17.2
Indore	203.3	218.0	1.07	443.0	45.9
Mandsaur	271.3	226.9	0.84	831.0	32.6
Narsinghpur	113.3	183.0	1.62	402.0	28.2
Ratlam	173.5	176.5	1.02	476.0	36.4
Shajapur	286.3	217.9	0.76	658.0	43.5
Tikamgarh	64.5	85.1	1.32	383.0	16.8
Ujjain	401.5	357.3	0.89	760.0	52.8
Chittorgarh[1]	81.0	74.6	0.92	594.3	13.6
Jhalawar[1]	118.0	135.9	1.15	453.8	26.0
Kota[1]	167.8	200.7	1.20	752.5	22.3
Dewas	231.1	232.9	1.01	548.0	42.2
Sehore	219.3	196.0	0.89	552.0	39.7
Wardha	83.9	108.4	1.29	385.0	21.8
Betul	181.1	189.3	1.05	529.0	34.2
Dhar	214.6	199.5	0.93	701.0	30.0
Hoshangabad	330.2	382.7	1.16	734.0	45.0
Rajgarh	207.7	142.9	0.69	565.0	36.8
Sagar	149.2	144.0	0.97	655.0	22.8
Seoni	91.0	103.1	1.13	465.0	19.6
Raisen	109.9	112.5	1.02	532.0	20.7
Nagpur	212.3	213.8	1.01	590.0	36.0
Total	4232.6	4216.1	1.04		
SD	86.4	78.9	0.20		
CV (%)	2	2	19		

1. Data for 1994/95.

We have identified 22 districts as those belonging to the secondary zone. Of these, 11 districts belong to Madhya Pradesh (Rajnandgaon district now transferred to Chattisgarh), 7 to Maharashtra, 2 to Uttar Pradesh (Nainital district now transferred to Uttaranchal), 1 to Karnataka, and 1 to Rajasthan (Table 1.3). The secondary soybean production zone overlaps parts of AEZs 4, 5, 6, 10, 11, 12, and 14. AEZs 4, 5, and 6 have Vertisols and Vertic Inceptisols, and semi-arid to sub-humid climate; the length of growing season varies from 120 to 180 days. In AEZs 10, 11, and 12 comprising central highlands, Maharashtra plateau, and eastern plateau, climate is sub-humid (dry), soils are Vertisols, Vertic Inceptisols, and Alfisols, and length of growing season varies from 150 to 210 days. AEZ 14 comprises the Terai region of Uttar Pradesh (now in Uttaranchal). It has perhumid climate with length of growing season varying

Table 1.3. Area and production of soybean in the secondary soybean production zone of India during 1996/97.

District	Area ('000 ha)	Production ('000 t)	Productivity (t ha^{-1})	Gross cropped area (GCA) ('000 ha)	Soybean area (% of GCA)
Amravati	94.0	100.4	1.07	1011.0	9.3
Chhatarpur	37.5	26.3	0.70	467.0	8.0
Damoh	67.9	60.1	0.89	378.0	18.0
Khandwa	77.7	43.0	0.55	524.0	14.8
Jabalpur	42.7	41.7	0.98	630.0	6.8
Jhabua	27.5	16.3	0.59	459.0	6.0
Rewa	29.4	17.2	0.59	492.0	6.0
Satna	46.0	27.8	0.60	473.0	9.7
Shivpuri	49.7	34.9	0.70	516.0	9.6
Vidisha	83.3	80.2	0.96	606.0	13.7
Khargone	34.1	23.3	0.68	742.0	4.6
Buldhana	24.4	28.8	1.18	814.1	3.0
Chandrapur	58.4	69.0	1.18	556.7	10.5
Kolhapur	48.2	98.4	2.04	615.2	7.8
Sangli	49.3	110.0	2.23	658.8	7.5
Yeotmal	35.4	53.0	1.50	971.6	3.6
Bundi[1]	31.2	27.9	0.89	334.2	9.3
Belgaum	41.7	33.0	0.79	999.9	4.2
Nainital	9.5	4.0	4.42	85.2	11.1
Akola	24.2	28.9	1.19	1049.3	2.3
Jhansi	46.7	36.5	0.78	401.4	11.6
Rajnandgaon	37.1	26.2	0.71	626.0	5.9
Total	995.9	986.9	0.96		
SD	20.6	29.4	0.46		
CV (%)	2	3	48		

1. Data for 1994/95.

from 270 to 300 days. The tertiary zone includes 42 districts with 12 districts of Madhya Pradesh (Bastar, Bilaspur, Durg, and Raipur now transferred to Chattisgarh), 13 of Maharashtra, 12 of Uttar Pradesh (Almora, Pithorgarh, Tehri Garhwal, and Uttar Kashi now transferred to Uttaranchal), 3 of Gujarat, and 2 of Karnataka (Table 1.4). Tertiary soybean production zone overlaps parts of AEZs 4, 5, 6, 9, 10, 11, 12, and 14. The characteristics of these zones, except AEZ 9, have been described above. AEZ 9 comprises the northern plain, having alluvial derived soils and semi-arid climate; the length of growing season varies from 120 to 150 days.

The development of soybean crop in the primary zone appears to be characterized by an exponential increase in area and production (Fig. 1.4). While the area under the crop and production were negligible in 1983/84, this zone produced 4.2 million t of soybean from an area of 4.2 million ha during 1996/97 (Table 1.1 and Fig. 1.4). The inset table in Figure 1.4 shows the compound growth rate (CGR) of soybean area, production, and productivity of the primary zone during the periods 1983–90, 1990–97, and 1983–97. The CGRs of soybean area and production in the zone during 1990–97 are lower compared to those during 1983–90. This implies that the development of the soybean crop in this zone has been relatively slower during 1990–97. However, the productivity growth rate during 1990–97 is about 30% higher than that attained during 1983–90. This suggests that soybean development in the primary zone was predominantly extensive during 1983–90 and relatively more intensive during the later period. However, crop intensification measures adopted to increase the productivity of the zone (as indicated by higher CGR) do not seem to have achieved the desired effect. The average productivity of the primary zone during 1983–90 was 0.76 t ha^{-1}. Despite efforts to enhance the productivity levels, the productivity increased marginally to 1.04 t ha^{-1} during 1990–97 (Table 1.1). The coefficient of variation (CV) for the primary zone productivity is 19%, indicating that efforts are needed to increase the productivity of soybean while maintaining low CV in productivity in the primary zone.

The soybean development pattern in the secondary zone is generally similar to that in the primary zone during 1983–97 (Fig. 1.5). Area and production showed an increasing trend until 1993–94 and these declined during 1994–95. The data on CGRs of area and production in the secondary zone reveal that the area under the crop increased at a slower rate during 1983–90 and later increased at a higher rate compared to that in the primary soybean zone. The productivity of this zone is marginally lower (0.96 t ha^{-1}) compared to that of the primary zone (1.04 t ha^{-1}) (Table 1.1). High CV in productivity (48%) indicates that high productivity levels need to be achieved while lowering the CV in productivity.

In the tertiary zone, soybean area and production peaked in 1985 (Fig. 1.6). Subsequently, there was a gradual decline until 1987 and a sharp decline in 1988. Only after 1992, the soybean crop has begun to spread again in this zone. Nevertheless, area and production values were lower in 1995 compared to those in 1985, and started increasing again after 1995. The area and production CGRs during 1983–90 were negative. The average productivity of the zone during

Table 1.4. Area and production of soybean in the tertiary soybean production zone of India during 1996/97.

District	Area ('000 ha)	Production ('000 t)	Productivity (t ha^{-1})	Gross cropped area (GCA) ('000 ha)	Soybean area (% of GCA)
Balaghat	0.3	0.4	1.33	353.0	0.1
Bastar	0.3	0.3	1.00	906.0	0.0
Bilaspur	5.9	4.8	0.81	1072.0	0.6
Datia	3.0	2.8	0.93	147.0	2.0
Durg	7.9	4.8	0.61	804.0	1.0
Gwalior	6.6	10.9	1.65	307.0	2.1
Mandla	12.1	10.8	0.89	574.0	2.1
Morena	14.0	17.9	1.28	484.0	2.9
Panna	5.6	3.7	0.66	280.0	2.0
Raipur	0.8	0.8	1.00	1188.0	0.1
Shahdol	5.7	3.2	0.56	576.0	1.0
Sidhi	0.7	0.4	0.57	483.0	0.1
Ahmednagar	0.8	1.1	1.38	1441.4	0.1
Aurangabad	3.5	4.5	1.29	941.0	0.4
Bhandara	11.2	12.9	1.15	416.0	2.7
Dhule	2.0	3.4	1.70	804.9	0.2
Jalgaon	3.6	5.5	1.53	1172.0	0.3
Nanded	1.8	3.0	1.67	816.0	0.2
Nasik	1.9	2.6	1.37	977.9	0.2
Parbhani	5.2	6.6	1.27	1285.1	0.4
Satara	9.8	14.8	1.51	685.0	1.4
Almora	0.4	0.2	0.47	174.1	0.2
Banda	2.7	2.1	0.77	600.9	0.4
Bareilly	0.4	0.3	0.76	522.4	0.1
Chamoli	0.1	0.1	0.48	66.7	0.2
Garhwal	0.9	0.4	0.4	135.8	0.7
Hamirpur	2.6	2.0	0.77	357.0	0.7
Jalaun	6.6	5.1	0.77	388.7	1.7
Pithorgarh	1.4	0.7	0.47	117.9	1.2
Shajahanpur	0.3	0.3	0.74	585.0	0.1
Tehri Garhwal	0.3	0.2	0.47	107.4	0.3
Uttar Kashi	0.1	0.0	0.47	46.6	0.2
Broach[1]	2.2	1.5	0.68	431.1	0.5
Dangs[1]	0.7	0.3	0.43	56.7	1.2
Vadodara[1]	7.6	10.6	1.40	567.1	1.3
Lalitpur	11.5	12.1	1.05	306.1	3.8
Beed	0.9	1.0	1.11	913.4	0.1
Jalna	4.0	3.3	0.83	722.7	0.6
Latur	4.2	4.6	1.10	69.3	0.6
Osmanabad	1.4	1.5	1.07	718.3	0.2
Bijapur	4.3	3.0	0.69	1554.0	0.3
Dharwad	2.5	2.0	0.78	1355.7	0.2
Total	158.0	166.5	0.95		
SD	3.7	4.5	0.38		
CV (%)	2	3	40		

1. Data for 1994/95.

this period was about 0.75 t ha^{-1}. During 1990–97, average soybean productivity in the tertiary zone was higher than that of the secondary zone and comparable to that of the primary zone. Although the average productivity levels of primary and tertiary production zones are similar, the variability associated with soybean yields in the tertiary zone is about twice that in the primary zone (Table 1.1), indicating that productivity gains are needed along with reduction in variability in yields in this zone.

Soybean in the primary zone

As seen in Table 1.2, the primary production zone accounted for 4.2 million ha (78% of the total soybean area) and produced 4.2 million t (78% of the annual production) of soybean in 1996–97. In contrast, negligible area was under soybean cultivation during 1983/84. Within a span of a decade or so, the primary zone has attained the status of a leading soybean producer in the country. This raises a few questions: How was such an impressive rate of growth in soybean cultivation achieved? Was it at the cost of other crops in the zone? To answer these questions, we analyzed the cropping pattern in the primary zone during 1983–95. Based on this analysis, the following observations have been noted.

Trends in area and production of important crops and land area left fallow in the primary zone during 1983–95 are shown in Figures 1.7 and 1.8 and Table 1.5. The primary zone produced 1.6 million t of sorghum from an area of 2.1 million ha during 1983/84. However, by 1994/95, the area under this crop was drastically reduced to 0.81 million ha with a production of 0.53 million t. It is clearly seen in Figure 1.7 that sorghum cultivation declined linearly during 1983–95. This is also evident from the negative CGRs of sorghum crop (see the inset table in Fig. 1.7). Initially, the rate of decline in sorghum area was slow (2.6% yr^{-1} during 1983–90). However, there was a pronounced decline (10.3% yr^{-1}) during 1990–95 (with an overall rate of decline of 5.5% yr^{-1} during 1983–95). Other important crops of the primary zone such as rice and pigeonpea also showed a similar trend during 1983–95. The rates of decline in area under rice and pigeonpea during this period were 1.8% and 1.7% respectively. However, these rates of decline were lower than that of sorghum. The trend in the annual fallow land shows an increase in the area until 1991/92 and a subsequent decrease. In recent years, the fallow land declined at the rate of 3.6% per year.

While area under sorghum, rice, pigeonpea, and fallow land have declined during 1983–95 in the primary zone, the area under soybean has continuously increased. Area sown to other minor crops in the zone also decreased from 1983 to 1995 (Table 1.5). Thus, we can conclude that soybean area has been expanding in the primary zone in the areas that were previously sown to sorghum, rice, pigeonpea, and other crops or left as cultivated fallow during the rainy cropping season (Fig. 1.8 and Table 1.5).

Table 1.5. Area, production, and productivity of rainy season crops in relation to gross cropped area (GCA) of soybean primary zone in India during 1983 and 1995.

Crop	Area ('000 ha)	Production ('000 t)	Productivity (t ha^{-1})	% of GCA
1983 (GCA = 11.887 million ha)				
Soybean	525	329	0.62	4.40
Sorghum	2069	1602	0.77	17.40
Rice	329	278	0.84	2.77
Pigeonpea	363	277	0.76	3.05
Groundnut	261	149	0.57	2.19
Linseed	257	78	0.30	2.16
Sesame	199	31	0.16	1.67
Minor pulses	890			7.48
Fallow	246			2.07
1995 (GCA = 13.547 million ha)				
Soybean	3532	3296	0.92	26.07
Sorghum	806	532	0.66	5.95
Rice	267	314	1.18	1.97
Pigeonpea	250	187	0.75	1.85
Groundnut	166	156	0.94	1.23
Linseed	147	61	0.42	1.09
Sesame	67	16	0.24	0.50
Minor pulses	603			4.45
Fallow	336			2.48

Simulated potential yields

Crop growth is a result of various complex and inter-related physical and physiological plant processes operating during the life cycle of a crop. Crop growth simulation models, which integrate these processes, provide the opportunity to simulate crop yields in a given climate-soil environment. These models can also be used to optimize agronomic management in response to single or multiple inputs to achieve a given level of crop yields. When coupled with historical weather data, these models could also be used to determine potential productivity, both water non-limiting and water limiting yields, and the yield variations caused by variable weather. In this study we have quantified the water limiting potential yields of soybean and yield variability for the 11 benchmark sites within the soybean-growing region (Table 1.6).

Table 1.6. Geographical location and climate of the benchmark sites in soybean production zones in India.

Location	Latitude (N)	Longitude (E)	Elevation (m)	Annual rainfall (mm)	Potential evapo-transpiration (mm)	Weather years
Primary zone						
Raisen	23° 24’	78° 12’	-	1141	-	17
Betul	21° 55’	77° 54’	658	1223	1370	22
Guna	24° 39’	77° 19’	478	1032	1511	21
Bhopal	23° 16’	77° 25’	523	1139	1554	28
Indore	22° 43’	75° 48’	567	1068	1814	13
Kota	25° 11’	75° 51’	257	734	-	30
Wardha	20° 36’	78° 12’	-	1113	-	18
Secondary zone						
Jabalpur	23° 10’	79° 57’	393	1548	1401	22
Amravati	20° 56’	77° 47’	-	856	-	19
Belgaum	15° 51’	74° 32’	753	1112	-	18
Tertiary zone						
Hyderabad	17° 27’	75° 54’	540	909	1758	26

To simulate the potential yields of soybean we used the soybean crop growth model available in the Decision Support Systems for Agro-technology Transfer (DSSAT) v 3.0 (Tsuji et al. 1994). The model needs inputs of daily weather data, soil, and the cultivar-specific parameters to simulate the plant growth. Past weather data were obtained either from the India Meteorology Department (Pune) or directly from the agricultural research stations that operate the meteorological stations (Table 1.6). Annual rainfall at the selected locations ranged from 734 to 1548 mm and potential evapotranspiration (PET) from 1370 to 1814 mm. Simulations were performed for the period ranging from 13 to 30 years depending upon the availability of data for the benchmark site. Wherever solar radiation data were not available, these were estimated from maximum and minimum temperatures.

The soils in the soybean-growing regions in India are mainly Vertisols and associated soils. The soils data were obtained from the soil survey reports published by the National Bureau of Soil Survey and Land Use Planning, Nagpur, India (Lal et al. 1994). For a given benchmark site the data of the nearest soil series were used for this analysis. The soils data file needed to execute the soybean model was created by using the software available in DSSAT and the data on soil characteristics of a location. This program estimated saturation, upper and lower limits of water availability, runoff curve number, and drainage coefficients. The depth of soils at various locations varied from 91 to 240 cm, and that gave extractable soil water-holding capacities ranging from 77 to 283 mm for the soil profiles (Table 1.7).

Table 1.7. Soils type and characteristics of benchmark locations used for soybean yield simulation.

Location	Soil type	Soil series	Soil depth (cm)	Maximum extractable water (mm)
Primary zone				
Raisen	Vertisol	Jamra	140	166
Betul	Vertisol	Jambha	240	283
Guna	Vertisol	Saunther	91	77
Bhopal	Vertisol	Jamra	140	166
Indore	Vertisol	Sarol	160	195
Kota	Vertisol	Chambal	188	224
Wardha	Inceptisol	Sukali	150	179
Secondary zone				
Jabalpur	Vertisol	Kheri	150	177
Amravati	Vertisol	Jambha	240	283
Belgaum	Vertisol	Achmatti	170	189
Tertiary zone				
Hyderabad	Vertisol	Kasireddipalli	112	153
			127	184

The simulations were performed for a widely cultivated cultivar (PK 472) for which the genetic coefficients were determined using crop growth and development data from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. This cultivar matures in about 95–100 days. A plant population of 35 plants m^{-2} at 30-cm row spacing was considered throughout the simulation study. The simulations were performed for a sowing window of June 1 to July 28. The simulated crop was sown on a day when the soil moisture content in the top 30-cm soil depth reached at least 40% of the extractable water-holding capacity. Sowing was not done if this condition was not satisfied. The model outputs for each year were: sowing and harvest dates, biomass and seed yields, and water balance components of soybean. The means, standard deviations, and the minimum and maximum values were also determined.

Simulated yields and yield gaps

Simulated yields showed year-to-year variation caused by weather variability. There was a large difference between the maximum obtainable yield and the minimum yields for the selected locations (Table 1.8). Mean simulated yield obtained for a location was compared with the mean

Table 1.8. Simulated soybean yields and yield gap for the selected locations in India.

Location	Mean sowing date	Mean harvest date	Simulated yields (kg ha^{-1}) Minimum	Maximum	Mean	SD	Mean observed yield[1] (kg ha^{-1})	Yield gap (kg ha^{-1})
Primary zone								
Raisen	22 Jun	11 Oct	367	4659	3051	1278	-	-
Betul	19 Jun	8 Oct	980	3423	2371	636	858	1513
Guna	30 Jun	14 Oct	322	2985	1695	957	840	855
Bhopal	16 Jun	8 Oct	805	3064	2310	615	1000	1310
Indore	22 Jun	10 Oct	796	3329	2305	980	1122	1183
Kota	3 Jul	16 Oct	0	3364	1249	979	1014	235
Wardha	17 Jun	6 Oct	1837	3973	2997	653	1042	1955
Secondary zone								
Jabalpur	23 Jun	11 Oct	1122	2864	2242	480	896	1346
Amravati	18 Jun	8 Oct	459	2744	1618	738	942	676
Belgaum	17 Jun	30 Sep	891	3179	1991	661	570	1421
Tertiary zone								
Hyderabad (shallow soil)	20 Jun	5 Oct	752	3370	2700	689	-	-
Hyderabad (medium-deep soil)	20 Jun	5 Oct	700	3396	2664	705	-	-

1. Mean of reported yields of last five years.

observed yield of the last five years to calculate the yield gap. The simulated mean yield in Raisen, Hyderabad, and Wardha was greater than 2500 kg ha^{-1} while in Betul, Jabalpur, Bhopal, and Indore it ranged from 2000 to 2500 kg ha^{-1}. In other locations the simulated mean yield ranged from 1200 to 2000 kg ha^{-1}. The yield gap in various locations ranged from 235 to 1955 kg ha^{-1}. The yield gap was minimal in Kota where sufficient soybean area is under irrigation. In Raisen, Betul, Bhopal, Indore, and Wardha, the mean yield gap ranged from 1183 to 1955 kg ha^{-1}. However, in some years greater yield gap is expected as indicated by the maximum obtainable yields. Based on the maximum obtainable yield, the yield gap ranged from 1812 to 2930 kg ha^{-1} for various locations. These results show that there is a considerable potential to bridge the yield gap between the actual and potential yield through adoption of improved resource management technologies.

Productivity constraints

Major constraints that limit the yields of soybean below the potential yield 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.
- Imbalanced use of chemical fertilizers and biofertilizers.
- Infestation by weeds, insect pests, and diseases.
- Lack of region-specific, high-yielding, and tolerant varieties to various abiotic and biotic stresses.
- 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.

Summary

Soybean is an important food crop grown during the rainy season in India. It is currently grown in the central-peninsular India on an area of about 6 million ha. It occupies a significant place in the agricultural economy of the country. The state of Madhya Pradesh contributes over 70% to the production and area in India. Other important soybean-growing states are Uttar Pradesh, Rajasthan, Maharashtra, Andhra Pradesh, Karnataka, Gujarat, and Tamil Nadu. The productivity of soybean, however, continues to be low, and it is estimated at less than 1 t ha^{-1}. Most of the increase in soybean production has come from area increase over the years. Potential mean yields across locations ranged from 1249 to 3050 kg ha^{-1}, whereas the observed yields ranged from 570 to 1120 kg ha^{-1}. Thus the mean yield gap across locations ranged from 235 to 1955 kg ha^{-1}. If water availability is not limiting soybean production, then the yield gap across locations ranges from 1810 to 2930 kg ha^{-1}. These results indicate that there is a tremendous scope for improving soybean yields. Currently the majority of the farmers do not use recommended plant protection or soil fertility management measures. Soil erosion is high in the Vertisol areas, thus reducing plant nutrients in the soil. The farmers add plant nutrients that are just adequate to meet the nutrient losses, and thus the yields are sustained at low levels. In order to bridge the yield gap, improved soil, water, and nutrient management practices on watershed basis, along with pest management, improved cultivars, use of improved farm machinery, and credit facilities to the small and marginal farmers are recommended for increasing productivity of soybean-based systems.

A good potential exists in India to increase soybean productivity. The soybean-growing region is endowed with relatively good quality soils and rainfall, which varies from 730 to 1550 mm annually. Through adoption of integrated watershed management approach, productivity of soybean-based systems could be substantially improved. However, the small and marginal farmers in the rural areas are constrained with inaccessibility to knowledge and scientific inputs and lack of credit availability. There is a scope for at least doubling the soybean productivity in the region by appropriate policy development and strengthening execution at grass-root level.

Section 2: Potential yields and yield gaps of selected crops in northeastern Thailand

Northeastern Thailand is situated between 14–19° N latitude and 101–106° E longitude. The area is about 17 million ha or one-third of the whole country. It covers 19 provinces: Ka La Sin, Khon Kaen, Chaiyaphum, Yasothon, Nakhon Phanom, Nakhon Ratchasima, Burirum, Maha Sarakham, Roi Et, Loei, Sri Sa Ket, Sakon Nakhon, Surin, Nong Kai, Udon Thani, Ubon Ratchathani, Mukdahan, Nong Bua Lam Phu, and Amnat Charoen (Fig. 2.1).

Despite the same amount of rainfall, northeastern Thailand is drier than northern and central Thailand because of the short rainy season. Farming is the main occupation and only 20% of total agricultural area is under irrigation. Land has potentially low productivity. The existing problems are salt affected soil, sandy soil, and soil erosion.

Topography

Northeastern Thailand or the "Khorat Plateau" is characterized by shallow basin (saucer-shaped basin) and slopes rather gently southeastward. The plateau consists of flat-topped mountain and dissected peneplain surface with undulating features. The elevation varies from 200 m above mean sea level (msl). The rim of the plateau is lifted and thus forms cuestas like mountain; steep escarpment bounded the plateau on the south and the west of the region. The elevation may rise to about 200–1000 m above msl. On the middle and the north of the region, Pu Pan range is located with bended shape directionally northwest and southeast. The elevation is greater than 600 m above msl. Considering differences in the geology, this region can be divided into 6 parts as given below.

Western Highland

The area is distinct by hilly to mountainous topography, except the area close to northeastern part which is undulating to rolling. It covers the province of Loei and some part of Udon Thani, Khon Kaen, Chaiyaphum, and Nakhon Ratchasima.

Northern Highland

The area is formed as thin strip on the northernmost part of the region. The topography is rolling to hilly lying underlaid by lower and middle Khorat group. It covers some part of Nong Kai province and Nakhon Phanom province.

Sakhon Nakhon Basin

The basin is in the north of the region. Sakon Nakhon province is located in the middle of the basin. The basin covers the provinces of Nakhon Phanom, Sakon Nakhon, Udon Thani, and Nong Kai.

Central Highland

The area is characterized by rolling to hilly topography. The range of Pu Pan is situated in the southeastern part.

Khorat Basin

The basin is located in the south of the region. Roi Et province and the north of Nakhon Ratchasima province are in the middle of the basin. Khorat Basin also covers the provinces of Surin, Sri Sa Ket, Nakhon Ratchasima, Ubon Ratchathani, Roi Et, Burirum, Maha Sarakham, Chaiyaphum, Yasothon, Khon Kaen, and Ka La Sin. The topography is flat or almost flat to undulating.

Southern Lowland

The area is situated on the southernmost part of the region, where Panom Dong Rak range is formed as a strip on the southernmost part. The topography slopes northward towards Mun river, and is characterized by flat to undulating land with some hilly topography in many areas especially the provinces of Surin and Burirum and the southeast of Nakhon Ratchasima province.

From the characterization given above, northeastern Thailand can be broadly divided into highlands, uplands, and lowlands (Fig. 2.2).

Climate

The northeastern Thailand, located in the low latitude, is influenced by tropical low rainfall climate and wet-dry monsoonal or tropical Savannah climate. During November to February, the area is influenced by the northeast monsoon from the Eurasian continent resulting in cooler and dry weather over the whole region. Southwest monsoon lasting from May to September brings warm and moist weather from the Indian Ocean to the region.

The mean annual rainfall in northeastern Thailand is 1,375 mm (Table 2.1 and Fig. 2.3). In the west and the middle of the region such as Chaiyaphum, Nakhon Ratchasima, Loei, Khon Kaen, and Roi Et province, the rainfall is lower than in the east and the north and is about 1,000–1,400 mm. Average number of rainy days in a year in this area is 108. On the east and the north such as Nakhon Phanom, Sakon Nakhon, Nong Kai, Ubon Ratchathani, Udon Thani, and Mukdahan provinces, the annual rainfall is about 1,500–2,300 mm. The highest rainfall (2324 mm) is in Nakhon Phanom province.

Table 2.1. Mean annual rainfall, number of rainy days, and mean annual temperature in northeastern Thailand during 1988–97.

Province	Mean annual rainfall (mm)	Number of rainy days in a year	Mean annual temperature (°C)
Mukdahan	1482	115	26.5
Sakon Nakhon	1593	123	25.7
Nong Kai	1755	128	26.5
Loei	1219	124	25.8
Udon Thani	1462	123	26.8
Ubon Ratchathani	1475	117	26.6
Nong Bua Lam Phu	1009	59	26.8
Amnat Charoen	1410	89	26.6
Chaiyaphum	1105	99	27.3
Ka La Sin	1131	86	26.7
Maha Sarakham	1382	71	26.5
Yasothon	1247	91	26.9
Nakhon Ratchasima	1034	104	27.4
Sri Sa Ket	1457	115	26.9
Khon Kaen	1202	107	27.3
Roi Et	1211	107	26.8
Nakhon Phanom	2324	135	26.2
Burirum	1244	86	26.7
Surin	1379	117	27.1
Average	1375	105	26.7

Source: Meteorology Department, Thailand.

The mean annual temperature during the 10-year period from 1988 to 1997 in northeastern Thailand was about 26.7°C. Summer extends from March to May; and winter from November to February. Maximum temperature is about 27.4°C in Nakhon Ratchasima province and about 25.7°C in Sakon Nakhon. Thus the year can be divided into three seasons: rainy season, winter, and summer.

Rainy season

Rainy season starts from May end or the beginning of June and extends up to the beginning of October due to the effect of the southwest monsoon. Because the ranges of Pnetchabun on the northeast and Dong Phayayen on the west, and the ranges of San Khampaeng and Phanom Dong Rak on the south serve as barriers, the rainfall due to the southwest monsoon is lower than the rainfall due to the depression from the South China Sea.

Winter

Winter lasts from mid-October to mid-February and is caused by the northeast monsoon from China which brings cool and dry climatic mass without vapor to the area. Thus it remains cooler in the north while the south remains warm.

Summer

The season extends from February to the end of May and is caused by the southeast monsoon from the South China Sea and the Gulf of Thailand. Because the northeast region is located far away from the Gulf of Thailand, the climate is hot and very dry in the region.

Soils

As recorded by the Survey Division, Thailand in 1996, northeastern Thailand has 9 soil sub-orders. These are: Usterts, Aquepts, Tropepts, Ustolls, Aqualfs, Ustalfs, Aquults, Ustults, and Udults (Fig. 2.4). The soils are characterized by sandy or sandy loam to sandy clay loam texture with low to medium fertility. Ustults is the largest one and mainly used for field crops, while Aquults is less than Ustults which is flat and mainly used for paddy rice.

Watershed area

Severity of land shortage and increased population has resulted in the encroachment of forest area for annual cultivation. Changes in economic system from agriculture to industry has resulted in increased demand for water. Unfortunately, surface water is available only in rainy season and some of it flows into the sea.

Soil erosion is the main cause of degradation of natural resources (Table 2.2 and Fig. 2.5). Sedimentation is the secondary process after soil erosion. The sediments may be transported to streams or reservoirs. Soil erosion has caused loss of nutrients from the soil. This has resulted in decreased crop production and increase in fertilizer application every year.

Table 2.2. Runoff in the three watersheds in northeastern Thailand.

Watershed	Drainage area (km^2)	Mean annual runoff (million m^3)	Capacity (million m^3)	Loss (million m^3)
Mae Khong	57422	15800	1378	14422
Chi	49477	8035	4179	3856
Mun	69700	17440	3400	14040
Total	176599	41275	8957	32318

Source: Royal Irrigation Department, Thailand.

Potential yields and yield gaps

The amount of rainfall in northeastern Thailand is lower than that received by other regions. Therefore, agriculture is based mainly on low water requirement crops (upland crops) such as cassava, sugarcane, maize, upland rice, groundnut, soybean, and sunflower, which are important crops of this region. Five crops (rice, maize, soybean, groundnut, and sunflower) were selected to study the yield gap.

Rice

Rice is an important crop for the Thai society which directly consumes rice products. The rest of the product is exported to the international markets. Since 1979, Thai rice export is in the first range of world export. Of the total crop area of 100,000 km^2, the northeastern rice production area is about 5 million ha. The yield is low compared to other regions (Table 2.3).

Table 2.3. Rice production in Thailand in 1998.

Region	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
Northeastern	4567	8009	1756
Northern	1795	4975	2775
Central Plain	1505	4290	2850
Southern	428	885	2069

Source: Office of Agricultural Economics, Thailand.

The actual yield of rice in the northeastern region is 50% lower than the experimental yield and 11% lower than the national yield. Considering the morphogeology of the northeastern region, yield in highland and upland areas is lower than that of the whole country while it is higher in the lowland area (Table 2.4).

Table 2.4. Yield gap of paddy rice in northeastern Thailand.

Description	Actual yield (kg ha^{-1})	Yield gap (kg ha^{-1}) Experimental yield	Yield gap (kg ha^{-1}) National yield
Experimental	3537	-	-
National	1962	1575 (44%)	-
Northeastern region	1756	1781 (50%)	206 (11%)
Northeastern highland[1]	1219	2319 (65%)	743 (38%)
Northeastern upland	1806	1731 (48%)	156 (8%)
Northeastern lowland	2169	1369 (38%)	–206 (11%)

1. Upland rice.

Source: Department of Agriculture; Office of Agricultural Economics, Thailand.

Upland rice is grown for household consumption. Farmers do not grow upland rice for trading, as the grain quality is not as good as the one required for the market. Moreover, yield is 50% lower than that of paddy rice. Though, there are many studies on selection of high-yielding varieties, upland rice is still not able to compare with the development of paddy rice variety. Upland rice yield of the northeastern region is about 18% lower than that of the experimental yield and about 7% lower than that of the whole country (Table 2.5).

Table 2.5. Yield gap of upland rice in northeastern Thailand.

Description	Actual yield (kg ha^{-1})	Yield gap (kg ha^{-1}) Experimental yield	Yield gap (kg ha^{-1}) National yield
Experimental	1487	-	-
National	1312	175 (11%)	-
Northeastern highland	1219	269 (18%)	94 (7%)

Source: Department of Agriculture; Office of Agricultural Economics, Thailand.

Maize

Maize is an important food crop for human and animal feed after rice. In Thailand, maize has been grown for more than 40 years. After importing from upcountry, selection and breeding for high yield has resulted in higher yields. During 1988–92, Thai maize production decreased by 7% because of low rainfall. Also, farmers shifted to other crops such as sugarcane and cassava. Of the total production area of 1.4 million ha, about 0.37 million ha are in northeastern Thailand. The yields are lower compared to other regions (Table 2.6).

Table 2.6. Maize production in Thailand in 1998.

Region	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
Northeastern	374	915	2450
Northern	657	1890	2875
Central Plain	365	1116	3062
Southern	17	44	2588

Source: Office of Agricultural Economics, Thailand.

Maize yield in the northeastern region is 47% lower than the experimental yield, and 12% lower than the national yield. Considering the morphogeology, yield in highland and upland areas is lower than that of the whole country while it is higher in the lowland area (Table 2.7).

Table 2.7. Yield gap of maize in northeastern Thailand.

Description	Actual yield (kg ha^{-1})	Yield gap (kg ha^{-1}) Experimental yield	Yield gap (kg ha^{-1}) National yield
Experimental	4706	-	-
National	2806	1900 (40%)	-
Northeastern region	2450	2256 (47%)	356 (12%)
Northeastern highland	1525	3181 (67%)	1281 (45%)
Northeastern upland	2387	2319 (49%)	419 (15%)
Northeastern lowland	3494	1212 (25%)	–687 (24%)

Source: Department of Agriculture; Office of Agricultural Economics, Thailand.

Soybean

In Thailand, soybean cultivation started in 1936. In northern Thailand, farmers were recommended to grow soybean after rice. The seed was imported from China and Japan which was not suitable for Thailand. In 1960, varietal improvement was initiated and many good varieties were produced. With the expansion of animal husbandry, requirement of soybean reached about 2 million t yr^{-1}. From the total production area of 0.43 million ha, 0.5 million t yr^{-1} soybean was produced.

Soybean yield of the northeastern region is 37% lower than that of the experimental yield and 1% lower than that of the whole country. Considering morphogeology, yield in highland and upland areas is lower than that of the whole country and higher in the lowland area (Tables 2.8 and 2.9).

Table 2.8. Soybean production in Thailand in 1998.

Region	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
Northeastern	56	72	1200
Northern	330	385	1200
Central Plain	49	70	1244
Southern	0.029	0.037	1269

Source: Office of Agricultural Economics, Thailand.

Table 2.9. Yield gap of soybean in northeastern Thailand.

Description	Actual yield (kg ha^{-1})	Yield gap (kg ha^{-1})	
		Experimental yield	National yield
Experimental	1912	-	-
National	1212	700 (36%)	-
Northeastern region	1200	712 (37%)	12.5 (1%)
Northeastern highland	975	937 (49%)	237.0 (19%)
Northeastern upland	1125	787 (41%)	87.5 (7%)
Northeastern lowland	1287	625 (32%)	–75.0 (6%)

Source: Department of Agriculture; Office of Agricultural Economics, Thailand.

Groundnut

Groundnut is an important legume crop to the economy of Thailand. It was introduced from Portugal. In 1962, the Department of Agriculture, Thailand started to improve groundnut varieties. Of 0.72 million ha of production area in the country, groundnut area in the northeastern region is about 36,570 ha. The yields are still low (Table 2.10).

Table 2.10. Groundnut production in Thailand in 1998.

Region	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
Northeastern	36	51	1337
Northern	47	70	1487
Central Plain	15	24	1544
Southern	5	3	674

Source: Office of Agricultural Economics, Thailand.

Yield of northeastern Thailand is 23% lower than the experimental yield and 7% lower than that of the whole country. Considering morphogeology, yield of highland and upland areas is lower than that of the whole country and higher in the lowland area (Table 2.11).

Table 2.11. Yield gap of groundnut in northeastern Thailand.

Description	Actual yield (kg ha^{-1})	Yield gap (kg ha^{-1})	
		Experimental yield	National yield
Experimental	1737	-	-
National	1444	294 (16%)	-
Northeastern region	1337	400 (23%)	106 (7%)
Northeastern highland	1162	575 (33%)	281 (19%)
Northeastern upland	1319	419 (24%)	125 (9%)
Northeastern lowland	1544	194 (11%)	–100 (7%)

Source: Department of Agriculture; Office of Agricultural Economics, Thailand.

Sunflower

Sunflower was introduced in Thailand in 1973. But it remained an unsuccessful crop because of its low yield and some marketing problems. It is grown to some extent in the central region of Thailand. In other regions it is grown by few farmers and still not classified as an economic crop (Table 2.12). In the northeastern region, the actual yield is 6% lower than the experimental yield and 0.4% lower than the national yield (Table 2.13).

Table 2.12. Sunflower production in Thailand in 1993.

Region	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
Northeastern	10	15	1469
Northern	28	43	1537
Central Plain	0.043	0.064	1487

Source: Department of Agriculture; Khon Kaen University, Khon Kaen; Land Development Department, Thailand.

Table 2.13. Yield gap of sunflower in northeastern Thailand.

	Actual	Yield gap (kg ha^{-1})	
Description	Yield (kg ha^{-1})	Experimental yield	National yield
Experimental	1594	-	-
National	1494	100 (6%)	-
Northeastern highland	1487	107 (6%)	6.25 (0.4%)

Source: Department of Agriculture; Khon Kaen University, Khon Kaen; Land Development Department, Thailand.

Productivity constraints

Major constraints that limit the yields of crops in northeastern Thailand are:

- Frequent droughts and floods.
- Low soil fertility.
- Soil erosion and land degradation.
- Poor soil water conservation practices.
- Low-yielding crop varieties.
- Shortage of labor.
- Poor agricultural extension for technology transfer.

- Uncertainty of prices and marketing problems.
- Uncertainty of tenure as a disincentive to invest in land development.
- Poor credit facilities and high interest rates by private money lenders.

Summary

Northeastern Thailand has 17 million ha or constitutes one-third of the country. It covers 19 provinces and plays a significant role in the agricultural economy of the country. Despite the same amount of rainfall as in the northern and central Thailand, northeastern Thailand is drier and has relatively short rainy season. Northeastern Thailand can be broadly divided into highlands, uplands, and lowlands. Mean rainfall in the region is about 1375 mm. Soils are sandy or sandy loam to sandy clay loam in texture with low to medium soil fertility. Increased population and shortage of land has resulted in encroachment of forest area for annual cultivation. This in turn has resulted in land degradation because of soil erosion and loss of soil fertility and thus crop yields obtained are lower than the potential yields. Yield gap of paddy rice ranges from 1369 to 2319 kg ha^{-1} (38 to 65%) and that of upland rice ranges from 175 to 269 kg ha^{-1} (11 to 18%) across northeastern Thailand. The yield gap of upland crops ranges from 1212 to 3181 kg ha^{-1} (25 to 67%) in maize, 32 to 49% in soybean (625 to 937 kg ha^{-1}), and 11 to 33% in groundnut (194 to 575 kg ha^{-1}). Sunflower has not been able to establish as a successful crop with the farmers. Bridging the yield gap of upland cropping systems would require adoption of improved soil and water conservation practices, integrated soil fertility management including the greater use of legumes, improved cultivars, stable land tenure system, affordable credit facilities and assured prices, and marketing of agricultural produce.

Section 3: Potential yields and yield gaps of selected crops in northern Vietnam

Vietnam lies between 8° 33' to 23° 21' N and 102° 10' to 109° 26' E. Administratively, the country is divided into 62 provinces. Although a humid country, it has tropical, subtropical, and temperate climates in pockets. This diverse climate provides for harnessing ecological productivity through various crops and cropping systems. Rice and maize among cereals, and groundnut, soybean, and mung bean among legumes are important crops in Vietnam (Chinh et al. 2001). Although land area of Vietnam is more than 330,000 km^2, about 75% is covered by mountains and midlands. Cultivated area is about 8.3 million ha, of which 4.2 million ha is occupied by rice. Arable area can be expanded up to 100 million ha or more, in plateau and slopes (<15% slope) with probability of drought and unfavorable growth conditions for crops. Average area for cultivation per head is approximately 0.1 ha. It is therefore necessary to enhance use of improved land management methods to ensure sustainability of land resources.

Agroecological zones of Vietnam

Vietnam has been divided into 9 AEZs based on soil type, rainfall, temperature, and length of growing period (Fig. 3.1). These zones are:

AEZ I – North-west

AEZ II – North-Hoang Lien Son

AEZ III – North-east

AEZ IV – Red River Delta

AEZ V – North-central Coast

AEZ VI – Central Highlands

AEZ VII – South-central Coast

AEZ VIII – North-east South

AEZ IX – Mekong River Delta

Northern Vietnam – the study area

Northern Vietnam comprises AEZ I to AEZ IV (Fig. 3.1). There are 25 provinces in AEZ I to AEZ IV (Fig. 3.2). The relief of the area consists of highlands, uplands, and lowlands (Fig. 3.3). About one-third area of northern Vietnam comprises of rainfed sloping lands. The yield gap study was conducted in the four provinces, namely Phu Tho, Vinh Phuc, Ha Tay, and Ninh Binh.

Physical environment

Topography

The rainfed sloping lands vary from densely packed hills to plains with isolated knolls. Hills are rounded, with level tops and convex slopes of 5–40°. Most slopes are 20–25° with elevations ranging between 15 m and 200 m above sea level. Between the hills are narrow valleys with alluvial soils used for irrigated rice cultivation (Long et al. 1999).

Climate

The climate is mainly monsoonal with hot, wet summer during April to August and cool, cloudy, moist winters during December to February. The total annual rainfall is 1100 to 3000 mm (Fig. 3.4). The average annual temperature is 25°C, with an average maximum of 35°C (in August) and an average minimum of 12°C (in January). The southwest monsoon occurs from May to October bringing high rainfall; temperature too is high. November to May is the dry season with a period of prolonged cloudiness, high humidity, and light rain. The length of growing season in northern Vietnam ranges from 180 to 365 days thus providing an opportunity for cropping throughout the year in some regions (Table 3.1 and Fig. 3.5).

Table 3.1. Features of the agroecological zones of northern Vietnam.

Agroecological zone (AEZ)	Provinces	Rainfall (mm)	Temperature	Soils	Length of growing period	Remarks
North-west (AEZ I)	Lai Chau, Son La, Hoa Binh	1108–3000	8–42°C	Plinthic Acrisols, Humic Ferralsols	NA[1]	Potential evaporation varies from 800 to 1818 mm. Important crops are maize, sweet potato, cassava, medicinal plants, and seed vegetables.
North-Hoang Lien Son (AEZ II)	Lao Cai, Yen Bai, Ha Giang, Tuyen Quang, Vinh Phuc, Phu Tho	1500–3000	10–15°C (in winter) >20°C (other months)	Ferric Acrisols	8–12 months	Severe soil erosion due to storms, intensive rains, and deforestation. Good potential for soybean, wheat, maize, cassava, medicinal plants, and timber and fruit trees.
North-east (AEZ III)	Cao Bang, Quang Ninh, Lang Son, Bac Can, Thai Nguyen, Bac Giang	1276	>20°C (November–March) <20°C (remaining months)	Flinthic Acrisols (yellow-red group)	7 months	Suitable for fruit trees, tea, tobacco, winter crops, medicinal plants, and seed. vegetables.
Red River Delta (AEZ IV)	Hanoi, Ha Tay, Hai Phong, Hung Yen, Hai Duong, Ha Nam, Nam Dinh, Thai Binh, Ninh Binh, Bac Ninh	1600–2200	NA	Fluvisols	10–11 months	Important crops are rice, maize, sweet potato, and food legumes.

1. NA = Information not available.

Source: Chinh (2001).

Soils

Soils are complex and varied. The basic process of soil formation is ferralitic, through weathering of the parent material, leading to accumulation of rather high amounts of iron and aluminum, with leaching silica and most base cations. The most common soil type is the red-yellow ferralitic (Plinthic or Ferric Acrisols, Humic Ferralsols) (Fig. 3.6). These soils accumulate iron and aluminum to form laterite. Mineralization is rapid, and organic substances quickly break down resulting in low humus content. Intensive surface cultivation and deep leaching processes make the soil very acidic and poor in nutrients. Nitrogen, phosphate, and cations are easily dissolved or carried away to such an extent that these soils cannot be cultivated for long before they suffer serious degradation. In extreme cases of erosion, a hardpan of laterite nodules is exposed (Long et al. 1999).

Vegetation

The monsoon tropical climate with high humidity prevailing in the rainfed sloping lands of northern Vietnam is quite favorable for forest growth and development. Originally these were almost completely covered by forest. At present, planted and natural forest covers only about 26% (Long et al. 1999).

Major crops

Rice, cassava, sweet potato, maize, tea, and groundnut are the most important crops in the production system of the rainfed sloping lands. The strategy of cultivation is mixed intensive lowland cultivation, so that land is covered by vegetation year-round (Long et al. 1999). The production system has a fixed topographic location. The lowland and terrace irrigated agricultural systems are used to grow rice. Crops such as cassava, maize, groundnut, mung bean, and soybean are found on the gentler upland slopes. Plantations for cash crops are located on the upper and medium slopes. These include tea, lacquer trees, and other forest plantations.

Rice

Rice is the most important food crop. It is the main source of nutrition for people and constitutes the basis of the daily diet. Until recently, the goal at both the district and household levels was to be self-sufficient in rice. The paddy fields are located where people prefer to concentrate their labor in preference to work on other crops. Cultivation is highly intensive and employs advanced technology, including pesticides, improved seed varieties, and fertilizer (both chemical and organic).

Two crops are grown: spring and summer. The first crop is sown in December and transplanted in late January to early February, and harvested in late May or early June. The second cropping season starts in June with preparation of the seedbed and sowing. Transplanting is performed in July; during October and early November, the crop is harvested. Both the cropping periods have problems. For the spring crop there is a shortage of water, and in the summer there is often a surplus so that flooding is a hazard. There is more land with sufficient water during summer which makes the summer crop production higher than the spring crop production. With minor adjustment of the rice planting schedules, it is possible to produce vegetables in between the two rice crops or to grow winter catch crops (mung bean, soybean, sweet potato, potato, maize) on drained paddy fields following the harvest of the summer rice crop.

Maize

In terms of land area, maize is the most important crop after rice. Maize is generally grown on gentle slopes and is also a popular catch crop on drained paddy lands in the off-season. Productivity of the maize crop is low, with annual average of about 1.7 t ha^{-1}; productivity of winter crops is slightly higher. Maize grains are used for both human consumption and livestock feed.

Sweet potato

Sweet potato is the most popular winter catch crop on drained paddy lands. Sweet potato tubers and leaves are used for both human consumption and animal feed.

Cassava

Cassava is an important crop because it can substitute for rice as a staple food when rice production is low. Cassava tubers also provide feed for pigs, and the leaves are fed to the fish. Soil conservation is seldom practiced in cassava cultivation; consequently soils are rapidly degraded and eroded. Due to low soil fertility, cassava yields are low, about 8–10 t ha^{-1} per year. Higher yields of 15–18 t ha^{-1} are possible on newly opened lands.

Groundnut

Groundnut is one of the main foreign exchange earning crops apart from being the source of oil and protein for people and fodder for cattle. Spring (February to June) is most important for production of the crop. The autumn crop is mainly for obtaining high quality seed for the spring crop. Spring groundnut is grown under rainfed production systems in northern Vietnam. It is predominantly grown as a sole crop, but in some areas it is intercropped with sugarcane, maize, cassava, and upland rice during rainy season. A noticeable increase in area under groundnut production has been observed since 1994. Total area under groundnut in Vietnam is >250,000 ha and northern Vietnam has a share of about 112,100 ha (Fig. 3.7).

Soybean

Soybean is the second most important legume in Vietnam. About 65% of soybean is grown in highlands on soils with low fertility (Fig. 3.8). Red River Delta (northern Vietnam) and Mekong River Delta (southern Vietnam) are also important areas for soybean production since soybean can be grown all round the year in various cropping systems. Spring crop (February to July) is grown under favorable weather conditions, while summer or summer-autumn crop (May–September) experience high temperature and rainfall during growth and development stages. In winter (mid-September to December), low temperature and terminal drought are the main production constraints. Soybean is mainly grown after spring and autumn rice in the Red River Delta.

Mung bean

Mung bean is the third most important legume after soybean and groundnut. It occupies about 60,000 to 70,000 ha with a production potential of 0.6 to 0.8 t ha^{-1}. In Red River Delta, mung bean is grown round the year under irrigation and high input conditions for vegetable purpose with good yield (about 1.0 t ha^{-1}). It is cultivated extensively in North-east ecoregion covering about 26% of the total cultivated area. However, yields are low (0.5 t ha^{-1}) due to lack of suitable genotypes with resistance to diseases and pests.

Potential yields and yield gaps

In this study the potential yield is defined as the maximum yield obtained in research station field experiments conducted under optimal management. Such experiments were conducted at five sites (Table 3.2). Potential yield ranged from 4199 to 5420 kg ha^{-1} for maize, 2530 to 3255 kg ha^{-1} for groundnut, and 2900 to 3050 kg ha^{-1} for soybean. On-farm yields of the three crops were obtained by monitoring yields of 50 farmers at each site. The average on-farm yields were variable across sites and farmers (Table 3.2). Average maize yield ranged from 3000 to 3700 kg ha^{-1} across five sites. The yield gap, which is defined as the difference in experimental yield and on-farm yields, ranged from 1199 to 1961 kg ha^{-1} representing 28.5 to 39.5% of potential yield. On-farm yields of groundnut ranged from 1400 to 1600 kg ha^{-1} giving a yield gap of 1055 to 1655 kg ha^{-1}, which amounted to 41.3 to 50.8% of potential yield possible at five locations. On-farm soybean yields ranged from 1200 to 1500 kg ha^{-1} giving a yield gap of 1600 to 1800 kg ha^{-1}, which amounted to 50.8 to 60% of potential yield. The above results on yield gap show that the farmers are able to get almost two-third of the potential yield of maize. However, for groundnut and soybean, the yield gap is wide (40 to 60% potential yield) which needs to be bridged by improving management of these legumes.

Productivity constraints

It appears that the legumes have major constraints for production than cereals in Vietnam. Major abiotic, biotic, and socioeconomic constraints to production of legumes have been reviewed by Chinh et al. (2001). These are lack of credit facilities, low and unstable market price, lack of high-yielding varieties with drought tolerance, disease and insect pest resistance, and lack of improved production practices including soil, water, and nutrient management options. Legume production in Vietnam can be increased substantially by addressing these production constraints, extending legume cultivation in rice fallows and through crop diversification. Major problem with cereals is the excessive use of nitrogen fertilizer to obtain higher yields. This needs to be replaced with organic sources of nitrogen supply or by introducing legumes into the rotation with cereals in order to minimize environmental degradation.

Table 3.2. Experimental and on-farm yields of maize, groundnut, and soybean and their yield gaps in five provinces of northern Vietnam.

Province	Experimental yield (kg ha^{-1})	On-farm yield (kg ha^{-1})	Yield gap (kg ha^{-1})	% yield gap
Maize				
Hoa Binh	4701	3000	1701	36.2
Ha Tay	5420	3700	1720	31.7
Phu Tho	4199	3000	1199	28.5
Vinh Phuc	4961	3000	1961	39.5
Ninh Binh	4757	3200	1557	32.7
Groundnut				
Hoa Binh	2649	1500	1149	43.4
Ha Tay	3255	1600	1655	50.8
Phu Tho	2555	1500	1055	41.3
Vinh Phuc	2799	1450	1349	48.2
Ninh Binh	2530	1400	1130	44.7
Soybean				
Hoa Binh	2900	1300	1600	55.2
Ha Tay	3050	1500	1550	50.8
Phu Tho	3000	1200	1800	60.0
Vinh Phuc	2950	1300	1650	55.9
Ninh Binh	3000	1250	1750	58.3

Summary

Northern Vietnam comprises 25 provinces within AEZs I to IV. The relief of the area consists of highlands, uplands, and lowlands. About one-third of the area of northern Vietnam is rainfed sloping lands. Total annual rainfall varies from 1100 to 3000 mm. The length of growing season varies from 180 to 365 days thus providing round the year cropping in some parts. The most common soil type is the red-yellow ferralitic, which is poor in soil nutrients and suffers from serious degradation. Major crops are rice and maize among the cereals, and groundnut, soybean, and mung bean among the legumes. Analysis of yield gap showed that the farmers are able to get almost two-third of the potential yield of maize; however, for groundnut and soybean the yield gap was wider and ranged from 40 to 60% of potential yield. The yield gap needs to be bridged by adopting improved soil and water management and fertility management practices and by alleviation of various production constraints described earlier.

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