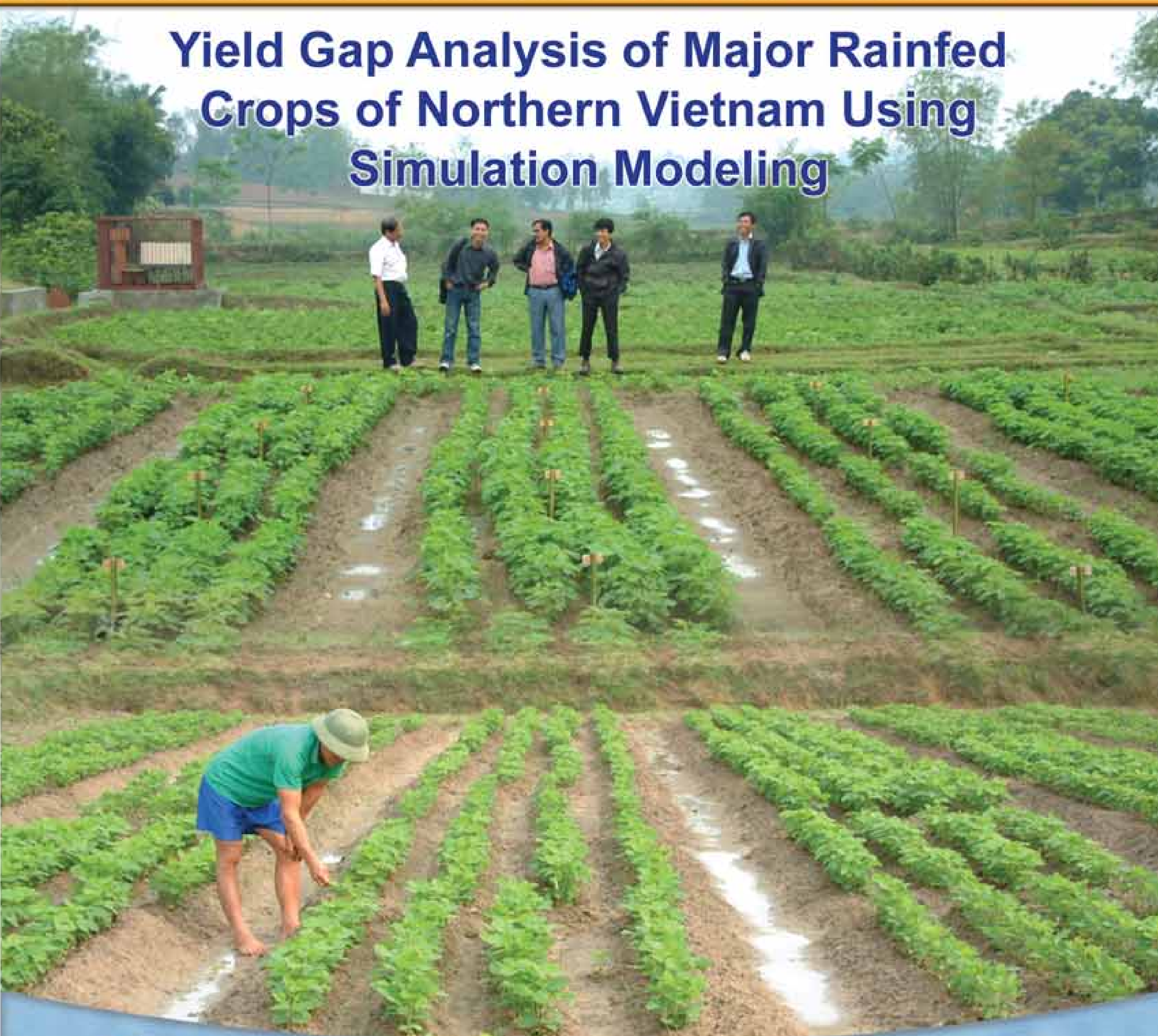
Global Theme on Agroecosystems

Report no. 26

Yield Gap Analysis of Major Rainfed Crops of Northern Vietnam Using Simulation Modeling



International Crops Research Institute for the Semi-Arid Tropics

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Comprehensive Assessment of Water Management in Agriculture

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Abstract

Total population of Vietnam is 82 million as of today. It is expected to increase to 95 million by 2010 and 126 million by 2020. With increasing demand for food in future, the pressure on uplands and midlands of northern Vietnam would increase to produce more food for millions of poor residing in Vietnam. Major crops of northern Vietnam are rice, sweet potato, maize, tea, peanut and soybean, in addition to other annual and perennial crops. The current study investigated the potential yields; yield gaps and water balance of maize, peanut and soybean crops, which have high potential in the region. We used crop simulation models of the three crops and the field data to evaluate the scope for increasing productivity and water harvesting in the six selected provinces of northern Vietnam. Analysis of the production data revealed that since 1994–95 the area, production and productivity of these crops have increased substantially. Improvements in productivity have been obtained with the introduction of improved crop varieties and management practices. However, large yield gaps still exist which are variable among districts and provinces. Overall, the yield gap is 1010 kg ha^{-1} for summer season and 680 kg ha^{-1} for spring season for soybean; 2650 kg ha^{-1} for spring season and 2010 kg ha^{-1} for autumn season for peanut; and for maize it is 1990 kg ha^{-1} for summer season and 1650 kg ha^{-1} for spring season, indicating the potential for future yield improvements. Because of high rainfall in northern Vietnam, significant amount of surface runoff and deep drainage occurs leading to land degradation. The vast potential of the rainfed areas of northern Vietnam could be harnessed through large-scale adoption of integrated genetic and natural resource management technologies in watershed context for increasing productivity and reducing land degradation.

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Yield Gap Analysis of Major Rainfed Crops of Northern Vietnam Using Simulation Modeling

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Contents

Introduction

Vietnam has a geographical area of 0.33 million km^2, out of which North Vietnam covers about 0.17 million km^2. North Vietnam has 2.95 million ha under agriculture, which constitutes 31% of the total agricultural land (9.4 million ha) in the country. Total population of Vietnam is 82 million and about 40.1 million live in North Vietnam. In terms of total population in the country, Vietnam ranks 7th in Asia and 12th in the world. Current annual rate of population growth is 1.47%. With this rate the population is expected to increase to 95 million by 2010 and 126 million by 2020 (Siem and Phien, 1999). About 80% of Vietnamese population lives in rural areas, employed in agriculture, forestry, fisheries and handicrafts (General Statistics Office, 2003).

Total food production in the country is 37.8 million tons and 14.2 million tons is contributed by North Vietnam. Of the total GDP of the country, the share of agriculture is 17.43%. Agriculture of North Vietnam contributes 6.42% to the total GDP of Vietnam. These data indicate the importance of North Vietnam to the economy of the country. The massive population growth has resulted in greater urbanization with more agricultural land being transferred to non-agricultural use. Most of the rice and peanut produced in the delta area is exported to UK, UAE, Canada, Iraq and Holland (FAO Trade, 1995–1999; General Statistics Office, 2003). Under such circumstances pressure on uplands and midlands is increasing for food production to fulfill the local demands and achieve food security for millions of poor residing in Vietnam. The Vietnam government has now a greater challenge on hand to achieve food security by 2010. Therefore, the uplands are expected to produce more food for meeting the local needs and supply to other regions.

Northern Vietnam comprises of approximately three-quarters of uplands (mountains and hills) and one-quarter of lowland. The per capita land area for agriculture is more than 1,840 m^2 in the uplands, while in the delta region it is only 300 m^2. The major crops of northern Vietnam are rice, sweet potato, maize, tea, peanut, mungbean and soybean. In the lowlands mainly annual crops are grown, while in the uplands both annual and perennial crops are grown. In the mountains, legume crops such as peanut, soybean and mungbean are grown after rice. These crops are important, as these are source of oil and protein for the ethnic minority people, fodder for cattle, and also help in improving soil fertility. Tea and cassava are also common crops as these are drought tolerant and have ability to grow under poor farm management practices, poor soil fertility and low inputs. Cassava is a staple food, when rice production is low and it also provides feed for animals in the upland area.

At present crop yields in northern Vietnam are low, which are 2.98 t ha^{-1} for maize, 1.63 t ha^{-1} for peanut and 1.22 t ha^{-1} for soybean. The main causes of low yields are the low adoption of improved soil, water, nutrient, crop and pest management practices. For enhancing productivity of the major crops in the region, it is important to assess their yield potential under rainfed conditions and identify constraints causing yield gaps. The main objectives of this study were:

i) To characterize natural resources of the six selected provinces in northern Vietnam particularly soils and climate, in relation to crop production.
ii) To estimate potential yields of rainfed maize, soybean and peanut using crop simulation modeling approach and research station experimental data; and
iii) To assess the yield gaps between water-limited potential yields (simulated yields or experimental yields) and achievable yields (farmer's yield under optimum management) and between achievable yields and province level yields.

The overall goal of this study was to estimate the potential contribution of northern Vietnam to the national food basket and to assess the yield gaps for maize, soybean and peanut crops and the constraints responsible for low yields.

Climate of northern Vietnam

Climate of northern Vietnam is monsoonal with hot and wet summers and cool, cloudy and moist winters. Total annual rainfall in northern Vietnam ranges from 1100–3000 mm (Fig.1). Average annual temperature is 25°C, with an average maximum of 35°C (in August) and minimum of 12°C (in January). Southwest monsoon occurs from May to October, bringing heavy rainfall and temperatures remain high. November to April is the dry season with a period of prolonged cloudiness, high humidity and light rain.

Climate of northern Vietnam can be sub-divided into four seasons, viz., spring, summer, autumn and winter. The spring season is from February to May; summer from June to July; autumn from August to October; and winter from November to January. Six benchmark sites selected for yield gap analysis are located in northern Vietnam, where the maximum rainfall occurs from July to September. June and July are the hottest months, while December and January are the coldest months of the years. The length of growing season ranges from 180 to 365 days (Fig. 2), which provides opportunity to grow two crops in a year during spring and summer or autumn-winter.

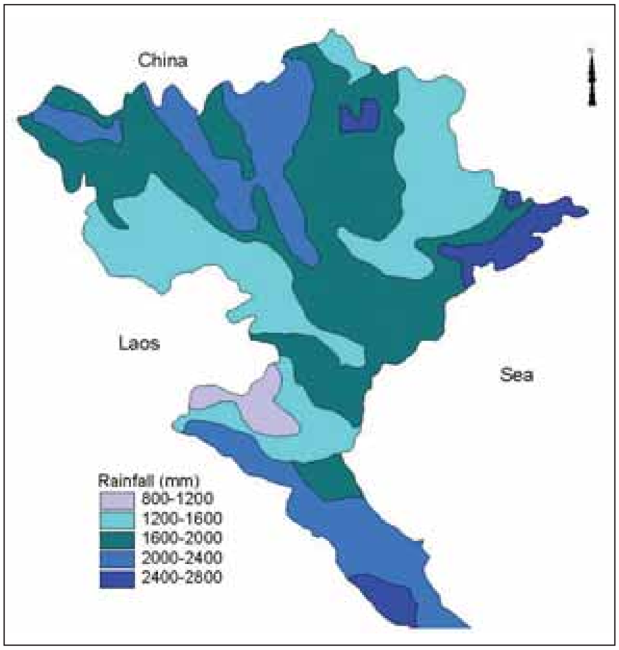


Figure 1. Annual rainfall in northern Vietnam.

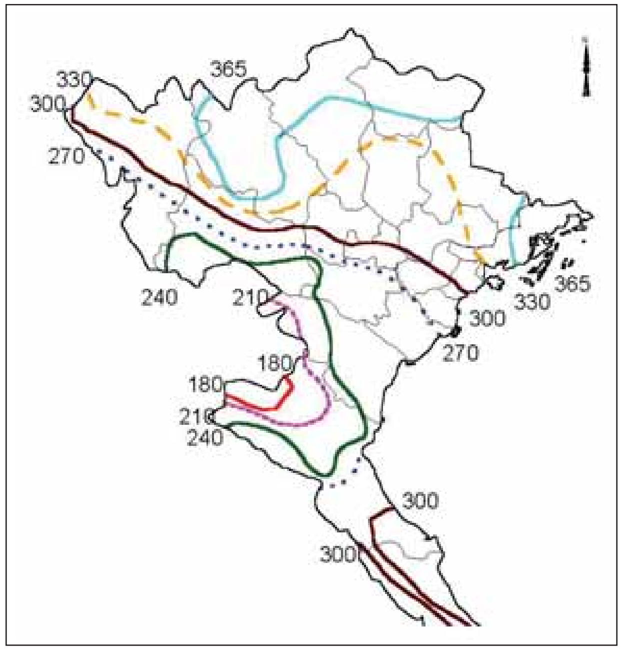


Figure 2. Length of growing season in Vietnam.

Soils of northern Vietnam

The soils of uplands and lowlands in northern Vietnam are quite diverse. These are classified into 14 groups and 68 soil types, of which 10 groups are present in the mountainous area (Siem and Phien, 1999). Main soil types in northern Vietnam are ferralsols, acrisols, andosols, fluvisols, gleysols and little of alfisols (Fig. 3). In general, farmers use these lands mainly for cultivation of irrigated rice and rain-fed crops such as maize, sweet potato, cassava, peanut, soybean, tobacco, sugarcane and tea. Two-thirds of the uplands in northern Vietnam have already lost their natural vegetation and the soils are exposed to intense soil erosion. In the upland areas several cultivation practices such as sloping gardens, rice terraces, intercropping and agro-forestry have been identified which have high potential for economic return and sustainability of soil resources.

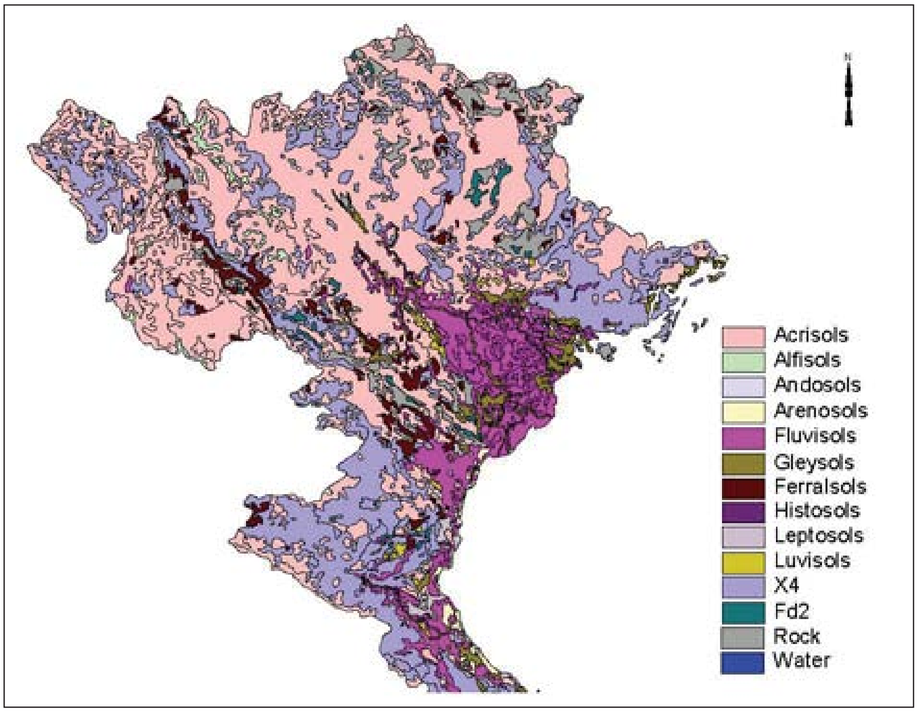


Figure 3. Soils of northern Vietnam.

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 leaching processes make the soils 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 sustainably cultivated for long and become degraded. In extreme cases of soil erosion, the hardpan of laterite nodules is exposed.

Land use Systems in Vietnam

According to General Statistics Office (2003), the agricultural land is 9.4 million ha and forestry land cover is 12.05 million ha. Most of the agricultural land is under annual crops and a small part allocated to perennial crops (Table 1).

Table 1. Agricultural land use in Vietnam as recorded in 2002. (Source: General Statistics Office, 2003).

Region	Total Land	Agricultural land	Forestry land	Specially used land	Homestead land
			(‘000 ha)		
Red river delta	1480	855	122	239	92
Northeast	6533	916	2840	217	61
Northwest	3564	414	1145	61	16
North center coast	5151	736	2300	244	54
South center coast	3307	549	1199	217	34
Central highlands	5448	1288	3016	148	35
Southeast	3474	1687	1068	254	61
Mekong river delta	3973	2962	361	237	100
Total country	32930	9407	12051	1616	451

Long-term yields of crops depend on soil type, slope, soil depth, soil fertility, environmental conditions and farm management in each region. Some annual crops are planted on sloping lands but the grain yields are normally less than those obtained on the lowlands due to limitation of water, soil, farm management practice and socioeconomic factors. In general, annual crops are grown in the lowlands and intercropping systems of annual and perennials in the uplands. The perennial crops are situated on uplands and hills. Most of the sloping lands are used for forestry, horticulture and agriculture and a large area in Vietnam remains unused. The uplands are not suitable for rice, therefore, perennial, industrial and forest trees have existed under rainfed conditions. However, in the uplands paddy rice is also planted in the valleys where irrigation facilities exist.

Province-wise Area, Production and Productivity of Crops in northern Vietnam

Northern Vietnam comprises of 25 provinces (excluding north central coast) and most of them have area under soybean, peanut and maize. There has been a general increase in area, production and productivity of soybean in northern Vietnam since 1994-95. The largest soybean area is in Son La in the northwest and Ha Tay in the red river-delta. The area under soybean in these provinces increased rapidly from 6000–8000 ha in 1994–1995 to 10000–11000 ha in 2001–2003. Productivity of soybean was 1.25–1.5 t ha^{-1} in Thai Binh and 0.75–1.0 t ha^{-1} in Ha Tay in 1994–1995, which increased to 2.0–2.05 t ha^{-1} in Thai Binh and 1.31–1.37 t ha^{-1} in Ha Tay in 2001–2003. These provinces are located in the red river delta, where lands have irrigation system and good farm management practices are followed compared to Lao Cai, Ha Giang and Cao Bang mountainous provinces (Fig. 4**)**.

Cultivation of peanuts also increased in most of the provinces, except Lao Cai, Yen Bai, Cao Bang and Hai Phong. Area in Phu Tho province has increased from 4000–6000 ha in 1994–1995 to 6000–8500 ha in 2001–2003 (Fig. 5). The productivity of peanuts over the years has increased in most of the provinces, except Son La and Cao Bang. It increased from 1.0–1.25 t ha^{-1} in 1994–1995 to 2.5–3.5 t ha^{-1} in 2001–2003 in Nam Dinh, Hung Yen and Hai Phong provinces (Fig. 5). Since 1999, polythene mulch technology for soil moisture conservation and increasing soil temperature during germination and early plant growth stage, and integrated pest management practices were applied in all the provinces of red river delta. This has improved the productivity of peanut by 30 to 70% as compared to absolutely no mulching and traditional practice (Chinh and Thang 2000; Chinh et al. 2002).

Maize is the main crop in the mountainous area of northern Vietnam. Maize area has increased in some provinces, particularly in Lao Cai, Son La and Ha Giang (Fig. 6). These provinces are located in northeast and northwest of Vietnam, and cover large upland areas. The maize area in these provinces increased from 20000 ha–30000 ha in 1994–1995 to over 40000 ha in 2001–2003. The productivity has rapidly increased in parts of red river delta such as Ha Tay, Hung Yen, Thai Binh, Hai Duong and Hai Phong provinces from 2.5–3.0 t ha^{-1} in 1994–1995 to 3.5–4.5 t ha^{-1} in 2001–2003. In the northeast region, which includes Tuyen Quang and Lang Son provinces, productivity increased from 2.0–2.5 t ha^{-1} in 1994–1995 to 3.5–4.5 t ha^{-1} in 2001–2003 (Fig. 6). Most of these provinces are growing hybrid maize cultivars and have applied improved crop management practices promoted by Vietnam Maize Research Institute since 1998.

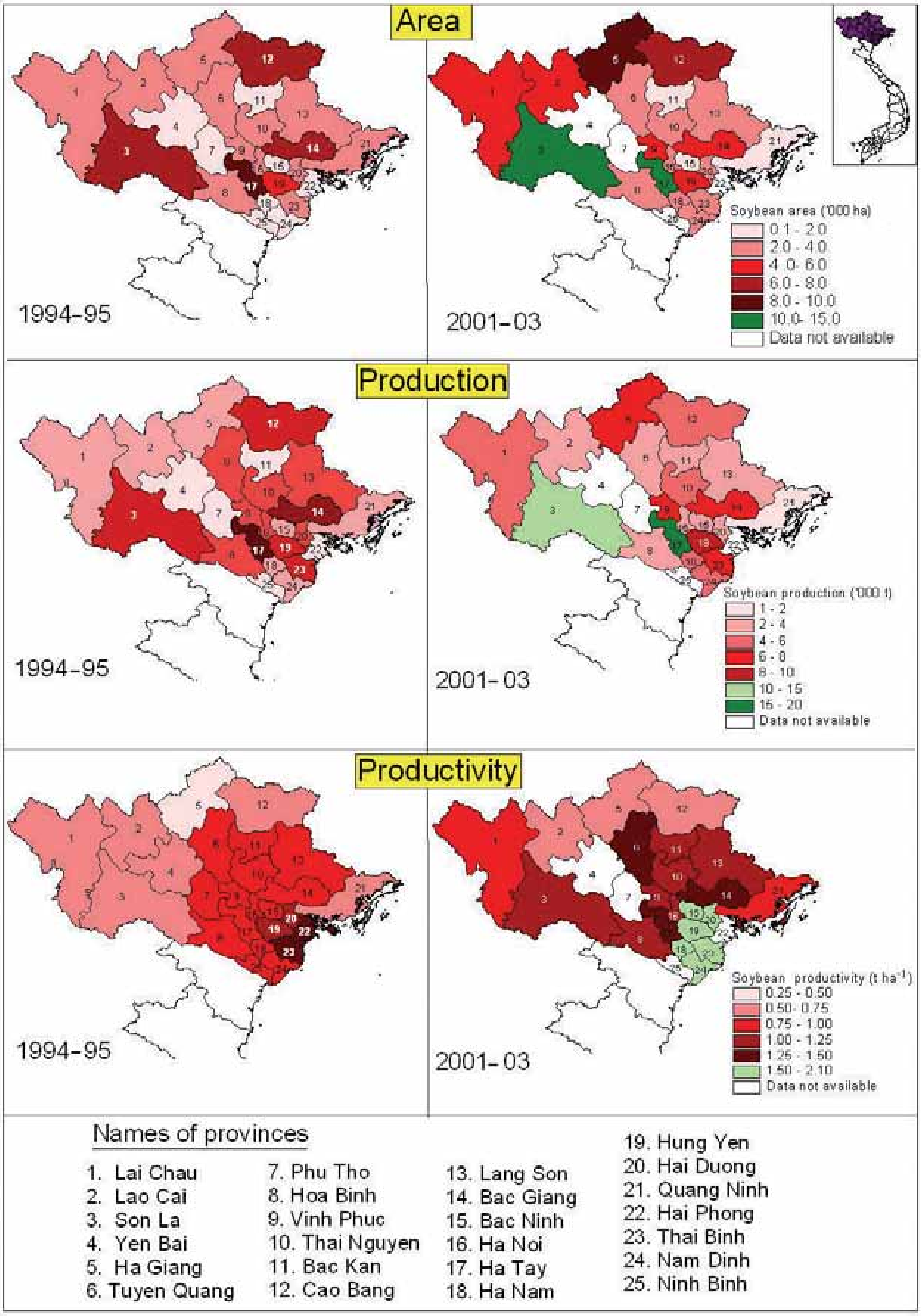


Figure 4. Province-wise changes in area, production and productivity of soybean in northern Vietnam.

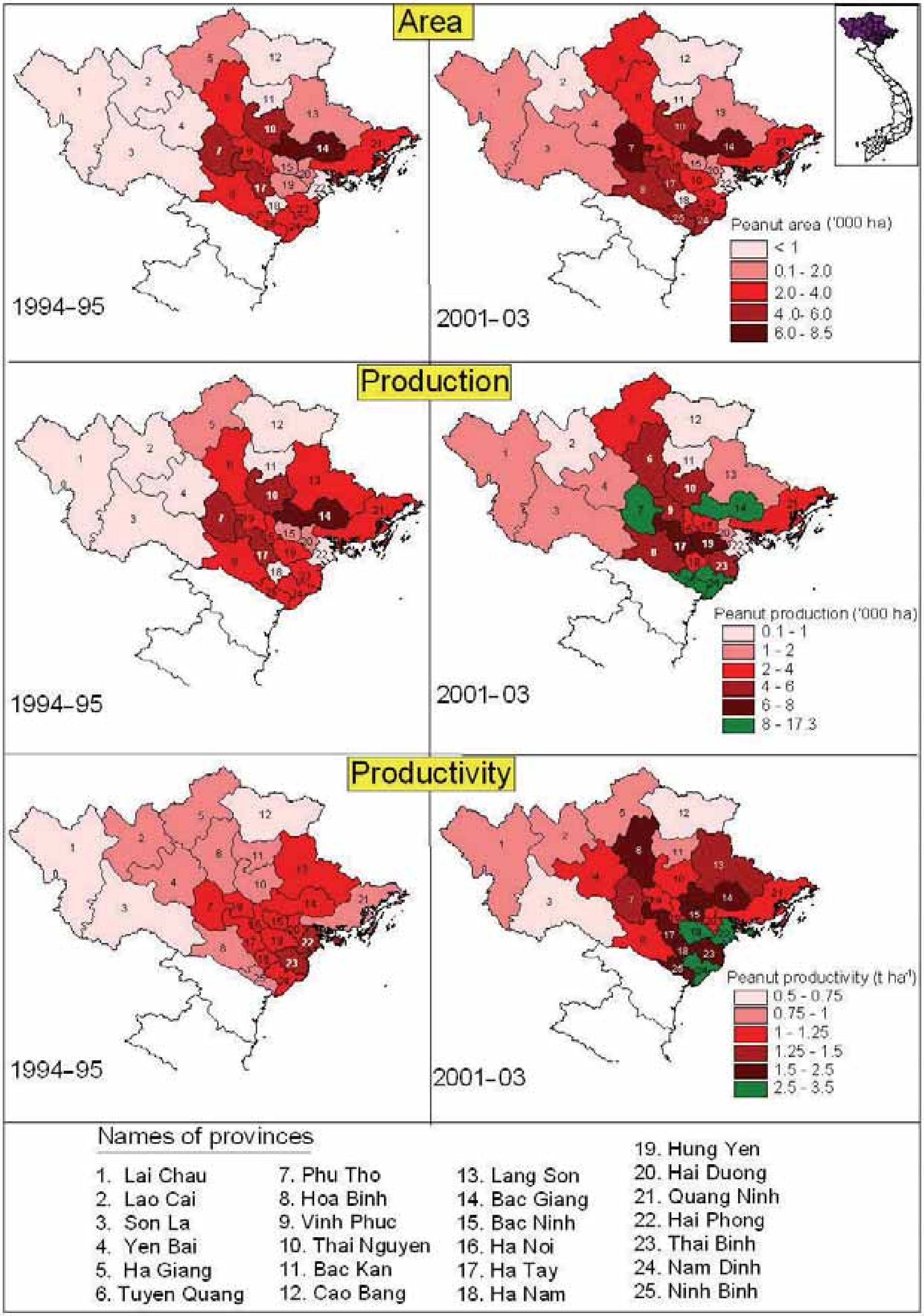


Figure 5. Province-wise changes in area, production and productivity of peanut in northern Vietnam.

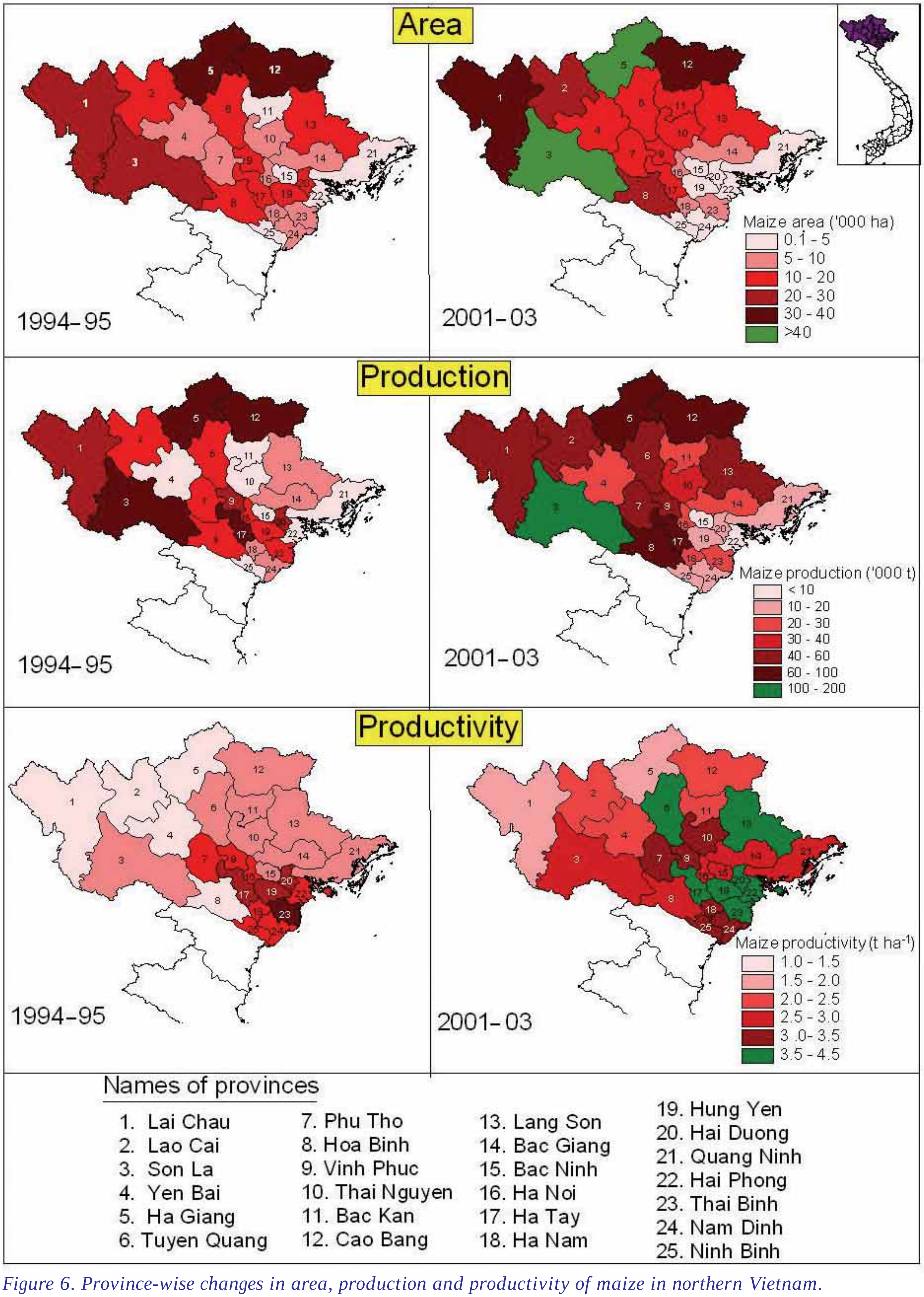
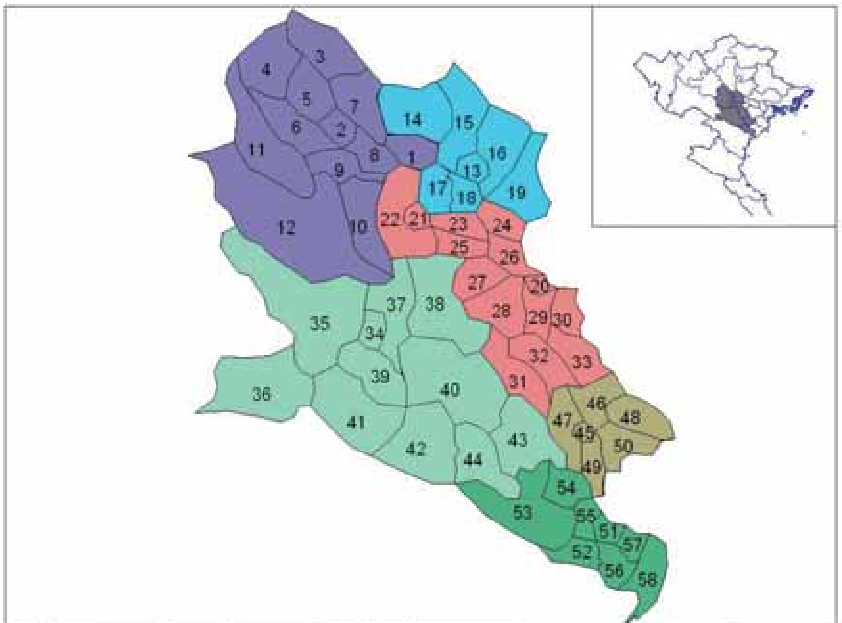


Figure 6. Province-wise changes in area, production and productivity of maize in northern Vietnam.

Crop Production in Six Selected Provinces of northern Vietnam

The six provinces selected for the study were Phu Tho, Vinh Phuc, Ha Tay, Hoa Binh, Ha Nam and Ninh Binh. The geographical location of provinces and the districts in each province are given in Figure 7.

Ha Tay, Ha Nam, Ninh Binh and Vinh Phuc provinces are located in the Red River Delta region. These provinces have both upland and lowland area sown to annual and perennial crops. The upland districts in the Ha Tay province are Son Tay, Phuc Tho and Ba Vi, and the other districts mostly have lowland



Names of provinces and districts

Phu Tho Province
1. Viet Tri cit
2. Phu Tho town
3. Doan Hung
4. Ha Hoa
5. Thanh Ba
6. Cam Khe
7. Phu Ninh
8. Lam Thao
9. Tam Nong
10. Thanh Thuy
11. Yen Lap
12. Thanh Son

Vinh Phuc Province
13. Vinh Yen town
14. Lap Thach
15. Tam Duong
16. Binh Xuyen
17. Vinh Tuong
18. Yen Lac
19. Me Linh

Ha Tay Province
20. Ha Dong Town
21. Son Tay
22. Ba Vi
23. Phuc Tho
24. Dan Phuong
25. Thach That
26. Hoai Duc
27. Quoc Oai
28. Chuong My
29. Thanh Oai
30. Thuong Tin
31. My Duc
32. Ung Hoa
33. Phu Xuyen

Hoa Binh Province
34. Hoa Binh tow
35. Da Bac
36. Mai Chau
37. Ky Son
38. Luong Son
39. Cao Phong
40. Kim Boi
41. Tan Lac
42. Lac Son
43. Lac Thuy
44. Yen Thuy

Ha Nam Province
45. Phu Ly town
46. Duy Tien
47. Kim Bang
48. Ly Nhan
49. Thanh Liem
50. Binh Luc

Ninh Binh Province
51. Ninh Binh town
52. Tam Diep town
53. Nho Quan
54. Gia Vien
55. Hoa Lu
56. Yen Mon
57. Yen Khanh
58. Kim Son

Figure 7. Districts in six selected provinces of northern Vietnam.

area. Out of six districts of Ha Nam province, Kim Bang, Ly Nhan and Thanh Liem mostly have rainfed area. Most of the area in the Ninh Binh province is rainfed. Major land use in Ninh Binh is forestry (20,000 ha) and it ranks second after Vinh Phuc province (30,000 ha). After forestry, in most of the areas perennial and industrial crops are grown and a small area is given to growing food crops.

Phu Tho province has now been divided into Phu Tho and Vinh Phuc provinces. Vinh Phuc is located in the Red River Delta with seven districts. Out of the seven districts Vinh Yen and Me Linh have lowland area, and other districts mostly have uplands with no irrigation system including the Tam Duong district where participatory watershed management project is being conducted. Phu Tho province is situated in the northeast region having twelve districts. All the districts are rainfed with impoverished soils and low economic efficiency of cropping systems due to many constraints such as lack of knowledge about cropping practices, poor socioeconomic conditions, marketing and transport limitation. Major crops are cassava, tea, maize, sweet potato and peanut.

Hoa Binh is in the north-west region. It covers eleven rainfed districts, in which Kim Boi is 70 km away from Ha Noi, where currently the watershed project is operational since 1999. Major crops of the province are maize, cassava, watermelon and tea.

Climate and Soils

Annual rainfall in the six provinces ranges from 1580 to 1930 mm. The maximum temperatures range from 32.7 to 33.6 °C, and the minimum temperatures from 14.0 to 14.9°C (Table 2). Both maximum and minimum temperatures have the lowest value in January and December. The temperatures start rising towards end of January and reach maximum value in June and July. Then they start falling again and reach the lowest value in January (Fig. 8). These data show that major variation in crop productivity in these provinces would be caused by amount and distribution of rainfall. In most provinces rainfall exceeds potential evapo-transpiration from March to October (8 months) indicating the positive water balance. Most of the sites have high potential harvest excess rainfall in surface ponds or for recharging the ground water. All the soils at benchmark sites are ferralitic, red-yellow in color and soil depth is more than 80 cm (Table 3).

Table 2. Geographical location and climate of the benchmark sites in northern Vietnam.

Location	Latitude (N)	Longitude (E)	Annual rainfall (mm)	Annual average max.temp.(°C)	Annual average min.temp.(°C)	Weather years
Vinh Yen, Vinh Phuc	21.17	105.35	1580	33.2	14.5	70–99
Ha Nam	20.32	105.60	1930	32.8	14.0	60–97
Ninh Binh	20.25	105.99	1820	32.7	14.6	60–03
Phu Ho, Phu Tho	21.25	105.16	1680	32.9	14.0	70–03
Son Tay, Ha Tay	21.08	105.25	1770	33.1	14.2	62–03
Chi Ne, Hoa Binh	20.30	105.50	1760	33.6	14.9	94–03

Table 3. Soils of the benchmark sites in northern Vietnam. (Source: Siem and Phien, 1999).

Location	Soil type	Soil series	Soil color
Vinh Phuc	Ferralitic	Tam Duong	Red-yellow
Ha Nam	Ferralitic	Duy Tien	Red-yellow
Ninh Binh	Ferralitic	Ninh Binh	Red-yellow
Phu Tho	Ferralitic	Phu Ho	Red-yellow
Ha Tay	Ferralitic	Ha Tay	Red-yellow
Hoa Binh	Ferralitic	Kim Boi	Red-yellow

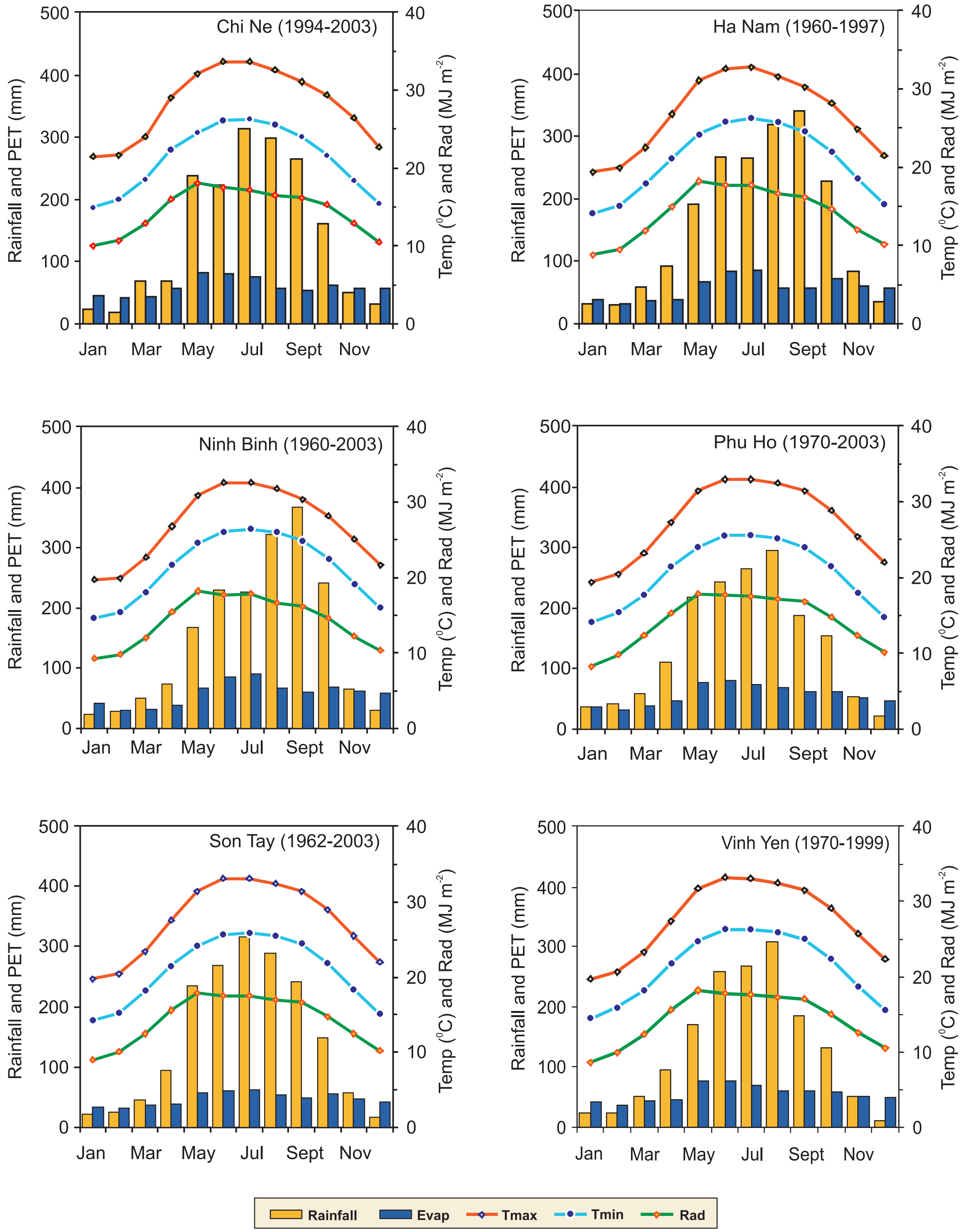


Figure 8. Monthly average rainfall (mm), potential evapo-transpiration (mm), maximum and minimum temperatures (°C) and solar radiation (MJ m^{-2}) of sites located in the six provinces of northern Vietnam.

Major Crops

The major crops grown in six benchmark locations are rice, maize, peanut, sugarcane, cassava and soybean (Fig. 9). Of these rice is the dominant crop in all the locations, whereas maize area is ranked second. Legume crops are new and their area is less when compared to other crops. Most of crop produce is consumed by ethnic minorities in the watershed. Rice, peanut and soybean (tofu) are popular in the family's meal and help in meeting the protein and vitamin requirements for poor farmers, who have low income. Cassava and maize are considered as staple food and also used for feeding domesticated animals in the mountainous area. It also becomes main food for human beings when rice harvest is lost.

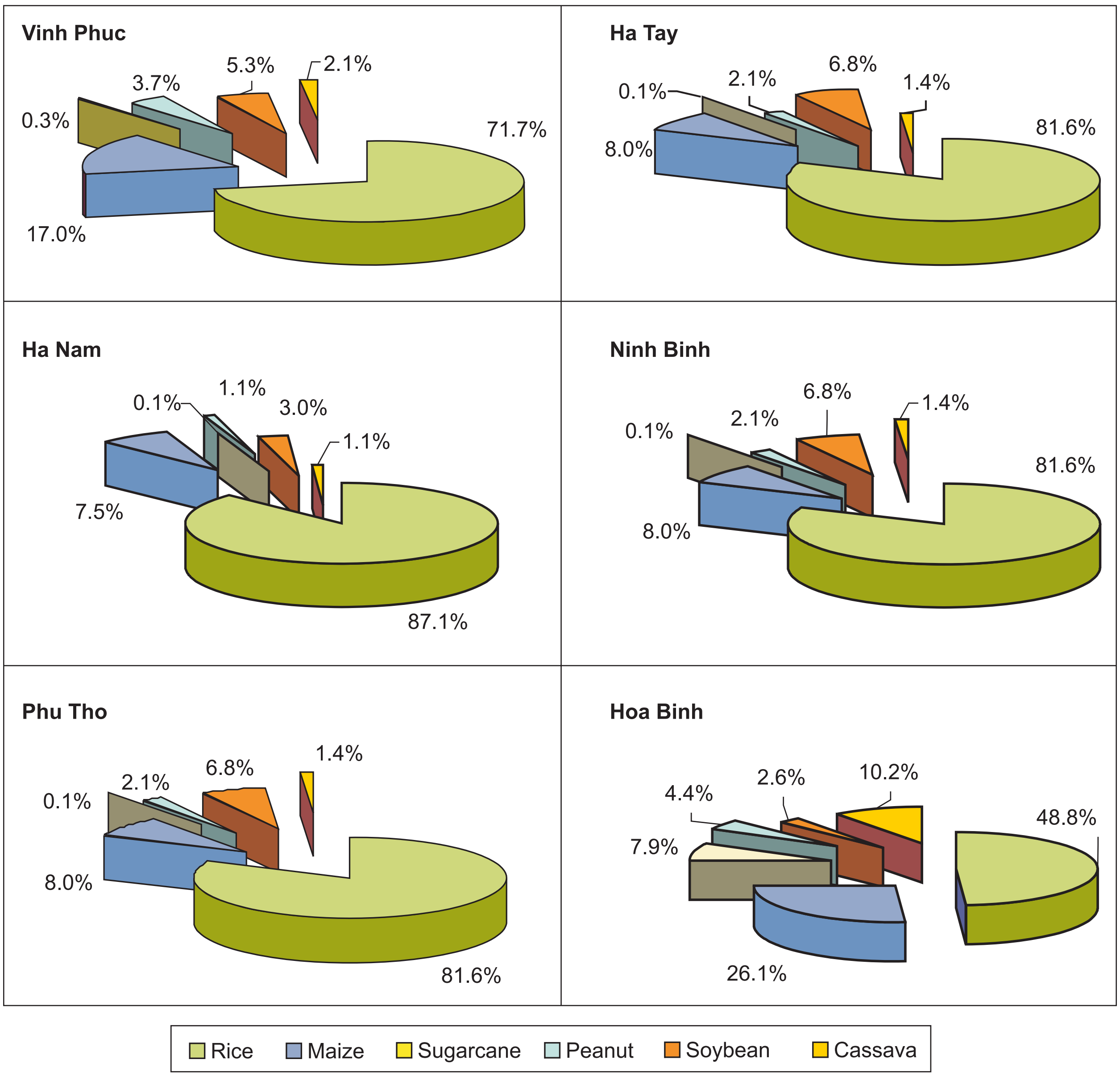


Figure 9. Land use in the six benchmark locations in northern Vietnam.
(Source: General Statistics Office, 2003).

Prominent Cropping Systems

The rotations of maize-soybean, peanut-maize, rainfed rice-maize and soybean-mung bean; and monocultures of sugarcane, cassava or tea are the main cropping systems practiced in the watershed area of six provinces, where legumes and maize appear in most of the crop rotations. Thus maize and legumes play an important role in the existing rainfed farming systems. The farmers normally cultivate two main crops under rainfed situations. Depending upon the amount of rainfall received, the first crop is sown in February to March and harvested by the end of May or during June. The second crop is sown in July and harvested in November (Fig.10). Cassava and sugarcane have long-duration and usually sown in January to February and harvested in November. Tea is a perennial crop planted in March to August and harvested throughout the year.

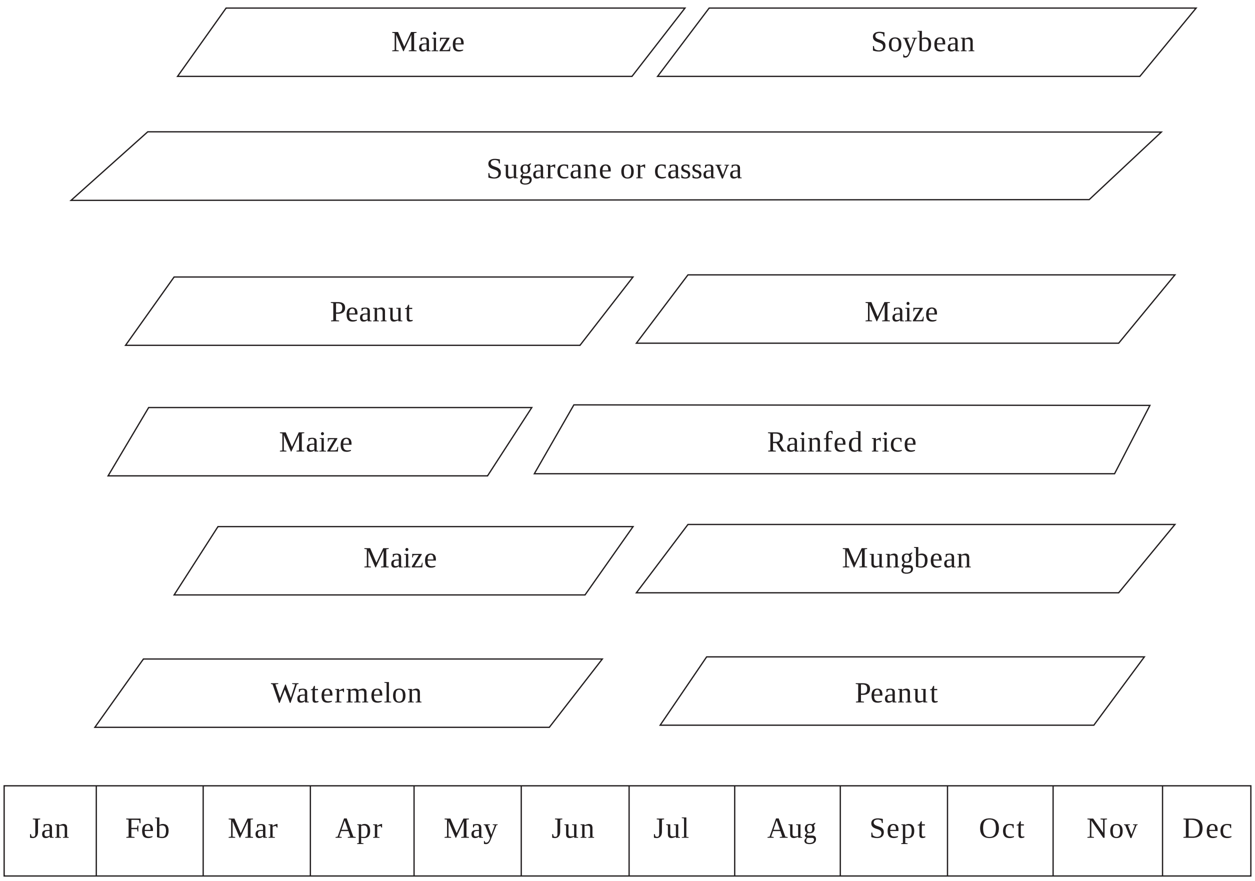


Figure 10. Major rainfed cropping systems at six benchmark sites.

Area Production and Productivity of Crops in the Provinces

In the six provinces maize is the main rainfed crop. However, legumes are important part of cropping system. Soybean area is small in all the six provinces. The highest area (>3000 ha) is in Ha Tay, while Ha Nam province achieved the highest productivity of about 1.6 t ha^{-1} (Fig.11 and 12). During the period 1995–1997, soybean was mostly grown in twelve districts out of sixty districts of six provinces. In 2001–2003 it expanded to sixteen districts. In Phu Xuyen district of Ha Tay province and in Vinh Yen district of Vinh Phuc province the area under the crop increased from 1200–1600 ha in 1995–1997 to 2000–2400 ha in 2001–2003. This increase in area occurred because of the

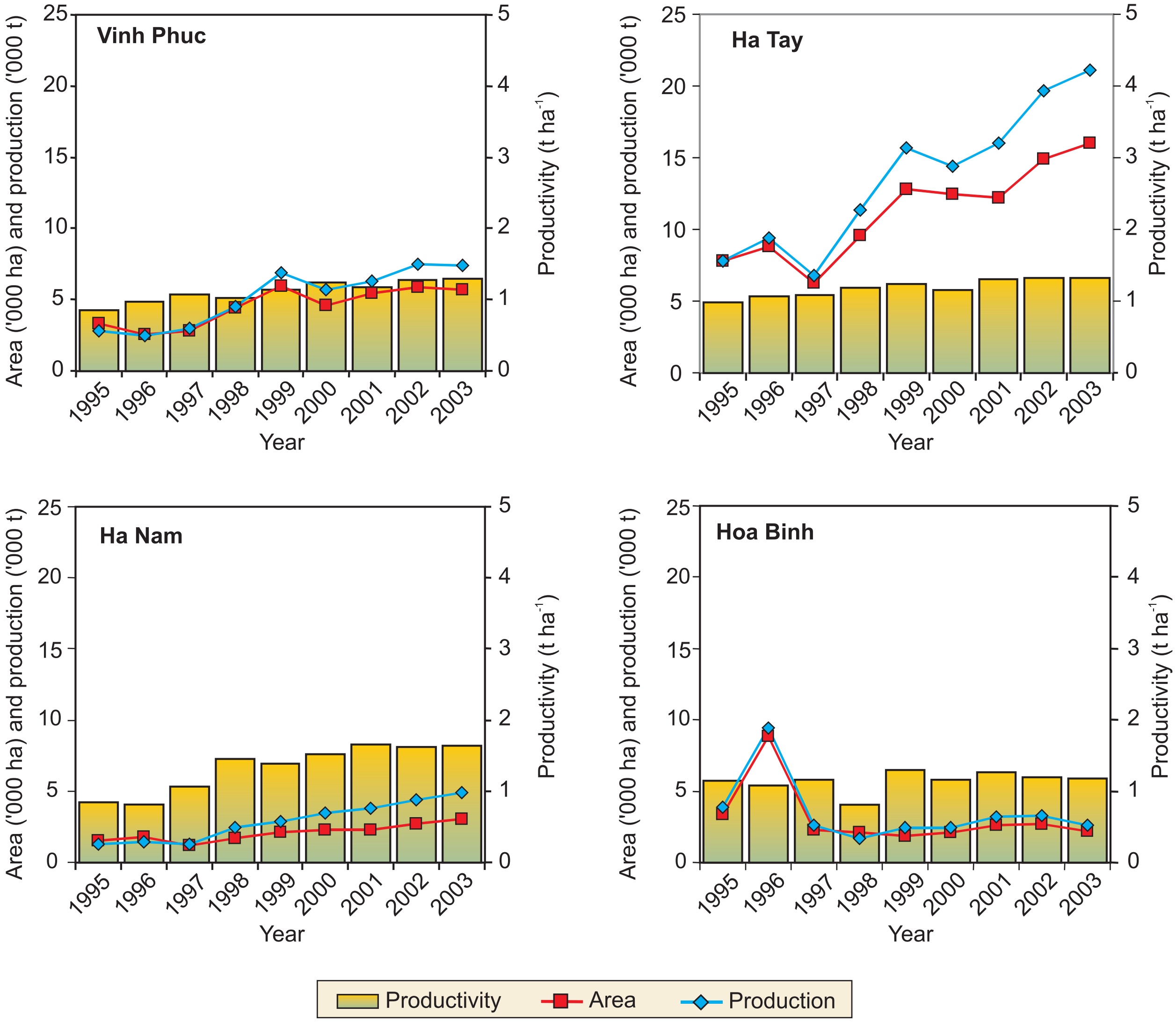


Figure 11. Area, production and productivity of soybean in different provinces in northern Vietnam.

introduction of new high-yielding soybean cultivars (such as AK 06, DT 84 and DT 12) and good farmer practice (minimum tillage) since 1999. Soybean is grown in the winter season with irrigation after rice harvest. Soybean productivity in the districts ranged from 0.4–0.8 to 2.0–2.4 t ha^{-1}.

Peanut is also grown in all the benchmark sites under rainfed condition as it is drought tolerant. However, its productivity is low and ranges from 1.1 to 2.2 t ha^{-1}. Currently the major peanut producing provinces are Ha Tay, Ninh Binh and Phu To (Fig. 13 and 14). The increase in production in these provinces occurred both due to increase in area and increase in productivity. No major increase in production occurred in Vinh Phuc, Ha Nam and Hoa Binh provinces since 1995, although large improvement in productivity occurred in Ha Nam. Currently Ha Nam and Ninh Binh have productivity levels exceeding 2.0 t ha^{-1}. Peanut was cultivated in twelve districts in 1998–2000 and it expanded to thirteen districts during 2001–2003. In the Phu Tho province, peanut area expanded from none in 1995–1997 to 1.8–2.4 thousand ha in 2001–2003, mostly in the Ha Hoa, Thanh Ba, Cam Khe, Yen Lap and Thanh Son districts. In the Ninh Binh province, the area increased from 24,000 in 1995 to 30,000 ha in 2003 in the Nho Quan district. Peanut productivity has increased in all

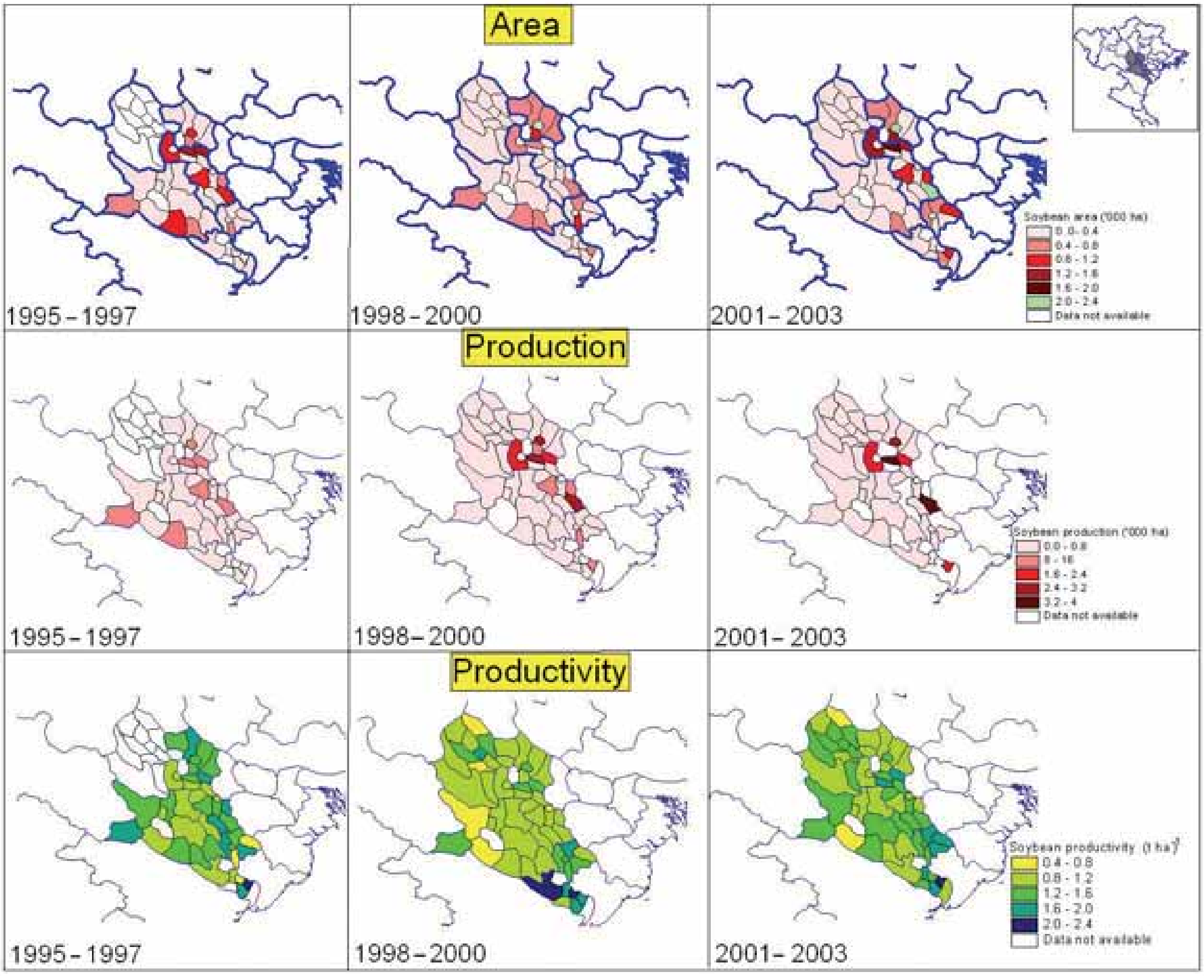


Figure 12. District-wise changes in area, production and productivity of soybean in selected provinces of northern Vietnam.

the six benchmark locations, which ranged from 1.8 to 2.2 t ha^{-1} during 2001–2003. In the Phu Xuyen and Thuong Tin districts of Ha Tay province, peanut productivity increased from 1.0–1.4 t ha^{-1} during 1995–1997 to 2.2–2.6 t ha^{-1} during 2001–2003 because of the adoption of improved peanut cultivars (MD7, L14 and L18) and polythene mulching technology.

Maize is a common crop in almost all the districts of the six provinces and since 1995, maize productivity has increased in all the six provinces (Figs. 15 and 16). The productivity levels in 2003 ranged from 2.7 to 4.1 t ha^{-1} across provinces. The highest increase being in Ha Tay (4.1 t ha^{-1}), where maize is partly grown on low lands with some irrigation. Maize area is more in Vinh Phuc, Ha Tay and Hoa Binh followed by Phu Tho, Ha Nam and Ninh Binh. The increase in total production in Vinh Phuc, Ha Tay, Ha Nam and Ninh Binh provinces has been primarily due to increase in productivity than increase in area. Whereas, in Phu Tho and Hoa Binh the production increased due to increase in both area and productivity. Availability of new hybrid cultivars and improved farm practices have been the reason for increased production and productivity of maize in the six provinces.

In general, the productivity of maize, peanut and soybean in benchmark watersheds is low compared to the potential yield of the cultivars. The reasons for low productivity could be low adoption of

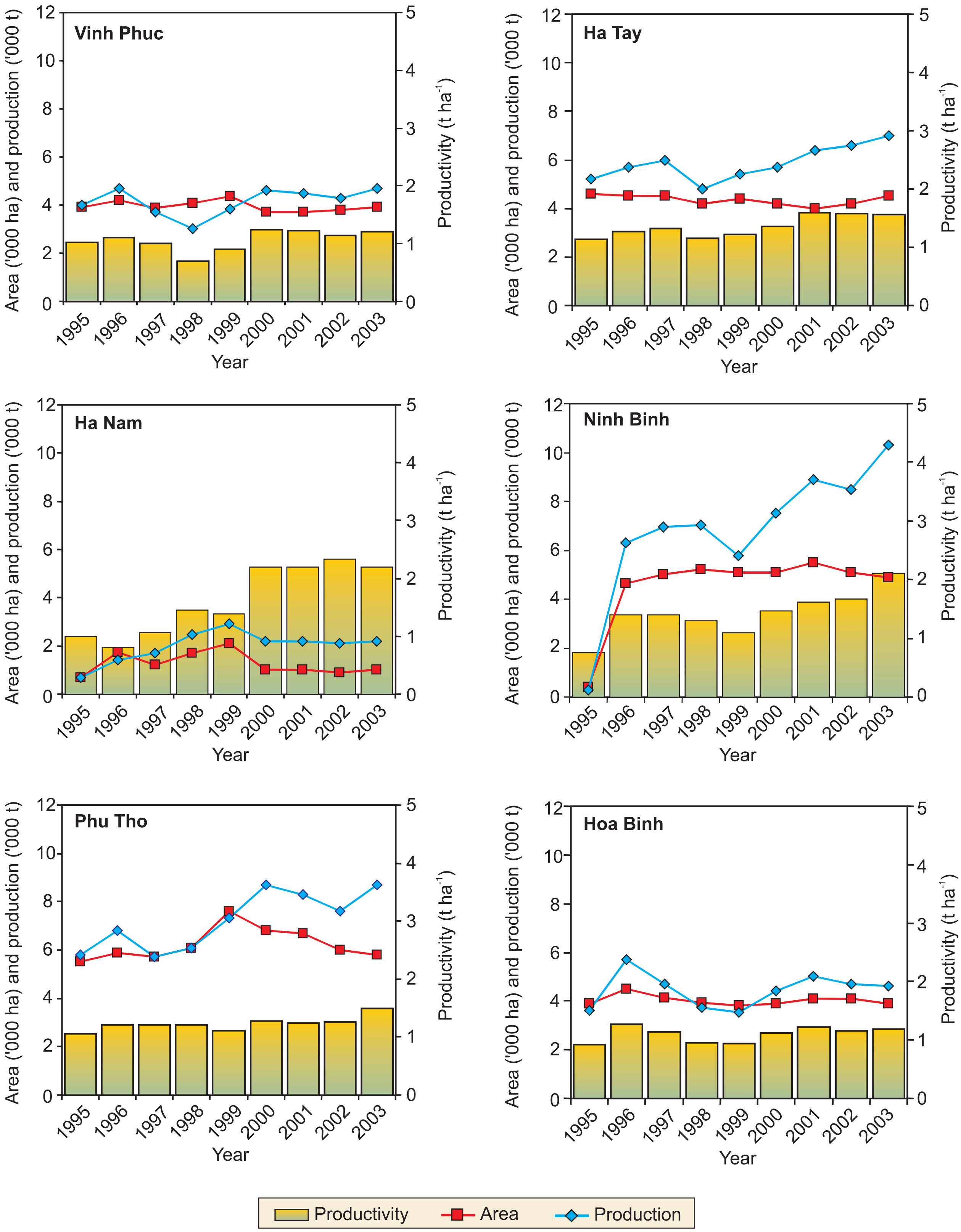


Figure 13. Area, production and productivity of peanut in different provinces in northern Vietnam.

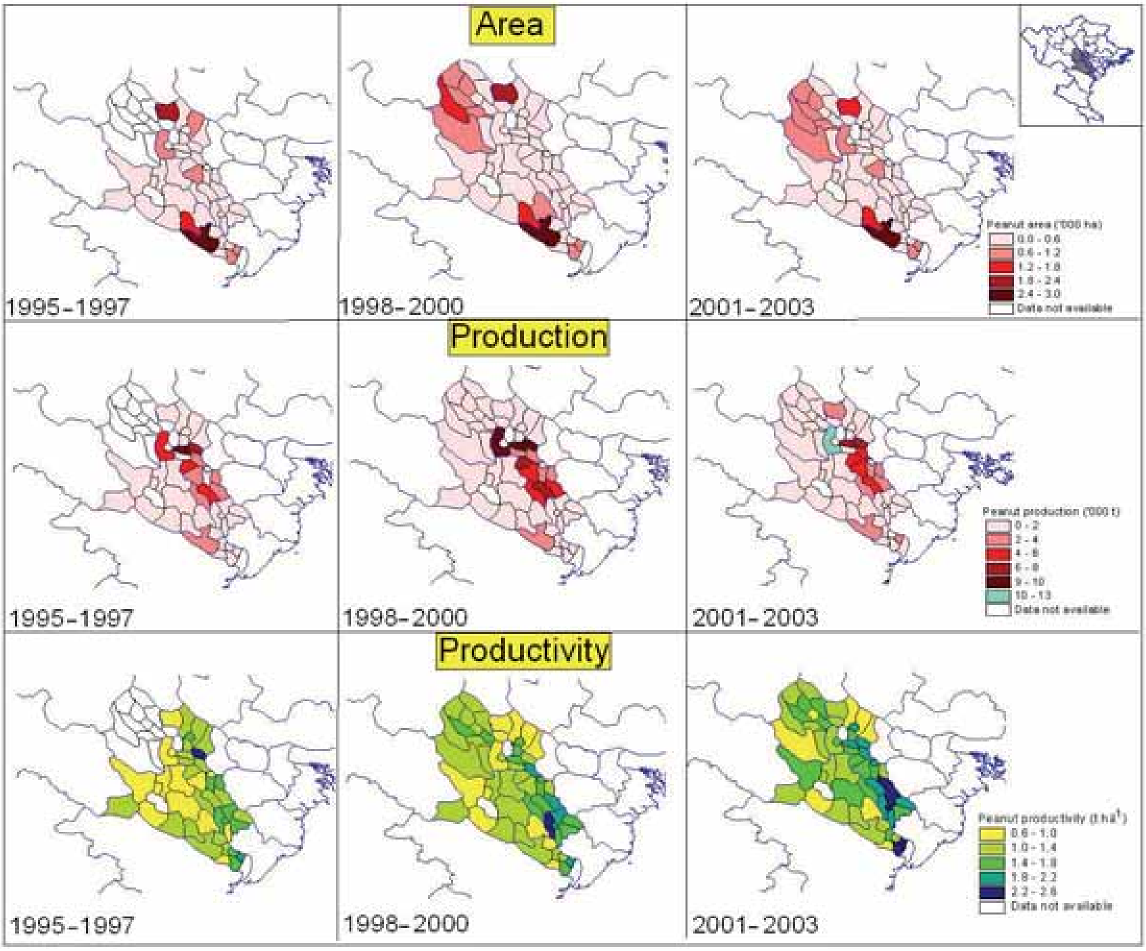


Figure 14. District-wise changes in area, production and productivity of peanut in different provinces of northern Vietnam.

improved management practices, poor socioeconomic condition of farmers, degraded soils and adverse climatic conditions. Yield gap analysis of three crops could help in identifying the major constraints to higher yields and a scope for yield improvement.

Potential Yields and Yield Gaps of Major Crops

Potential yield is defined as the maximum possible yield of a crop obtained under optimum management. Under irrigated conditions, radiation and temperature during the season determine the upper limit of the potential yield under optimum management. Whereas under rainfed conditions, potential yields are primarily limited by water availability and considered as water-limited potential yields. Maximum experimental yields obtained at research stations, under irrigated or rainfed situation, are usually considered as the potential yields for estimating the yield gaps.

Traditional Method of Yield Gap Analysis

In the traditional method, experiment station yields along with the average yield of at least 10 on-farm trials, and district average yield were used for calculating yield gaps. The on-farm trials were

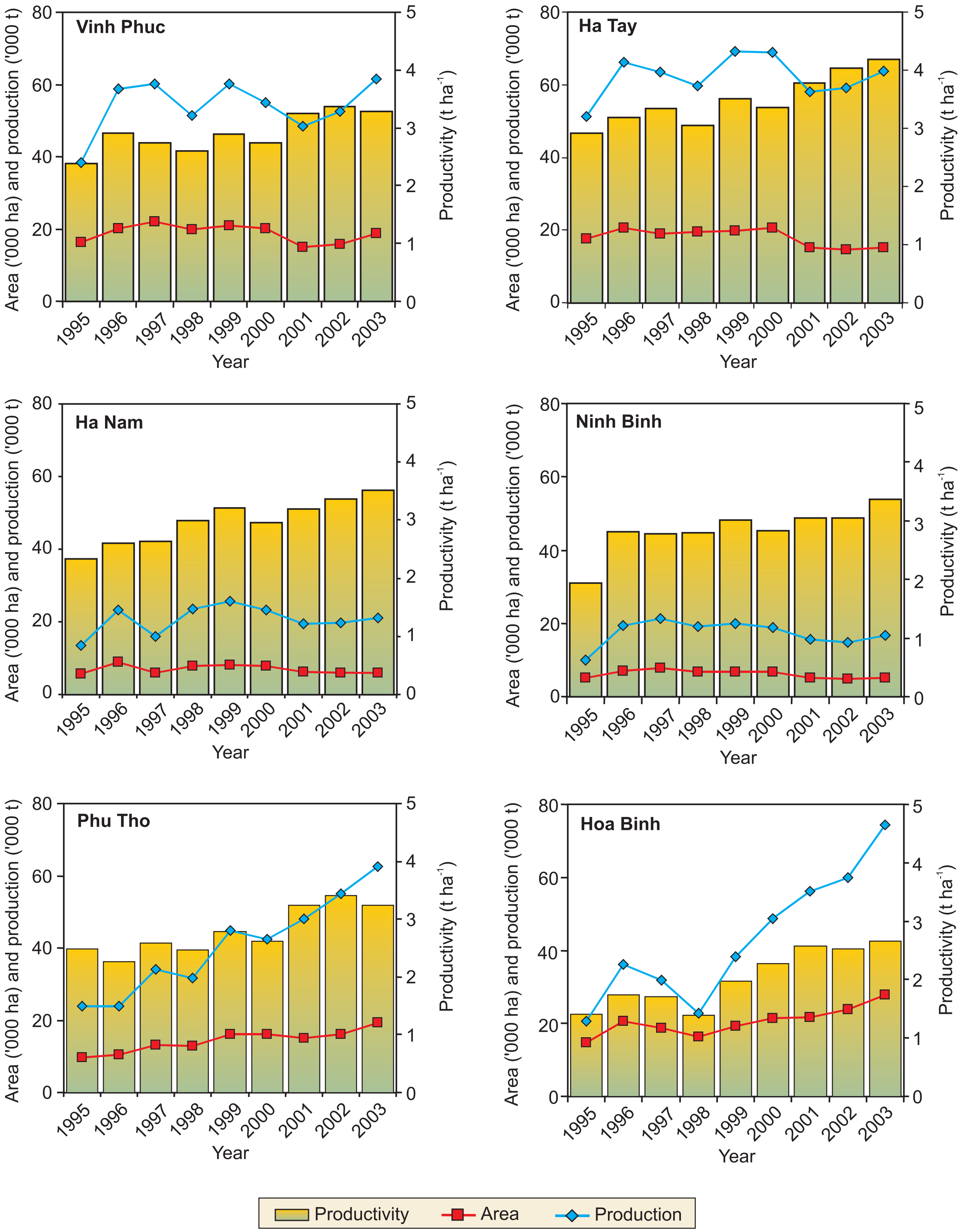


Figure 15. Area, production and productivity of maize in different provinces in northern Vietnam.

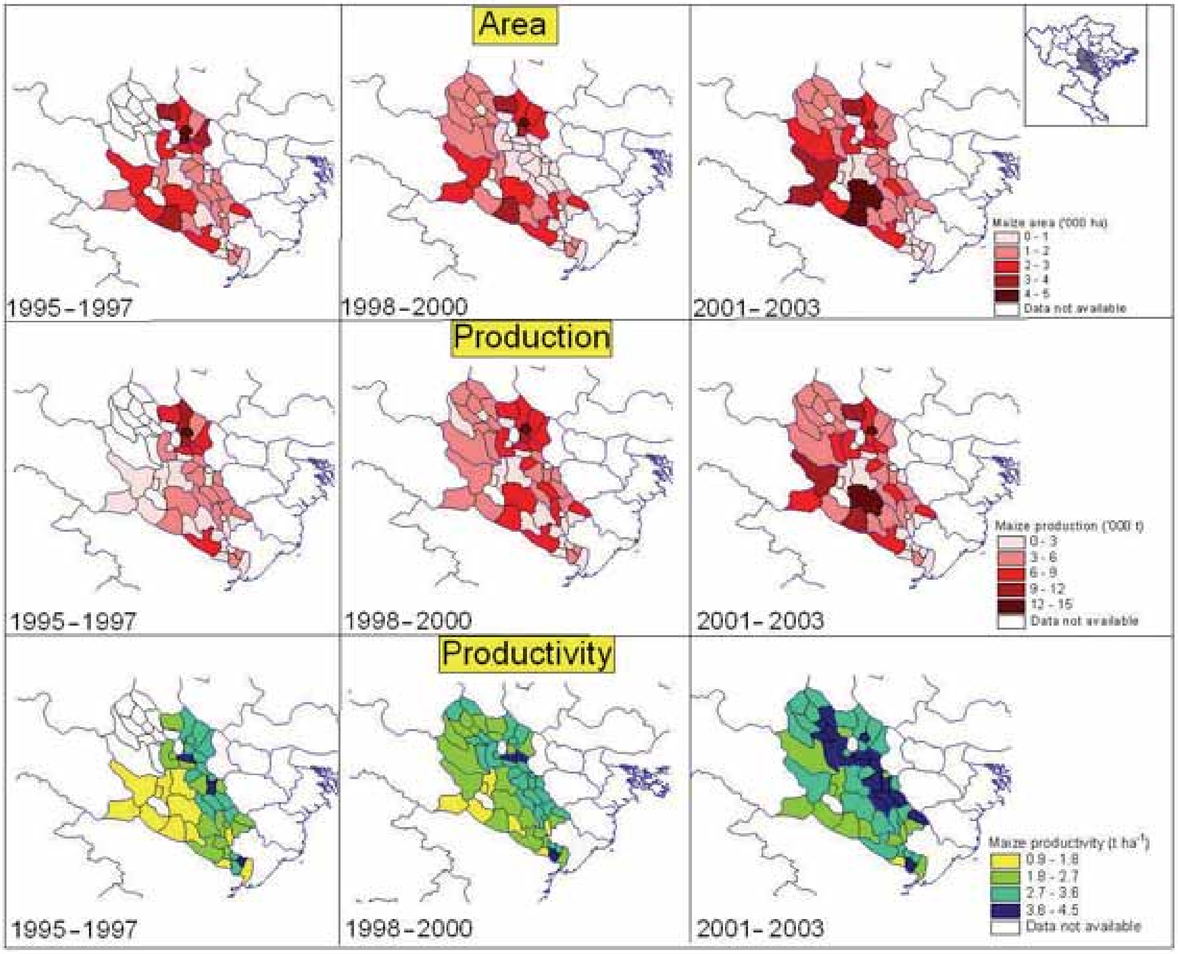


Figure 16. District-wise changes in area, production and productivity of maize in different provinces in northern Vietnam.

conducted both with improved technology (integrated management) and traditional management practices. Total yield gap was expressed as the difference in yield between experimental station yield and the district average yield. This was further partitioned into yield gap I and yield gap II. Yield gap I was defined as the difference in yield between the experiment station maximum yield and the on-farm trial yield under improved management, whereas yield gap II was the difference in yield between the on-farm trial yield under improved management and the district average yield.

Experimental station yields and yield gap of soybean: The soybean experiments were mostly conducted in spring with some irrigation and in summer as rainfed, while in lowlands it is mostly planted in winter after rice harvest, with irrigation. Large differences exist in soybean yield between rainfed and irrigated eco-system. Average potential yield (experimental) under rainfed condition ranged from 1720 to 2180 kg ha^{-1} (Table 4). Total yield gap (between experimental station yield and district average) soybean is quite large, ranging from 510 to 1260 kg ha^{-1}. Maximum total yield gap was observed at Tan Lac, while the minimum was at Kim Boi in Hoa Binh province. Yield gap I (between the experimental station yield and on-farm trial) was quite narrow ranging from 180 to 420 kg ha^{-1} for the locations. The yield gap II ranged from 180 to 980 kg ha^{-1}.

Experimental yield of irrigated soybean during winter season ranged from 2310 to 2620 kg ha^{-1} across the provinces. When compared with the district average yields, the total yield gap ranged from 1010

Table 4. Experimental station and on-farm yield and the yield gap of rainfed soybean at benchmark locations in northern Vietnam.

Province	District	Period	Season	Expt. stn. yield	On-farm yield Imp*	On-farm yield Trad**	District yield	Yield gap I	Yield gap II	Yield gap Total
				(kg ha^{-1})						
Vinh Phuc	Tam Duong	98–04	Summer	1810	1580	1170	1030	260	810	780
	Vinh Tuong	98–04	Summer	2040	1790	1330	1160	230	610	880
Hoa Binh	Kim Boi	99–03	Summer	1990	1680	1560	1350	210	330	540
	Tan Lac	99–03	Summer	2010	1730	—	750	280	980	1260
Ninh Binh	Nho Quan	96–99	Summer	2050	1630	1350	920	420	710	1130
	Yen Khanh	96–99	Summer	2180	1820	1720	1640	360	180	530
Mean				2000	1710	1430	1140	290	600	860
Hoa Binh	Kim Boi	99-03	Spring	1860	1620	1470	1350	240	270	510
	Tan Lac	99-03	Spring	1720	1540	1330	750	180	790	970
Mean				1790	1580	1400	1050	210	530	740

*Imp = Improved **Trad = Traditional

Table 5. Experimental station and on-farm yield and yield gap of irrigated soybean at benchmark locations in northern Vietnam.

Province	District	Period	Season	Expt. stn. yield	On-farm yield Imp*	On-farm yield Trad**	District yield	Yield gap I	Yield gap II	Yield gap Total
				(kg ha^{-1})						
Ha Tay	Ung Hoa	98–01	Winter	2510	2310	1620	1140	190	1170	1360
	Phu Xuyen	98–01	Winter	2310	2030	1530	1230	290	800	1080
	Thuong Tin	98–01	Winter	2330	1940	1620	1060	390	880	1270
Ha Nam	Duy Tien	96–99	Winter	2480	2180	1560	1470	300	710	1010
	Binh Luc	96–99	Winter	2620	2380	1590	1470	250	910	1160
Mean				2450	2170	1580	1270	280	890	1180

*Imp = Improved **Trad = Traditional

to 1360 kg ha^{-1}. The minimum yield gap was observed at Duy Tien, while Ung Hoa has the maximum yield gap. The yield gaps were larger under the irrigated conditions than under rainfed conditions because of higher potential yields with irrigation. These results indicate the importance of supplemental irrigation with water harvesting to bridge the yield gaps.

Experimental station yields and yield gap of peanut: Peanut is an important legume crop and is better adapted to rainfed conditions. However, the pod yield varies among locations due to differences in soil, climate, cultivars and management practices. In the spring season, experimental yield (cultivar L14) of rainfed locations ranged from 2200 to 3740 kg ha^{-1}. The maximum pod yield was observed at Kim Boi, while minimum yield was recorded at Tam Duong (Table 6). Total yield gap ranged from 1050 to 2550 kg ha^{-1}, the largest at Kim Boi and the smallest at Son Tay district. Yield gap II ranged from 460 to 1810 kg ha^{-1}. In the autumn season, the experimental yields ranged from 1910 to 2300 kg ha^{-1} and the yield gap from 710 to 1060 kg ha^{-1}.

The yield gap of irrigated peanut for some of the locations was also calculated. The largest total yield gap was observed at Chuong My, Ha Tay and the smallest at Duy Tien, representing 1780 kg ha^{-1} and 810 kg ha^{-1}, respectively (Table 7). It was observed that yield gap (II) and total yield gap varied among locations.

Table 6. Experimental station and on-farm yield and yield gap of rainfed peanut at benchmark locations in northern Vietnam.

				Expt. stn.	On-farm yield		District	Yield gap		
				yield	Imp*	Trad**	yield	I	II	Total
Province	District	Period	Season	(kg ha^{-1})						
Ha Tay	Son Tay	99–02	Spring	2430	1980	1720	1380	440	600	1050
	Ba Vi	99–02	Spring	2580	2190	1700	1070	390	490	1510
Ha Nam	Binh Luc	99–02	Spring	3370	2850	2350	1620	520	1230	1740
	Kim Bang	99–02	Spring	3300	2920	2520	2110	380	810	1190
Ninh Binh	Nho Quan	00–03	Spring	2550	2020	1680	1210	530	1120	1350
Vinh Phuc	Tam Duong	98-00	Spring	2200	1780	1460	940	420	840	1260
	Vinh Tuong	98-00	Spring	2570	1960	1660	1500	610	460	1070
Hoa Binh	Kim Boi	97	Spring	3740	3000	2190	1190	740	1810	2550
		00-02	Spring	3120	2440	1960	1300	720	1140	1810
	Tan Lac	03	Spring	2490	2000	1770	940	490	1060	1550
Mean				2830	2310	1900	1330	520	960	1510
Vinh Phuc	Tam Duong	03	Autumn	2300	2080	1800	-	220	-	-
Hoa Binh	Tan Lac	03	Autumn	2000	1710	1500	940	290	770	1,060
	Tan Lac	99	Autumn	1910	1600	1400	1200	310	400	710
Mean				2070	1800	1570	1070	270	590	890

*Imp = Improved **Trad = Traditional

Table 7. Experimental station and on-farm yield and yield gap of irrigated peanut at benchmark locations in northern Vietnam.

				Expt. stn.	On-farm yield		District	Yield gap		
				yield	Imp*	Trad**	yield	I	II	Total
Province	District	Period	Season	(kg ha^{-1})						
Ha Nam	Duy Tien	99–02	Spring	3200	2800	2400	1950	400	850	1250
		00–02	Spring	3380	3040	2670	2570	350	470	810
Ha Tay	Chuong My	99–02	Spring	3250	2840	2600	1500	410	1360	1780
Ninh Binh	Yen Khanh	00–03	Spring	3670	3110	2740	2500	550	1240	1170
Mean				3380	2950	2600	2120	430	980	1250

*Imp = Improved **Trad = Traditional

Simulation Approach of Yield Gap Analysis

Simulation of rainfed potential yields: Using a crop growth simulation model for determining potential yields requires inputs of weather, soil and cultivar-specific parameters (genetic coefficients) and crop management data. The crop growth model must be calibrated for the soil and cultivar-specific parameters through several model iterations such that the simulated results match the observed data on phenology, crop growth, yield and soil water dynamics. Once the model is validated it can be used to simulate variations in water-limited potential yields caused by weather variability using historical records of weather. Genetic coefficients of the crop cultivars were determined according to Hunt's (1988) approach. This was accomplished iteratively by executing the model with approximate coefficients, comparing model output with actual data and then re-adjusting the coefficients and the repeating process until acceptable fits are obtained. Genetic coefficients were calculated from the field data using GENCALC, a utility module embedded in DSSAT v3.5 (Hoogenboom et al. 1999). All the genetic coefficients of maize (Var. VN 10), peanut (Var. L 14) and soybean (Var. AK 06) were estimated by using phenology and growth data from experiments conducted from 2000 to 2003 at Thanh Ha watershed.

Soil file for each watershed sites was created using soil physical and chemical proprieties data for the watershed area and the soil profile utility program available in DSSAT v3.5 software. The soil parameters were further modified to make them more specific to the experiment site (Naab et al. 2004). This was accomplished by changing the soil parameters and comparing the model output on soil water dynamics with the observed data until both matched. First the upper (DUL) and lower limits (LL), and saturation limits (SAT) of the soil layers were set. Then, the runoff and drainage coefficients and root-distribution coefficients were adjusted such that the soil water changes for each layer matched the observed data. All parameters were modified through iterations of the model run to fit between observed and simulated data for three crop experiments such as maize (spring 2000, summer 2000 and spring 2001); soybean (spring 2000, 2001 and 2002); and peanut (spring 2000, 2001 and 2002). Physical parameters of the soil profiles of six benchmark sites used for simulation is given in Table 8. All experiment files, containing crop, soil, climate and management data were entered in soybean, peanut and maize model directories. Multi-year seasonal analysis was used to determine potential yields for the six locations. All results were used to analyze yield gaps for the three crops in benchmark locations in northern Vietnam.

Simulated potential yield and yield gap of soybean: For simulating the potential yield of soybean, sowing window was setup for different seasons. Sowing window was 15–30 April for all locations, except for Ninh Binh and Phu Tho provinces because of late rainfall in spring season. In the model, sowing was considered to have taken place when at least 40% of extractable soil moisture was presented in the top 30 cm soil layer. The sowing window for summer sowing was 30 June to 15 July. Simulations were made for the six locations, using long-term weather data records available (Table 9).

Means of simulated yields were compared with the means of rainfed experimental and province yields to calculate yield gaps. Total yield gap for rainfed soybean ranged from 610 to 1110 kg ha^{-1} in both the

Table 8. Soil depth, saturation limit (SAT), drained upper limit (DUL), lower limit (LL), extractable water capacity (EXTW), USDA runoff curve number (CN2) and drainage coefficient (SLDR) of the soil profiles used for simulation.

Location	Depth (cm)	SAT (mm)	DUL (mm)	LL (mm)	EXTW (mm)	CN2	SLDR
Vinh Phuc	100	350	211	195	116	68	0.70
Ha Nam	120	535	406	200	206	76	0.60
Ninh Binh	150	572	512	351	161	76	0.60
Phu Tho	100	436	411	292	122	80	0.60
Ha Tay	100	478	403	230	174	80	0.60
Hoa Binh	120	441	345	197	149	76	0.70

seasons (Table 10). The largest yield gap between potential yield and province yield of rainfed soybean was observed at Ha Tay and the lowest at Ha Nam provinces. The yield gaps were large in summer as compared to those in spring; hence, it is seen that there is a high potential for increasing yield for soybean in summer season than in the spring.

Table 9. Sowing window and simulation date for soybean during spring and summer seasons used in seasonal analysis.

Location	Sowing window: Spring	Sowing window: Summer	Simulation date: Spring	Simulation date: Summer	Years
Vinh Phuc	15–30 Apr	30 Jun–15 Jul	01 Feb	30 Apr	28
Ha Nam	15–30 Apr	30 Jun–15 Jul	01 Feb	30 Apr	28
Ninh Binh	20 Apr–5 May	30 Jun–15 Jul	01 Feb	30 Apr	28
Phu Tho	20 Apr–5 May	30 Jun–15 Jul	01 Feb	30 Apr	28
Ha Tay	15–30 Apr	30 Jun–15 Jul	01 Feb	30 Apr	28
Hoa Binh	15–30 Apr	30 Jun–15 Jul	01 Feb	30 Apr	10

Table 10. Simulated potential yield, experimental station yield, provincial average yield and yield gap of rainfed soybean in the spring and summer seasons at benchmark locations in northern Vietnam.

Location	Simulated yield	Expt. yield	Province yield	Yield gap I	Yield gap II	Yield gap Total
	(kg ha^{-1})					
Spring season						
Vinh Phuc	1950	1750	1300	200	450	650
Ha Nam	2240	1860	1630	380	230	610
Ninh Binh	1810	1740	1180	70	560	630
Phu Tho	1760	1600	-	160		
Ha Tay	2150	1900	1320	250	580	830
Hoa Binh	2110	1790	-	320		
Mean	2000	1770	1360	230	460	680
Summer season						
Vinh Phuc	2330	1920	1300	410	630	1030
Ha Nam	2480	1860	1630	620	230	850
Ninh Binh	2230	2110	1180	110	930	1050
Phu Tho	2160	1790	-	370		
Ha Tay	2430	2140	1320	290	820	1110
Hoa Binh	2440	1950	-	490		
Mean	2350	1960	1360	380	650	1010

Simulated soybean yield showed a strong linear relationship with seasonal rainfall ($Y = 0.78 x + 1315.7$; and $R^2 = 0.67$). In which Y = simulated soybean yield (kg ha^{-1}) and x = rainfall (mm) during crop growth season. This implies that the production potential of soybean increases as the seasonal rainfall increases. (Fig.17). Surface runoff and deep drainage from the soil profile were also strongly correlated with seasonal rainfall (for runoff: $Y = 0.38x – 144.81$ and $R^2 = 0.74$, and for deep drainage: $Y = 0.29 x – 50.866$ and $R^2 = 0.54$). In which Y = simulated runoff or deep drainage (mm) and x = rainfall (mm) during crop growth season. These results indicate the potential for runoff water harvesting and groundwater recharging at six benchmark locations as the amount of rainfall increases (Fig. 17).

Simulated potential yield and yield gap of peanut: The spring season for peanut starts earlier as compared to soybean and maize, as peanut is more drought tolerant during initial stages of its growth under rainfed condition. The sowing window for spring season was kept between 15 March and 15 April and simulation started 2 January. Autumn-winter sowing window was kept between 15 August to 15 September after soybean and maize and simulation started on 29 June for all the locations (Table 11).

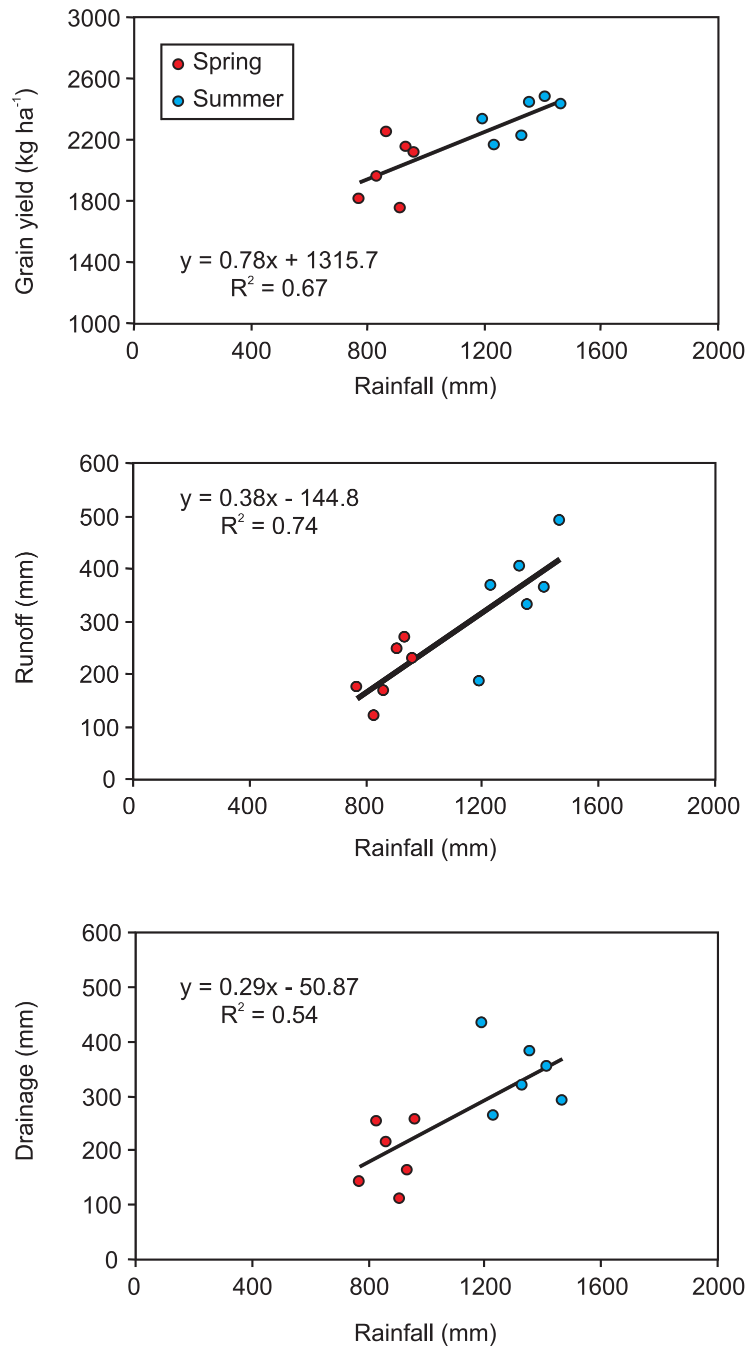


Figure 17. Relationship of soybean yield, surface runoff and deep drainage with seasonal rainfall during spring and summer seasons at six benchmark locations.

Mean simulated yields were compared to rainfed experimental and province yields for each location to calculate yield gaps. Because of high potential yield due to more favorable climate for peanut growth, the yield gap was larger in spring season (Table 12). These results support the earlier finding of Reddy (1988) that peanut crop yields are higher when temperatures are between 20–30°C and rainfall is well distributed. Total yield gaps observed at Hoa Binh (3,050 kg ha^{-1}), Ha Tay (3,000 ha^{-1}) and Vinh Phuc (2,700 ha^{-1}) were larger compared to other sites during the spring season.

The simulated yield of peanut in autumn-winter was less compared to the yield in spring due to variability in the amount and distribution of rainfall. If autumn-winter season crop is sown between 15 August and 15 September, then flowering takes place between 25 September and 25 October. During this period low radiation decreases flowering, pegging, pod numbers, pod filling and maturity of crop (Reddy 1998).

Table 11. Simulation dates and sowing windows for six watershed sites used for seasonal analysis of rainfed peanut.

	Sowing window		Simulation date		
Location	Spring	Autumn-winter	Spring	Autumn/ winter	Weather years
Vinh Phuc	15 Mar–15 Apr	15 Aug–15 Sep	2 Jan	29 Jun	28
Ha Nam	15 Mar–15 Apr	15 Aug–15 Sep	2 Jan	29 Jun	28
Ninh Binh	15 Mar–15 Apr	15 Aug–15 Sep	2 Jan	29 Jun	28
Phu Tho	15 Mar–15 Apr	15 Aug–15 Sep	2 Jan	29 Jun	28
Ha Tay	15 Mar–15 Apr	15 Aug–15 Sep	2 Jan	29 Jun	28
Hoa Binh	15 Mar–15 Apr	15 Aug–15 Sep	2 Jan	29 Jun	10

Table 12. Simulated potential, experimental and province average pod yield and yield gap of rainfed peanut in the spring and autumn-winter seasons at benchmark locations in northern Vietnam.

				Yield gap		
	Simulated yield	Exptl. yield	Province yield	I	II	Total
Location	(kg ha^{-1})					
Spring season						
Vinh Phuc	3900	2380	1200	1500	1180	2700
Ha Nam	4700	3330	2200	1360	1130	2500
Ninh Binh	3740	2550	1710	1190	840	2030
Phu Tho	3870	3400	1270	470	2130	2600
Ha Tay	4560	3200	1560	1360	1640	3000
Hoa Binh	4230	3200	1180	1030	2020	3050
Mean	4170	3010	1520	1150	1490	2650
Autumn-winter season						
Vinh Phuc	3270	2300	1200	970	1100	2070
Ha Nam	3920	2780	2200	1140	580	1720
Ninh Binh	3430	2700	1710	730	990	1720
Phu Tho	2910	-	1270			1640
Ha Tay	3880	2500	1560	1379	940	2320
Hoa Binh	3760	2800	1180	960	1620	2580
Mean	3530	2620	1520	1040	1050	2010

Pod yields were significantly correlated with the amount of rainfall received during spring and autumn-winter seasons (spring season: Y= 3.17 X + 1935.81, R^2 = 0.35; autumn winter season: Y= 2.78 X + 1102.69, R^2 = 0.48). However, the pod yields were low during the autumn-winter season because of the limitation imposed by the availability of solar radiation and low temperatures (Fig.18). The relationships of surface runoff and drainage with seasonal rainfall were strong (for runoff: Y = 0.41x – 143.36; R^2 = 0.82 and for deep drainage: Y = 0.31x - 91.24; R^2 = 0.69).

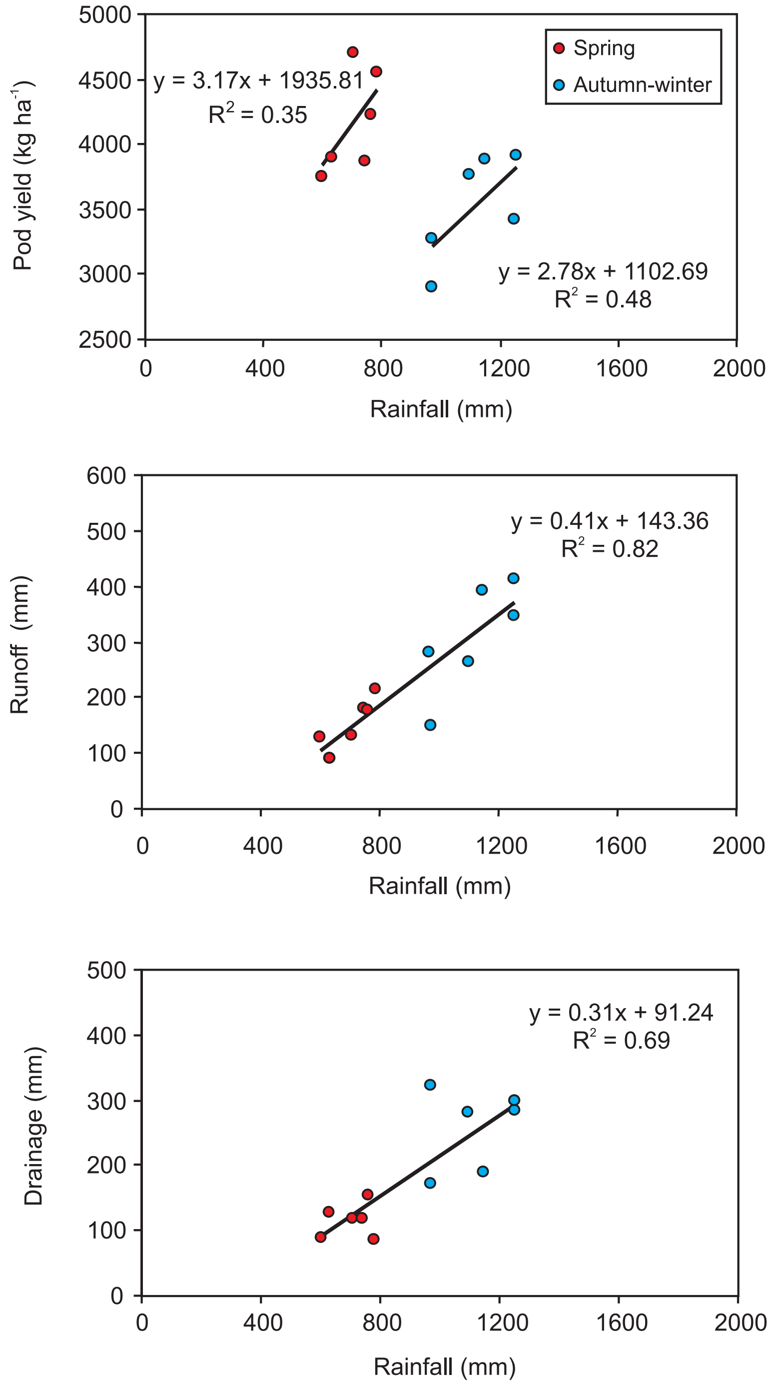


Figure 18. Relationship of peanut yield, surface runoff and deep drainage with seasonal rainfall during spring and summer seasons at six benchmark locations.

Simulated potential yield and yield gap of maize: Maize is normally sown in spring and summer in the rainfed area of northern Vietnam. Sowing window for spring season was 1 to 15 April and for the summer season it was 1 to 15 June. The crop was sown whenever the soil water in the top 30 cm soil depth reached at least 40% of available water capacity. Seasonal analysis for maize yields was done for 28 years for the five locations (Vinh Phuc, Ha Nam, Ninh Binh, Ha Tay and Phu Tho) and 10 years for the Hoa Binh (Table 13).

Yield gap was calculated between simulated and province yields. It ranged from 1030 kg ha^{-1} (19.7%) in Ha Tay in the spring season to 2650 kg ha^{-1} (49.9%) in Hoa Binh in summer season. Simulated yields in summer season were more than those in spring season, hence total yield gap is larger in summer season (Table 14).

Relationship between grain yield and rainfall was very strong ($Y = 0.69 X + 4419.3$; $R^2 = 0.60$). Similarly surface runoff and deep drainage were also very strongly correlated with seasonal rainfall (for runoff: $Y = 0.38 x - 137.2$; $R^2 = 0.78$; for deep drainage: $Y = 0.25 x - 46.5$, $R^2 = 0.62$) (Fig.19).

Table 13. Sowing window and simulation date for rainfed maize in the seasonal analysis.

Location	Sowing window		Simulation date		Weather years
	Spring	Summer	Spring	Summer	
Vinh Phuc	01–15 Apr	15–30 Jun	1 Feb	15 Apr	28
Ha Nam	01–15 Apr	15–30 Jun	1 Feb	15 Apr	28
Ninh Binh	01–15 Apr	15– 30 Jun	1 Feb	15 Apr	28
Phu Tho	01–15 Apr	15–30 Jun	1 Feb	15 Apr	28
Ha Tay	01–15 Apr	15–30 Jun	1 Feb	15 Apr	28
Hoa Binh	01–15 Apr	15–30 Jun	1 Feb	15 Apr	10

Table 14. Simulated potential and province average yield and yield gap of rainfed maize in the spring and summer seasons at benchmark locations in northern Vietnam.

Location	Simulated yield (kg ha^{-1})	Province yield (kg ha^{-1})	Yield gap (kg ha^{-1})	Yield gap(%)
Spring season				
Vinh Phuc	4890	3290	1600	33
Ha Nam	5430	3520	1910	35
Ninh Binh	4800	3360	1440	30
Phu Tho	4980	3240	1740	35
Ha Tay	5210	4180	1030	20
Hoa Binh	4850	2660	2190	45
Mean	5030	3380	1650	33
Summer season				
Vinh Phuc	5330	3290	2040	38
Ha Nam	5570	3520	2050	37
Ninh Binh	5310	3360	1950	37
Phu Tho	5250	3240	2010	38
Ha Tay	5420	4180	1240	23
Hoa Binh	5310	2660	2650	50
Mean	5370	3380	1990	37

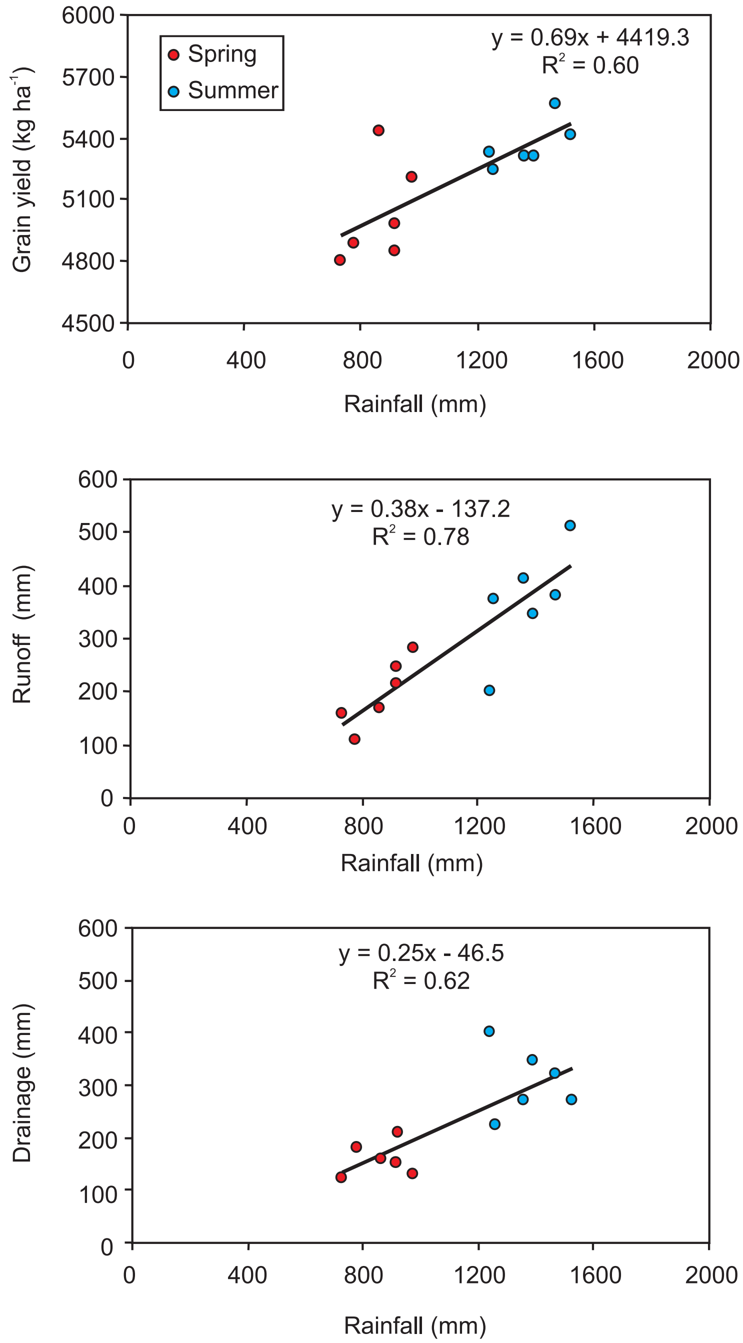


Figure 19. Relationship of maize yield, surface runoff and deep drainage with seasonal rainfall during spring and summer seasons at six benchmark locations.

Constraints and Opportunities for Bridging the Yield Gaps

The main constraints for low yields of rainfed crops in northern Vietnam are undulating topography, poor soil fertility, drought and less adoption of improved soil, water, nutrient, crop and pest management practices leading to inefficient use of natural resources such as rainfall (Wani 2003).

Socioeconomic factors (socioeconomic status, farmer's traditions and knowledge, family size, household income/expenses/investment) and institutional/policy factors such as government policy, product prices, credit, input supply and market, land tenure, linkages factors that consist of the competence and facilities of extension staff; integration among research, development and extension; farmers' resistance to new technology; knowledge and skills; weak linkages among public, private and non-governmental extension staff also contribute to the problem significantly.

The results from the current study revealed that quite large yield gaps exist between the potential yields and current yields of maize, peanut and soybean in six provinces of northern Vietnam. This vast potential of the rainfed areas of northern Vietnam need to be harnessed through large-scale adoption of improved soil, water, crop and pest management options available. Traditionally much emphasis is put on developing new cultivars, however, the findings from the current study and a number of earlier studies suggest that without appropriate soil, water and nutrient management options the true potential of improved cultivars cannot be harnessed. Availability of soil moisture during the crop growth period is very critical as evident from the significant and strong relationship between rainfall and crop yields.

There is also a strong relationship between rainfall, runoff and deep drainage, highlighting the urgent need to develop appropriate rainwater management strategies in northern Vietnam to minimize land degradation and to increase productivity of rainfed crops for achieving food security and improved livelihoods. Integrated watershed management approach, which is evaluated by VASI and ICRISAT at benchmark watersheds in Hoa Binh and Vinh Phuc provinces have shown the large potential for reducing land degradation and increasing productivity of crops by adopting integrated genetic and natural resource management (IGNRM) approach (Wani 2003).

A yield gap reduction can be seen as the local solution to a global problem. It can lead to increased production with the additional incentive of cost reduction, poverty alleviation, social justice and equity and also minimize land degradation while improving environmental quality. While no major breakthrough is expected immediately, reducing the yield gap alone could supply 20 to 60% of the increased annual food demand by the year 2025 (FAO 2004).

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Appendix I

Rainfed soybean yield and yield gap (kg ha^{-1}) at benchmark locations in northern Vietnam.

					Farmer's yield		District	Yield gap		
				Expt.stn.	Imp. mgt.	Trad. mgt.	yield	I	II	Total
Province	District	Year	Season	1	2	3	4	1-2	2-4	1-4
Vinh Phuc	Tam Duong	1998	Summer	1700	1563	1300	959	137	604	741
		1999		1850	1500	1200	1150	350	350	700
		2000		1900	1600	1000	971	300	629	929
		2004		1790	1650				1650	1790
			Average	***1810***	***1578***	***1167***	***1027***	***262***	***808***	***1,040***
	Vinh Tuong	1998	Summer	2000	1800	1400	1144	200	656	856
		1999		1900	1700	1300	1075	200	625	825
		2000		2100	1800	1300	1253	300	547	847
		2004		2145	1842					
			Average	***2036***	***1786***	***1333***	***1157***	***233***	***609***	***843***
Hoa Binh	Kim Boi	1999	Summer	1820	1700	1523	1190	120	510	630
		2000		1900	1650	1563	1170	250	480	730
		2001		1823	1689	1598	1170	134	519	653
		2002		2000	1659	1500	1710	341	-51	290
		2003		1900	1700	1600	1500	200	200	400
			Average	***1889***	***1680***	***1557***	***1348***	***209***	***332***	***541***
	Tan Lac	1999	Summer	2200	1800		800	400	1000	
		2000		1852	1300		630	552	670	
		2001		1900	1765		720	135	1045	
		2002		2200	2000		800	200	1200	
		2003		1890	1800		810	90	990	
			Average	***2008***	***1733***		***752***	***275***	***981***	
Ninh Binh	Nho Quan	1996	Summer	1800	1540	1100	682	260	858	1118
		1997		2200	1600	1400	971	600	629	1229
		1998		2000	1654	1354	692	346	962	1308
		1999		2200	1723	1540	1333	477	390	867
			Average	***2050***	***1629***	***1349***	***920***	***421***	***710***	***1131***
	Yen Khanh	1996	Summer	2100	1800	1560	1413	300	387	687
		1997		2100	1700	1600	1332	400	368	768
		1998		2300	1823	1700	1895	477	-72	405
		1999		2200	1953	2000	1936	247	17	264
			Average	***2175***	***1819***	***1715***	***1644***	***356***	***175***	***531***
Hoa Binh	Kim Boi	1999	Spring	1900	1659	1523	1190	241	469	710
		2000		2200	1750	1654	1170	450	580	1030
		2001		1800	1700	1562	1170	100	530	630
		2002		1800	1600	1523	1710	200	-110	90
		2003		1600	1385	1100	1500	215	-115	100
			Average	***1860***	***1619***	***1472***	***1348***	***241***	***271***	***512***
	Tan Lac	1999	Spring	1800	1600	1300	800	200	800	1000
		2000		1560	1523	1400	630	37	893	930
		2001		1700	1425	1300	720	275	705	980
		2002		1821	1624	1400	800	197	824	1021
		2003		1720	1542	1268	810	178	732	910
			Average	***1720***	***1543***	***1334***	***752***	***177***	***791***	***968***

Appendix II

Irrigated soybean yield and yield gap (kg ha^{-1}) at benchmark locations in northern Vietnam.

					Farmer's yield		District	Yield gap		
				Expt.stn.	Imp. mgt.	Trad. mgt.	yield	I	II	Total
Province	District	Year	Season	1	2	3	4	1-2	2-4	1-4
Ha Tay	Ung Hoa	1998	Winter	2493	2200	1800	1130	293	1070	1363
		1999		2354	2300	1700	1010	54	1290	1344
		2000		2631	2400	1500	1040	231	1360	1591
		2001		2548	2354	1469	1390	194	964	1158
			Average	***2507***	***2314***	***1617***	***1143***	***193***	***1171***	***1364***
	Phu Xuyen	1998	Winter	2300	2000	1500	1180	300	820	1120
		1999		2350	1950	1650	1210	400	740	1140
		2000		2200	1952	1650	1190	248	762	1010
		2001		2400	2210	1300	1350	190	860	1050
			Average	***2313***	***2028***	***1525***	***1233***	***285***	***796***	***1080***
	Thuong Tin	1998	Winter	2400	2005	1700	1130	395	875	1270
		1999		2300	2100	1750	1080	200	1020	1220
		2000		2100	1854	1540	1010	246	844	1090
		2001		2500	1800	1500	1010	700	790	1490
			Average	***2325***	***1940***	***1623***	***1058***	***385***	***882***	***1268***
Ha Nam	Duy Tien	1996	Winter	2400	2100	1500	1250	300	850	1150
		1997		2400	2000	1453	1320	400	680	1080
		1998		2600	2300	1623	1890	300	410	710
		1999		2500	2300	1654	1400	200	900	1100
			Average	***2475***	***2175***	***1558***	***1465***	***300***	***710***	***1010***
	Binh Luc	1996		2500	2300	1742	1510	200	790	990
		1997		2600	2400	1356	1260	200	1140	1340
		1998		2700	2300	1569	1620	400	680	1080
		1999		2689	2500	1687	1470	189	1030	1219
			Average	***2622***	***2375***	***1589***	***1465***	***247***	***910***	***1157***

Appendix III

Rainfed peanut yield and yield gap (kg ha^{-1}) at benchmark locations in northern Vietnam.

					Farmer's yield		District	Yield gap (kg ha^{-1})		
				Expt.stn.	Imp. mgt.	Trad. mgt.	yield	I	II	Total
Province	District	Year	Season	1	2	3	4	1-2	2-4	1-4
Ha Tay	Son Tay	1999	Spring	2200	1756	1500	1210	444	546	990
		2000		2400	1958	1658	1500	442	458	900
		2001		2600	1900	1700	1550	700	350	1050
		2002		2500	2314	2000	1260	186	1054	1240
			Average	***2425***	***1982***	***1715***	***1380***	***443***	***602***	***1045***
	Ba Vi	1999	Spring	2163	1823	1321	800	340	502	521
		2000		2346	2000	1752	1000	346	248	752
		2001		2900	2500	1800	1080	400	700	720
		2002		2900	2415	1912	1380	485	503	532
			Average	***2577***	***2185***	***1696***	***1065***	***393***	***488***	***631***
Ha Nam	Binh Luc	1999	Spring	3300	2500	2100	1560	800	940	1740
		2000		3259	3000	2800	1430	259	1570	1829
		2001		3400	3100	2500	1500	300	1600	1900
		2002		3500	2789	2015	2000	711	789	1500
			Average	***3365***	***2847***	***2354***	***1623***	***518***	***1225***	***1742***
	Kim Bang	1999	Spring	3600	3000	2600	2420	600	580	1180
		2000		3200	2865	2745	1930	335	935	1270
		2001		3300	2958	2436	1910	342	1048	1390
		2002		3100	2859	2300	2190	241	669	910
			Average	***3300***	***2921***	***2520***	***2113***	***380***	***808***	***1188***
Ninh Binh	Nho Quan	2000	Spring	2493	2300	1700	1109	193	1191	1384
		2001		2400	2100	1953	1278	300	822	1122
		2002		2700	1789	1450	1231	911	558	1469
		2003		2612	1900	1600		712	1900	2612
			Average	***2551***	***2022***	***1676***	***1206***	***529***	***1118***	***1647***
Vinh Phuc	Tam Duong	1998	Spring	2200	1800	1500	1060	400	740	1140
		1999		2100	1650	1300	767	450	883	1333
		2000		2300	1900	1569	1005	400	895	1295
			Average	***2200***	***1783***	***1456***	***944***	***417***	***839***	***1256***
	Vinh Tuong	1998	Spring	2400	2000	1632	1234	400	766	1166
		1999		2500	1569	1354	1428	931	141	1072
		2000		2800	2300	2000	1843	500	457	957
			Average	***2567***	***1956***	***1662***	***1502***	***610***	***455***	***1065***
Hoa Binh	Kim Boi	1997	Spring	3743	3000	2185	1190	743	1810	2553
		2000	Spring	2418	1704	1540	1160	714	544	1258
		2001		3000			1330			1670
		2002	Spring	3300	2600	2150	1530	700	1070	1770
			Average	***3115***	***2435***	***1958***	***1303***	***719***	***1141***	***1813***
	Tan Lac	2003	Spring	2492	2000	1771	940	492	1060	1552
Vinh Phuc	Tam Duong	2003	Autumn	2300	2079	1800		221	2079	2300
Hoa Binh	Tan Lac		Autumn	2000	1712	1500	940	288	772	1060
	Tan Lac	1999	Autumn	1910	1600	1400	1200	310	400	710

Appendix IV

Irrigated peanut yield and yield gap (kg ha^{-1}) at benchmark locations in northern Vietnam.

					Farmer's yield		District	Yield gap (kg ha^{-1})		
				Expt. stn.	Imp. mgt.	Trad. mgt.	yield	I	II	Total
Province	District	Year	Season	1	2	3	4	1-2	2-4	1-4
Ha Nam	Duy Tien	1999	Spring	3200	2800	2400	1950	400	850	1250
		2000		3500	3200	2900	2670	300	530	830
		2001		3450	3000	2600	2580	450	420	870
		2002		3200	2912	2500	2460	288	452	740
			Average	***3338***	***2978***	***2600***	***2415***	***360***	***563***	***923***
Ha Tay	Chuong My	1999	Spring	3200	2493	2200	1250	707	1243	1950
		2000		3300	2900	2700	1430	400	1470	1870
		2001		3200	2956	2700	1560	244	1396	1640
		2002		3300	3000	2800	1660	300	1340	1640
			Average	***3250***	***2837***	***2600***	***1475***	***413***	***1362***	***1775***
Ninh Binh	Yen Khanh	2000	Spring	3600	3400	2900	2500	200	900	1100
		2001		3700	3300	3000	2500	400	800	1200
		2002		3569	2879	2521	2500	690	379	1069
		2003		3800	2875	2523	-	925	2875	3800
			Average	***3667***	***3114***	***2736***	***2500***	***554***	***1239***	***1792***

Appendix V

Water balance components (mm) of simulated soybean in seasonal analysis for six locations of watershed.

		Rainfall				Surface runoff				Deep drainage				Evapotranspiration				Extractable water			
Location	Season	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)
Vinh Phuc	Spring	485	1471	830	29.0	19	457	120	83.9	45	596	253	54.9	348	519	466	7.3	31	124	104	19.7
Ha Nam		494	1392	865	24.8	61	343	168	48.2	22	578	214	57.8	463	538	496	4.3	88	254	188	22.0
Ninh Binh		387	1705	772	28.4	17	610	175	55.0	0	404	141	71.5	353	499	445	8.3	90	182	142	19.0
Phu Tho		503	1876	910	30.8	36	176	246	75.5	17	727	112	88.1	436	563	502	7.3	58	127	103	19.0
Ha Tay		211	1716	935	27.8	0	818	270	56.2	0	364	163	64.0	408	561	501	7.5	93	200	158	17.7
Hoa Binh		472	1702	960	39.1	40	548	230	73.5	6	658	256	82.8	429	544	486	7.2	78	173	132	21.7
Vinh Phuc	Sum-Aut	658	1935	1192	27.3	32	500	186	63.5	145	776	432	43.5	416	554	487	7.4	40	121	80	29.1
Ha Nam		672	2413	1413	28.5	103	769	364	49.3	0	941	353	62.3	433	610	500	8.3	126	251	192	15.9
Ninh Binh		576	2624	1330	35.3	65	1020	402	59.6	4	943	320	69.2	373	500	453	7.7	104	182	150	12.0
Phu Tho		748	2615	1232	30.9	121	1326	366	64.1	34	677	264	55.5	438	592	504	8.4	64	128	94	19.9
Ha Tay		955	2570	1466	29.0	194	1206	490	50.0	1	699	292	60.1	446	611	534	7.3	91	193	144	18.9
Hoa Binh		992	1743	1354	20.7	161	537	330	39.6	165	692	383	45.1	471	577	517	6.1	100	148	124	13.5

Appendix VI

Water balance components (mm) of simulated peanut in seasonal analysis for six locations of watershed.

		Rainfall				Surface runoff				Deep drainage				Evapotranspiration				Extractable water			
Location	Season	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)
Vinh Phuc	Spring	276	1271	631	31.4	9	438	91	98.1	0	415	126	77.6	291	505	436	9.4	45	125	91	28.7
Ha Nam		442	1067	705	22.8	29	265	133	42.4	0	343	119	78.5	436	558	483	5.5	76	242	171	24.4
Ninh Binh		351	919	601	28.5	18	332	128	62.3	8	197	90	68.9	368	511	430	7.7	57	180	122	27.0
Phu Tho		414	1274	744	29.4	30	417	182	58.6	0	400	118	91.0	359	592	464	9.1	44	128	96	22.6
Ha Tay		401	1182	784	24.0	65	428	214	44.3	0	251	86	90.9	398	547	469	7.1	37	198	147	27.5
Hoa Binh		334	1699	763	52.5	14	555	177	93.2	0	631	155	125.7	387	569	466	11.0	32	172	110	36.3
Vinh Phuc	Aut-Win	355	1427	972	27.0	9	390	150	64.1	0	584	322	47.4	332	501	446	9.6	7	108	48	58.9
Ha Nam		749	2056	1254	29.5	90	757	346	55.3	3	750	284	67.0	411	630	473	8.3	40	210	148	29.9
Ninh Binh		636	2288	1251	33.1	126	907	412	56.0	58	842	299	59.6	362	507	425	9.1	47	146	110	22.7
Phu Tho		450	2179	969	33.5	61	1139	281	72.7	0	522	173	67.4	349	567	445	9.9	16	113	66	37.9
Ha Tay		601	2114	1148	32.9	108	1034	392	57.2	0	530	189	75.4	393	531	482	6.6	28	164	87	43.4
Hoa Binh		742	1428	1097	19.0	114	403	263	38.2	126	543	282	46.7	430	523	489	5.8	20	117	64	49.7

Appendix VII

Water balance components (mm) of simulated maize in seasonal analysis for six locations of watershed.

		Rainfall				Surface runoff				Deep drainage				Evapotranspiration				Extractable water			
Location	Season	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)
Vinh Phuc	Spring	476	1460	777	28.3	17	465	110	88.6	32	533	182	63.7	367	581	509	8.0	18	124	90	30.5
Ha Nam		520	1372	864	23.6	54	356	170	46.7	0	495	160	71.9	509	627	557	4.4	50	255	178	28.6
Ninh Binh		396	1217	730	28.3	17	432	160	57.5	9	387	122	74.3	402	565	490	8.6	60	182	126	27.0
Phu Tho		503	1895	918	33.6	43	1025	249	77.4	3	417	150	72.9	423	678	542	9.0	25	128	93	29.8
Ha Tay		545	1439	975	24.0	101	562	283	43.9	0	339	130	76.9	456	630	544	6.8	62	201	150	25.2
Hoa Binh		485	1766	920	45.7	33	555	215	85.3	0	667	210	101.1	445	632	527	9.8	55	154	112	32.9
Vinh Phuc	Summer	662	1994	1243	27.6	34	529	202	61.9	128	772	400	47.5	468	632	562	6.8	25	125	73	42.0
Ha Nam		710	2480	1470	28.7	103	792	382	48.7	0	912	320	71.1	525	659	583	6.5	71	234	181	21.1
Ninh Binh		596	2675	1360	35.5	66	1045	412	60.3	0	901	272	80.9	467	599	532	7.3	52	182	134	22.7
Phu Tho		771	2643	1258	31.5	126	1348	375	64.0	1	628	226	66.1	479	673	578	8.4	37	124	75	37.3
Ha Tay		825	2611	1523	30.4	199	1220	512	51.3	0	677	270	65.9	523	685	608	7.5	63	201	134	28.4
Hoa Binh		1003	1800	1392	20.4	161	548	346	37.6	122	660	347	50.3	538	620	586	4.2	88	142	114	16.1

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