Chapter VI

Measurement of Agricultural and Water Productivity
CHAPTER VI
MEASUREMENT OF AGRICULTURAL AND WATER PRODUCTIVITY

This chapter deals with the measurement of land and water productivity of major crops that play a significant role in agricultural development in the state. Crop productivity and demarcation of productivity regions have been considered by taking into account major groups of crops-cereals, pulses, oilseeds and cash crops by applying Yang's 'crop yield index' method. Further, crop water requirements, i.e. the evapotranspiration, during the crop growing seasons were calculated applying a statistical formula devised for this purpose and water productivity for four major crops of wheat, rice, maize and sugarcane were measured for each district of the state. As there are substantial variations in water productivity, some measures have also been put forward for increasing water productivity in the crops considered.

A. Measurement of Agricultural Productivity and Productivity Regions
a. The concept of agricultural productivity

Agricultural productivity refers to the output produced by a given level of input(s) in the agricultural sector of a given economy (Fulginiti and Perrin, 1998). It can be defined as the ratio of the index of total agricultural output to the index of total input used in farm production (Olayide and Heady 1982; Shafi, 1984). It is, therefore, a measure of efficiency with which inputs are utilised in production, other things being equal. It is physical rather than a value concept that describes relationship between output and the major inputs utilized in production (Zaman and Rahman, 2009).

Measurement of crop productivity is one of the important concepts to examine the performance of agriculture and its transformation. It includes ascertaining the impact of technological advancement, effective management of available water resources and organizational set up for the agricultural production. These factors in turn affect the relative productivity in a region. In order to mark out variations in agricultural productivity, attention of many of the researchers and planners has been focused in India as well as in other countries of the world.

Productivity of the crop is judged not only from the view of quantity but also variety and quality of crop produce. Irrigation water and its adequate availability not
only enhances productivity per hectare but also promotes adoption of new agricultural technology embodied in the form of use of HYVs, fertilizers and plant protection measures along with the practices of improved water management. Accelerated development of irrigation may substantially boost the prospects for raising agricultural production provided it is accompanied by appropriate technological developments and more efficient water management. Another desirable influence of irrigation is that, it induces a higher degree of stability in yields per hectare and thereby, reduces fluctuations in production levels. Thus, irrigation together with new technology package raises substantially the productive capacity of land.

Agricultural productivity in India in terms of output per unit area and per worker is low in comparison to the world averages and has attained the same status for many decades. The most significant development in agricultural productivity in India has been in recent years in the form of a shift from traditional based agriculture to modern methods. Modern agriculture has ushered a change in techniques and use of production inputs that were unknown to farmers few decades ago. This change has increased considerably the yield per hectare of several crops and thereby average productivity. However, the average yields of many crops are still below the world averages and far behind the developed countries of Europe, Anglo America, and even some Asian countries (Doorenbos and Pruitt, 1977). The unimpressive change in average productivity in India is due to unequal diffusion of new agricultural technology from one area and crop to another. In some regions, where the new agriculture has taken a firm hold, productivity has recorded a remarkable increase, whereas in other regions it has changed a little (Dayal, 1984).

b. Agricultural productivity and methods of its measurement

Definition and measurement of productivity in agriculture has always been debatable. Analysis of agricultural productivity has attracted the attention of a large number of geographers and economists working in this discipline. Many attempts have been made to measure it and marked out the variations in food crop productivity in India as well as in other countries of the world. In an earlier attempt, Thompson (1926) measured productivity of British and Danish farming by taking into consideration seven aspects related to farming: the yield per acre of crops; the number of livestock per 100 acres; the gross production or output per 100 acres; the
production of arable land; the number of persons employed; the cost of production expressed in terms of wages and labour costs, rent or interest on capital; and prices, relative profitability and general economic conditions. Ganguli (1938) presented a theoretical discussion for computing productivity in agriculture in the Ganga Valley (India). Firstly, he took into account the area under any crops ‘A’ in a particular unit area belonging to a certain region. This area is expressed as a proportion of the total cropped area under all the selected crops. Secondly, Ganguli tried to obtain the index number of yield. This is found by dividing the yield per hectare for the entire region as the standard. This yield may be expressed as a percentage and the percentage may be regarded as the index number of yield. Thirdly, the proportion of area under A and the corresponding index number of yield were multiplied. There are two apparent advantages of this method, i.e. (a) the relative importance of the crop A in that unit of study, and (b) the yield of crop A in comparison to the regional standard. The product thus obtained indicates actually an index of the contribution of crop A to the productivity of the unit considered. Kendall (1939) treated it as a mathematical problem and initiated a system of four coefficients (a) productivity coefficient, (b) ranking coefficient, (c) money value coefficient and (d) starch equivalent or energy coefficient. Kendall pointed out that the productivity coefficient and the ranking coefficient are concerned only with the yield per acre, but are not in any way weighted according to the volume of production. He, therefore, evolved a measure of crop productivity by using index number technique. In this technique the yield of different crops are expressed in terms of some common units. Kendall pointed out that, there are two common units which can be taken note of: first, the money value ‘as expressed in price’ and second, energy ‘as expressed in starch value equivalent.’

Hirsch (1943) has suggested, ‘Crop Yield Index’ as the basis of productivity measurement. According to him, it expresses the average of yields of various crops on a farm or in a locality relative to the yield of the same crops on another farm in a second locality. Zobel (1950) has attempted to examine the labour productivity. He considered productivity of labour as the ratio of total crop output to the total man-hours consumed in the production of that output, resulting in an estimate of output per man-hour. Stamp (1952) applied Kendall’s ranking coefficient technique on an international level to determine agricultural efficiency considering a number of countries as well as some major crops. Huntington and Valkenburg (1952) considered land productivity on the basis of acre yields of eight crops raised very widely in
Europe as a whole, and assumed as an index per 100 for it, and thus calculated the specific yield index of each country. Stamp (1958) suggested a method for measuring the agricultural productivity, i.e., to convert total agricultural production in calories. The caloric intake is a measure of the general health of a person because it determines the amount of heat and energy needed by the human body. Shafi (1960) applied the technique 'ranking coefficient' of Kendall for measuring the agricultural efficiency in the state of Uttar Pradesh taking into account eight food crops grown in each of forty-eight districts of the state for two quinquennial years ending 1952 and 1957.

Loomis and Barton (1961) have measured United States agricultural input and productivity in aggregate. To them, aggregate productivity depends upon conceptually consistent measures of agricultural output and input. The measures of inputs include all the production factors that depend directly on the decisions of farmers. Meiburg and Brandt (1962) have surveyed the earlier indices relating to agricultural output, e.g., output estimates of total productivity of the United States. Mackenzie (1962) has measured the efficiency of production in Canadian agriculture by using the coefficient of output relative to input. He mentioned that the concept of productivity measurement in agriculture is difficult to define and even more difficult to quantify.

Oommen (1962) while working out the trends of productivity in agriculture of the state of Kerala (India) has measured productivity on the basis of yield per acre. Enyedi (1964), while describing geographical types of agriculture in Hungary refers to a formula for determining agriculture productivity. Horring (1964) has suggested that the concept of productivity is based not only on the single relationship between output and input but rather on the differences between two or more relationships, i.e., differences in the same agricultural region or sub-region as between successive periods (in time), and between similar agricultural regions in different countries or regions during the same period (in space).

Sapre and Deshpande (1964) have attempted to refine further the Kendall’s ‘ranking coefficient method’. For this, they used 'weighted average of ranks' instead of the simple average of ranks. Thus, it incorporates the proportion of crop area to the total cropped area of the district. Khusro (1965) has linked assessment of productivity with the output per unit of a single input and output per unit of cost of all inputs in the agricultural production. Saran (1965) has applied Cobb-Douglas
'Production Function' approach for the measurement of productivity. The common purpose of this function is to express input/output relationship between several inputs and one output in the agricultural systems. Shaft (1965) has assessed the productivity on the basis of labour population engaged in agriculture. According to him, it can be computed by dividing the gross production in any unit area by the number of man-hours or less precisely by the numbers employed in agriculture. Agarwal (1965) has suggested 'Factorial Approach' while measuring agricultural efficiency in Bastar district of Madhya Pradesh. A number of human controlled factors relating to agricultural production as: crop superiority, crop commercialization, crop security, land use intensity and power input have been selected, excluding the environmental factors.

Dovring (1967) has measured the productivity of labour in the United States agriculture in aggregate since 1919 to 1954 for the entire period, as well as commodity-wise. Bhatia (1967) while assessing the changes and trends in agricultural efficiency in Uttar Pradesh during 1953-1963 adopted Ganguli's method of productivity measurement. Shaft (1967 and 1969) applied Stamp's 'Standard Nutrition Unit' technique for measuring the efficiency of agriculture in India. He considered the district as the areal unit and has selected all the food crops grown in the country. Sinha (1968) has adopted a standard deviation formula to determine agricultural efficiency in India. For this purpose he selected all the twenty-five major crops grown in the country these were grouped into as: cereals, pulses, oilseeds and cash crops and specific yields per hectare of cereals, pulses and oilseeds were taken into account.

Shaft (1970) attempted to compute the index of productivity coefficient following the formula initiated by Enyedi for each district of India with regard to twelve food crops. In another study Shafi (1972), while commenting on the formula presented by Enyedi in determining productivity index of an area with reference to the national scale pointed out that there are certain cases where the results obtained by the formula are influenced by the magnitude of the area under a particular crop when the yield of the district is either the same or is less than the national yield. Relman (1976) while examining the impact of mechanization on food crop productivity in the districts of Uttar Pradesh applied Kendall's ranking coefficient method.

Bhalla (1978) considered output per person on constant average price for
measuring the productivity of labour in Indian agriculture on the basis of nineteen crops grown during the triennials 1962-65 and 1970-73 for each district of the country. Singh (1979) devised a method for presenting a two-dimensional picture of agricultural productivity comprising two components, viz., intensity and spread considering three variables (i) yield, (ii) grain equivalent, and (iii) cropping system in the districts of Andhra Pradesh state. Accordingly, a relative share of intensity and spread for each micro unit (district) has been computed to the macro unit (state) separately for the above three variables with the help of equations that have been derived.

Bhalla and Tyagi (1989) followed a method of production aggregation (in terms of money) which can be considered a method noticeable for showing diversification in agricultural production patterns in India. However, there is still a question among scholars whether total production of crops achieved on a piece of land is considered, which a product of many factors like agro-ecological conditions of land, technological enhancement and labour employed for agriculture. If it is a result of combination of all such geographical factors, the question of isolating effects of such different production factors is still debatable (Sharma, 2012). Rehman and Hussain (2003) in their study of North Bihar Plain used Kendall’s method of ranking coefficient for measuring agricultural efficiency considering nine major crops grown for two periods of 1990-95 and 1995-2000. Zaman and Rahman (2009), and Umar and Rehman (2011), while determining productivity regions in the Ganga-Yamuna doab and in the state of U.P., respectively applied Yang’s Crop Yield Index method.

c. Agricultural Productivity Regions: Based on Crop Yield Index method

For the present study, productivity indices were calculated following Yang’s Crop Yield Index method (1965) for three consecutive periods of time, i.e. 1995-2000, 2000-05 and 2005-10. Computation of crop yield index involved the yield of all crops grown in the district compared with the average crop yield of the entire region. Before calculating the crop yield index for a particular farm, the average yield of each of the crops grown in the region must be determined. Then, by dividing the yield per hectare of a crop on a particular farm by the average yield of the crop in the region, a percentage figure is obtained which when multiplied by 100, gives the index number, as shown in column 5 (Table 6.1). By using the area devoted to each
crops as a weight to multiply this percentage index, the products are obtained as listed in column 6 of table. By adding the products and dividing the sum of the products by the total crop area (in ha) of the farm (the sum of column 4), the average index is the desired crop index for the particular farm, using crop area as a weight. All of the major 18 crops grown in the state were taken into account for computing crop yield index. For the sake of convenience, all crops were categorized into four major groups: cereals (wheat, rice, barley, jowar, bajra and maize); pulses (urad, moong, arhar, gram, masoor and peas); oilseeds (mustard and rapeseed, soyabean, groundnut and til); and cash crops (to include sugarcane and potatoes), and a composite index for all the groups of crops were also computed applying the same method.

Table 6.1 Method of calculating crop yield index of a farm

<table>
<thead>
<tr>
<th>Crops</th>
<th>Yield in quintals per hectare</th>
<th>Hectares of crop on farm X</th>
<th>Crop yield on farm X as a percentage of the region (Col. 3/Col.2)*100</th>
<th>Percentage multiplied by hectares (Col.4*Col.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>20</td>
<td>22</td>
<td>10</td>
<td>94</td>
</tr>
<tr>
<td>Rye</td>
<td>18</td>
<td>17</td>
<td>10</td>
<td>94</td>
</tr>
<tr>
<td>Barley</td>
<td>22</td>
<td>20</td>
<td>5</td>
<td>91</td>
</tr>
<tr>
<td>Maize</td>
<td>30</td>
<td>36</td>
<td>15</td>
<td>120</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td>40</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Crop index on farm X = 4,295/40 = 107 per cent.


i. Crop productivity regions: Based on cereal crops

Cereal crops constitute an important item in the diet of a large chunk of population in the state, because they are comparatively a cheap source of calories. The importance of cereals is increasing day by day because of increasing demand of the growing population. Cereal crops do not fix atmospheric nitrogen in soils for enrichment as the pulses do, but the residues of cereals return more organic matter to the soils than do the pulse crops. The main cereal crops: wheat, rice, maize, barley, jowar and bajra, provide about 75 per cent of calories needed in human diet at a cheaper rate as compared to other crops. Protein content in cereals ranges in between 6 and 12 per cent. Rice contains 7.5 per cent, maize 9.5 per cent, and barley 11 per cent. Besides protein, cereal crops also contain fats, calcium and iron. With regard to caloric content, 100 gram of wheat contains 330 calories, rice 357, maize 356 and barley 330 calories (Aykroyd and Doughty, 1970).
UTTAR PRADESH
Agricultural Productivity Regions
Cereal Crops
1995-2000

Fig. 6.1
Crop yield indices were computed on the basis of Yang's method for cereals, pulses, oilseeds and cash crops during the periods of 1995-2000, 2000-05 and 2005-10. During the period of 1995-2000, very high productivity of cereals was seen in the districts of upper Ganga-Yamuna doab namely, Bulandshahr (132.35), Meerut (132.31), Baghpat (131.22), Ghaziabad (125.79) and Muzaffarnagar (123.38), the districts of Hathras (127.06) and Agra (122.69) of middle doab and two districts of Rohilkhand plains namely, Pilibhit (122.79), and Rampur (120.22) also belonged to this category. Following these, there were 16 districts which lie in the Ganga-Yamuna doab and Rohilkhand plains of the state including some eastern districts namely, Maharajganj, Kushinagar, Ambedkar Nagar and Chandauli, also recorded high productivity with index values between 105 and 120, whereas, an equal number of districts had medium productivity with index values in between 90 and 105, which did not form a contiguous belt and scattered in all parts of the state, except the districts of upper doab (Fig. 6.1). Low productivity (75-90) was marked in 22 districts, and 7 districts namely, Unnao (74.62), Chitrakoot (70.57), Shrawasti (64.06), Banda (61.88), Bahraich (61.19), Lalitpur (60.82) and Sonbhadra (58.77) characterized with very low productivity.

During the period of 2000-05, the highest productivity was recorded by Bulandshahr district (133.16) of upper doab and the lowest in Mahoba (57.81) district of Bundelkhand region. During this period, the number of districts in the category of high productivity (105-120) increased from 16 in 1995-2000 to 24 during 2000-05 (Table 6.2). It is evident from Fig. 6.2 that, the districts extending from Saharanpur in the north up to Kanpur Nagar in the Ganga-Yamuna doab, almost all the districts of Rohilkhand plains, and the districts Kheri and Bambanki of Awadh plains, along with 3 eastern districts attained very high and high productivity during this period. Medium productivity was seen in 14 districts, most of these were lie in Awadh and Purvanchal regions. Low productivity was marked in 19 districts, and 3 districts of Bundelkhand region and Sonbhadra of Purvanchal formed a region of very low productivity.

It is shown in Fig. 6.3 that, during 2005-10, very high productivity of cereal crops was recorded in 10 districts which belonged entirely to the Ganga-Yamuna doab and Rohilkhand plains. The district of Ghaziabad recorded the highest productivity with an index value of 130.41.
Table 6.2 Productivity regions of cereal crops in Uttar Pradesh

<table>
<thead>
<tr>
<th>Category (Range)</th>
<th>1995-2000</th>
<th>2000-03</th>
<th>2005-10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Name of district</td>
<td>No.</td>
</tr>
<tr>
<td>Very high (Above 120)</td>
<td>9</td>
<td>Bulandshahr, Meerut, Baghpat, Hathras, Ghaziabad, Muzaffarnagar, Pilibhit, Agra and Rampur</td>
<td>8</td>
</tr>
<tr>
<td>Medium (90-105)</td>
<td>16</td>
<td>Varanasi, S.R.Nagar, Bareilly, Mainpuri, Kheri, Esh, Jalaun, Faizabad, Kanpur Nagar, Barhampur, Sultanpur, Budaun, Deoria, Fatehpur, S.K.Nagar and Ghazipur</td>
<td>14</td>
</tr>
<tr>
<td>Low (75-90)</td>
<td>22</td>
<td>Farrukhabad, Kamalapur, Mirzapur, Hardoi, Azamgarh, Basti, Pratapgarh, Mau, Allahabad, Gorakhpur, Siddharthnagar, Sitapur, Ballia, Jaunpur, Lucknow, Jaunpur, Rae Bareli, Kausambi, Ballia, Jaunpur, Moradabad, Allahabad and Mahoba</td>
<td>19</td>
</tr>
<tr>
<td>Very low (Below 75)</td>
<td>7</td>
<td>Unnao, Chitrakoot, Shrawasti, Banda, Bareli, Laliipur and Sonhada</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.

Number of districts marked with high productivity decreased from 24 to 15. There were 25 districts with the category of medium productivity. Low productivity was recorded in 13 districts, which belonged to Awadh and Purvanchal regions, whereas, the district of Jhansi of Bundelkhand, and 7 other districts were marked having very low productivity in cereals, these are namely, Mirzapur (74.58),
UTTAR PRADESH
Agricultural Productivity Regions
Cereal Crops
2000-05

Fig. 6.2
Fig. 6.3

UTTAR PRADESH
Agricultural Productivity Regions
Cereal Crops
2005-10

Index
Very high
High
Medium
Low
Very low
Above 120
105-120
90-105
75-90
Below 75

20 0 20 40 60 80 100
Km

Fig. 6.3
Hamirpur (72.75), Lalitpur (69.75), Chitrakoot (55.89), Banda (52.22), Sonbhadra (50.67) and Mahoba (50.13).

During the period of 1995-2000 to 2000-05, there were 48 districts to record a positive growth in productivity of cereals, whereas during 2000-05 to 2005-10, 31 districts showed a positive growth. For the sake of convenience, growth in productivity indices were grouped into four grades in order of high (above 10 per cent), medium (0 and 10 per cent), low (-10 and 0 per cent) and very low (below -10 per cent). During the former period, high growth in cereal crops was recorded in 10 districts namely, Bahraich, Farrukhabad, Kannauj, Shrawasti, Unnao, Gonda, Jaunpur, Hardoi, Lalitpur and Barabanki. During the later period, the districts of Balrampur, Siddharthnagar and Firozabad belonged to this category (Table 6.3). Medium growth was noticed in 38 and 28 districts, respectively, and there were 18 and 31 districts belonging to low category in respective periods. Very low growth was seen in 4 and 8 districts, respectively. These districts were namely, Varanasi, Chandauli, S.R.Nagar and Mahoba during the previous period, and the districts namely, Jhansi, Hathras, Hamirpur, Mahoba, Jalaun, Banda, Sonbhadra and Chitrakoot represented this category during the later period.

<table>
<thead>
<tr>
<th>Category</th>
<th>Range (Per cent)</th>
<th>1995-2000 to 2000-05</th>
<th>2000-05 to 2005-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Above 10</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Medium</td>
<td>0 to 10</td>
<td>38</td>
<td>28</td>
</tr>
<tr>
<td>Low</td>
<td>-10 to 0</td>
<td>18</td>
<td>31</td>
</tr>
<tr>
<td>Very low</td>
<td>Below -10</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.

ii. Crop Productivity regions: Based on pulse crops

Productivity of pulse crops in the state during 1995-2000 ranged highest with an index value of 145.03 for the district of Kaushambi and lowest with the index value of 69.28 for G.B.Nagar, both of these belong to the Ganga-Yamuna doab. Very high productivity characterized with 140 and above was recorded in 3 districts of lower doab namely, Kaushambi (145.03), Auraiya (144.17) and Kanpur Dehat (142.81). Some adjoining districts of middle doab and Muzaffarnagar of upper doab also belong to high productivity regions (Fig. 6.4).

A total of 18 districts recorded medium productivity with index value in between 100 and 120, whereas, 34 districts were having low productivity in between
UTTAR PRADESH
Agricultural Productivity Regions
Pulse Crops
1995-2000

Fig. 6.4
Table 6.4 Productivity regions of pulse crops in Uttar Pradesh

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Name of district</td>
<td>No.</td>
</tr>
<tr>
<td>Very high (Above 140)</td>
<td>3</td>
<td>Kaushambi, Auraiya and Kanpur Dehat</td>
<td>7</td>
</tr>
<tr>
<td>High (120-140)</td>
<td>9</td>
<td>Etawah, Agra, Kanpur Nagar, Muzaffarnagar, Kannauj, Allahabad, Fatehpur, Farrukhabad and Etah</td>
<td>9</td>
</tr>
<tr>
<td>Medium (100-120)</td>
<td>18</td>
<td>Bijnor, Chitrakoot, Mainpuri, Pratapgarh, Saharanpur, J.P. Nagar, Moradabad, Rampur, Lalitpur, Sultanpur, Jaunpur, Kushinagar, Firozabad, Jalaun, Budaun, Ambedkar Nagar, Varanasi and Meerut</td>
<td>17</td>
</tr>
<tr>
<td>Very low (Below 100)</td>
<td>6</td>
<td>Mathura, Hathras, Balmampur, Lucknow, Deoria, G.B. Nagar</td>
<td>7</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.
UTTAR PRADESH
Agricultural Productivity Regions
Pulse Crops
2000-05

Fig. 6.5
UTTAR PRADESH
Agricultural Productivity Regions
Pulse Crops
2005-10

Fig. 6.6
the index values of 80 and 100, and 6 districts namely, Mathura, Hathras, Balrampur, Lucknow, Deoria and G.B.Nagar recorded very low productivity indices of 80 and below (Fig. 6.4).

During the period of 2000-05, the districts namely, Moradabad (164.27), J.P.Nagar (158.42), Rampur (151.51) and Bijnor (147.56) of Rohilkhand plains got shifted from medium to very high productivity category. Another set of 3 districts namely, Kanpur Dehat (153.29), Etawah (143.48) and Kannauj (141.10) of lower doab also follow the same pattern. Conversely, very low productivity in pulses was seen in 7 districts namely, Mahoba (77.46), Siddharthnagar (77.35), S.K.Nagar (72.26), Gorakhpur (71.54), Basti (71.54) Chaudauli (69.06) and Deoria (67.53) of Bundelkhand and Purvanchal regions, respectively (Fig. 6.5). Medium and low productivity were recorded by 17 and 30 districts, respectively.

The districts namely, J.P.Nagar, Moradabad, Rampur and Budaun of Rohilkhand, and Kanpur Dehat, Auraiya, Etawah and Kannauj of lower doab recorded very high productivity during 2005-10 (Table 6.4). During this period, 6 adjoining districts belonging to former region also attained high productivity in pulse crops. There were in total 32 districts, which recorded medium productivity, and low productivity was confined to 20 districts to form a part of Awadh and Purvanchal regions of the state, along with the districts of Saharanpur and Aligarh of doab and Jhansi of Bundelkhand. Very low productivity was seen in 4 districts namely, Chitrakoot, Hamirpur, Banda and Mahoba of Bundelkhand region (Fig. 6.6).

Table 6.5 Growth in productivity indices of pulse crops in Uttar Pradesh

<table>
<thead>
<tr>
<th>Category</th>
<th>Range (Per cent)</th>
<th>1995-2000 to 2000-05</th>
<th>2000-05 to 2005-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Above 10</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>Medium</td>
<td>0 to 10</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Low</td>
<td>-10 to 0</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Very low</td>
<td>Below -10</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 6.5 shows that, during 1995-2000 to 2000-05, high growth in pulse crops productivity above 10 per cent was recorded by 18 districts of the state, and during later periods of 2000-05 to 2005-10, there were 22 districts, which belonged to this category. Medium growth (0-10 per cent) was seen in 24 districts during both the periods. There were 14 and 12 districts, respectively which were characterized.
with low growth (-10 to 0 per cent), and very low growth was seen in 14 and 12 districts of the state in the respective periods.

iii. Crop Productivity regions: Based on oilseed crops

With respect to productivity in oilseeds, an interesting picture emerges out from Fig. 6.7 that during 1995-2000, the districts of Ganga-Yamuna doab extending from Saharanpur (in the north) up to Allahabad were characterized with very high and high productivity with the index values of above 100, along with the districts of Jhansi and Lalitpur, Bijnor, Rampur and S.K.Nagar which represented three regions namely, Bundelkhand, Rohilkhand and Purvanchal, respectively. It is evident from Table 6.6 that, the number of districts increased from 8 to 14 during 2000-05 with very high category, whereas with high category, their number decreased from 21 to 13. Medium productivity was recorded in 17 districts during the previous period. During 2000-05, there were 21 districts to be included with the category of medium productivity. There were 18 districts which had low productivity and 6 districts namely, Mirzapur (69.90), Ghazipur (69.51), Varanasi (66.23), Balrampur (65.59), Chitrakoot (57.96) and Sonbhadra (55.84) recorded very low productivity of oilseeds during 1995-2000, and 15 and 7 districts during 2000-05 had low and very low productivity, respectively (Fig. 6.8).

During 2005-10, the number of districts decreased to 12 in the category of very high productivity. Among these the districts namely, Mathura, Etah, Agra, Firozabad and Aligarh belong to middle doab, Mainpuri, Etawah, Farrukhabad and Kannauj of lower doab and Bijnor and Unnao of Rohilkhand and Awadh plains, respectively fall in this category. Out of 24 districts of high productivity, 12 lie in Purvanchal region and the remaining districts fall in western part of the state along with Hardoi and Jalpa of Awadh and Bundelkhand regions, respectively. Medium productivity of oilseed crops was observed in 19 districts and low productivity was occupied by 10 districts of the state. There were 5 districts namely, S.R.Nagar, Sonbhadra, Hamirpur, Mahoba and Chitrakoot which had very low productivity indexes (Fig. 6.9).

With respect to growth in productivity of oilseed crops, high growth of above 10 per cent was seen in 14 and 20 districts during the periods under consideration, respectively. Medium growth was recorded in 27 and 23 districts, respectively, and low growth (-10 to 0 per cent) in 20 and 14 districts of the state in respective periods.
Table 6.6 Productivity regions of oilseed crops in Uttar Pradesh

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High (100-115)</td>
<td>21</td>
<td>G.B.Nagar, Meerut, Ghaziabad, Baghat, Pratapgarh, Kannauj, Kaushambi, Auraiya, Etah, Fatehpur, Bulandshahar, Mathura, Jhansi, Lalitpur, Kanpur, Nagpur, Hathras, Mainpur, Bijou, Muzaffarnagar, Raupur, S.K.Nagar and Rae Bareli</td>
<td>13</td>
<td>J.P.Nagar, Chandauli, Jaunpur, Ballia, Ghazipur, Fatehpur, Main, Moradaab, Kanpur Nagpur, Budaun, Uman, Mirzapur, Gorakhpur, Jhansi, Rae Bareli, Shahjahanpur, Lalitpur, S.K.Nagar, Barabanki and Jalal</td>
<td>24</td>
<td>Lalitpur, Hathras, Kanpur Dehat, Banda, Rampur, Deoria, Jhansi, Sultanpur, Barabanki, Ambedkar Nagar, Faizabad, Bahraich, Rae Bareli, Lucknow, Kanpur Nagar, Allahabad, J.P.Nagar, Sitapur and Fatehpur</td>
</tr>
<tr>
<td>Medium (85-100)</td>
<td>17</td>
<td>Mau, Deoria, Basti, J.P.Nagar, Gorakhpur, Siddharthnagar, Jaunpur, Bareilly, Azamgarh, Ballia, Budaun, Uman, Hardoi, Barabanki, Moradabad and Mahanagaaj</td>
<td>21</td>
<td>Basti, Siddharthnagar, Bareilly, Sitapur, Fauzpicbhad, Ambedkar Nagar, Mahanagaaj, Lucknow, Bahrabich, Kushinagar, Kheri, Hamirpur, S.K.Nagar, Pilibhit and Shahjahanpur</td>
<td>19</td>
<td>Patalganga, Bareilly, Gonda, Shajahanpur, Kheri, Shrawasti, Pilibhit, Balrampur, Maharajganj and Kushinagar</td>
</tr>
<tr>
<td>Low (70-85)</td>
<td>18</td>
<td>Chandauli, Sitapur, Lucknow, Kushinagar, Sultanpur, Bahraich, Kheri, Mahoba, Pilibhit, Faizabad, Banda, Shahjahanpur, Ambedkar Nagar, Hamirpur, Gonda, Jalal, S.R.Nagar and Shrawasti</td>
<td>15</td>
<td>Basti, Siddharthnagar, Bareilly, Sitapur, Faizabad, Ambedkar Nagar, Maharajganj, Lucknow, Bahraich, Kushinagar, Kheri, Hamirpur, S.K.Nagar, Pilibhit and Shrawasti</td>
<td>10</td>
<td>Patalganga, Bareilly, Gonda, Shajahanpur, Kheri, Shrawasti, Pilibhit, Balrampur, Maharajganj and Kushinagar</td>
</tr>
<tr>
<td>Very low (Below 70)</td>
<td>6</td>
<td>Mirzapur, Ghazipur, Varanasi, Ballarpur, Chitrakoot and Sonbhadra</td>
<td>7</td>
<td>Sitapur, Balrampur, Gonda, Sonbhadra, Banda, Mahoba and Chitrakoot</td>
<td>5</td>
<td>S.R.Nagar, Sonbhadra, Hamirpur, Mahoba and Chitrakoot</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.

Table 6.7 Growth in productivity indices of oilseeds crops in Uttar Pradesh

<table>
<thead>
<tr>
<th>Category (Per cent)</th>
<th>Range</th>
<th>Number of districts</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Above 10</td>
<td>14</td>
</tr>
<tr>
<td>Medium</td>
<td>0 to 10</td>
<td>27</td>
</tr>
<tr>
<td>Low</td>
<td>-10 to 0</td>
<td>20</td>
</tr>
<tr>
<td>Very low</td>
<td>Below -10</td>
<td>9</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.
UTTAR PRADESH
Agricultural Productivity Regions
Oilseed Crops
1995-2000

Index
Very high Above 115
High 100-115
Medium 85-100
Low 70-85
Very low Below 70

Fig. 6.7
UTTAR PRADESH
Agricultural Productivity Regions
Oilseed Crops
2005-10

Index
Very high	Above 115
High	100-115
Medium	85-100
Low	70-85
Very low	Below 70

Fig. 6.9
There were 9 and 13 districts, respectively which recorded very low growth during these periods (Table 6.7).

iv. Crop Productivity regions: Based on cash crops

It is depicted in Table 6.8 that, during the period of 1995-2000, only 2 districts namely, Agra and Firozabad of middle *doab* occupied very high productivity in cash crops with yield indices of 146.10 and 125.47, respectively. The districts marked with high productivity were namely, Hathras (120.28), Muzaffarnagar (113.39), Farrukhabad (112.53) and Baghpat (111.64) during the same period (Fig. 6.10). During 2000-05, 2 districts again belonged to the category of high productivity; the highest index was recorded by the district of Hathras (137.27) replacing Agra to second place with index value of 131.20. Medium productivity regions with indices values ranging from 95 and 110 during both the periods were confined to western parts of the state, except the districts of Barabanki and Mirzapur of Awadh and Purvanchal, respectively in both the periods. All districts belonging to Awadh plains, Purvanchal and Bundelkhand were having low (80 to 95) and very low (below 80) productivity (Fig. 6.11).

The period of during 2005-10 shows not a single district belonging to very high category of productivity. There were 6 districts namely, Auraiya, Baghpat, Firozabad, Hathras, Meerut and Muzaffarnagar which recorded high productivity in cash crops. Medium productivity with indices in between 95 and 110 were recorded in 24 districts whereas, low productivity was seen in 32 districts of the state. The districts namely, Azamgarh, Mau, Rae Bareli and Kaushambi of Purvanchal, Awadh and lower *doab* regions, respectively and 4 districts of Bundelkhand were characterized with very low productivity in cash crops (Fig. 6.12).

With respect to growth in productivity of cash crops, Table 6.9 shows that during 1995-2000 to 2000-05, high growth above 10 per cent was recorded by 6 districts namely, Mirzapur, Banda, Hathras, Bahraich, Ghazipur and Shrawasti whereas, in later period high growth was attained by the districts of Unnao, Auraiya, S.R.Nagar, Pratapgarh, Chandauli and Lucknow.

Medium growth (0-10 per cent) was recorded in 31 and 33 districts, respectively. There were 29 and 22 districts, which recorded low growth during the respective periods. The districts of Agra (-10.20), Firozabad (-10.25) Fatehpur (-13.29) and Pratapgarh (-15.22) had shown a very low growth during the previous
UTTAR PRADESH
Agricultural Productivity Regions
Cash Crops
1995-2000

Index
Very high
High
Medium
Low
Very low
Above 125
110-125
95-110
80-95
Below 80

Fig. 6.10
Table 6.8 Productivity regions of cash crops in Uttar Pradesh

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Name of district</td>
<td>No.</td>
<td>Name of district</td>
</tr>
<tr>
<td>Very high (Above 125)</td>
<td>2</td>
<td>Agra and Firozabad</td>
<td>2</td>
<td>Hathras and Agra</td>
</tr>
<tr>
<td>High (110-125)</td>
<td>4</td>
<td>Hathras, Muzaffarnagar, Farrukhabad and Baghpat</td>
<td>6</td>
<td>Muzaffarnagar, Farrukhabad, Firozabad, Muzaffarnagar, Baghpat, and Ghaziabad</td>
</tr>
<tr>
<td>Low (80-95)</td>
<td>26</td>
<td>Jhansi, Kheri, Etah, Basti, Baranpur, Fatehpur, Lalitpur, Kushinagar, Sitapur, Mahanagarjipur, Gonda, Lucknow, Chitrakoot, Jaunpur, Ambedkar Nagar, Faizabad, Shrawasti, S.K. Nagar, Deoria, Sonbhadra, Unnao, Pratapgarh, Chandauli, Hardoi, Varnasi and Bahraich</td>
<td>31</td>
<td>Kheri, Shahjahanpur, Shrawasti, S.K.Nagar, Jhansi, Siipur, Latipur, Sonbhadra, Mahanagarjipur, Etah, Faizabad, Bhilwara, Barabanki, Kushinagar, Basti, Bahraich, Allahabad, Chitrakoot, Siddharthnagar, Jalaun, Ambedkar Nagar, Gonda, Gonda, Ghaziapur, Mahoba, Jampur, Bansdih, Maun and Bajia</td>
</tr>
<tr>
<td>Very low (Below 80)</td>
<td>15</td>
<td>Gorakhpur, Siddharthnagar, Rae Bareli, Sultanpur, Mirzapur, Jalaun, Azamgarh, Ulta, Mahoba, S.R.Nagar, Maun, Ghaziapur, Kaushambi, Hamirpur and Banda</td>
<td>12</td>
<td>Hamirpur, Sultanpur, Lucknow, S.R.Nagar, Fatehpur, Azamgarh, Unnao, Varanasi, Chandauli, Rae Bareli, Kaushambi and Pratapgarh</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various Issues), Directorate of Agriculture, Lucknow.

period and in the later period, there were 9 districts namely, Barabanki, Ghaziabad, Rae Bareli, Hathras, Agra, Mahoba, Hamirpur, Banda and Jalaun to be incorporated in very low growth category.

v. Productivity regions: Based on composite yield index

It can be seen from Table 6.10 and Fig. 6.13 that, composite productivity
Fig. 6.11
UTTAR PRADESH
Agricultural Productivity Regions
Cash Crops
2005-10

Fig. 6.12
Table 6.9 Growth in productivity indices of cash crops in Uttar Pradesh

<table>
<thead>
<tr>
<th>Category</th>
<th>Range (Per cent)</th>
<th>Number of districts</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Above 10</td>
<td>6</td>
</tr>
<tr>
<td>Medium</td>
<td>0 to 10</td>
<td>31</td>
</tr>
<tr>
<td>Low</td>
<td>-10 to 0</td>
<td>29</td>
</tr>
<tr>
<td>Very low</td>
<td>Below -10</td>
<td>4</td>
</tr>
</tbody>
</table>

Sources: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.

index, considering all the major categories of crops (cereals, pulses, oilseeds and cash crops), the western part of the state has shown very high and high productivity during 1995-2000. Very high composite yield indices were observed in 11 districts namely, Agra (134.83), Etawah (118.99), Aumiya (118.54), Muzaffarnagar (117.90), Kanpur Dehat (116.03), Firozabad (114.92), Meerut (113.55), Saharanpur (111.60), Farrukhabad (111.07), Baghat (110.89) and Bijnaur (110.16). High productivity was seen in 16 districts with the productivity indices in between 100 and 110. Medium and low productivity was found in 13 and 24 districts, respectively, whereas, 6 districts namely, Gonda (79.53), Balrampur (78.46), Shrawasti (76.33), Bahraich (75.39), Banda (74.44) and Sonbhadra (70.74) were characterized with very low productivity.

During the period of 2000-05, very high productivity was recorded by 20 districts, and very low productivity in 6 districts namely, Hamirpur, Balrampur, Chitrakoot, Sonbhadra, Banda and Mahoba. There were 9 districts which attained high productivity, and medium and low productivity areas were seen in 20 and 15 districts, respectively during this period (Fig. 6.14).

During the period of 2005-10, there were 19 districts to record very high productivity having index values above 110. High productivity was confined in 11 districts. There were 26 and 9 districts, respectively to show medium and low productivity, and 5 districts namely, Sonbhadra (74.28), Banda (71.84), Hamirpur (68.82), Chitrakoot (64.71) and Mahoba (59.51) recorded very low productivity during this period (Fig. 6.15).

During the period of 1995-2000 to 2000-05, positive growth in productivity was observed in 43 districts, and high growth (above 10 per cent) in 9 districts namely, Moradabad, Hardoi, Budaun, Ghazipur, Bahraich, Jalaun, J.P.Nagar, Rampur and Mirzapur. During 2000-05 to 2005-10, the districts namely, Siddharthnagar, Balrampur, Unnao, Mathura, Basti, Chaudhali, S.K.Nagar, Firozabad, Gorakhpur and
Table 6.10 Composite productivity regions in Uttar Pradesh

<table>
<thead>
<tr>
<th>Category (Range)</th>
<th>No.</th>
<th>Name of district</th>
<th>No.</th>
<th>Name of district</th>
<th>No.</th>
<th>Name of district</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very high</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>24</td>
<td>S.K. Nagar, Rae Bareilly, Kheri, Sultanpur, Batala, Jalaun, Mau, Varanasi, Siddharthanagar, Azamgarh, Faislabad, Deoria, Harda, Ballia, S.R. Nagar, Gorakhpur, Sitapur, Mirzapur, Ghazipur, Chitradour, Unnao, Lucknow, Mahoba and Hamirpur</td>
<td>15</td>
<td>Azamgarh, Rae Bareilly, Deoria, S.K. Nagar, Lucknow, Chandauli, Bahraich, Gorakhpur, Lalitpur, Sitapur, S.R. Nagar, Batala, Shrawasti, Siddharthanagar and Gorakhpur</td>
<td>9</td>
<td>Kushinagar, Maharajganj, Pratapgarh, Gonda, Deoria, Jhansi, Rae Bareilly, S.R. Nagar and Shrawasti</td>
</tr>
<tr>
<td><strong>Very low</strong></td>
<td>6</td>
<td>Gonda, Bahrampur, Shrawasti, Bahraich, Banda and Sonbhadra</td>
<td>6</td>
<td>Hamirpur, Bahrampur, Chitradour, Sonbhadra, Banda and Mahoba</td>
<td>5</td>
<td>Sonbhadra, Banda, Hamirpur, Chitradour and Mahoba</td>
</tr>
</tbody>
</table>

*Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.*
UTTAR PRADESH
Agricultural Productivity Regions
(Based on Composite Yield Index)
1995-2000

Fig. 6.13
UTTAR PRADESH
Agricultural Productivity Regions
(Based on Composite Yield Index)
2000-05

Fig. 6.14
UTTAR PRADESH
Agricultural Productivity Regions
(Based on Composite Yield Index)
2005-10

Fig. 6.15
Auraiya occupied a place with high category (Table 6.11). Medium growth in productivity was seen in 34 and 27 districts in respective periods. There were 26 and 29 districts which characterized with low growth, respectively and very low growth was recorded by Mahoba (-15.02) during the previous period, and Agra (-10.63), Mahoba (-12.81), Hamirpur (-13.78) and Chitrakoot (-15.17) during the later period.

Table 6.11 Growth in composite productivity indices in Uttar Pradesh

<table>
<thead>
<tr>
<th>Category</th>
<th>Range (Per cent)</th>
<th>Number of districts</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Above 10</td>
<td>9</td>
</tr>
<tr>
<td>Medium</td>
<td>0 to 10</td>
<td>34</td>
</tr>
<tr>
<td>Low</td>
<td>-10 to 0</td>
<td>26</td>
</tr>
<tr>
<td>Very low</td>
<td>Below -10</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Bulletin of Agricultural Statistics (various issues), Directorate of Agriculture, Lucknow.

d. Relationship between irrigated area and crop yield indices of major crops

The impact of irrigation on the yield indices of crops was computed by applying the Karl Pearson's coefficient of correlation technique and the magnitude of the relationship was judged by regression analysis. Table 6.12 shows a correlation matrix of irrigated area under major crops and the crop yield indices during the period 2005-10. Percentage of irrigated area under cereals ($X_1$), under oilseeds ($X_3$) and total irrigated area of all crops ($X_5$) show a high positive correlation with their respective crop yield indices ($X_6$, $X_8$ and $X_{10}$) and the coefficient values emerged were in order of 0.500, 0.434 and 0.609, respectively at 1 per cent significance level.

Table 6.12 Correlation matrix of irrigated area and crop yield index, 2005-10

<table>
<thead>
<tr>
<th>Variables</th>
<th>$X_1$</th>
<th>$X_2$</th>
<th>$X_3$</th>
<th>$X_4$</th>
<th>$X_5$</th>
<th>$X_6$</th>
<th>$X_7$</th>
<th>$X_8$</th>
<th>$X_9$</th>
<th>$X_{10}$</th>
</tr>
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<tbody>
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<td>$X_1$</td>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>$X_2$</td>
<td>.294*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X_3$</td>
<td>.337**</td>
<td>.634**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X_4$</td>
<td>.371**</td>
<td>.215</td>
<td>.175</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$X_5$</td>
<td>.859**</td>
<td>.456**</td>
<td>.608**</td>
<td>.323**</td>
<td>1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$X_6$</td>
<td>.500**</td>
<td>.358**</td>
<td>.728**</td>
<td>.059</td>
<td>.709**</td>
<td>1</td>
<td></td>
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<tr>
<td>$X_7$</td>
<td>.300*</td>
<td>.078</td>
<td>.430**</td>
<td>.119</td>
<td>.419**</td>
<td>.542**</td>
<td>1</td>
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<tr>
<td>$X_8$</td>
<td>.250*</td>
<td>.538**</td>
<td>.434**</td>
<td>.289*</td>
<td>.433**</td>
<td>.529**</td>
<td>.467**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X_9$</td>
<td>.101</td>
<td>.478**</td>
<td>.566**</td>
<td>.094</td>
<td>.360**</td>
<td>.661**</td>
<td>.442**</td>
<td>.422**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>$X_{10}$</td>
<td>.376**</td>
<td>.499*</td>
<td>.669**</td>
<td>.180</td>
<td>.609**</td>
<td>.851**</td>
<td>.800</td>
<td>.769*</td>
<td>.754**</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: (i) * Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

(1) $X_1$-Irrigated area of cereals to total cropped area under cereals (%); $X_2$-Irrigated area of pulses to total cropped area under pulses (%); $X_3$-Irrigated area of oilseeds to total cropped area under oilseeds (%); $X_4$-Irrigated area of cash crops to total cropped area under cash crops (%); $X_5$-Irrigated area to gross cropped area (%); $X_6$-Crop yield index of cereals; $X_7$-Crop yield index of pulses; $X_8$-Crop yield index of oilseeds; $X_9$-Crop yield index of cash crops; $X_{10}$-Composite yield index of crops.

Fig. 6.16 Relationship between Crop Yield Indices and Irrigated Area in Uttar Pradesh, 2005-10
This shows that, in the districts which were having high irrigated area, productivity index values of crops were also high. Irrigated area under pulses and cash crops ($X_2$ and $X_4$), the correlation coefficient values with respective yield indices ($X_7$ and $X_9$) were positive but insignificant.

Linear relationship as depicted in Figs. 6.16 (i) to 6.16 (v) shows that, there is a positive and linear relationship between irrigated area and the yield index of all crops, but the relationship emerged for pulses and cash crops was very weak. This shows that productivity of pulses and sugarcane has not always high in those districts where irrigated area under these crops is high. This indicates that, there are other factors influencing agricultural productivity along with irrigation. These factors may be size of holding, the fertility of soil, climate, HYV of seeds, fertilizer and farm mechanization etc.

B. Measurement of Water Productivity in Crop Cultivation

Water is a crucial factor in plant growth. It is an essential wealth and property of any country that largely depends on efficient use of water for agricultural production. Recently, the attention of researchers and scientists working in different disciplines has been shifted from measuring the irrigation efficiency to measuring the water productivity or 'more crop per drop'. The patterns of water productivity in four major crops of wheat, rice, maize and sugarcane grown in 70 districts of the state of Uttar Pradesh has been statistically examined by adopting and applying the methods described in Food and Agriculture Organization (FAO) and International Water Management Institute (IWMI) studies, because the experimental data of elements of weather and other related parameters cannot be gathered for such a vast state. For the analysis, at first, districtwise total consumptive water use (CWU) for each crop was computed taking into consideration the climatic parameters of evaporation and transpiration along with the information of irrigation and crop-coefficient, then water productivity (kg/m$^3$) of four selected crops, which altogether constitute nearly 75 per cent of total cropped area of the state, were worked out in the districts for triennium ending years 2001 and 2011. It was also tried to evaluate the scope to improve water productivity in water-scarce and water-rich regions of the state.

a. The concept of Water Productivity (WP)

With increasing population and changing consumption pattern, the demand of
water is rapidly increasing, and there has been an increasing pressure on available water resources. The demand of water in agriculture always remains high to grow food and non-food crops to feed the country’s millions and for other agro-based needs. Globally, 70 per cent of fresh water diverted for human use goes to agriculture and irrigation water demand is still increasing because the area irrigated continues to expand (FAO, 2002). Irrigation accounts for over 90 per cent of water consumption in India itself, as in many South Asian countries (Rosegrant et al. 2002; FAO 2003). At present, India’s population is 1.12 billion, and is expected to reach 1.35 billion by 2025 (Hira, 2009). To produce more food using less water for such a large population is one of the great challenges of 21st century. Since the beginning of the green revolution in India, irrigated agriculture has become a major contributor to foodgrains production. It is expected that in coming future, irrigation will play a major role in increasing the yield of crops and the amount of food needed to support the country’s growing population (Dehghanisani et al., 2006). Moreover, crop production can be increased many fold (4 to 10 times) if irrigation is provided to areas lying in semi-arid tropics, where rainfall is inadequate, erratic, ill-distributed and often leads to drought conditions.

Water productivity is a new concept in agricultural water management studies. World over, agriculture has very low water productivity when compared to manufacturing and the situation is not different in India. Agriculture continues to be the largest user of diverted water in the country (GOI, 1999). Moreover, productivity of water in India is very low for major crops in terms of the amount of biomass produced per unit of water depleted (Amarasinghe et al., 2008). Low yields in tropical agro-ecosystem of India are explained and manifested by on-farm blue water (irrigation) losses in terms of both surface runoff, limiting infiltration to the root zone and percolation to groundwater, and on non-productive vapour flow component (evaporation), reducing the productive vapour flow (plant transpiration). If all amount of water accessible in the root zone could be used productively, i.e., without non-productive vapour losses and nutrient deficiency, the potential yield in crops would reach to its maximum (Rockstrom et al., 2007). It can be inferred that future crop production under irrigated conditions depends solely on efficient and judicious use of water to realize the cherished gains from irrigation (Goud, 1989). In some regions of the country, the expansion of surface water use appears to be approaching the physical limit, and groundwater abstractions are increasingly exceeding rates of
replenishment. Meanwhile, industrial and domestic water demand has been increasing rapidly as a result of development and urbanization (Rosegrant et al., 2000). Only one-third of agricultural production in India comes from rain-fed areas that account for two-thirds of croplands. It is, therefore, needed to grow more crops by using less water with high efficiency in these regions.

Water productivity has been defined as ‘crop production’ per unit ‘amount of water used’ (Molden, 1997). Concept of water productivity in agricultural production systems is focused on ‘producing more food with the same water resources’ or ‘producing the same amount of food with less water resources’. Initially, irrigation efficiency or water use efficiency was used to describe the performance of irrigation systems. In agronomic terms, ‘water use efficiency’ is defined as ‘the amount of organic matter produced by a plant divided by the amount of water used by the plant in producing it’ (De Wit, 1958). However, in terminology used ‘water use efficiency’ does not follow the classical concept of ‘efficiency’, which uses the same units for input and output. Therefore, IWMI has proposed a change of the nomenclature from ‘water use efficiency’ to ‘water productivity’. Water productivity can further be defined in several ways according to the purpose, scale and domain of analysis (Molden et al. 2001; Bastiaanssen et al. 2003).

In general term ‘Water Productivity’ (WP) refers to the ratio of crop output to water either diverted or consumed. In other words, it may be defined as, the ratio between the actual yield achieved (Ya) and water use, expressed in kg/m³, but the denominator may refer to the total water use (TWU), including rainfall (Pereira and Pires, 2011). The major crop water productivity parameters used in literature are the physical productivity of water expressed in kilogram of crop per cubic metre of water diverted or depleted (kg/m³); net or gross present value of the crop produced per cubic metre of water (Rs/m³) known either as economic efficiency of water use or combined physical and economic productivity of water and net or gross present value of the crop produced against the value of the water diverted or depleted (Kijne et al., 2003). However, this term is used with different meanings. According to Molden et al. (2003) water productivity is scale dependent which can be analysed at the plant, field, farm, system and basin level, and its value would change with the changing scale of analysis.

Historically, three and a half century ago, the Flemish pharmacist van Helmont found that water is essential input for plants to reach at a certain weight.
Later, another scientist Woodward was the first to relate the water loss during plant growth to the gain in plant’s dry weight. In the middle of the 20th century, a meteorologist named Penman gave this a new conceptual name of ‘water productivity’ or ‘crop per drop’. He introduced the concept of potential transpiration, defined as water loss from an extended surface of a short green crop, actively growing, completely shading the soil and never short of water. The ecologist De Wit (1958) reasoned that, Penman’s conditional "never short of water" meant that the concept is of little value where water is limiting, as in dry-farming and often for shorter or longer periods in rain-fed agriculture. His approach was welcomed by many dry farming researchers, but found little acceptance within the world of the irrigation engineers. Later, Thornthwaite (1944) complained about irrigation engineers not distinguishing between actual and so called potential evapotranspiration, a term he introduced at that time. This difference became less important from the 1960’s onwards, after Penman’s formula became the “standard” to aim at in the calculation of crop water requirements under irrigation engineers worldwide. Since then, crop water requirements under irrigation were defined as the water crops need to reach their final yields under unrestricted growth conditions, not only of nutrients, pests and competition from weeds, also of the water for transpiration and evaporation (Zoebl, 2006).

b. Factors affecting water productivity

Water Productivity varies from field to field and even region to region depending upon the factors which influence crop-water requirements. These are climate (sunshine and temperature, precipitation, humidity and wind speed), crop water needs, type and soil texture etc. Crops grown in sunny and hot climate needs more water per day than the crops grown in cloudy and moderately cool climate. Thus, the highest crop water needs occur in areas characterized with hot, dry, windy and sunny weather. The lowest water requirement occurs when it is cool, humid and cloudy with little or without wind. Crop type has an influence on the duration of total growing season (i.e. short duration crops like, peas which is matured within 90-100 days, and sugarcane which needs more than a year for its maturity), and on total crop water requirements. The other factors influencing WP of crops are irrigation, field

The weight of any plant (or other organism) part after all its water content has been removed by drying.
water management, infrastructure and inputs including labour, fertilizers etc.

d. Consumptive Water Use (CWU)

Every crop has its own agronomic requirements and water needs for successful cultivation and gives maximum yield. The term ‘consumptive water use’ or ‘water requirements of crop’ means the total quantity and the way in which a crop requires water, from the time, it is sown to the time it is harvested. In general CWU is the water required to meet the demand of evapotranspiration and metabolic activities. Since water requirements in metabolic activities are insignificant (about 1 per cent). Therefore, water requirement of plant is considered to be equal to Evapotranspiration (ET) (Mahmood and Ahmad, 2005). Moreover, evapotranspiration of water is the amount of water which crop transpires in course of its growth, and which evaporates from the bare soil surface in the fields (Vaidyanathan and Sivasubramaniyan, 2004).

As regards the demand for water or crop evapotranspiration mainly determines the requirement of water for agriculture (Kumar et al., 2011). Every crop requires a certain amount of water with a specific interval, throughout its growth period. If the rain water is sufficient and timely, so as to fulfill the requirements, no irrigation is required to raise that crop. But in a tropical country like India, the rainfall is either insufficient or the water does not reaches with a fixed interval, as required by the crop; certain crop may require irrigation. About 70 to 90 per cent of rainfall in India is received during the rainy season from July to September. The onset of monsoon each year, however, remains uncertain and the rainfall received is
erratic in nature. Sometimes, failure of monsoon even causes drought conditions that very badly affect large areas in the country. So, it becomes necessary to provide water through other means of irrigation in areas where deficiency occurs (Garg, 1995).

d. Methods of measurement of CWU and WP

At the first instance, the CWU were calculated by using reference evapotranspiration$ (E\text{r})$ and rainfall data. *Crop coefficient* approach to the specific crops was used along with the values of $E\text{r}$ for computing the total CWU at different crop growth stages (i.e. the initial stage, crop development stage, mid-season stage and late-season stage). For irrigated areas, reference evapotranspiration was used to compute CWU, and for rain-fed areas evapotranspiration or effective rainfall, whichever minimum was taken into account. Districtwise CWU and WP the crops were computed by adopting the formula referred by Amarasinghe and Sharma (2009).

(i) The consumptive water use in irrigated areas for the $j^{th}$ crop in the $i^{th}$ season:

$$CWU_{ij}^{IR} = \text{Area}_{ij}^{IR} \times \left( \sum Kc_{jk} \times \left( \Sigma E_{i}^{P} \right) \right)$$

where,

- $Kc$ is the crop coefficient varying over four growth periods
- $E_{i}^{P}$ is monthly reference evapotranspiration.

(ii) The consumptive water use in rain-fed areas is the only effective rainfall during the season, and can be estimated as:

$$CWU_{ij}^{RF} = \text{Area}_{ij}^{RF} \times \min \left( Kc_{jk} E_{i}^{P}, ERF_{i} \right)$$

where,

- $ERF_{i}$ is the effective rainfall of $i^{th}$ month in the $k^{th}$ growth period.

(iii) Total annual CWU of a district can be estimated as:

$$CWU = \sum \sum \left( CWU_{ij}^{IR} + CWU_{ij}^{RF} \right)$$

---

8The evaporation rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as $E_{r}$. The reference surface is a hypothetical grass reference crop with specific characteristics (FAO, 1998).

9Crop coefficient ($Kc$) is dynamic in nature and varies in accordance with crop characteristics, dates of planting, stages of growth and climatic conditions.

10The portion of rainfall that contributes to the crop production including that used for special purposes such as land preparation, leaching etc. is called effective rainfall. About 80 per cent of the rainfall occurs during the growing period of crop.
(iv) Total WP of a district can be estimated as:

\[ WP = \frac{\text{average yield} \times (\text{Area}^R + \text{Area}^P)}{\text{CWU}} \]

Applying the formula, for computing the Consumptive Water Use (CWU) for wheat crop in Saharanpur district:

1. CWU for irrigated wheat (IR)
   - Area irrigated under wheat = 1,12,206 (in ha)
   - Crop coefficient (Kc) for wheat = 0.85
   - Reference Evapotranspiration (Et\(^r\)) = 283 (mm.)
   - i. \( \text{CWU}^R = 1,12,206 \times 283 \)
     = 2,70,25,569 (ha.mm.)

2. CWU for rain-fed wheat (RF)
   - Rain-fed area under wheat = 8508 (in ha.)
   - Effective rainfall (ERF) = 31 (mm.)
   - ii. \( \text{CWU}^P = 8,508 \times 31 \)
     = 266,181 (ha.mm.)

Total Consumptive Water use (TCWU) = i + ii

\[ = 2,70,25,569 + 2,66,181 \]
\[ = 2,72,91,750 \text{ (ha.mm.)} \]

3. Water Productivity (WP) for wheat
\[ WP = \frac{\text{yield (kg/ha)} \times (\text{irrigated area} + \text{rain-fed area})}{\text{TCWU}} \]
\[ = \frac{(2,70,25,569 \times 1,12,206 + 8,508)}{2,72,91,750} = 1.32 \text{ kg/m}^3 \]

Therefore, the district of Saharanpur with WP value of 1.32 kg/m\(^3\) is more efficient in water consumption in the state.

Z-score values of the crops were computed from the original WP values for the years 2001 and 2011, so that the data can be put on a common scale for comparison by applying composite z-score technique. Karl Pearson's coefficient of correlation technique was applied to find out the strength of relationship between the indicators, and the linear regression technique was used to establish the statistical relationship.

Statistical information pertaining to area and yield of each crop considered in the analysis were obtained for each district from office of the State Directorate of Agriculture, Lucknow for three consecutive years and averaged for the periods of
Table 6.14 Sowing and harvesting seasons, number of watering and the most critical stages crops in Uttar Pradesh

<table>
<thead>
<tr>
<th>Crops</th>
<th>Sowing period</th>
<th>Harvesting period</th>
<th>No. of watering</th>
<th>CWU (mm.)</th>
<th>Most critical stages of crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>Jun. to Aug.</td>
<td>Nov. to Dec.</td>
<td>10-15</td>
<td>800-1200</td>
<td>Max. tillering and grain filling, tiller initiation, primordial initiation and flowering</td>
</tr>
<tr>
<td>Maize</td>
<td>Jun. to Jul.</td>
<td>Aug. to Oct.</td>
<td>2</td>
<td>500-800</td>
<td>Tasselling and silking</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>Sept. to Apr.</td>
<td>Oct. to June</td>
<td>8-10</td>
<td>1500-2500</td>
<td>Tillering and peak growth phase</td>
</tr>
</tbody>
</table>


1999-2001 and 2009-11. The averages were done to minimize short term variations in the data. Statistics related to reference evapotranspiration and monthly rainfall for the corresponding years were obtained from the Meteorological Department of India, Pune. Crop coefficient values pertaining to growth period of individual crops used in the analysis were obtained from two studies carried out in 1979 and 1998 by Food and Agricultural Organization (FAO).

e. Water Productivity Regions: Based on Wheat, Rice, Maize and Sugarcane crops

i. Water productivity of wheat

Wheat (Triticum sativum) is the most dominant crop in the state. It is generally sown in all of the 70 districts as first, second and third ranking crops (Lata and Rahman, 2011) from second fortnight of October to early November during the rabi season, and harvested in the months of March to May (Table 6.14). The most ideal conditions for cultivation of wheat are cool and moist weather during the vegetative growth period and dry weather during the grain formation period. After the harvest of kharif season the field is irrigated and with optimum workable moisture content in the soil, land is generally ploughed once or twice. In rainfed areas, collection and conservation of soil moisture and timely cultivation is most beneficial. From a number of studies, it has been established that, early wheat sowing in October-November results in higher yields as compared to sowing in December-January, and each day of delay in wheat sowing after mid- November could reduce yield by 30 kg/ha (Hussain et al., 2003; Nagaranjan 1998).

Wheat covered the largest cultivated area in the state and occupied 9.20 and 9.46 million ha. of land during 2001 and 2011, respectively of which 96.09 and 97.44 per cent was irrigated. The district of Mathura in 2001 and Gorakhpur in 2011 cultivated the largest area under wheat that shared about 50 per cent to the gross
UTTAR PRADESH
Water Productivity of Wheat
2001

UTTAR PRADESH
Water Productivity of Wheat
2001

Fig. 6.17

Fig. 6.18
cropped area, followed by other districts namely, Unnao, Hardoi, G.B.Nagar, S.R.Nagar, Budaun, Shahjahanpur, Deoria and Mainpuri. The districts of Sonbhadra, Hamirpur, Bijnor, Mahoba, Meerut, Muzaffarnagar, Faizabad, Chitrakoot, Etawah and Saharanpur had the lowest cultivated area under wheat. CWU of wheat in the state varies from the lowest value of 272 mm to the highest of 326 mm in 2001 and 256 mm to 349 mm in 2011, respectively, and the yield of the crop ranged in between 1,401 and 3,815 kg/ha, and 1,466 and 3,747 kg/ha in respective years.

It is seen from Table 6.15 and Fig. 6.17 that the districts of upper doab, starting from Muzaffarnagar in the north to Bulandshahr in the south showed a very high WP of wheat in 2001, including Rampur district of Rohilkhand plains. WP in this region ranged from 1.38 to 1.52 kg/m$^3$. In 2011, excluding Muzaffarnagar and Rampur, the respective districts also lie in the category of very high WP with values ranging between 1.47 and 1.51 kg/m$^3$. The district of Balrampur attained the highest WP of 1.52 kg/m$^3$ in 2011 leaving behind Ghaziabad and Meerut districts on second and third ranks, respectively. This has been due to decrease of CWU of Balrampur district from 306 mm to 284 mm (the denominator), though irrigated area of the crop has increased from 64.4 to 73.4 per cent that lead to achieve high yield of the crop from 2,277 to 3,096 kg/ha (the numerator).

High WP from 1.18 to 1.32 kg/m$^3$ in 2001 was noticed surrounding the former region of very high WP to start with Saharanpur in the extreme north, three districts of Rohilkhand region, four districts of middle doab and a single district of Balrampur of Awadh plains including an another continuous range from Pilibhit in the north up to Kanpur Dehat during 2001 and in 2011, eight more districts namely, Muzaffarnagar, G.B.Nagar, Rampur, Mau, Sonbhadra, Kheri, Budaun and Mainpuri were added in this category (Figs. 6.17 and 6.18). It is clear from the figures that, most of the districts of high WP are concentrated mainly in the western region of the state as we move eastward and southward, WP of wheat starts declining, and this trend of decline continues up to Deoria in extreme east and southward up to Lalitpur district, respectively. Very low WP (-1.76 to -1.57 kg/m$^3$ in 2001 and -1.96 to -1.66 kg/m$^3$ in 2011) occurred in Chandauli and Lalitpur districts in the previous period, and three more districts of Banda, Mahoba and Chitrakoot of Bundelkhand region were added in this category during the later period. Low WP with values in between 0.79 and 0.95 kg/m$^3$ (in 2001), and 0.78 and 0.96 (in 2011) were observed in 27 and 23 districts of the state, respectively. Medium WP areas, as appeared in Figs. 6.17
and 6.18, fall in between high and low water productivity regions of the state.

Table 6.15 Water productivity of wheat in Uttar Pradesh, 2001 and 2011

<table>
<thead>
<tr>
<th>Category/Range (z-score)</th>
<th>2001</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of district</td>
<td>No.</td>
<td>Name of district</td>
</tr>
<tr>
<td>Very high (Above 1.50)</td>
<td>Meenut, Bulandshahr, Muzaffarnagar, Baghpat, Ghaziabad, Rampur and G.B.Nagar</td>
<td>7</td>
</tr>
<tr>
<td>High (0.50 to 1.50)</td>
<td>Saharanpur, Hathras, Mathura, Aligarh, Pilibhit, Farrukhabad, Agra, Moradabad, J.P.Nagar, Shahjahanpur, Bijnor, Kannauj, Bulanpur, Dehat and Amriya</td>
<td>15</td>
</tr>
<tr>
<td>Medium (-0.50 to 0.50)</td>
<td>Mainpuri, Bakh, Bareilly, Budaun, Kheri, Jalaun, Shrawasti, Firozabad, Kanpur Nagar, Phawah, Sonabdra, Bareilly, Barabanki, Siddharthnagar, Kushinagar, Maharajganj, Gonda, Hardoi and Jhansi</td>
<td>19</td>
</tr>
<tr>
<td>Very low (Below -1.50)</td>
<td>Chandauli and Lalitpur</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: Computed by the author from Appendix IX.

Regional variations in WP of wheat in the state occur due to variations in the use of production factors such as the inputs of irrigation and fertilizer which act as the resultant factors in output in terms of yield of the crop. The districts having very high WP account for high level of irrigation development (Rahman and Late, 2012) having nearly 100 per cent of area under irrigation under this crop, except the district of Balrampur, however, CWU is lower mainly due to low evapotranspiration losses.

Hence, irrigation along with the advanced techniques of farming is a major factor leading to the higher yield of wheat in these districts which in turn contributes to high WP. Conversely, in the districts marked with very low WP, CWU during the crop growing season is higher due to high evaporation losses than the districts with high WP; as a result, yield of the crop is much lower in these districts, which results in low WP of the crop. Irrigated area under wheat in low WP districts of Banda, Mahoba and Chitrakoot was in order of 73.45, 73.66, and 83.31 per cent, respectively. In spite of high proportion of irrigated area (99.21 per cent) in Lalitpur
district, WP was very low because of much lower yield in comparison to the districts forming western parts and CWU is highest in Lalitpur (Appendix IX).

ii. Water productivity of rice

Rice (*Oryza sativa*) growing season vary in different parts of the state depending on temperature, rainfall and local weather conditions. Rice is a *kharif* season crop and like wheat it is also grown in different parts of the state, and most of its cultivation is confined to eastern districts of the state. Rice is sown during the months of June to August and harvested during the months of September to November. This crop is grown under a very wide range of agro-climatic conditions and on a wide variety of soils. One important characteristic of soil in which rice is sown that, it should remain submerged at least for some time during the growth period of the crop. Rice is generally grown under dry or wet cultivation methods. Dry system of rice cultivation is confined to upland areas which may have no standing water on the soil surface for at least 48 hours after cessation of rain or irrigation. In wet system, the crop is grown under wet season right from the start. Field is brought to soil puddle (wet land preparation) by repeated ploughings with 5-7 cm. standing water. After getting requisite puddle, rice seedlings are transplanted or sprouted seeds are directly seeded to the field.

In 2001, rice accounted for 5.9 million ha. of area in the state, out of which 68 per cent was irrigated, and in 2011 the cultivated area under it slightly decreased to 5.6 million hectares, whereas the extent of irrigated area increased to 80 per cent. In both the periods, the largest cultivated area of above 40 per cent under rice was registered by the district of Siddharthnagar, followed by the districts namely, Maharrjganj, Chandauli, S.K.Nagar and Mau of Purvanchal region of the state, and the lowest area of less than 1 per cent was acquired by the districts of Bundelkhand region, and the district Agra of middle *doab*. Rice is the largest consumer of water in Asia, probably accounting for more than half of irrigation water withdrawals (Cai and Rosegrant, 2003). CWU of rice in the state in 2001 ranged from a minimum of 1291 mm (in Baghpat) to a maximum of 1687 mm (in Lalitpur) during the crop growing season, and the yield of crop ranged from 834 to 2,860 kg/ha, whereas in 2011, the CWU ranged in between 1,219 mm and 1,838 mm, while the yields were from 544 to 2,988 kg/ha, respectively. In both years the district of Lalitpur registered the lowest yields.
Table 6.16 Water productivity of rice in Uttar Pradesh, 2001 and 2011

<table>
<thead>
<tr>
<th>Category/Range (z-scores)</th>
<th>2001</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Name of district</td>
</tr>
<tr>
<td>Very high (Above 1.50)</td>
<td>6</td>
<td>S.K.Nagar, Gonda, Basti, Deoria, Maharajganj and Bahmilich</td>
</tr>
<tr>
<td>High (0.50 to 1.50)</td>
<td>11</td>
<td>Shrawasti, Bijnor, Gochakpur, Siddharthnagar, Kushinagar, Balrampur, Kheri, Pillubhit, Chandauli, Azamgarh and Varanasi</td>
</tr>
<tr>
<td>Medium (-0.50 to 0.50)</td>
<td>35</td>
<td>Mau, Ambekar Nagar, Sultanpur, Baghel, Mirzapur, Muzaffarnagar, S.R.Nagar, Kushinagar and Faizabad, Shahjahanpur, Jaunpur, Saharanpur, Sonthadra, Rampur, Farrukhabad, Ballia, Ghazipur, Meerut, G.B.Nagar, Moradabad, J.P.Nagar, Auraiya, Etawah, Barabanki, Agra, Kanpur Dehat, Ghazibad, Bulandshahr, Allahabad, Sitapur, Hathras, Mathura, Bareilly, Kannauj and Maupur</td>
</tr>
<tr>
<td>Low (-0.50 to -1.50)</td>
<td>13</td>
<td>Penipgadh, Fatehpur, Hardoi, Aliagar, Rae Bareli, Etah, Kanpur Nagar, Firozabad, Budhun, Lucknow, Hamipur, Mahoba and Unnao</td>
</tr>
<tr>
<td>Very low (Below -1.50)</td>
<td>5</td>
<td>Banda, Chitrakoot, Jhansi, Jahan and Lalitpur</td>
</tr>
</tbody>
</table>

Source: Computed by the author from Appendix IX

Water productivity of rice also marked out significant variations in the state. WP values of the crop ranged from the lowest of 0.105 kg/m$^3$ to the highest of 0.411 kg/m$^3$ in 2001, and 0.077 to 0.518 kg/m$^3$ in 2011, but rice shows much lower WP than wheat owing to high water needs during its growth period. It is clearly seen from Fig. 6.19 that, very high WP (0.356 to 0.411 kg/m$^3$) shown by the districts in 2001 were located in a semi-circular belt in relatively high rainfall area of tarai in the north-east stretching from Maharajganj in the extreme east to westward up to Bahrai. Deoria district also holds its place in the same region. Surrounding the districts of very high WP, the districts of Shrawasti, Balrampur and Siddharthnager in the north, the districts namely, Kushinagar, Gorakhpur, Azamgarh, Varanasi and Chandauli of extreme south, and Kheri and Pillubhit in west of Bahrai were marked with high WP (0.291 to 0.331 kg/m$^3$). The district of Bijnor forming part of Rohilkhand plains was also placed in this region. This region coincides with the districts of very high and high concentration of rice, which is found in high rainfall regions. The concentration of rice cultivation decreases from the east and north-east to west and south-west (Hussain, 1970).

In 2011, there were only two districts of Maharajganj and S.K.Nagar of tarai...
region with rice yield of 2,321 and 1,916 kg/ha, and CWU of 1,344 and 1,483 mm respectively, occupied their place in very high category of WP. High WP (0.270 to 0.324 kg/m³) was seen in some scattered pockets in western and eastern parts of the state mainly in the districts of Firozabad, Auraiya, Kannauj, Pilibhit, Etawah, Baghpat, Balrampur, Siddharthnagar, Ambedkar Nagar, Kushinagar, Chaudauli, and Basti respectively (Table 6.16). Again, very low WP was seen in the districts of Bundelkhand region; the lowest value has been in Lalitpur in both years. In these districts, yield of rice was very low and CWU is high, consequently, the districts formed part in the lowest WP region. The regions forming the medium water productivity were scattered over the entire state from western to eastern parts in 2011 (Fig. 6.20). The districts of Lalitpur and Banda with 0 and 91 per cent irrigated area, respectively, have much higher CWU than Maharajganj and S. K. Nagar districts which fall in this category. Evaporation losses with meagre groundwater resources are responsible for high CWU, and lower yield has pushed the region to lie in lowest WP.

iii. Water productivity of maize

Maize (Zea mays) is one of the major kharif season (summer) crops grown in a tropical country like India. It is consumed by human beings and constitutes a basic raw material for manufacturing a number of items. Climate is the main environmental determinant influencing yield of the crop. Maize is grown in climates ranging from tropical to temperate during the period in which mean daily temperatures remain above 15°C and nights are frost-free. Successful cultivation of maize depends on the right choice of varieties, so that, the length of the growing period matches with the length of growing season, and the purpose for which the crop is to be grown (FAO, 2011). It is a high water demanding crop and gives higher yields when adequate amount of water is provided. However, maize is very sensitive to water stress. Flowering period is the most sensitive stage to water deficit, with reductions in biomass, yields and harvest index. At this stage crop yield is affected due to flower abortions, and hence a decrease occurred in number of grains per m³ of water (Otegui et al., 1995; Farre and Faci, 2009; Karrou et al., 2012).

In the state maize was grown on 0.91 (3.6 per cent of GCA) and 0.76 million ha. (3.04 per cent) of area in 2001 and 2011, respectively, out of which only 27 and 32 per cent of area, received irrigation. During both the years, it was grown over large
Table 6.17 Water productivity of maize in Uttar Pradesh, 2001 and 2011

<table>
<thead>
<tr>
<th>Category/Range (z-scores)</th>
<th>2001</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high (Above 1.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Name of district</td>
<td>Farnukhabad and Kannauj</td>
<td>Agra, Maharajganj, Kaushambi and Bijnor</td>
</tr>
<tr>
<td>High (0.50 to 1.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>Name of district</td>
<td>Allahabad, Bulandshahr, Kaushambi, Pratapgarh, Fatehpur, Auraiya, Allahabad, Etawah, Saharanpur, Mainpuri, Firozabad, Hathnua, Meerut, Etah, Pilibhit, Mathura, Ghazipura, Barailly, Shahjahanpur, Agra and Hardoi</td>
<td>Firozabad, Meetut, Mahak, Rax Barati, Chandauli and Mathura</td>
</tr>
<tr>
<td>Medium (-0.50 to 0.50)</td>
<td>26</td>
<td>42</td>
</tr>
<tr>
<td>No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (-0.50 to -1.50)</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of district</td>
<td>Chitrakoot, Mahat, Banda, Gonda, Hamirpur, Deoria, Rae Bareil, Bahraich, Moradapur, S.R. Nagar, Sitapur, Kheri, Basti and Shravasti</td>
<td>Jaulmir, Hamirpur, Saharanpur, Lucknow, Banda, Mirzapur, S.R. Nagar, Lallipur, Balaumpur, Bahraich, Sonbhadra, Gonda, Kheri, Sitapur, Jhansi, Gorakhpur, Barein, and Shrawasti</td>
</tr>
<tr>
<td>Very low (Below -1.50)</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of district</td>
<td>Jalaunpur, Lucknow, S.K. Nagar, Siddharthnagar, Sonbhadra, Jhansi, and Jalaun</td>
<td></td>
</tr>
</tbody>
</table>

Source: Computed by the author from Appendix IX.

area in the districts of Kannauj, Farnukhabad, Bahraich, Mainpuri, Gonda, Bulandshahr and Etah, the yields of maize were in order of 1,742, 2,116, 1,113, 2,134, 919, 2,037 and 2,139 kg/ha, respectively in the year 2011.

Maize during its cultivation needs more water in comparison to other cereal crops. Estimations of maize water requirements are essential to be made in order to curtail excessive application of water than needed, which can cause crop damage, poor trafficability, soil erosion, excessive leaching and the wastage of water, labour and energy (Tekwa and Bwade, 2011). CWU of maize crop in the state varied from 718 to 1,037 mm in 2001, and between 602 and 1,077 mm in 2011, whereas the yields of maize ranged between 710 to 2,217 kg/ha, and 457 to 5,587 kg/ha in respective years.

Table 6.17 and Fig. 6.21 clearly show that, in 2001, the districts marked with very high and high WP (0.431 to 0.546 kg/m³) of maize crop were located in an entire Ganga-Yamuna doab region stretching from the district of Saharanpur in the
north up to Allahabad in the south. This belt is intermingled with the districts having medium WP and covers most of the areas in Rohilkhand plains and Purvanchal region of the state. A cluster of four districts namely, Bareilly, Pilibhit, Shahjahanpur and Hardoi also formed part in this category. In 2011, there were few districts scattered all over the state belonged to this category of high and very high WP (0.58 to 1.76 kg/m^3). These districts were namely, Agra, Maharajganj, Kaushambi, Bijnor, Firozabad, Meerut, Mahoba, Rae Bareli, Chandauli and Mathura. Agra ranked first in WP with crop yield of 5,031 kg/ha and the lowest CWU of 602 mm in the growing season. The district of Maharajganj, with the highest yield of 5,587 kg/ha ranked second having highest WP. The districts with low and very low WP of maize formed parts of northern districts of Awadh and Purvanchal regions, all of the Bundelkhand districts, and districts forming the southeastern part of the state, appeared in this region in both the years. In 2001, most of the districts having medium WP are located in eastern UP, Awadh plains and few of them formed part in Rohilkhand and upper doub regions of the state (Figs. 6.21 and 6.22).

**d. Water productivity of sugarcane**

Sugarcane (*Saccarum officinarum*) is one of the major cash crops grown in the state. It can successfully be grown on a variety of soils, varying from sandy to heavy clays, provided climate, soil texture and depth, and root developments are favourable. Being a year long crop its water requirements usually remain very high from 90 to 120 cm. during the entire growth period (Dhindwal and Kumar, 2005). Soil moisture must be in good depth, without salt and compactness. If the soil is well prepared, it can improve the tilth, which promotes a good germination stand and ensures higher yields of the crop. Spring season planting is done in the state during the months of February-March, and autumn season planting in September-October. Its cultivation is propagated by vegetative methods, which involve the planting of sections of the stem of immature cane: Buds on the setts germinated promote the plants. The planting material is known as ‘seed pieces’ or ‘setts’. If planting setts are good and healthy, rich in nutrients and free from pests and diseases, they can give higher yields.

Sugarcane covered an area of about 2 million ha. (nearly 8 per cent of GCA) in the state, out of which 93 per cent of area was irrigated. It is seen from Figs. 6.23 and 6.24 that, WP of sugarcane varied in between 2.13 and 6.53 kg/m^3 in 2001, but it
Table 6.18 Water productivity of sugarcane in Uttar Pradesh, 2001 and 2011

<table>
<thead>
<tr>
<th>Category/Range (z-scores)</th>
<th>No.</th>
<th>Name of district</th>
<th>No.</th>
<th>Name of district</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high (Above 1.50)</td>
<td>4</td>
<td>Bahraich, Balrampur, Kushinagar and Shrawasti</td>
<td>5</td>
<td>Kushinagar, Bahraich, Baghpat, Meerut and Muzaffarnagar</td>
</tr>
<tr>
<td>High (0.50 to 1.50)</td>
<td>18</td>
<td>Budaun, Kheri, Muzaffarnagar, Aligarh, Baghpat, Bijapur, Ghaziabad, Meerut, Sitapur, Maharajganj, G.B. Nagar, Lucknow, Saharanpur, Faizabad, Barabanki, Rampur and Gonda</td>
<td>16</td>
<td>Budaun, G.B. Nagar, Saharanpur, Budaun, Bijapur, Maharajganj, Lucknow, Ghaziabad, Balanadshahr, Aligarh, J.P. Nagar, Pilibhit, Sonbhadra, Kheri, Barabanki and Moradabad</td>
</tr>
<tr>
<td>Medium (-0.50 to 0.50)</td>
<td>24</td>
<td>Bulandshahr, Etah, Siddharthnagar, J.P.Nagar, Bareilly, Gorakhpur, S.K.Nagar, Auraiya, Hathras, Morena, Farrukhabad, Mainpuri, Fatehpur, Hardoi, Ambedkar Nagar, Basti, Shahjahanpur, Mizapur, Mathura, Aga, Firozabad, Sonbhadra, Allahabad and Kanauj</td>
<td>34</td>
<td>Rampur, Bareilly, Mirzapur, S.R. Nagar, Shahjahanpur, Hathras, Jaunpur, Faizabad, Farrukhabad, Etah, Unnao, Gorakhpur, Siddharthnagar, Sitapur, Ambedkar Nagar, Basti, S.K. Nagar, Gonda, Chandauli, Kannauj, Etawah, Auraiya, Sultanpur, Allahabad, Hardoi, Kaushambi, Pratapgarh, Shrawasti, Fatehpur, Deoria, Aga, Firozabad, Mainpuri and Mathura</td>
</tr>
<tr>
<td>Low (-0.50 to -1.50)</td>
<td>22</td>
<td>Deoria, Chitrakoot, Hamirpur, Etawah, Rae Bareli, Mahoba, Kanpur Dehat, Pratapgarh, Jhansi, Jajmau, Mir, Sultanpur, Lalitpur, Jalaun, Azamgarh, Ballia, Ghazipur, Kanpur Nagar, Uihna, Bandha, Chandauli and Vrindavan</td>
<td>10</td>
<td>Varanasi, Kanpur Dehat, Azamgarh, Ghazipur, Mir, Hamirpur, Kanpur Nagar, Ballia, Chitrakoot and Mahoba</td>
</tr>
<tr>
<td>Very low (Below -1.50)</td>
<td>2</td>
<td>Raunthamba and S.R. Nagar</td>
<td>5</td>
<td>Rae Bareli, Bandha, Lalitpur, Jalaun and Jhansi</td>
</tr>
</tbody>
</table>

Source: Computed by the author from Appendix IX.

declined with values ranged from 1.21 to 4.83 kg/m³ in 2011, whereas the average value for the state was 3.53 and 3.26 kg/m³, respectively. In 2001, very high WP of sugarcane (4.90 to 6.53 kg/m³) was achieved by the districts of Bahraich, Balrampur, Kushinagar and Shrawasti of tarai belt of the state, whereas, in 2011, there were three districts of upper doab namely, Baghpat, Meerut and Muzaffarnagar added to this category by replacing some districts of eastern UP. CWU in the state in 2011 varied in between 1,837 and 2,488 mm in Muzaffarnagar and Bareilly districts, respectively whereas, the yields varied from 17,371 to 69,385 kg/ha.

In 2001, a continuous range from the district of Saharanpur in the north up to Aligarh, including Bijnor, Budaun, Rampur and Pilibhit districts of Rohilkhand and some districts of Awadh plains forming a semi-circular belt from Kheri up to Gonda along with a distant district of Maharajganj of tarai belt were characterized with high WP in between 3.90 and 4.32 kg/m³. The districts forming the western part of the state were also marked with high WP in 2011 covering all the districts of upper doab, and most of the districts of Rohilkhand plains of the state (Figs. 6.23 and 6.24).
UTTAR PRADESH
Water Productivity of Sugarcane
2001

Very high  Above 1.50
High      0.50 to 1.50
Medium    0.50 to 0.50
Low       -1.50 to -0.50
Very low  Below -1.50

Fig. 6.23

Fig. 6.24
During this period some scattered districts of Awadh plains and *tarai* region also attained high WP during 2011. With the exception of few districts of *tarai* and Bundelkhand region, all the districts of the state showed that irrigation to sugarcane areas was provided in between 95 to 100 per cent. The districts of Kaushambi and S.R Nagar showed a very low WP of 2.13 and 2.36 kg/m$^3$ respectively, whereas a linear stretch from the district of Lalitpur of Bundelkhand up to Ballia in the extreme east attained low WP in between 2.49 and 3.17 kg/m$^3$ in 2001, and in 2011 Jhansi (1.21), Jalaun (1.56), Lalitpur (1.60), Banda (1.97) and Rae Bareli (2.18) were marked with very low WP of sugarcane, along with the remaining districts of Bundelkhand; Kanpur Nagar and Kanpur Dehat of Awadh plains, and four districts of eastern UP. The districts of Jhansi, Jalaun and Lalitpur with lowest crop yields in order of 17,371, 24,718 and 24,720 kg/ha respectively were also marked with lowest WP in the state (Appendix IX).

### f. Relationship between CWU, Yield and WP of Crops

Results of linear regression analysis of WP vs. CWU, yield vs. CWU and WP vs. yield for the crops of wheat, maize, rice and sugarcane are presented in Figures 6.25 and 6.26 for both the years. It is clear from figure which shows linear but inverse relationship between CWU and WP for wheat that, a unit increase in CWU from an optimum level, WP of the crop may decrease to 1.24 and 0.87 per cent, respectively. This relationship is explained by $R^2$ values of 0.6976 and 0.4743. Similarly, other crops also support this negative relationship, but for sugarcane in 2011, it was positive but too weak with $R^2$ of 0.0123, showing that WP of sugarcane can increase with a unit increase of CWU. The negative relationship can also be explained with correlation coefficient ($r$) values of -0.836, -0.472, -0.162 and -0.479 for wheat, rice, maize and sugarcane, respectively at 1 per cent significance level for the year 2001. In 2011, a similar trend was followed by all crops, except sugarcane, that shows a weak but positive correlation with $r$ value of 0.111 (Table 6.19). In 2001, the relationship between yield and CWU seems to be negative and inverse with $R^2$ values being 0.6086 for wheat, 0.4122 for rice, 0.0095 for maize, and 0.4155 for sugarcane (Figs. 6.25(i) to 6.25(xii)), and $r$ values of -0.781, -0.642, -0.098 and -0.644, respectively.

It is worth mentioning that, the relationship between WP and yield is linear and positive showing $R^2$ values of 0.7353 for wheat, 0.4537 for rice, 0.4743 for
g. Scope for increasing yields and water productivity of major crops

Since the beginning of green revolution, many efforts have been made in water management practices to achieve high irrigation efficiency in agriculture in the country. One of the important schemes the Coordinated Research Scheme on Water Management and Soil Salinity was started in 1967, at three centres namely, Hisar (Bhakra Project), Siriguppa (Tungabhadra Project) and Chiplima (Hirakund Project Area). The main thrust of the scheme was on rational use of water resources. Experiments have shown that, the submergence of rice plant in water at more than 5 cm. is unnecessary. Maximum pay-off from irrigation in any crop comes from watering at critical stages of plant growth. As shown in Table 6.14, in wheat, the crown root initiation and ripening are very critical stages, and tillering, grain filling and initial stages are the most sensitive for the rice crop. In another research project on Coordinated Scheme for Cropping Patterns and Water Management, the main
Fig. 6.25 Relationship among CWU, Yield and WP of Wheat, Rice, Maize and Sugarcane in Uttar Pradesh, 2001
Fig. 6.26 Relationship among CWU, Yield and WP of Wheat, Rice, Maize and Sugarcane in Uttar Pradesh, 2011
objectives incorporated were to develop suitable cropping patterns for optimizing efficiency of irrigation and other inputs in new irrigation command areas (Kanwar, 1972).

As mentioned earlier, WP is relatively a new concept and quite a large gap exists in available knowledge and its beneficial applications (CGIAR, 2001a). Therefore, to satisfy the growing demand for agricultural commodities, the attention in this direction has to be shifted to potentials of improved management of water resources that will increase WP (Kijne et al., 2003). According to Lee (1999) 'producing more from less' requires optimization of crops and all inputs. The highest crop yield can be achieved by adopting HYVs, with optimal water supply, soil fertility and crop production measures. Previous studies undertaken suggest that, WP of crops can be increased by two possible ways. First, by decreasing the CWU of crops or decreasing the denominator and second, by increasing the yield of crops or increasing the numerator (see equation 4). Limited water supply in high water use districts by using deficit irrigation can reduce the CWU, in which water supply is less than the crop's full requirements, and mild stress is allowed during the stages of growth that are less sensitive to moisture deficiency. Yield reduction in this method will be limited; it is expected that additional benefits are gained by diverting the saved water to irrigate other crops (FAO, 2011).

Supplemental irrigation is a key strategy to bridge dry spells in rain-fed agriculture, and has the potential of increasing yields and minimizing risks for rain induced yield losses. The existing evidence indicates that supplemental irrigation ranging from 50-200 mm/season is sufficient to mediate yield reducing dry spells in most years and rain-fed systems, and thereby stabilize and optimize yield levels (Joshi et al., 2005). Since irrigation water productivity is much higher when used conjunctively with rainwater (supplemental), it is logical that under limited water resources priority in water allocation may be given to supplementary irrigation (Sharma et al., 2008).

Over centuries in India, irrigation waters were predominantly applied to crops using conventional methods. Generally, with these methods of irrigation, water is supplied through unlined canals and field channels to crops, where controllability of water is not easily possible and therefore, conveyance and distribution losses are substantial. Many studies based on experimental data suggest that, the crops cultivated under micro-irrigation require relatively less amount of water to produce.
one unit of output. One of the main reasons for adopting micro-irrigation in crop
cultivation is to save water and increase the efficiency of water use. Unlike
conventional methods of irrigation, micro-irrigation methods (both sprinkler and drip
irrigation) supply water to crop by using a pipe network along with drippers, emitters
and nozzles. As a result, supplying water directly to the crop or to the field, the
conveyance and distribution losses become absent under micro-irrigation method.

Drip irrigation method (DIM) appears to be more efficient (Dehghanisanij et
al., 2006). First, the evaporation and distribution losses of water are very minimum
or completely absent. Second, unlike flood method of irrigation (FIM), water is
supplied under DIM at a required time and at required level and thus, over-irrigation
is totally avoided. Third, under the conventional method of irrigation, water is
supplied for the whole cropland, whereas DIM irrigates only the plants. Apart from
reducing water consumption, drip method of irrigation also helps in reducing cost of
cultivation and improving productivity of crops as compared to the same crops
cultivated under flood method of irrigation (FAO, 2011). A large number of studies
have shown that sprinkler irrigation method (SIM) is suitable even for foodgrain
crops, such as wheat, maize, pulses and groundnut, etc. Thus, the adoption of micro
irrigation methods in the districts of the state can increase the gross irrigated area,
cropping intensity, and will help farmers to switch over to the cultivation of cash
crops.

I. Wheat crop

An improvement in WP of wheat was noticed in 2011 in the districts of
Rohilkhand and Awadh plains of the state. These were having medium WP in 2001,
but attained high WP in 2011. Most of the districts of Purvanchal and Bundelkhand
regions attained more or less the same status. For enhancing WP in the districts of
Purvanchal region of high CWU (above 300 mm) and lower yield, deficit irrigation
with improved water management practices and proportionate use of agricultural
inputs like fertilizers, if applied can increase the yield and WP of the crops.
Conversely, in rain-fed or water-stressed districts of Bundelkhand region, crop yields
can be increased by providing water through supplemental irrigation (SI) through
tubewells during the critical periods of crop growth (Table 6.14).

Studies at International Centre for Agricultural Research in Dry Areas
(ICARDA) have found that, applied as supplemental irrigation along with good
management practices, a cubic meter of water can produce 2.5 kg of grains. It can be optimized by deliberately allowing crops to sustain a degree of water deficit, if integrated with improved varieties and good soil and nutrition management (FAO, 2011). Therefore, in the districts of Bundelkhand region, WP can be increased through the incorporation of some technological changes in farm operations: genetically improved crop varieties with better tolerance to drought and minimizing the evapotranspiration losses should be preferred to grow (Amarasinghe et al., 2010). Improved agronomic and farm management practices, which include the use of new varieties of seeds of wheat (WH 542 and PBW 343) and recommended doses of fertilizers and enhancing the role of extension services to farmers for dissemination of up-to-date knowledge on appropriate sowing dates, and quantities and timing of application of inputs, particularly irrigation water can increase the yield and water productivity of wheat (Hussain et al., 2003).

ii. Rice crop

As mentioned earlier, WP of rice in the state is not satisfactory high. An integrated approach of International Rice Research Institute (IRRI), using genetics, breeding and integrated resource management to increase rice yield and to reduce water demand for rice production can be applied (Tuong and Bouman, 2003) in low WP districts of the state, that the water saved at the field level can be used more effectively to irrigate previously un-irrigated or low-productivity lands (Tuong et al., 2005). WP of rice in the state can be increased by adopting three possible ways. First, adopting new rice varieties developed by IRRI, All India Agricultural Research Institute (IARI), New Delhi and G.B. Pant University of Agriculture and Technology, Pant Nagar. These hybrid varieties have potentials to reduce crop maturity duration and increasing the yield to about three-fold in comparison to the traditional varieties. Improved agronomic practices, such as nutrient management, weed management and proper land levelling can increase yield of rice significantly without affecting the losses through evapotranspiration, which may increase water productivity.

Second method is to reduce the unproductive water losses and depletions in the form of seepage, percolation, evaporation etc. during land preparation and crop growth period through minimizing the idle periods during by supplying irrigation water directly to nurseries without having submerged in main fields or using direct seedling. Instead of keeping the rice field continuously flooded with 5-10 cm. water,
the floodwater depth can be decreased; the soil can be kept around saturation. Saturated Soil Culture (SSC) or Alternate Wetting and Drying (AWD) can be imposed (Tuong and Bouman, 2003). In some areas the regime of AWD can even be doubled in WP compared with flood irrigation, but with yield reductions up to 30 per cent.

Third method to increase WP is to make rainfall more effective by using dry-seeded-rice technology. This technology offers significant opportunity for conserving irrigation waters by using rain water more effectively. This method can be followed for land preparation under dry or moist soil conditions, and can be started with the early monsoon rains. These methods can reduce the use of irrigation water, and ultimately WP can be increased by using water in an effective and efficient manner.

iii. Maize crop

Lower WP of maize crop that was noticed in Bundelkhand and northern part of Awadh plains of the state and the districts belonging to southeastern region. For maximum production a medium maturity grain crop requires 500 to 800 mm. of water depending on climatic characteristics. In these districts, water losses during conveyance and application must be avoided. The effect of limited water on maize grain yield is considerable and careful control of frequency and depth of irrigation is required to optimize yields under conditions of water shortage. Maize flourishes on well-drained soils and waterlogging should be avoided, particularly during the flowering and yield formation periods because waterlogging during flowering can also reduce grain yields by 50 per cent or more (FAO, 2011).

iv. Sugarcane crop

In UP, sugarcane is grown by using conventional methods of irrigation that are inefficient in use of available water. Therefore, it is of utmost importance that efficient water management practices be adopted for sustained sugarcane production throughout the crop growth period. The micro-irrigation techniques have a major role to play in mitigating the water scarcity situation by enhancing the productivity of water in effective and scientific manner. Importantly with this method, water savings in sugarcane, water-intensive crop is over 65 per cent per hectare, when compared to conventional methods of irrigation (Shinde and Jadhav, 2001).

To sum up, the key principles for improving WP in UP at field, farm and
basin level in the districts of rain-fed or irrigated are: (i) increase the marketable yield of the crop for each unit of water transpired by it, (ii) reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop transpiration, and (iii) increase the effective use of rainfall, stored water, and water of marginal quality.
References


