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# Optimal cropping pattern in a canal command area

D.K. Singh[a,*], C.S. Jaiswal[b], K.S. Reddy[a], R.M. Singh[a], D.M. Bhandarkar[b]

[a]*Irrigation and Drainage Engineering Division, Central Institute of Agricultural Engineering, Nabibagh, Berasia Road, Bhopal 462038, Madhya Pradesh, India*

[b]*College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar 263145, Uttar Pradesh, India*

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**Abstract**

The irrigation water requirements of major crops and the total available water through canal and ground water in the command of Shahi Distributory was estimated. A linear programming model was formulated to suggest the optimal cropping pattern giving the maximum net return at different water availability levels. The objective function of the model was subject to the following constraints: total available water and land during different seasons, the minimum area under wheat and rice for local food requirements, farmers' socio-economic conditions, and preference to grow a particular crop in a specific area. This model gave the optimal cropping pattern for a command area of 11,818 ha at water availability levels of 100, 70 and 50 and net returns of Rs. 185, 146 and 114 million, respectively. It was found that the water available in the command area may support optimally 4981, 3560, 1817, 632, 355, 87 and 3653 ha of wheat, sugarcane, mustard, lentil, potato, chick pea, and rice, respectively, to get a maximum net return of Rs. 185 million at 100% water availability level. Wheat appears to provide the most consistent profit in the command area.


*Keywords:* Irrigation water requirement; Water availability levels; Area utilization; Cropping pattern; Linear programming model

## 1. Introduction

To fulfill the high demand for food, fiber and fuel to an increasing population, it is necessary to bring more area under cultivation or to increase production per unit area of available land and water resources. Bringing additional area under cultivation is difficult due to urbanization and a reluctance to disturb natural environments. Also, the allocation

* Corresponding author. Tel.: +91-755-537191; fax: +91-755-734016.
*E-mail address*: dksingh@ciae.mp.nic.in (D.K. Singh).


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of water for irrigation will probably decrease from the present level by 90 to 75–80% over the next 10–15 years (Sivanappan, 1995). Therefore, it is important to optimize the available land and water resources to achieving maximum returns. The existing cropping pattern has been the same for many years and may not utilize resources at maximum economic efficiency. Diversification of cropping pattern could maximize the net return per unit quantity of land and water available from different sources. Linear programming models can handle a large number of constraints and thus, are an effective tool to aid in the optimization process. Hall and Dracup (1970) proposed a linear programming model to maximize net return and select an optimal cropping pattern. Panda et al. (1983) applied linear programming models for conjunctive use of surface and groundwater to a canal command area of Punjab and observed considerable improvement in both the economic return as well as utilization of land and water resources by adopting an optimal cropping pattern. The present study was conducted with the objective of finding the optimal cropping pattern giving the maximum net return at different water availability levels.

## 2. Material and methods

The solution to the linear programming model was obtained using the Simplex method with a commercially available computer program. The study was conducted for the command area of the Shahi Distributory, situated at the tail end of the Richha branch in the Sharda Canal Command. It is located in Bareilly, district of Uttar Pradesh state in India.

### 2.1. Land area availability and utilization

The command area of the Shahi Distributory is 11,818 ha. The crops occupying the major area of the command are wheat, paddy (rice) and sugarcane. Crops such as oilseeds, potato, barley, chick pea, lentil, green gram, maize, *barseem* (green fodder), pea, etc. are also grown in small areas.

### 2.2. Total water availability

Besides rainfall, canal water from the Shahi Distributory and groundwater through tubewells are the two major sources of water for irrigation in the command area. The average water supply through the canal was estimated from 18 years (1978–1995) of data available from the office of irrigation engineer in the Bareilly district of Uttar Pradesh state. The conveyance, field canal, and application efficiency were assumed to be 70.70 and 80%, respectively (Doorenbos and Pruitt, 1977). The overall efficiency for tubewell irrigation was assumed to be 80% for the study area (Singh, 1996).

### 2.3. Irrigation requirement of crops

Reference crop evapotranspiration was calculated using the following equation (Doorenbos and Pruitt, 1977):

$$\mathrm{ET_o} = K_p E_{\mathrm{pan}} \quad (1)$$

where $ET_o$ is the reference crop evapotranspiration (millimeter per day), $K_p$ the pan coefficient for the study area for USWB Class A pan, and $E_{pan}$ the pan evaporation (millimeter per day).

Crop evapotranspiration was calculated by

$$ET_{crop} = K_c ET_o \qquad (2)$$

where $ET_{crop}$ is the crop evapotranspiration (millimeter per day) and $K_c$ the crop coefficient.

Appropriate $K_c$ values were selected for each crop which take into account the crop characteristics, time of planting or sowing, stages of crop development and general climatic conditions (Doorenbos and Pruitt, 1977). To account for the long duration of sowing of crops in an area, the composite crop coefficient curves were prepared for calculating appropriate $K_c$ values (Singh et al., 1998). The net irrigation requirement of all crops was calculated individually as follows:

$$I_n = ET_{crop} - (P_e + G_e + W_b) \qquad (3)$$

where $I_n$ is the net irrigation requirement of crop (mm), $P_e$ the effective rainfall (mm), $G_e$ the groundwater contribution (mm) and $W_b$ the stored soil water (mm).

The effective rainfall was taken as rainfall at 50% cumulative probability (Singh, 1996). The groundwater contribution to each crop was estimated for different depths of groundwater table below the root zone depth (Doorenbos and Pruitt, 1977). It was assumed that there is no change in the value of stored soil water before and after the crop cultivation.

### 2.4. Area allocation model

The model used is a linear programming model consisting of three parts: (i) a linear objective function for maximization of net return; (ii) a set of linear constraints; and (iii) a set of non-negativity constraints. The model was formulated to allocate the land area between various crops in order to maximize the net return from the command area. It was subject to the availability of canal water as well as groundwater, land area limitations under different crops and in different seasons of the year. The model (Singh et al., 1997) used was as follows.

1. The objective function:

$$\text{Maximize } Z = \sum C_i X_i; \quad \text{for } i = 1, 2, 3, \ldots, N \qquad (4)$$

where $Z$ is the total net return from all the crops (Rs.), $N$ the number of crops, $C_i$ the net return from $i$th crop (Rs./ha), $X_i$ the crop area under $i$th crop (a decision variable) (ha).

The objective function was subject to linearity and non-negativity constraints.

2. The linearity constraints were:
   - Water availability constraints:

$$\sum W_i X_i \leq W_t \qquad (5)$$

where $W_i$ is the water requirement for $i$th crop (cm), $W_t$ the total water available from canal and ground water (ha cm).

- Land area constraints in different seasons:

$$\sum X_i \leq A_k \quad (6)$$

where $A_k$ is the area available for cultivation in different seasons of a year: $i = 1$–$6$ for wheat, sugarcane, mustard, lentil, potato and chick pea, respectively in post-monsoon (*rabi*) season ($k = 1$); $i = 7$ and 2 for summer green gram and sugarcane ($k = 2$); $i = 8$ and 2 for rice and sugarcane in monsoon (*kharif*) season ($k = 3$).

- Food production constraints to fulfill the demand for rice and wheat to the population in the area:

$$\sum Y_i X_i \geq F_j \quad (7)$$

where $Y_i$ is the yield of $i$th crop (quintals/ha), $F_j$ the total food requirement of $i$th crop (quintals), $i = 1$, $j = 1$ for wheat and $i = 8$, $j = 2$ for rice.

- Crop area constraints:

$$E_i \leq X_i \leq M_i \quad (8)$$

where $E_i$ is the existing area under $i$th crop (ha), $M_i$ the maximum area which may be kept under cultivation of $i$th crop (ha), $i = 1-8$ for wheat, sugarcane, mustard, lentil, potato, chick pea, green gram and rice, respectively.

3. Non-negativity constraints:

$$X_i \geq 0 \quad (9)$$

The area was surveyed and farmers were interviewed to determine their preferences on the area to keep under cultivation of different crops, and for what reasons, in order to subject some area constraints to the model. Because of the limitations of the farmers to provide timely field operations and the input like quality seeds, labor and chemicals and fertilizer to wheat and rice, the maximum area was limited to 120% of the existing area under these crops. The maximum area under cultivation of potato depends upon the product-handling capacity of the farmers and access to cold storage as it is a semi-perishable crop. The maximum area under sugarcane depends on both the farmers' capacity to provide inputs and the capacity of mills to handle it for processing. At the same time, farmers preferred not to reduce the existing area under mustard, lentil, potato and chick pea to meet their own consumption need. The model was run at 100, 70 and 50% of total water availability levels subject to the constraints of water availability, land area constraints in different seasons, food production constraints from rice and wheat to meet the food requirements of the local population, crop area constraints of (i) maximum area under wheat, rice and sugarcane not more than 120% of the existing area under these crops; (ii) maximum area under potato not more than 355 ha; (iii) minimum area constraints for mustard, lentil, potato and chick pea equal to or more than the existing area under each crops, and non-negativity constraints.

## 3. Results and discussion

### 3.1. Land area availability and utilization

The area utilization by the farmers for cultivation of different crops is shown in Table 1. It may be observed that wheat, rice and sugarcane are the most important crops occupying 35, 38 and 25% of total command area, respectively. Wheat and rice are the important crops of post-monsoon and monsoon seasons, respectively, and occupy maximum area in their respective seasons. Sugarcane and pigeon pea are long duration crops. The oilseed crops are mustard and sesame. Green gram, chick pea, pigeon pea and lentil are the crops grown to use as pulses for food. *Berseem* and sorghum are grown for fodder.

### 3.2. Total water availability

The estimated surface water is presented in Table 2. It may be observed that the gross average and net volume of water available in a year is 250,000 and 98,000 ha cm, respectively. The largest volume of surface water is available in September, which is 13.80% of total volume of water available in the year. The second largest volume is available in August. The lowest and the second lowest volume is observed in March and April, respectively. Water available in the 5 months from June to October is 61% of the total surface water. The groundwater availability was 350,000 ha cm and only 85% of this volume may be utilized without causing any deficit in the ground water storage. The net volume of 240,000 ha cm of ground water may be utilized for irrigation.

### 3.3. Irrigation requirement of crops

The estimated net irrigation requirement of crops is given in Table 3. Sugarcane, *berseem* and green gram require maximum depth of net irrigation water. Their

Table 1
Area occupied by different crops under existing cropping pattern

| No. | Crops | Area (ha) | Command area (%) |
|---|---|---|---|
| 1 | Wheat | 4151 | 35.1 |
| 2 | Sugarcane | 2966 | 25.1 |
| 3 | Barley | 20 | 0.2 |
| 4 | Chick pea | 88 | 0.7 |
| 5 | Potato | 36 | 0.3 |
| 6 | Pea | 63 | 0.5 |
| 7 | *Berseem* | 209 | 1.8 |
| 8 | Mustard | 321 | 2.7 |
| 9 | Maize | 126 | 1.1 |
| 10 | Sesame | 4 | 0.1 |
| 11 | Pigeon pea | 95 | 0.8 |
| 12 | Rice | 4522 | 38.3 |
| 13 | Sorghum | 740 | 6.3 |
| 14 | Green gram | 11 | 0.1 |
| 15 | Lentil | 632 | 5.4 |

Table 2
Surface water availability in different months of a year in the command of Shahi Distributory

| No. | Months | Gross volume of water (ha cm) | Net volume of water (ha cm) |
|---|---|---|---|
| 1 | January | 20275 | 7948 |
| 2 | February | 16503 | 6469 |
| 3 | March | 6307 | 2472 |
| 4 | April | 8601 | 3372 |
| 5 | May | 18575 | 7281 |
| 6 | June | 29041 | 11384 |
| 7 | July | 27321 | 10710 |
| 8 | August | 30951 | 12133 |
| 9 | September | 34436 | 13499 |
| 10 | October | 29339 | 11501 |
| 11 | November | 13918 | 5456 |
| 12 | December | 14160 | 5551 |
| Total | | 249427 | 97775 |

requirements are 43.0, 43.9 and 40.8 cm net depth of water, respectively. For some crops, like maize and sorghum, no irrigation water is required, because their demand is fulfilled by the effective rainfall and the groundwater contribution.

### *3.4. Area allocation under crops*

A total of eight crops (wheat, sugarcane, chick pea, potato, mustard, lentil, green gram and rice) were considered for the allocation model. These crops are preferred by the farmers, demand a comparable volume of water for irrigation, and already occupy a

Table 3
Irrigation water requirement of different crops in the command of Shahi Distributory

| No. | Crops | Net depth of irrigation (cm) |
|---|---|---|
| 1 | Wheat | 12.2 |
| 2 | Sugarcane | 43.0 |
| 3 | Barley | 8.5 |
| 4 | Chick pea | 12.4 |
| 5 | Potato | 13.9 |
| 6 | Pea | 9.8 |
| 7 | *Berseem* | 43.9 |
| 8 | Maize | 0.0 |
| 9 | Sesame | 1.2 |
| 10 | Pigeon pea | 3.3 |
| 11 | Rice | 7.1 |
| 12 | Sorghum | 0.0 |
| 13 | Green gram | 40.8 |
| 14 | Lentil | 9.3 |
| 15 | Mustard | 4.2 |

Table 4
Net return per unit area of allocated crops

| No. | Crops | Net return (Rs./ha) |
|---|---|---|
| 1 | Wheat | 10980 |
| 2 | Sugarcane | 24587 |
| 3 | Mustard | 4940 |
| 4 | Lentil | 3699 |
| 5 | Potato | 13265 |
| 6 | Chick pea | 3453 |
| 7 | Green gram | 4172 |
| 8 | Rice | 7173 |

considerable part of the study area. The net return obtained per unit area of these crops is given in Table 4. It was calculated by subtracting the production cost of the crop from the gross profit received due to yield and the crop price. The production cost includes the cost of field operations, seeds, chemical and fertilizer, water, harvesting and labor, etc. The optimal cropping pattern resulting from this area allocation model at different water availability is given in Table 5. It may be observed that the cultivation area under potato and wheat is the maximum imposed area for both crops giving the highest and second highest net return, respectively (Table 5); there was no change even at reduced water availability levels.

The area under sugarcane is reduced from 3560 ha at 100% water availability level to 2402 and 765 ha at 70 and 50% water availability level, respectively. The area under mustard increased from 1817 ha at 100% water availability level to 2975 and 4611 ha at 70 and 50% water availability levels, respectively. It may be because of irrigation water requirement and net return per unit net depth of applied irrigation to mustard is lower and higher than sugarcane, respectively. Also, there was no higher and lower limit imposed to the area under cultivation of mustard and sugarcane, respectively. It may also be noted

Table 5
Net return received and area allocated under crops at different water availability levels

| No. | Crops | Area allocated at water availability levels (ha) | | |
|---|---|---|---|---|
| | | 100% | 70% | 50% |
| 1 | Wheat | 4981 | 4981 | 4981 |
| 2 | Sugarcane | 3560 | 2402 | 765 |
| 3 | Mustard | 1817 | 2974 | 4612 |
| 4 | Lentil | 632 | 632 | 632 |
| 5 | Potato | 355 | 355 | 355 |
| 6 | Chick pea | 88 | 88 | 88 |
| 7 | Green gram | 00 | 00 | 00 |
| 8 | Rice | 3653 | 1465 | 1465 |
| Net return (Rs.)[a] | | 185 | 146 | 114 |

[a] Rupees in million.

that at reduced water availability level, the area left from sugarcane cultivation is occupied by cultivation of mustard. The cultivation area under lentil and chick pea remains unchanged even at reduced water availability levels and occupy the minimum area imposed under each crop.

The area occupied by rice crop is reduced from 3653 ha at 100% water availability levels to 1465 ha at 70% water availability level and there after no change in area is observed at 50% water availability level because of lower limit to the cultivation area under it to meet the demand of the local population for rice. Summer green gram does not appear at all in the allocation plan because it is a more water-consuming crop with respect to its net return. The net return of Rs. 185, 146 and 114 million may be achieved at 100, 70 and 50% of water availability level, respectively. The net return is reduced to 78.92 and 61.62% at 70 and 50% water availability level, respectively.

## 4. Conclusions

Linear programming models can be used as an effective tool for optimal cropping pattern in the command areas. The constraints imposed on the objective function of the model should incorporate components that account for farmers' preference on the area to keep under cultivation of different crops. In the command area of the Shahi Distributory, wheat, sugarcane and rice are the most important crops occupying the maximum area in their respective growing seasons. Optimally, the total available water can support 42, 30, 15, 5, 3, 1 and 31% of the command area under cultivation for wheat, sugarcane, mustard, lentil, potato, chick pea and rice, respectively, to achieve self-sufficiency in food and optimal utilization of resources. At reduced water availability levels area under mustard may be increased while the area under sugarcane and rice may be decreased, while the same cultivation area under wheat, lentil, potato, chick pea and 40% of rice cultivated area at 100% water availability level may be continued. The cultivation of summer green gram should be avoided under all water availability levels.

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