

## Strategies of optimizing crop production in rainfed areas\*

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(Received 2 February 1981)

**सार** — इस लेख में वर्षा सिंचित क्षेत्रों में फसल उत्पादन प्रणाली के संकल्पनात्मक निदर्श का विकास किया गया है। इसका उद्देश्य उत्पादन को अधिकतम करने के लिये कार्यविधियों का एक उपयुक्त संग्रह विकसित करना है। निदर्श कृषि योग्य भूमि की जल-भण्डारण तत्व के स्वरूप में कल्पना करता है। जैसे-2 समय बीतता है इस भण्डार में से पानी कम होता जाता है क्योंकि इसका उपयोग फसल की पैदावार में होता रहता है। बाद में वर्षा जल से यह भण्डार पुनः जल से पूरा हो जाता है। यदि वर्षा अपर्याप्त हो तो मृदा में स्थित जल-भण्डार फसल को ही सहारा नहीं दे सकेगा। इस लेख में विभिन्न मात्राओं में अनुकूल मृदा नमी की अवस्थाओं में अधिक से अधिक फसल प्राप्त करने की विधियों का प्रस्ताव किया गया है। इस निदर्श में ऋतुनिष्ठ वर्ष के अलावा पांच तत्व तथा उर्वरक अनुप्रयोग, फसल की कटाई के समय का चयन, सांस्कृतिक रीति रिवाज तथा सिंचित वर्षा जल के द्वारा सम्भावित अधिकतम सिंचाई आदि बातें समाहित हैं। इस प्रणाली के पांच तत्व हैं। (1) कृषि के अन्तर्गत क्षेत्र, (2) मृदा उप-प्रणाली, (3) खरीफ फसल उप-प्रणाली, (4) रबी मृदा फसल उप-प्रणाली तथा (5) व्यर्थ में बह कर चले जाने वाले वर्षा जल को लिये जलाशय या जल-भण्डारण साधन। इस प्रणाली से फसल उत्पादन तथा व्यर्थ फसल दोनों ही प्राप्त होते हैं और दोनों ही उपयोग करने के योग्य हैं और उनका महत्व है। प्रणाली की विशेषताओं की जानकारी रखते हुए इस लेख में प्रस्तावित प्रणाली निदर्श का उपयोग करते हुए अधिकतम फसल उत्पादन प्राप्त करने के लिये नीति निर्धारण किया जा सकता है।

**ABSTRACT.** The paper develops a conceptual model of crop production system in rainfed areas with an objective to develop appropriate package of practices for maximising production. The model visualises the arable land as a water storage element from which water is depleted over time due to its utilization in crop growth and is replenished by rains. If the rains are scant the water reservoir in the soil is unable to support the crops. The paper proposes how to seek the best crop yields under moisture conditions sometimes unfavourable to them in varying degrees. The model comprises five elements besides the natural input in terms of seasonal rains and designed strategies involving rate of fertilizer application, choice of harvest time, cultural practices and possible irrigation through stored rain water. The five elements of the system are: (i) a region under cultivation, (ii) soil sub-system, (iii) kharif soil crop sub-system, (iv) rabi soil-crop sub-system, and (v) reservoir for run-off water from rains. The outputs of the system are crop yields and the crop wastes both of which are usable and have a value. With the known system characteristics, strategies for optimizing the crop yields can be designed using the system model proposed in this paper.

### 1. Introduction

Plant growth and the subsequent crop yield have a strong functional relationship with the availability of water in the root zone of the plant. Persistent water deficiency in the soil causes moisture stress which inhibits plant growth and if allowed to exceed a certain level results in irrecoverable damage to crop yield. Soil water status in the root zone of the plant affects the plant water status on which depend the metabolic and physiological functions of the plant. The water applied to soil as irrigation or rain is taken up by the plant to meet the evaporative demand of the atmosphere. Soil water, therefore, functions as an important

control variable in the crop production process. It is because of this reason that massive effort to bring more and more cultivable land under irrigation is afoot.

Unfortunately, however, there are vast areas where one has to depend only upon natural rain for raising crops. This may be because either ground water exploitation is not economical or a canal network for surface irrigation does not exist or both. Such areas will continue to be under rainfed farming. If the rains in these areas are plentiful and well distributed during monsoon and the soil has good water storage capacity kharif crops can be raised successfully. Also, the residual soil moisture after the kharif harvest

\*The paper was presented in the symposium "Indo-French school on recent advances in Computer Techniques in Meteorology Biomechanics & Applied Systems" held at I.I.T., New Delhi, February 1980.

will be adequate for seed germination, seedling emergence and plant growth in the "rabi". The winter rains further help in the growth process and lead to a successful raising of rainfed crops. However, good monsoons do not occur every year and constraints on the availability of water become severe. It is, therefore, profitable to devise a strategy for maximizing yields of rainfed crops.

For this purpose we have attempted a conceptual model of crop production system for rainfed areas with the objective to develop an appropriate package of practices for maximizing production. The model visualizes the arable land as a water storage element in the form of soil moisture from which water is depleted over time through utilization by crops and replenished by rains over the year. The model becomes very useful when drought conditions prevail and the water reservoir in the soil is unable to support the crops.

## 2. Development of the model

The model comprises five elements. These five elements of the system are conceived to be :

- (i) region under rain-fed farming.
- (ii) soil sub-system
- (iii) *kharif* soil-crop sub-system
- (iv) *rabi* soil-crop sub-system
- (v) reservoir for storing run-off water.

The system input consists of seasonal rains and designed strategies involving rate of fertilizer application, cultural practices, harvesting schedule and irrigation through stored rain water. The system outputs are grain and crop residues both of which have an economic value.

We consider the elements of the system one by one in a little more detail.

### 2.1. Region under rain-fed farming

The regional characteristics regarding run-off are important for establishing linkages with the other elements of the model. Run-off results where the rain water does not enter the soil as fast as it is received at the surface. The surplus water is lost as overland flow. Fig. 1 shows this element which is considered over the monsoon season only.

Run-off in the region depends on the topography of the region, soil characteristics, rainfall characteristics involving intensity and frequency of rain and land use

(Verma *et al.* 1979). Rainfall received in the region during monsoon season which is not lost in run-off infiltrates into the soil. The water balance of the region is given by the equations :

$$R = \sum_{i=1}^n k_i r_i \quad (1)$$

$$S = \sum_{i=1}^n (1-k_i) r_i + \sum_{i=1}^m r_i \quad (2)$$

where,

$r_i$  — rainfall (mm) in the  $i$ th rainstorm

$k_i$  — fraction of the rainfall as run-off during the  $i$ th rainstorm

$n$  — number of rainstorms resulting in run-off

$m$  — number of rainstorms which do not result in run-off

$R$  — total run-off in mm

$S$  — total water in mm that infiltrates into the soil

Extensive data on run-off under different rainfall characteristics for different regions are available and can be used in the study.

### 2.2. Soil sub-system

The soil sub-system is the chief element in the study of the total system. It acts as the storage reservoir of water for use of the plants. The part of the rainfall which infiltrates into the soil sub-system establishes a soil moisture status in the soil profile. Depending upon the moisture retention characteristics of the soil and the amount of water that infiltrates into the soil, a part of it flows beyond the potential root zone of the crops and is lost as deep seepage. Fig. 2 shows the input and outputs of this element.

The water balance is given by the following equations :

$$S_{ds} = D_s S \quad (3)$$

$$S_{mk} = T (S - S_{ds}) \quad (4)$$

where,

$D_s$  — Seepage coefficient

$S_{ds}$  — Water in mm lost to deep seepage

$S_{mk}$  — Soil moisture status in terms of soil water potential in 'kharif'

$T$  — Operator to convert soil water storage to soil water potential.

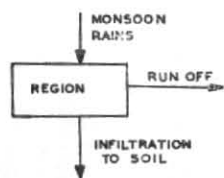


Fig. 1. Region under rainfed farming (during monsoons)

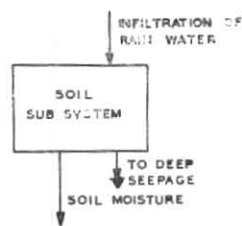


Fig. 2. Soil sub-system

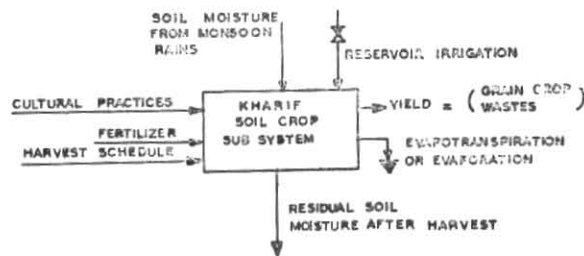


Fig. 3. Kharif soil-crop sub-system

This element primarily deals with the soil water storage. While moisture retention characteristics of the soil in different regions have been investigated extensively (Singh *et al.* 1975 and Prihar *et al.* 1979), little data are available on deep seepage as related to different water inputs to the soil sub-system. This information gap needs to be filled.

### 2.3. Kharif soil crop sub-systems

This is the soil sub-system with the kharif crops grown on it. It has moisture in the soil profile on account of the water received from the monsoon rains. Partly anticipated in nature, a decision is made as to which crop is to be grown. If adequate rainfall is expected, a kharif crop can be grown. If, however, the monsoons rains are scanty, the field may be left fallow or a short duration crop can be raised. The important thing is that moisture in the soil needs to be conserved so that the combined yield in the kharif and rabi can be maximized. For this the residual moisture after the kharif harvest should be adequate for rabi sowing and stand establishment. The sub-system may also receive irrigation from the stored rain water in the reservoir. However, unless the kharif crop has great demand for water reservoir irrigation may not be necessary since abundance of stored rain water in the reservoir and plentiful soil moisture on account of natural rains go together.

It is this sub-system where the policies formulated for moisture conservation coupled with optimizing fertilizer application will be implemented. These policies involve a variety of cultural practices, rates of fertilizer application, harvesting schedule for crops being raised, and application of reservoir of irrigation.

Fig. 3 shows the various inputs and outputs of this sub-system.

The water balance equations can be written as follows. If reservoir irrigation is used, we have

$$S_{mk}^1 = T(S - S_{ds} + H_k) \quad (*)$$

where,

$S_{mk}^1$  is soil moisture status resulting from reservoir irrigation.

$H_k$  is water applied (in mm) to kharif crop from the reservoir.

This soil moisture continues to be depleted through evapotranspiration as the kharif crop grows. Therefore, for cropped conditions another term " $cE_0$ " has to be put in the parenthesis in R.H.S. of Eqn. (5) and it can be written as

$$S_m = T(S - S_{ds} + H_k - cE_0) \quad (6)$$

where,

$S_m$  is the soil moisture status during the growth phase of the crop and  $cE_0$  is the depletion of water by the crop. Depletion of moisture by the crop depends upon the evaporative demand of the atmosphere  $E_0$  and coefficient 'c'. Value of the coefficient is determined by soil water status, depth of rooting and the size of the crop canopy. Further, the crop coefficient also varies with the age of the crop.

The residual soil moisture status after the kharif harvest can be denoted by  $S_{mr}$ . It is in this subsystem that we start obtaining yields from the crop in the form of grain and crop residue. The vector equation to give the kharif yield in a functional relationship may be written as

$$Y_k = f(S_{mk}, S_{mr}, F_k) \quad (7)$$

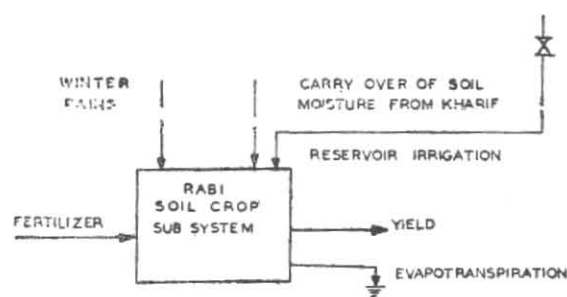


Fig. 4. Rabi soil-crop sub-system

where the vector  $Y_k$  embodies the grain and crop residue yields as components,  $F_k$  denotes the fertilizer application and other management practices and  $S_{mr}$  denotes the predetermined residual soil moisture sufficient for successful rabi sowing, if rabi crop is to be taken.

The cultural practices involving tillage, mulching etc. are used to increase soil moisture storage and conserve water in the seed zone of the crop (Gill *et al.* 1977 & Prihar *et al.* 1979). In some cases where soil is to be kept fallow during kharif it has been found profitable to grow some legume crop early in the season and spread it over the soil surface after harvest. This provides an effective moisture conservation method together with a supply of nitrogen. Also, cultivation reduces moisture loss in the soil by killing weeds as well as by reducing the drying rate of the soil layers immediately below the tilled layer Gill (1978).

Data on the effect of several cultural practices and fertilizer response to crops are available for many situations. However, data on soil moisture status as it relates with crop growth both in terms of grain and vegetative yield needs to be generated. This would provide a basis for decisions regarding pre-mature harvesting of the kharif crop for retaining adequate soil moisture for successful rabi sowing.

Fixing the minimum residual moisture at kharif harvest would also require information on the availability of reservoir water, water needs for stand establishment and expectations of the quantum of winter rains.

#### 2.4. Rabi soil-crop sub-systems

In most situations the yield obtained in the rabi season is of great economic value. Most of the effort directed at moisture conservation during kharif are to raise the crop profitably. Water availability,

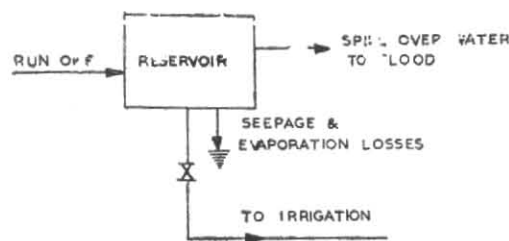


Fig. 5. Reservoir for run-off water

particularly at the sowing time and fertilizer application have a marked influence on rabi yields. It has been reported that for proper utilization of water it is important that the soil be treated adequately with balanced doses of fertilizer nutrient. It has generally been reported by agricultural scientists working in dry-land areas that the fertilized crops withstand drought conditions better than the unfertilized crops. However, it will be useful to conduct field experiments to generate data on water availability fertilizer interactions on different soils. This would allow optimization studies in respect of fertilizer use in limited water availability conditions.

The yield of *rabi* crops as influenced by the availability of soil water, fertilizer doses, winter rains and protective irrigation from reservoir can be expressed as

$$Y_r = g(S_{mr}, r_w, F_r, H_r) \quad (8)$$

The crop residues are usually related to the grain yield and their yields can be computed from  $Y_r$ . The winter rains,  $r_w$  are uncertain,  $H_r$  is the reservoir irrigation in *rabi* and  $F_r$  denotes the fertilizer application in *rabi*. Some work in regard to predicting yields in relation to stored water and pattern of rainfall distribution is available (Arora 1979). However, more work for soils of different characteristics and in different regions is needed to develop more useful models.

Fig. 4 displays the input-output relations for rabi soil-crop sub-system.

#### 2.5. Reservoir for storing run-off water

The run off from rains is usually lost to the region. However, if a reservoir is constructed to store this rain water, it may be used for protective irrigation in case of drought conditions and for supplementary irrigation otherwise. The capacity of the reservoir, evaporation data of the region, seepage losses and the run-off characteristics are the important attributes of this sub-system. Fig. 5 shows the input and outputs of this sub-system.

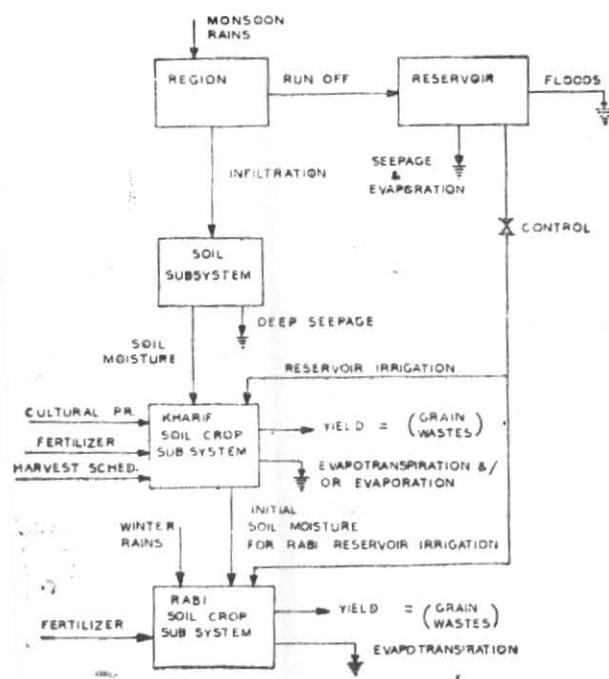


Fig. 6. Model for rain-fed farming system

Excess run-off over the reservoir capacity goes to floods. The stored rain water in the reservoir through control policies can be used for protective or supplementary irrigation both in *kharif* and *rabi* for high pay-offs. The height of water  $H$  in the reservoir, taken as rectangular, is given by

$$H = \begin{cases} \lambda PR & \text{if } H < H_m \\ H_m & \text{if } H \geq H_m \end{cases}$$

where,  $P$  is reservoir constant depending on the ratio of area of region to area of base of reservoir and  $\lambda$  is the loss coefficient involving evaporation and seepage. The value of this has to be determined for the reservoir in a region.

### 2.6. The overall model

The five elements of the crop production system outlined in the above paragraphs can be combined together to give an overall model. The model as conceptualized is given in Fig. 6. The soil sub-system, *kharif* soil-crop sub-system and *rabi* soil-crop sub-system are one and the same elements physically, but differ agronomically and have, therefore, been treated as separate sub-systems. The overall model developed provides a useful framework in which the strategies for selection, of suitable crops to be grown in the rainfed areas, appropriate cultural practices, fertilizer application, harvesting schedule for the *kharif* season and controlled irrigation from reservoir containing stored rain water can be formulated for maximizing the crop yields.

### 3. Conclusion

The paper has developed a conceptual model of crop production system in rain-fed areas. It considers the regional characteristics like topography, rainfall and soil characteristics together with the *kharif* and *rabi* crops to be grown in the area as the structure of the system where the choice of crops in the two seasons can be left as flexible. With the known system characteristics one can proceed to design the strategies for optimizing the crop yields. It has been proposed in the paper that effective cultural practices for moisture conservation, fertilizer application rates during both the crop seasons, harvesting schedule of *kharif* crop and the supplementary irrigation through the reservoir containing stored rain water can serve as potent policies for maximizing the yields under rain-fed conditions.

The paper has also indicated what data regarding the system characteristics are available and what data needs to be generated for a gainful study of the over-all system. Data on crop growth vs. soil moisture status, deep seepage vs. moisture input to the soil and water availability-fertilizer interactions on different soils will be useful. These data need to be collected for different crops under different regional conditions and with various proposed policies for a purposeful crop production programme. Finally, the study provides a holistic approach to investigate the crop production system in rainfed areas systematically.



## References

- Arora, V. K., 1979, Predicting yield of dryland wheat from available soil water at seeding and growing season rainfall, M.Sc. thesis, submitted to Punjab Agricultural University, Ludhiana.
- Gill, K. S., Jalota, S. K., Prihar, S.S. and Chaudhary, T. N., 1977, Water conservation by soil mulch in relation to soil type time of tillage, tillage and evaporativity, *J. Indian. Soc. Soil.Sci.*, **25**, 360-366.
- Gill, K. S., 1978, Nature of moisture profile during soil drying as affected by cultivation and the effect of seed zone soil moisture conditions on seedling emergence, Ph. D. thesis, submitted to Punjab Agricultural University, Ludhiana.
- Prihar, S. S., Singh, Ranjodh, Singh, Nathu and Sandhu, K. S., 1971, Yield and water use of dryland crops as affected by mulching in standing maize and fallow, *Exptl. Agril.*, **15**, 129-135.
- Singh, Ranjodh, Singh, Yadvinder, Prihar, S. S. and Singh, Piara, 1975, Effect of N fertilization on yield and water use efficiency of dryland winter wheat as affected by stored water and rainfall, *Agron. J.*, **67**, 599-603.
- Verma, H. N., Singh, Ranjodh, Prihar, S. S. and Chaudhary, T. N., 1979, Run-off as affected by rainfall characteristics and management practices on gently sloping sandy loam, *J. Indian Soc. Soil Sci.*, **27**, 18-22.
- Verma, H. N., Prihar, S.S. Singh, Ranjodh, and Singh, Nathu, 1978, Yield of sub-humid rainfed crops in relation to soil water retention and cropping sequence, *Exptl. Agri.* **14**, 253-260.
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