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# Evaluation of agricultural drought using probability distribution of soil moisture index

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**सार** — खरीफ फसल की ऋतु के लिए जुलाई से अक्तूबर तक 33 वर्षों का दिल्ली का साप्ताहिक मृदा नमी बजट ज्ञात किया गया है । इस ऋतु में दिल्ली की जलवायु अर्धशुष्क होती है । इस के लिए जलवायु के आंकड़ों का उपयोग करके स्टेयर (1960) द्वारा सुझाई पग फलन विधि का अनुसरण किया गया है । मृदा जड़ क्षेत्र में उपलब्ध जल और उपलब्ध जल धारिता का अनुपात मृदानमी सूचकांक कहलाता है । यह वास्तविक एवं संभावित वाष्पोत्सर्जन के अनुपात से सीधा संबंधित है । मृदानमी सूचकांक के साप्ताहिक मानों के बारंबारता बंटन को ज्ञात करके बीटा बंटन से उसकी गणना की गई है । समंजन-सुष्ठता का कालमोगोरोव-समिरनोव परीक्षण यह दर्शाता है कि मानसून सीजन के मृदानमी सूचकांक के सन्निकटन के लिए बीटा बंटन उपयुक्त सांख्यिकीय निदर्श है ।

दिल्ली क्षेत्र में उगाई जाने वाली खरीफ की फसलें जैसे ज्वार, बाजरा, मक्का, धान एवं मूंगफली के मूलक्षेत्र में कृषि सूखे के साथ-साथ संभावित नमी की दशाओं से संबंधित प्रभाव सीमा के मानों के लिए विभिन्न घटनाक्रमों में मानसून के दौरान कृषि सूखे के पड़ने की बारंबारता को ज्ञात किया गया है । इन परिणामों पर क्षेत्र विशेष के वर्षा बंटन के अनुरूप बनाए गए फसल निदर्श के चयन के संदर्भ में चर्चा की गई है।

ABSTRACT. Weekly soil moisture budget was worked out for kharif cropping season July through October for 33 years (1940-1972) for Delhi which has a semi-arid monsoonal climate. For this purpose the step function approach using climatological data suggested by Slatyer (1960) was followed. Soil moisture index (SMI), the ratio of available water to available water capacity in the soil root zone is directly related to the ratio of actual and potential evapotranspiration. Frequency distribution of weekly SMI values were evaluated and compared with the Beta distribution. Kolmogorov-Smirnov test of goodness of fit indicated the Beta distribution to be a suitable statistical model for approximating the frequency distribution of SMI for the monsoon season.

For the threshold values corresponding to agricultural drought as well as potential moisture conditions in the root zone in respect of kharif crops, *viz.*, sorghum, pearlmillet, corn, paddy and peanut crops grown in the Delhi region, the frequency of occurrence of agricultural drought during the monsoon season in the different phenological stages was determined. These results are discussed with reference to selection of a cropping pattern tailored to rainfall distribution of the region.

## 1. Introduction

High spatial and temporal variability is the main characteristic of rainfall in the monsoon region. This variability is reflected in untimely and unpredictable floods and droughts which have adverse effects on crop production. In the Delhi region, bulk of the sowing of *kharif* crops is done in the first week of July with the onset of monsoon; the crops come to harvest in late October, about 4 weeks after monsoon withdrawal. Occurrence of dryspells caused by breaks in the monsoon season is one of the major factors affecting crop growth and development in this region. Apparently the primary climatic limitation here is the limited and variable moisture supply.

Many climatological studies have been undertaken earlier to determine the nature of the droughts using rainfall, Palmer's index and aridity anomaly indices (Appa Rao *et al.* 1981, George and Kalyanasundaram 1969, George *et al.* 1973, Subrahmanyam & Sastry 1969). However, these have not been related to phenological development of crops. In this paper, agricultural drought during monsoon season in relation to the different phenological stages has been evaluated for the *kharif* crops, *viz.*, pearlmillet, sorghum, corn, upland paddy and peanut crops grown in the Delhi region, using probability distribution of Soil Moisture Index (SMI), which is the ratio of 'available water' to 'available water capacity' in the root zone. SMI is known to be directly related to the ratio of actual to potential evapotranspiration (Baier 1961).

## 2. Material and methods

Weekly rainfall and pan evaporation for the monsoon months July to October for 33 years (1940-1972) recorded at the farm observatory of the Indian Agricultural Research Institute, New Delhi have been utilized in the present study. The analysis covers 18 weeks of the *kharif* cropping season. (Standard weeks 27 to 44 followed by India Met. Dep.). The 27th week starts on 2 July, and the 44th week ends on 4 November. With pan evaporation and weekly rainfall as inputs, weekly water balance in the root zone 0-100 cm was worked out following the step function approach suggested by McAlpine (1970). 100 mm was considered as available water capacity of the soil in the root zone. SMI values were computed for 33 years

**TABLE 1**

**Probability of occurrence of soil moisture indices at different phenological stages of *kharif* crops**

| Growth phase | Duration | Probability of SMI | |
|---|---|---|---|
| | | Drought | Potential moisture |
| *Pearlmillet* | | $p \leq 0.5$ | $p \geq 0.7$ |
| Sowing and germination | 2 weeks (2-15 July) | .67 | .27-.28 |
| Tillering | 4 weeks (16 Jul-12 Aug) | .42-.60 | .31-.37 |
| Flowering | 2 weeks (13-26 Aug) | *.40-.42* | *.41-.44* |
| Ear emergence and maturity | 5 weeks (27 Aug-30 Sep) | .42-.64 | .23-.38 |
| *Sorghum* | | $p \leq 0.5$ | $p \geq 0.8$ |
| Sowing and germination | 1 week (2-8 Jul) | .67 | .24 |
| Panicle initiation | 3 weeks (9-28 Jul) | .56-.67 | .22-.26 |
| Flowering (Anthesis) | 4 weeks (30 Jul-26 Aug) | *.40-.47* | *.28-.36* |
| Maturity | 5 weeks (27 Aug-30 Sep) | .42-.64 | .15-.30 |
| *Peanut* | | $p \leq 0.5$ | $p \geq 0.8$ |
| Germination and establishment | 4 weeks (2-29 Jul) | .56-.67 | .22-.25 |
| Flowering and pod development | 8 weeks (30 Jul-23 Sep) | *.40-.63* | *.15-.36* |
| *Corn* | | $p \leq 0.6$ | $p \geq 0.9$ |
| Germination | 2 weeks (2-15 Jul) | .70 | .16-.19 |
| Vegetative | 7 weeks (16 Jul-2 Sep) | .49-.64 | .11-.24 |
| Tasselling | 3 weeks (3-23 Sep) | *.54-.70* | *.08-.19* |
| Ripening and maturity | 5 weeks (24 Sep-28 Oct) | .69-1.00 | 0-.12 |
| *Upland Paddy* | | $p \leq 0.75$ | $p \geq 1.00$ |
| Vegetative | 10 weeks (2 Jul-9 Sep) | .61-.76 | 0 |
| Reproductive | 2 weeks (10-23 Sep) | *.66-.81* | 0 |
| Maturity | 4 weeks (24 Sep-21 Oct) | .78-1.00 | 0 |

from 27th to 44th week and incomplete beta distribution was fitted following Yao (1969). Kolmogorov-Smirnov test showed that the absolute maximum distance, $D$, between sample and theoretical values are not significantly different at 5 per cent level, showing the adequacy of the model. Ravelo and Decker (1979) observed that the beta distribution was a good statistical model for daily as well as 10 and 30-day mean values of SMI and our results are in conformity with this. For determining the probability of occurrence of agricultural drought and potential moisture conditions for crop growth, $I_W$/CPE ratios determined from field experiments on water management were utilized (Rajput 1979, Yadav 1977).

## 3. Results and discussion

Probability of occurrence of agricultural drought and potential moisture conditions in the respective phenological stages of five *kharif* crops namely pearlmillet, sorghum, corn, upland paddy and peanut are shown in Table 1.

### 3.1. *Probability of occurrence of agricultural droughts*

Of the five *kharif* crops considered, it is seen that the probability of occurrence of agricultural drought in the Delhi region is relatively the lowest in respect of pearlmillet. Of all the stages, flowering and grain filling periods are known to be critical as far as root zone moisture is concerned (Salter & Goode 1967). When this criterion is applied, it is seen that the probability of occurrence of agricultural drought at the flowering stage for pearlmillet, sorghum, peanut, corn and upland paddy range from 40-42, 40-47, 40-63, 54-70 and 66-81 per cent respectively. Starting from pearlmillet, the different crops are prone to increasing agricultural drought in the order mentioned above.

### 3.2. *Probability of occurrence of potential moisture conditions in the root zone*

The probability of getting potential moisture conditions for *kharif* crops at different phenological stages are given in Table 1. It is seen that during the moisture sensitive stage of the crops (flowering), the probability of getting potential moisture conditions in the root zone of pearlmillet, sorghum, peanut, corn and upland paddy ranges from 41-44, 28-36, 15-36, 8-19 and zero per cent respectively. These probabilities can also be interpreted in terms of potential crop yields as these are related to potential moisture conditions in the root zone (Dale & Shaw 1965). The occurrence of favourable conditions for potential yields of crops show a decrease starting from pearlmillet in the order indicated.

Judging from the criteria for both agricultural drought and potential yield in terms of probabilities of SMI values, it is apparent from the foregoing results that pearlmillet and sorghum crops are suited to the semi-arid environment of the Delhi region, whereas upland paddy, corn and peanut are not suitable. Thus, evaluation of the probability distribution of SMI is of great use in determining the land suitability in regions with marginal rainfall for determining cropping patterns based on rainfall distribution.

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