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A Study on Association of Combined Effect of Rainfall Patterns on Crop Yields

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SUMMARY

For studying crop yield weather relations, a non-parametric approach based on the concept of two-way contingency tables has been proposed to account for the associations of combined effect of rainfall pattern on crop yield. The approach identifies both the different rainfall patterns and the levels of crop yields that are likely to occur during the crop season and then attempts to measure their associations. The approach was applied for studying the weather (rainfall) effect on the three crops viz., Jowar, Groundnut and Cotton by using 40 years crop yield-rainfall data (1961-2000) of Anantapur district of Andhra Pradesh. The analysis provides useful information about the yield response range corresponding to the different rainfall patterns that are likely to occur during the crop growth season.

Keywords : Cluster analysis, Average linkage method, Contingency table, Crop yield weather relations.

1. Introduction

Multiple regression has been the most commonly applied approach for formulating and estimating the crop yield weather relations. In this approach, the weather variables, which significantly influence the crop yields, are identified and are retained in the relationship for estimation/forecasting of crop yields. There were several refinements in the applicability of the approach. Some of these were Jain *et al.* (1980), Agarwal *et al.* (1986) and Kulkarni and Pandit (1988).

In rain-fed agriculture, the crop yield recorded during a year can be regarded as the combined influence of weather factors prevailing during the crop growth stages of the year.

In the present study, a non-parametric procedure has been proposed for studying the association between the crop yields and the combined effect of rainfall pattern prevailing during the crop growth stages.

2. Materials and Methods

Rainfall is an important component of weather. Every amount of rainfall received during the crop growth stages has its own share in influencing the crop yields. Thus this combined effect of rainfall on the crop yields can be studied on the basis of rainfall pattern prevailing during the crop growth stages. The approach, therefore involves identification of rainfall patterns (prevailing during the crop stages) and establishing association between rainfall patterns and the crop yields.

Identification of Rainfall Patterns : Rainfall recorded during the different periods (months) of the crop growth is generally inter-related. Hence the pattern of occurrence of rainfall during any period cannot be independently studied (estimated) by fitting suitable statistical distributions to the rainfall data recorded over the years. Therefore, a multivariate approach that identifies the pattern of rainfall during the entire crop growth periods of the crop season has been proposed below.

Let X be a random vector consisting of k variables. Let these variables represent the rainfall record of the k periods (which may be either week or month) of the crop season. Suppose that time series data for N years are available on the observation vector X.

The N years of rainfall data on X can be then subjected to cluster analysis. The analysis would provide clusters (groups) consisting of years of 'similar' rainfall. Corresponding to each cluster, the averages of rainfall variables based on the number of observations in the cluster (i.e., the number of years clustered) can be computed. These cluster averages indicate different patterns of rainfall, which are likely to occur during the crop period (season). Among these, the cluster that is relatively more frequent can be considered as representing the general pattern of rainfall. This general pattern can then be superimposed on the time series data on crop yields (for the same N years) for studying its possible association.

Association between Rainfall Pattern and Crop Yields : The crop yields (i.e., the productivity, kg/ha) recorded over the N years are affected by several factors such as the technological innovations being adopted time to time as well as the weather. Hence, for studying the influence of weather on the crop yields, the elimination of the factor effects such as the technology forms the basic step. The effect of technology can be identified through several approaches such as estimating the time trend in the crop yields by fitting suitable trend equations or by identifying the quantal jumps in the yields resulting out of replacement of technology, through graphical analysis [Kulkarni and Pandit (1988)].

A relatively more general approach would be to obtain a clustering of the time series data on the crop yields. The analysis would identify clusters of years with similar level of crop yields. Each cluster, therefore, represents different level of yield, which can be attributed to the replacement of technology or the effect of abnormal weather conditions prevailing during the years that are clustered.

The association of these crop yield clusters with those of rainfall patterns identified through several clusters can be studied with a Two-way Classification Table of frequency of years based on the concept of Contingency Table, as follows

Table : Two-way Contingency Table for crop yield-rainfall association

Rainfall Patterns	Crop Yield					
	Cluster-1	Cluster-2	...	Cluster-j	...	Total
Cluster-1	f_{11}	f_{12}	...	f_{1j}	...	R (1)
Cluster-2	f_{21}	f_{22}	...	f_{2j}	...	R (2)
:	...	...	...	:	...	:
Cluster-i	...	...	...	f_{ij}	...	R (i)
:	:	:	...	:	...	:
Total	C (1)	C (2)	...	C (j)	...	N

Let the two attributes of the two-way table be the 'Crop Yield Levels' represented by its clusters and the 'Rainfall Patterns' again represented by its clusters. Further, each cell of this table represents the frequency f_{ij} of the years 'in common' with i-th cluster of rainfall and j-th cluster of crop yields. The association between the attributes can then be quantified in the form of proportions of each of the (i, j)-th cells as: $[f_{ij}/C(j)]$. These proportions indicate the 'association' accounted by a level of crop yield with the corresponding rainfall pattern.

The approach outlined above was applied for studying the crop yield-weather (rainfall) association in the context of three major crops of Anantapur District. Anantapur district belongs to the Scarce Rainfall Zone of Andhra Pradesh State. The crops selected were Jowar, Groundnut and Cotton. These are kharif season crops and the duration of the crops that approximately cover the crop growth stages is 5 months from June (Sowing) to October (Harvesting/ maturity). Hence the observation vector was defined with monthly rainfall of 5 months (June to October). 40 years of crop yield-rainfall data covering the years 1961 to 2000 was used for this purpose. Season and Crop Reports and the Statistical Abstracts of A.P. State were the sources for data.

3. Results and Discussion

The Average Linkage method of clustering was carried out for identifying the distinct clusters of rainfall as well as crop yields. In this method the objects (i.e., the N years of rainfall / crop yield data in the present case) are classified into distinct clusters on the basis of the relative distance between the objects, which measure the degree of closeness between them. The most suitable measure for this purpose is the Mahalanobis Standardized distance, defined in the context of (i, j)th pair of objects as

$$d_{ij}^2 = (X^{(i)} - X^{(i)})' S^{-1} (X^{(i)} - X^{(j)}), \text{ for } i \neq j = 1, \ldots, N$$

where $(X^{(i)}, X^{(j)})$ are the observation vectors of (i, j)-th objects and S is the Variance-Covariance Matrix. The following steps are involved in application of the method

(a) The inter-object distances (d_{ij}^2 or d_{ij}) are computed to form the initial distance matrix D(0) and from this matrix the most closest pair (in terms of the distance) is identified as the initial cluster C_1 with objects, say (1, 2).

(b) The distance matrix D(0) is then revised to D(1). D(1), which is of the order of (N -1), contains distances of j-th object ($j \neq 1, 2$) with C_1. The distance is computed as the average distance $d(1, 2)_j = (d_{1j} + d_{2j})/2$.

(c) Again the search for the closest pair is continued from D(1). The procedure of identifying the closest pair and revising the distance matrix is repeated till all the objects are classified in a single cluster.

(d) A dendrogram (tree diagram) is then plotted out of the distances computed in the distance matrices by taking the objects (as these are screened) on X Axis and the distances on Y Axis. Cluster formation can be then viewed from this diagram by defining a threshold distance d_0 such that inter cluster distances of all the clusters are $\geq d_0$. The choice of d_0 is arbitrary and depends on how close the clusters are to be formed.

The cluster analysis applied to the 40 years of rainfall data identified 7 different patterns through the clusters. Among these, 6 clusters were formed with single years, while there was a single largest cluster (cluster 2) formed with 34 years. This cluster can be regarded as representing the general pattern of occurrence of rainfall during the 5 months of the season (Table 1). It can be observed that relatively low rainfall during the crucial crop growth stages, i.e., July and August months are the characteristic of the cluster. Cluster 5 represents the most favourable pattern for crop growth. However, it is relatively less frequent. The other single year clusters exhibit abnormalities (deviations) in the occurrence of rainfall.

Table 1. Pattern of rainfall in Anantapur district (1961 – 2000)

Cluster	No. of Years	Mean Rainfall in "mm"				
		JUN	JUL	AUG	SEPT	OCT
1	1	81.00	47.00	248.00	21.00	136.00
2	**34**	**51.88**	**53.15**	**80.15**	**127.44**	**111.85**
3	1	59.00	135.00	38.00	229.00	60.00
4	1	24.00	124.00	91.00	131.00	248.00
5	1	13.00	158.00	234.00	265.00	25.00
6	1	48.00	280.00	28.00	203.00	24.00
7	1	131.00	19.00	25.00	76.00	197.00

The variation in the crop yields of the same 40 years was found to be conveniently summarized with 3 clusters. The average yield level of these clusters can be clearly attributed to the replacement of existing 'low yielding technology' to the 'high yielding technology'. The results of crop yield levels together with their association with rainfall patterns are presented crop wise in Tables 2 to 5.

Table 2. Crop yield patterns in Anantapur district (1961 – 2000)

Crop	Average yield levels (kg/ha)		
	Cluster-1	Cluster-2	Cluster-3
Jowar	513.76(29)	1448.30(10)	2830.00(1)
Groundnut	356.60(5)	702.13(31)	1169.25(4)
Cotton	55.15(20)	165.20(5)	247.27(15)

Figures in parenthesis indicate the number of years included in the cluster

Table 3. Rainfall – Jowar yield association

Rainfall Pattern	Levels of crop yields (kg/ha) represented in		
	Cluster-1	Cluster-2	Cluster-3
Cluster-1	326.00 (3.45)	-	-
Cluster-2	**515.37 (82.75)**	**1471.67 (90.00)**	**2830.00 (100)**
Cluster-3	222.00 (3.45)	-	-
Cluster-4	426.00 (3.45)	-	-
Cluster-5	772.00 (3.45)	-	-
Cluster-6	784.00 (3.45)	-	-
Cluster-7	-	1238.00 (10.00)	-
Average (Kg/ha)	513.76 (100)	1448.30 (100)	2830.00 (100)

Figures in parenthesis indicate the relative frequency (percent) over the total number of years in the respective yield cluster

Table 4. Rainfall – Groundnut yield association

Rainfall Pattern	Levels of crop yields (kg/ha) represented in		
	Cluster-1	Cluster-2	Cluster-3
Cluster-1	396.00 (20.00)	-	-
Cluster-2	**346.75 (80.00)**	**700.35 (83.90)**	**1169.25 (100)**
Cluster-3	-	668.00 (3.22)	-
Cluster-4	-	720.00 (3.22)	-
Cluster-5	-	839.00 (3.22)	-
Cluster-6	-	665.00 (3.22)	-
Cluster-7	-	665.00 (3.22)	-
Average (Kg/ha)	356.60 (100)	702.13 (100)	1169.25 (100)

Figures in parenthesis indicate the relative frequency (percent) over the number of years in the respective yield cluster

Table 5. Rainfall – Cotton yield association

Rainfall Pattern	Levels of crop yields (kg/ha) represented in		
	Cluster-1	Cluster-2	Cluster-3
Cluster-1	64.00 (5.00)	-	-
Cluster-2	**54.41 (85.00)**	**165.25 (80.00)**	**250.07 (86.66)**
Cluster-3	54.00 (5.00)	-	-
Cluster-4	60.00 (5.00)	-	-
Cluster-5	-	165.00 (20.00)	-
Cluster-6	-	-	224.00 (6.67)
Cluster-7	-	-	234.00 (6.67)
Average (kg/ha)	55.15 (100)	165.20 (100)	247.27 (100)

Figures in parenthesis indicate the relative frequency (percent) over the total number of years in the respective yield cluster

Crop Yield Rainfall Associations – Jowar : It was observed that Cluster 1 of Jowar yield was formed with 'low yield' year from 1961 to 1989 (29 years); while Cluster 2 with 'high yield' years from 1990 to 1999 (10 years). This shift from low yield to high yield years is precisely identified. The shift can also be observed from Fig. 1 around the year 1990. The average yield levels of these two clusters were respectively, 513.76 kg/ha and 1448.30 kg/ ha. The number of years in each cluster can be regarded as the 'incubation' period for adopting these technological innovations.

The crop yields of low yield (Cluster 1) and high yield (Cluster 2) years had relatively maximum association with those of the general rainfall pattern represented by Cluster 2. The association accounted for 82.75 per cent in case of 'low yield' years while it was 90 per cent for the high yield years. Further, the abnormal rainfall patterns were also found to have association with the low yield years. The yield levels corresponding to these abnormal rainfall patterns ranged from 222 kg/ha to 784 kg/ha corresponding to the combinations (3, 1) and (6, 1) of Table 3. However, under normal rainfall pattern (Cluster 2 of rainfall patterns), the 'assured' crop yield level from low and high yielding technologies is respectively 515.37 kg/ha and 1471.67 kg/ha (Table 3).

Crop Yield Rainfall Associations – Groundnut: It can be observed from Fig. 2 that the groundnut yields fluctuated between 600 kg/ha and 800 kg/ha. This was aptly represented in Cluster 2 (31 years) with average yield of 702.13 kg/ha (Table 2). The yields classified in the smaller clusters, i.e., Cluster 1 and Cluster 3 can be thus regarded as abnormalities.

The association that existed between the yields of Cluster 2 and the normal rainfall pattern (Cluster 2 of rainfall patterns) accounted for 84 per cent i.e., the normal rainfall pattern was responsive for attaining the average yield of 700.35 kg/ha of the crop yield of Cluster 2. The abnormal rainfall patterns were also found to have association with the abnormalities in the crop yields. However, the association was of relatively low order, 3.22 per cent (Table 4).

Fig 1 : JOWAR YIELDS IN ANATAPUR

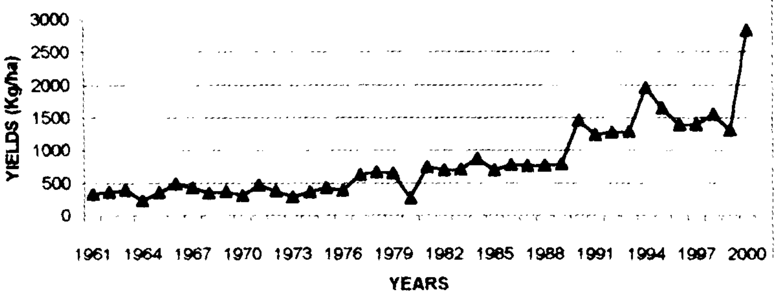


Fig 2: GROUNDNUT YIELDS IN ANANTAPUR

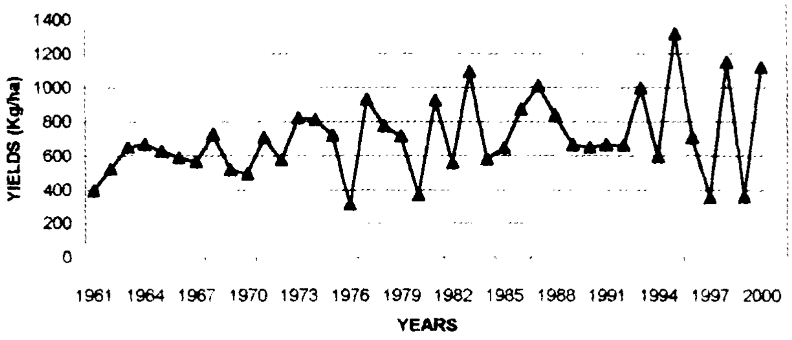
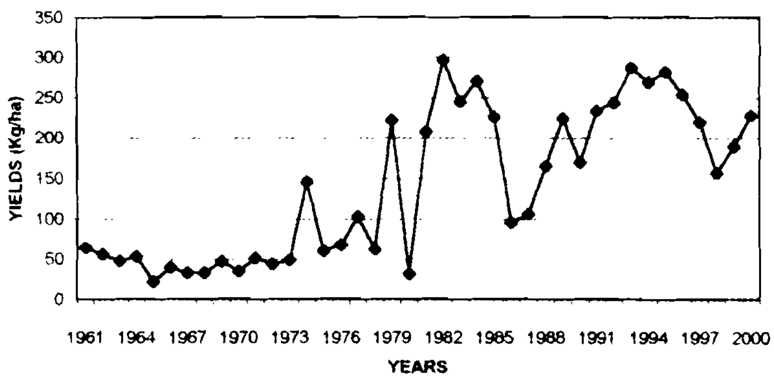


Fig 3 : COTTON YIELDS IN ANANTAPUR



Crop Yield Rainfall Associations – Cotton: The 40 years of cotton yield data exhibited two patterns: the shift from low yield pattern to the high yield pattern occurred around 1980 (Fig. 3). These shifts were precisely identified through three clusters. The average yield levels of these clusters were 55.15 kg/ha (Cluster 1 : 20 years), 165.20 kg/ha (Cluster 2 : 5 years) and 247.37 kg/ha (Cluster 3 : 15 years), (Table 5).

It is interesting to observe that the yields of all the three clusters obtained had relatively strong association with the years of normal rainfall pattern. The association ranged from 80 per cent (Cluster 2 yields) to about 87 per cent (Cluster 3 yields). The normal rainfall pattern was thus responsive for attaining the average yield levels of 54.41 kg/ha (from low yield years) to 250.07 kg/ha (high yield years). The association of crop yields with the abnormal rainfall patterns was either not existing or of relatively low order, ranging from 5 per cent to 20 per cent (Table 5).

4. Conclusions

The non-parametric approach based on the two way classification duly accounts for the combined effect of the rainfall pattern on the levels of crop yields and also enables to quantify the yield response corresponding to the different rainfall patterns that are likely to occur in the crop season. The approach based on Cluster analysis precisely identifies the different rainfall patterns, which are 'likely' to occur during the crop season. Further, the approach also isolates the level of crop yields that can be attributed to 'assignable' factors.

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