Rainfall, Acreage and Wheat Production in West Pakistan: A Statistical Analysis

by

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INTRODUCTION

Reliable knowledge about the factors causing variability in agricultural production is indispensible in the process of planning for economic development in Pakistan. This holds particularly for the major foodgrains, wheat and rice, which account for at least 40 per cent of gross national product. If we can determine the extent to which factors beyond our control (*e.g.*, weather) cause year-to-year fluctuations in output, we should be able to estimate more accurately the increases in output attributable to our own development efforts (*e.g.*, increased use of fertilizers, pest-control measures, *etc.*).

In the case of wheat production in West Pakistan, our immediate concern is to study factors that determine acreage and production in any cropping season. With reliable indicators of the probable wheat production earlier than the month of September when official estimates are made available, government policy-measures with respect to foodgrain import and storage could be taken to ensure a more stable domestic supply and price level.

There is a general feeling—perhaps justified— that a "good rainfall year" means a good wheat-crop. Statistically, however, this relationship is by no means obvious on such an aggregative level. In fact, the simple correlation coefficient between total rainfall in a year and wheat production in West Pakistan is close to zero.

The purpose of this paper is to make a somewhat more refined analysis of this problem so as to work out concepts of rainfall and production that can be useful for predicting total output. In particular, we shall try to estimate production on the basis of not only the quantity but also the distribution of rainfall during the presowing, sowing and growing periods of wheat. We shall limit ourselves in this paper to three districts in the northern Punjab, namely Rawalpindi, Jhelum and Campbellpur where more than 97 per cent of wheat acreage is dependent on rainfall. These districts account for 8 per cent of total wheat grown in West Pakistan and 34 per cent of total wheat grown on unirrigated land.

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The data underlying our analysis are for a 30-year period, 1931/32 to 1960/61, for which both rainfall and production statistics were available.

II. DESCRIPTION AND USE OF DATA

Rainfall

The meteorological department of undivided India published monthly rainfall figures by districts. These are simple averages of the actual rainfall measured in one or more meteorological stations in each district[1]. After Partition, this work was continued by the meteorological department of Pakistan. The data is complete for all years from 1931 to 1961 and is highly reliable.

The recorded average rainfall cannot be used directly for analytical purposes as a portion of it is lost through run-off, drainage and evaporation. Sometimes, the rainfall in a month exceeds the waterholding capacity of the rootzones of crops, and to the extent that it does, it is of no use to crops. An allowance for these factors must, therefore, be made to get a rainfall series that represents its useful contribution for crop production. This adjustment is particularly important since the relationship between rainfall and wheat production is of a technical nature: additional rainfall results in increased production without requiring any extra effort on the part of farmers.

The method adopted for this adjustment follows that used by the U.S. Bureau of Reclamation[2]. It consists essentially of applying a declining percentage for each additional inch of rain in each month. Of the first inch, 95 per cent is taken as effective rainfall; for the rainfall exceeding six inches, only five per cent is considered as useful. The schedule of the maximum-effective rainfall is given in Appendix Table A-1. The rainfall data thus adjusted is called "maximum-effective rainfall".

The relationship between total recorded rainfall and the maximum-effective rainfall during the period under consideration in three districts is shown in Appendix Tables A-2, A-3, and A-4 and is summarized in Table I.

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1 District Campbellpur has stations at Campbellpur, Talagang, Fatehjang, Hasan Abdal, Pindigheb, Lawa and Taman. District Rawalpindi has stations at Rawalpindi, Gujar Khan, Kahuta and Murree. District Jhelum has stations at Jhelum, Chakwal and Pind Dadan Khan.

2 Tipton and Kalmbach, Inc., *Report on Irrigation Water Requirements for West Pakistan.* (Denver, Colorado: Tipton and Kalmbach, Inc., for the Pakistan Delegation, 1957, unpublished), p. 12.

For another method, *see*, Harold H. Mann, *Rainfall and Famine: A Study of Rainfall in the Bombay Deccan, 1865--1938.* (Bombay: Indian Society of Agricultural Economics, 1955), p. 8. Mann uses daily rainfall figures and has different rules to exclude the portion of rainfall which is not of any use to the crop. We could not use this method as no detailed data were available.

It is clear from Table I that there are considerable interdistrict differences in the rainfall pattern. Compared with Jhelum and Campbellpur, Rawalpindi has a less erratic rainy season and receives a larger quantity of rainfall. Jhelum and Campbellpur are similar in that both districts have relatively more variable and lower average-rainfall. The table also shows considerable interdistrict differences between actual and effective rainfall, which makes it essential to adjust crude rainfall before analysis of production. As one would expect, the ratios of mean effective rainfall to mean total rainfall show striking differences between districts. This ratio is highest for Campbellpur which has the lowest mean rainfall, and lowest for Rawalpindi which has the highest mean rainfall.

TABLE I

VARIABILITY IN RAINFALL DURING JULY TO MARCH

(1931/32 to 1960/61)

	Rawalpindi	Jhelum	Campbellpur
Total Rainfall			
Mean rainfall (inches)	34.34	18.88	18.34
Standard deviation (inches)	6.96	5.27	4.37
Coefficient of variation (per cent)	20.27	26.50	23.88
Maximum-Effective Rainfall			
Mean rainfall (inches)	20.24	14.60	13.94
Standard deviation (inches)	2.66	2.57	2.43
Coefficient of variation (per cent)	13.14	17.43	17.60
Mean Effective Rainfall as per cent of Mean Total Rainfall	58.94	73.44	76.01

Source: Appendix Tables A-2, A-3 and A-4.

Acreage and Production

The sources of acreage and production data are the *Season and Crop Reports for Punjab*, published since the turn of the century by the Director of Land Records, Punjab and since 1955 by the Director of Land Records, West Pakistan, Northern Zone, Lahore. This data has been compiled in a statistical publication of the Institute of Development Economics[3].

[3] A. Rab, *Acreage, Production and Prices of Major Agricultural Crops of West Pakistan (Punjab) ; 1931-59*. (Karachi: Institute of Development Economics, 1961).

While the data for rainfall are accurate and the only problem is estimating the portion which is of use to the crop, the same cannot be said for the crop data. Walter Falcon[4] has shown that official acreage estimates in West Pakistan are reasonably accurate so that they can be used without too much reservation. Production figures, on the other hand, are subject to large errors. A recent comparison of official estimates with estimates based on crop-cutting experiments for wheat in West Pakistan has shown that the official figures differ significantly from those derived from the crop-cutting surveys. These comparisons indicate that the official production estimates have underestimated total wheat output on the average by about 21 per cent and that there has been a tendency for official estimates to overestimate the actual output in poor seasons and to underestimate it in good seasons[5]. The deficiencies in crop-production data result from the procedures being used for estimating crop production. Production is the multiplicand of sown area, normal yield and a seasonal condition factor. Normal yield is, in fact, a five-year moving average of results obtained from crop-cutting surveys. This tends to dampen the amplitude of the deviations from the true average. The seasonal condition factor is subjectively estimated by the local revenue officer and is, therefore, statistically unreliable.

From the point of view of our analysis, the tendency for official figures to reduce the amplitude of the variability is a more serious problem than the error in the absolute level of output. Unfortunately, there is no basis on which the official figures can be corrected for the errors present in them; and the estimates of wheat output from crop-cutting surveys are too few to be used in a time-series model.

III. IRRIGATION AND VARIABILITY IN WHEAT PRODUCTION

Wheat is the staple food in West Pakistan. More than 95 per cent of the country's wheat production is being produced in West Pakistan. About 30 per cent of the cultivated area of West Pakistan and 60 per cent of the major food-crop area is under wheat. About 23 per cent of the wheat production in West Pakistan is in areas where rain is the only source of moisture for the plants.

Irrigation gives the farmer some degree of control over his crops since his dependence on rainfall is considerably reduced. Statistically, this is reflected in Table II and Figure I which show the variability in wheat production in the former Punjab area on irrigated and nonirrigated lands[6].

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4 Walter Falcon, "Reliability of Punjab Agricultural Data" in A. Rab, *op. cit.*, p. 3.

5 C. Beringer, *The Use of Agricultural Surplus Commodities for Economic Development in Pakistan.* (Karachi: Institute of Development Economics, December 1963).

6 We have restricted our observations to the former Punjab area as no breakdown into irrigated and nonirrigated wheat production was available for the rest of West Pakistan.

FIGURE 1

VARIATION IN INDICES OF WHEAT PRODUCTION (PUNJAB, WEST PAK.)

IRRIGATED AND NONIRRIGATED LANDS

(1947/48 = 100)

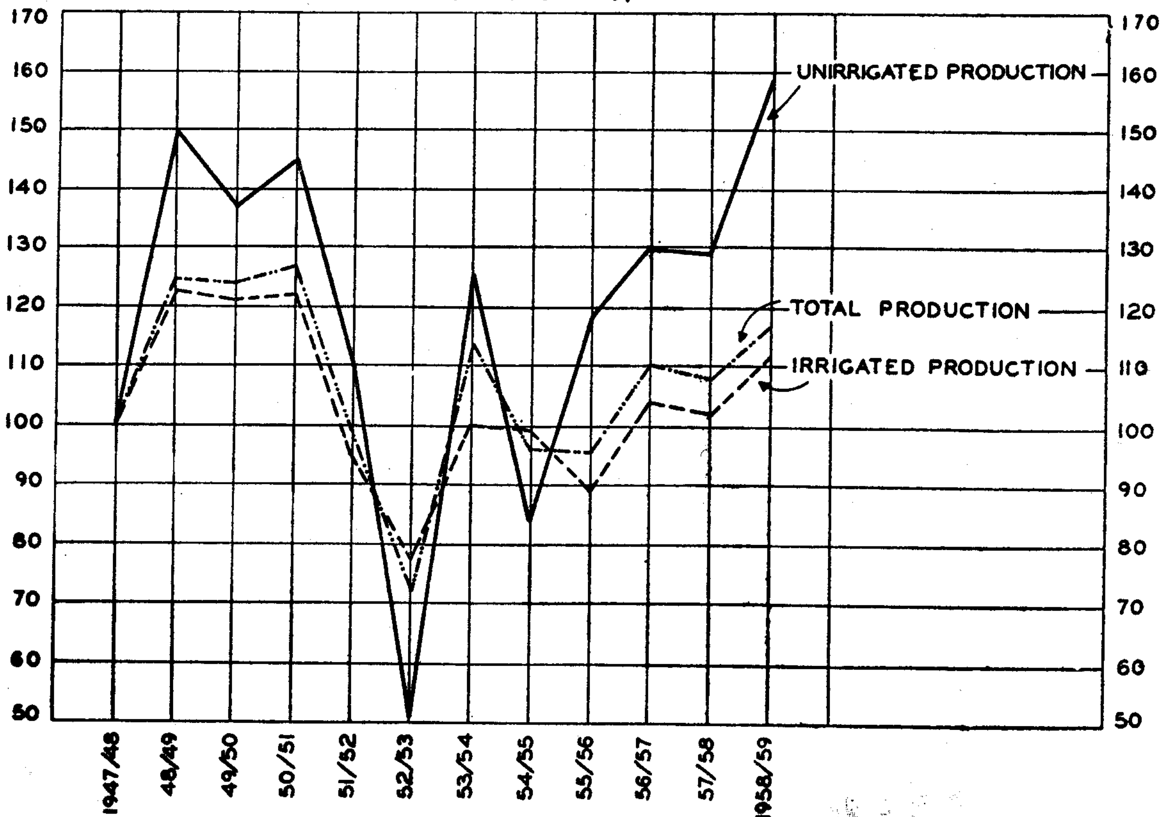


TABLE II

VARIABILITY IN WHEAT PRODUCTION IN PUNJAB: IRRIGATED AND NONIRRIGATED AREAS

(1947/48 to 1958/59)

	Mean production	Standard deviation	Coefficient of variation
	(.................000 tons	..................)	(per cent)
Irrigated wheat	1942.8	236.9	12.2
Nonirrigated wheat	597.4	143.9	24.1
Total wheat	2540.2	306.5	16.0

It is apparent that the variability of nonirrigated wheat is twice as high as that of irrigated wheat. Although unirrigated wheat accounts for only 25 per cent of the total production, a substantial part of the variability in total wheat output is accounted for by the variation in *barani*[7] wheat production. Knowledge of factors affecting variation in production on *barani* land is, therefore, likely to be useful in planning.

IV. VARIABILITY IN ACREAGE AND PRODUCTION BY DISTRICTS

Although the districts chosen for analysis account only for 34 per cent of the wheat production on unirrigated land in West Pakistan, their behaviour can be taken as an indicator for other areas growing *barani* wheat.

During the period from 1931/32 to 1960/61, Rawalpindi, Jhelum and Campbellpur Districts showed wide fluctuations in wheat production. The variation in acreage is considerable but variation in production is even more marked. The annual data for acreage and production are shown in Appendix Tables A-5 and A-6. Table III and Figures II and III show the variability in acreage and production.

Rawalpindi has relatively smaller variation in wheat production than the districts Jhelum and Campbellpur, but even so it is much larger than the variability in irrigated wheat production. This interdistrict difference in the variability in acreage and production corresponds to the variation in the rainfall in the three districts. Jhelum and Campbellpur are characterized by high variability in rainfall, acreage and production while Rawalpindi exhibits relatively less variation in these three magnitudes. The ralationship suggested above is,

7 *Barani* is derived from the Persian word *Baran* which means 'rain'. In the agricultural statistics of West Pakistan *Barani* refers to the unirrigated areas that depend on rainfall for cultivation.

FIGURE II

WHEAT ACREAGE IN RAWALPINDI, JHELUM AND CAMPBELLPUR DISTRICTS

(1931/32 TO 1960/61)

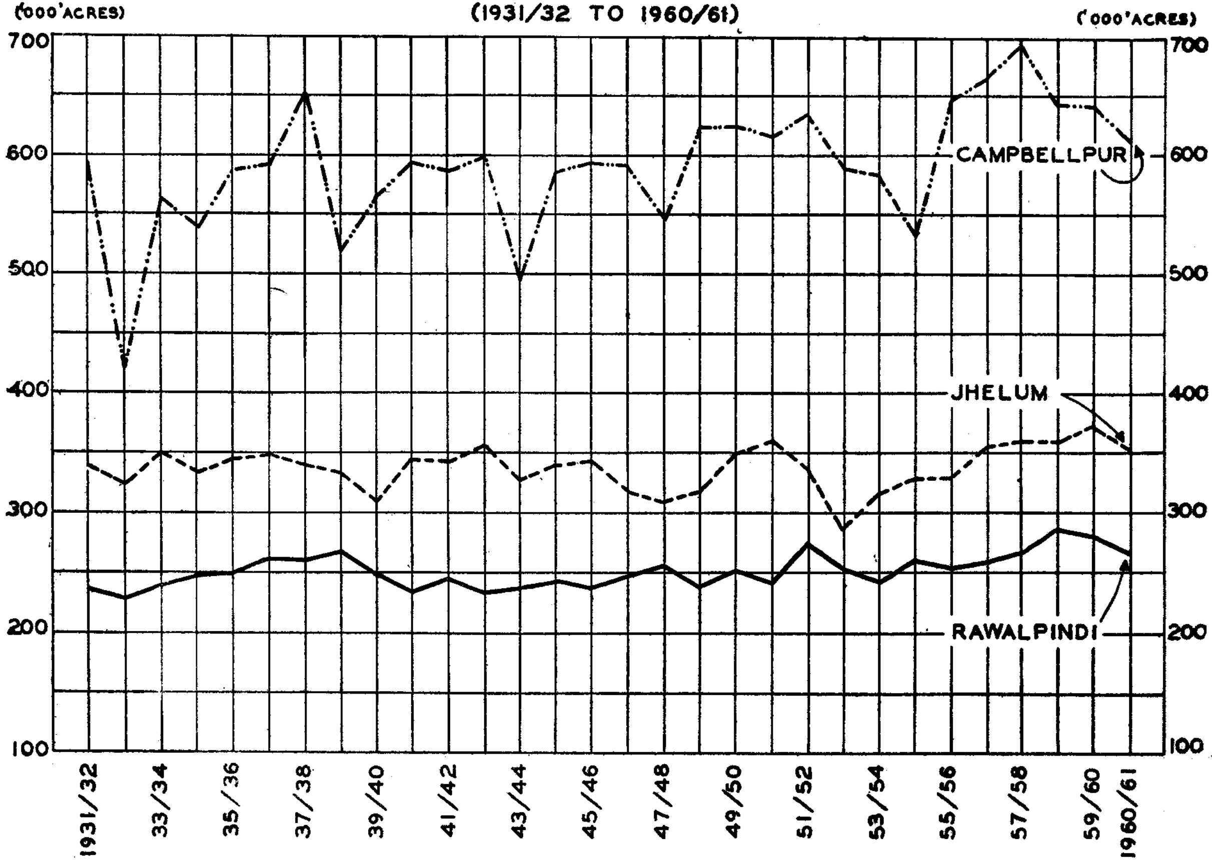
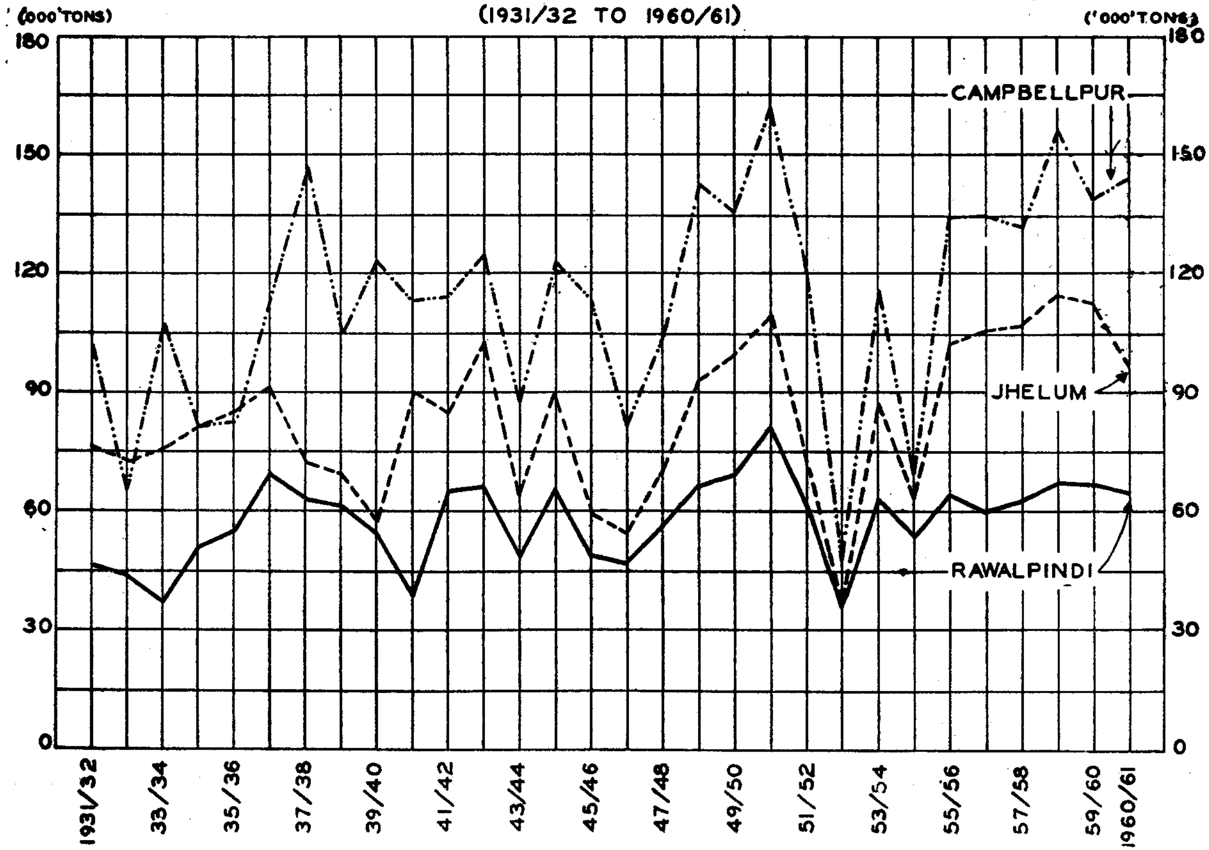


FIGURE III

WHEAT PRODUCTION IN RAWALPINDI, JHELUM AND CAMPBELLPUR DISTRICTS

(1931/32 TO 1960/61)



however, based on a high level of aggregation and needs a careful analysis for its substantiation.

TABLE III

VARIABILITY IN ACREAGE AND PRODUCTION IN THREE DISTRICTS

(1931/32 to 1960/61)

Districts	Acreage		Production	
	Mean (thousand acre)	Coefficient of variation (per cent)	Mean (thousand tons)	Coefficient of variation (per cent)
Rawalpindi	251.32	5.47	57.4	18.20
Jhelum	337.30	6.37	82.3	22.60
Campbellpur	588.10	9.17	112.8	24.90

Source : Appendix Tables A-5 and A-6.

V. FACTORS CAUSING VARIATION IN WHEAT ACREAGE

It is customary to use the relative prices of competing crops as an explanatory variable in supply models of agricultural commodities. A positive price-response is considered to be consistent with economic rationality on the part of farmers. Consequently, the relative prices of different farm products can be relied upon to explain the process of allocation of crop land among the competing crops. Recently, however, there has been a growing awareness of factors that may limit the price responsiveness of the farmers in a developing country[8]. The two major factors cited are the desire to grow a sufficient quantity of foodgrains for home consumption and the limited choice between alternative crops due to climatic conditions in a particular region.

These same considerations may justify our neglect, in the present analysis, of price as a determining variable in the explanation of variations in wheat acreage in the *barani* areas of West Pakistan. Because of limitations on water availability, there are very few substitute crops available to the farmers of the region. None of the cash crops that are important in irrigated areas can be

[8] For example, *see*, W.P. Falcon, *Farmer Response to Price in An Underdeveloped Area—A Case Study of West Pakistan*. Unpublished Ph. D. Thesis, Harvard University, 1962.

grown on *barani* land[9]. Gram and barley are the only alternative crops to wheat. However, these crops have less food value per acre than wheat, and are, therefore, not considered important by farmers who aim to be self-sufficient in food production.

Soil moisture is an important requisite for preparing any piece of land for sowing and for proper germination of any seed. The only source of such moisture in these districts is the rainfall. It is, therefore, presumed that acreage of wheat is a positive function of rainfall during the presowing (July to September) and sowing (October to December) periods. The concept of rainfall implied in the hypotheses is the actual rainfall and not the maximum-effective rainfall that we shall use in relating rainfall to production in subsequent section. The reason for using the actual rainfall in the acreage function is that a farmer's decision on how much acreage he should sow in any season is not based on the exact calculation of the usable portion of the rain received in any season but somehow on the basis of how good the rainy season has been in the immediate past and how good the season will be when the wheat seed has to germinate. Rainfall during the presowing period is used in the acreage function for two reasons. *First,* it is required for the preparation of land for ultimate sowing. *Second,* the soil moisture from the presowing period can be preserved to supplement the soil moisture available from the sowing-period rain.

To provide some information on the relationship between wheat acreage and rainfall over the period from 1931/32 to 1960/61, three regression equations have been fitted to the available data of the three districts under study. The results are presented in Table IV below.

9 Oilseeds are the only cash crop in the districts under study. The percentage distribution of *rabi* crops is shown below:

PRODUCTION OF *RABI* CROPS BY DISTRICT
(1955/56 TO 1958/59 AVERAGE)

Crops	*Rawalpindi*	*Jhelum*	*Campbellpur*
Wheat	89.3	84.7	82.0
Barley	1.9	0.8	2.5
Gram	4.3	8.9	9.5
Oilseeds	4.5	5.6	6.0
Total *Rabi*:	100.0	100.0	100.0

Source: *Statistics of West Pakistan: Agricultural Data by Division and District, 1947-48 through 1958-59.* (Lahore: Bureau of Statistics, Planning and Development Department, Government of West Pakistan).

TABLE IV

ESTIMATED RELATIONSHIPS BETWEEN ACREAGE AND RAINFALL IN THE THREE DISTRICTS; 1931/32 to 1960/61

Districts	Estimated equation	Degree of freedom	Coefficient of determination (R^2)
Rawalpindi	$Y=247.587 - 0.251X_1 + 3.374X_2$ (.0547) (.1433)	27	.4507
Jhelum	$Y=314.207 + 1.241X_1 + 5.003X_2$ (.0711) (.4212)	27	.2355
Campbellpur	$Y=551.380 + 0.871X_1 + 18.916X_2$ (.3850) (.9764)	27	.3144

Y = Wheat acreage in thousand acres.
X_1 = Actual rainfall in inches during the pre-sowing period.
X_2 = Actual rainfall in inches during the sowing period.

Note: Figures in parantheses show the standard errors of regression coefficients.

The relationship between wheat acreage and rainfall during presowing and sowing periods can be easily seen from the regression equations. An increase in rainfall by one inch during the sowing period leads to an increase in wheat acreage by 3774, 5003 and 18916 acres respectively in Rawalpindi, Jhelum and Campbellpur Districts. One additional inch of rain during the presowing period increases wheat acreage by 1241 and 871 acres respectively in Jhelum and Campbellpur, but it reduces the wheat acreage in Rawalpindi by 251 acres. The different behaviour in Rawalpindi may be explained by the fact that the presowing period for wheat is also the sowing and growing period for the summer crops which generally require heavy rainfall for proper growth and maturity. The average rainfall in districts Jhelum and Campbellpur during July to September is low compared with Rawalpindi. In the low-rainfall districts, summer crops are not grown on a large scale and the land is earmarked for wheat. However, in Rawalpindi the rainfall conditions permit the growing of larger summer crops. The ratios of average area under summer crops to the average total cropped area for the period 1955/56 to 1958/59 were 20 per cent, 26 per cent and 46 per cent respectively in Campbellpur, Jhelum and Rawalpindi. In good rainfall years, the land is diverted more towards the summer crops, thereby reducing the land available for the wheat crop.

The higher value of R^2 in Rawalpindi requires some comment. Rawalpindi has relatively less erratic rainfall than Jhelum or Campbellpur, which means that actual rainfall in the sowing period approximates more closely the farmers' expectation in Rawalpindi than in Jhelum and Campbellpur. Total variance in acreage is also less in Rawalpindi campared with Jhelum and Campbellpur.

The coefficients of determination (R^2) are not very high. About 45 per cent of the variation in acreage is explained by variations in rainfall in Rawalpindi, while the variation in acreage explained in the other two districts is even lower. Factors other than rainfall are extremely important in the determination of wheat acreage. However, the regression coefficients are significant at the 99-per-cent confidence level in all districts.

Having discussed the relationship between rainfall and acreage in absolute terms, we pass on to the estimation and interpretation of the acreage elasticities with respect to rainfall in different periods. The use of elasticities eliminates the problem of differences in absolute size of districts and allows us to isolate the relative effects of rainfall on acreage in each district. Since the elasticity changes with the size of the independent variable because of the particular form chosen for the regression equation, we shall measure acreage elasticity in each district at the respective mean levels of rainfall in both periods. These elasticities are shown in Table V.

TABLE V

ACREAGE ELASTICITIES WITH RESPECT TO RAINFALL AT MEAN LEVELS OF RAINFALL IN EACH PERIOD

Districts	Presowing period		Sowing period	
	Mean rainfall $\bar{X}_1$ (inches)	Acreage elasticity	Mean rainfall $\bar{X}_2$ (inches)	Acreage elasticity
Rawalpindi	23.29	—.02	2.54	.04
Jhelum	14.06	.05	1.13	.02
Campbellpur	12.20	.02	1.38	.04

For Rawalpindi, an elasticity of —0·02 would mean that holding rainfall during the sowing period constant at its mean level of 2.54 inches, one-per-cent increase in rain during the presowing period will decrease the acreage by 0.02 per cent of the average acreage. Similarly, holding rainfall constant at 23.29 inches during the presowing period, a one-per-cent increase in rainfall during the sowing period will lead to an increase in acreage by 0·04 per cent of the average acreage. Other elasticities can be read in a similar way. Since the intercept in the three regression equations is positive for all observed values of X_1 and X_2, the acreage elasticity with respect to rainfall in each period will be an increasing function of the amount of rainfall in each period. However, we should not expect much from this property of the acreage elasticities.

The interdistrict differences in the acreage elasticities are quite revealing. In Rawalpindi and Campbellpur, acreage is relatively more elastic to the sowing-period rain and less elastic to the presowing-period rain while in Jhelum the acreage is relatively more elastic to the presowing-period rain and less elastic to the sowing-period rain. The different districtwise behaviour may be explained by a simple hypothesis. Assuming that soil-moisture requirements for the germination of wheat plant are the same in the three districts, districts which receive low average-rainfall during the sowing period have to depend much more on rains in the presowing period than those districts that receive relatively larger amounts of rain during the sowing season. In our case, the average rainfall in Jhelum is 18 per cent less than the rainfall in Campbellpur and 56 per cent less than the rainfall in Rawalpindi. It is, therefore, understandable that farmers in Jhelum have to be more concerned with the effective utilization of rain received during the presowing period than their counterparts in Campbellpur or Rawalpindi who, in turn, respond more (in acreage) to increases or decreases in the sowing-period rain.

VI. FACTORS AFFECTING VARIATION IN PRODUCTION

Two hypotheses are advanced to explain the variation in the levels of wheat production in any cropping season. *First*, we presume that wheat production is a positive function of rainfall in the presowing, sowing and growing periods. For explaining the interrelationship between rainfall in any period and wheat production, it is convenient to think of production as the multiplicand of the area under the crop and the yield per acre. Presowing- and sowing-period rains affect production through changes in acreage and the yield while growing-season rain influences production only through its effect on the yield per acre. *Secondly*, production is influenced by the pattern of rainfall in different periods. Low rainfall in each of the three periods is likely to give a poor crop while good rainfall in all periods will give a bumper crop. Good early rains and low follow-up rains may give high acreage and low yield resulting in average production. Poor early rains combined with good follow-up rains may give low acreage but good yields again resulting in average production. These are the hypotheses that we test in this section.

The results of fitting linear-regression equations to the production and rainfall data for the three districts for the period 1931/32 to 1960/61 are given in Table VI. However, it should be remembered that the production figures may deviate from their true levels by as much as plus or minus 30 per cent[10]. All the regression coefficients are significantly different from zero at 99-per-cent confidence level. All the signs of the regression coefficients are consistent with the

10 *See*, p. 569.

TABLE VI

ESTIMATED RELATIONSHIPS BETWEEN PRODUCTION AND RAINFALL IN THE THREE DISTRICTS: 1931/32 to 1960/61

Districts	Estimated equation				Degree of freedom	Coefficient of determination (R^2)
Rawalpindi	$Y=29.042$	$+.224X_1$ (.0156)	$+.757X_2$ (.0408)	$+2.648X_3$ (.1640)	26	.3261
Jhelum	$Y=34.005$	$+1.835X_1$ (.319)	$+6.526X_2$ (.391)	$+3.483X_3$ (.299)	26	.4664
Campbellpur	$Y=66.581$	$+2.110X_1$ (.215)	$+6.810X_2$ (.545)	$+2.692X_3$ (.507)	26	.2512

Y = Wheat production in thousand tons.
X_1 = Actual rainfall in inches during July to September.
X_2 = Actual rainfall in inches during October to December.
X_3 = Maximum-effective rainfall during January to March.

Note: Figures in parantheses show standard errors of regression coefficients.

hypothesis of a positive relationship between rainfall and production. This is true even in the case of presowing-period rainfall in Rawalpindi where an increase of one inch of rain increases wheat production by 244 tons. The explanation for the difference in the effect of presowing rainfall on acreage and production is that although one inch of additional rainfall during July to September decreases wheat acreage by 251 acres, its beneficial effect on the yield is apparently so strong that wheat production is increased by 224 tons despite reduced acreage.

The production elasticities with respect to rainfall in different periods are presented in Table VII. These are computed from the regression equations listed in Table VI above.

TABLE VII

PRODUCTION ELASTICITIES WITH RESPECT TO RAINFALL AT MEAN LEVELS OF RAINFALL

Districts	Presowing period		Sowing period		Growing period	
	Mean rainfall $\bar{X}_1$ (inches)	Production elasticity	Mean rainfall $\bar{X}_2$ (inches)	Production elasticity	Mean rainfall $\bar{X}_3$ (inches)	Production elasticity
Rawalpindi	23.29	0.09	2.54	0.08	7.03	0.32
Jhelum	14.06	0.31	1.13	0.09	4.33	0.18
Campbellpur	12.20	0.23	1.38	0.08	4.12	0.10

The production elasticities with respect to rainfall during the sowing period are of the same magnitude in all the three districts. However, there are marked interdistrict differences regarding the elasticities with respect to the presowing- and growing-period rainfall. Production is relatively more elastic with respect to X_3 in Rawalpindi than in Jhelum or Campbellpur, whereas it is more elastic with respect to X_1 in Campbellpur and Jhelum than in Rawalpindi. The difference among districts can be explained in terms of the relative importance of different periods' rainfall as a source for the soil moisture required by the wheat plant. In Rawalpindi, the average rainfall during January to March is higher than the other two districts; and, consequently the need to preserve soil moisture from the early two periods is less pressing in Rawalpindi than Jhelum and Campbellpur. Since production will tend to be more sensitive to rainfall in that period whose rainfall is more crucial for the determination of production levels, it is understandable that the production elasticity with respect to growing-period rainfall is relatively higher in Rawalpindi and the elasticity with respect to presowing period relatively higher in Jhelum and Campbellpur.

Distribution of Rainfall and Wheat Production

So far we have been concerned with the effect on production of changes in the quantity of rainfall in any one period holding rainfall levels constant in the other two periods. Now we turn to our second hypothesis concerning the relationship between different patterns of rainfall distribution in any season and the wheat production. The cropping season, July to March, is divided into two periods: July to December (Period 1) and January to March (Period 2). The years from 1931/32 to 1960/61 are grouped into four categories according to different annual patterns of rainfall. Pattern I is characterized by those years when rainfall was below average in each of the two periods; Pattern II, by those years when rainfall was below average in Period 1 but above average in Period 2; Pattern III, by those years when rainfall was above average in Period 1 but below average in Period. 2; and Pattern IV, by those years when rainfall was above average in both periods. The average production per year in each group is computed. The results appear in Table VIII[11].

[11] The number of years in each rainfall pattern in the three districts is shown below:

DISTRIBUTION OF YEARS ACCORDING TO DIFFERENT RAINFALL PATTERNS

Rainfall pattern	*Rawalpindi*	*Jhelum*	*Campbellpur*
I.	8	8	7
II.	11	11	10
III.	6	6	7
IV.	5	5	6
Total No. of years	30	30	30

Source: Appendix Tables A-2, A-3 and A-4.

TABLE VIII

SEASONAL DISTRIBUTION OF RAINFALL AND WHEAT PRODUCTION (1931/32 to 1960/61)

	Rainfall pattern		Rawalpindi	Jhelum	Campbellpur
			(................	000 tons	................)
	July to December	*January to March*			
I.	Below average	above average	50.27	69.06	94.75
II.	Below average	above average	57.71	78.17	108.72
III.	Above average	below average	53.85	89.82	119.14
IV.	Above average	below average	64.00	95.86	148.63

It is clear from Table VIII that the distribution of rainfall in the two periods has a clear-cut relationship to the level of production. In all districts the figures support our hypothesis: Patterns I and IV are the extreme cases of poor and bumper crops while the other two patterns are the intermediate, average cases of wheat production. The fact that presowing- and sowing-period rains are more crucial for wheat production in Jhelum and Campbellpur and that the growing-period rains are more important in Rawalpindi is also borne out from the above table. Poor early rains followed by good growing-period rains (Pattern II) results in more production in Rawalpindi than does a pattern of good early rains and poor follow-up rains (Pattern III). On the other hand, Pattern III gives higher production in Jhelum andCampbellpur than does Pattern II, showing that wheat production is hit harder when the rains are low in Period 1 than when the rains are low in Period 2 in Jhelum and Cambpellpur.

Production as explained by Acreage and Rainfall

The regression equations of the preceding sections have established significant relationships between acreage, rainfall and wheat production in the *barani* districts. One of the purposes of this study, however, is to see if these relationships can be used as the basis for improved estimates of wheat production prior to September when official crop-estimates become available. Since acreage figures are known in January of each year, short-run forecast can be based on the estimated relationship between production, acreage and rainfall during January to March. In Table IX, regression equations linking these three variables are presented for the three districts under consideration.

The regression coefficients are all significantly different from zero at 99-per-cent confidence level. The coefficients of determination are higher in each district than in the case when production was explained on the basis of rainfall in different periods. The variation explained in production is 59 per cent in

TABLE IX

ESTIMATED RELATIONSHIPS BETWEEN PRODUCTION, ACREAGE AND RAINFALL : 1931/32 to 1960/61

Districts	Estimated equation	Degree of freedom	Coefficient of determination
Rawalpindi	$Y = -30.731 + \underset{(.0286)}{.293X_1} + \underset{(.1591)}{2.064X_2}$	27	.3958
Jhelum	$Y = -188.820 + \underset{(.0232)}{.784X_1} + \underset{(.2440)}{1.565X_2}$	27	.5945
Campbellpur	$Y = -139.525 + \underset{(.0132)}{.405X_1} + \underset{(.3633)}{3.427X_2}$	27	.5913

Y = Wheat production in thousand tons.
X_1 = Wheat acreage in thousand acres.
X_2 = Maximum-effective rainfall during January to March in inches.

Note: Figures in parantheses show standard error of regression coefficients.

districts Jhelum and Campbellpur and about 40 per cent in Rawalpindi whereas the variation explained in production by rainfall in three periods was only 32 per cent, 25 per cent and 46 per cent respectively in Rawalpindi, Jhelum and Campbellpur. It is not difficult to explain these results, particularly in Jhelum and Campbellpur. The earlier analysis showed that both production and acreage are related significantly to the rainfall of the presowing and sowing periods and that rainfall affects production partly through acreage changes. The substitution of acreage for early-period rainfall in the production function reduces the error in the independent variable and so explains a larger amount of variation in the dependent variable, *i.e.*, production. Since early rains are more crucial for wheat production in Jhelum and Campbellpur, the R^2s in their case improve to a much larger extent than in Rawalpindi where early rains are not that crucial. To eliminate the effect of absolute differences in the geographic size of the districts, the production elasticities with respect to acreage and rainfall have been computed and are shown in Table X.

TABLE X

PRODUCTION ELASTICITIES WITH RESPECT TO ACREAGE AND RAINFALL AT MEAN LEVELS OF ACREAGE AND RAINFALL : 1931/32 to 1960/61

Districts	Acreage		Growing-period rainfall	
	Mean acreage $\bar{X}_1$ (thousand acres)	Production elasticity	Mean rainfall $\bar{X}_2$ (inches)	Production elasticity
Rawalpindi	251.321	1.28	7.03	0.25
Jhelum	337.300	3.21	4.33	0.08
Campbellpur	582.106	2.11	4.12	0.12

The production elasticity with respect to growing-period rainfall is higher in Rawalpindi than in Jhelum or Campbellpur. This is presumably because of the relative importance of January-to-March rainfall in Rawalpindi versus the other two districts where sowing and presowing rainfall is more crucial to wheat production. The production elasticity with respect to acreage has the reverse pattern in the three districts, being higher in Jhelum and Campbellpur than in Rawalpindi. One reason for this different interdistrict behaviour has already been mentioned that presowing and sowing rainfall is relatively more crucial for wheat production in Jhelum and Campbellpur. However, another factor appears to be that the high average rainfall in Rawalpindi has helped farmers to bring the marginal land under cultivation and any increase in rainfall now extends cultivation to less fertile land. In the other two districts where the general deficiency in rainfall has not permitted cultivation to extend to lands that are really marginal, an increase in rainfall extends cultivation to relatively more fertile lands. Hence, there is a relatively greater change in wheat production. The data on the extent of land utilization in the three districts supports this explanation. For example, the current fallow was 2.5 per cent of the total area in Rawalpindi while this percentage was 4.33 and 5.27 respectively in Jhelum and Campbellpur suggesting that cultivation is nearer the margin in Rawalpindi than in the other two districts.

We have so far studied the relationship between production and two determinants: acreage and rainfall. An alternative way of looking at this relationship would be the regression of rainfall during January to March on the *yield per acre*. For this purpose, regression equations for each district were fitted between the yield and rainfall data for the period from 1931/32 to 1960/61. The estimated relationships are shown in Table XI. The regression coefficients are all significant at 99-per-cent confidence level but the coefficients of determination are very low.

TABLE XI

ESTIMATED RELATIONSHIPS BETWEEN YIELD PER ACRE AND RAINFALL DURING JANUARY TO MARCH FOR THREE DISTRICTS (1931/32 to 1960/61)

District	Estimated equation	Degree of freedom	Coefficients of determination (R^2)
Rawalpindi	$Y = .168 + 0.0085X$ (.0003)	28	0.13
Jhelum	$Y = .220 + 0.0052X$ (.0005)	28	0.33
Campbellpur	$Y = .172 + 0.0044X$ (.0001)	28	0.12

Y = Yield per acre in thousand tons.
X = Maximum-effective rainfall in inches during January to March.

Note: Figures in parantheses show the standard error of the regression coefficients.

Our study covered the period from 1931/32 to 1960/61. The results, however, should be useful for predicting wheat output in any other year provided the acreage and rainfall lie within the range of the observed values in the fitted relationships. There are three alternative methods for predicting wheat output in any year. *First,* the set of equations relating production to acreage and rainfall during January to March could be used since acreage and rainfall are known by April every year[12]. We shall denote this as "Method1'. *Second,* the yield per acre could be predicted every year with the help of the set of equations relating the yield to rainfall during January to March. By multiplying the yield thus predicted with wheat acreage we get an estimate of wheat production. This method is denoted as 'Method 2'. *Third,* the simple model of multiplying wheat acreage in any year with the long-run average yield in each district would give us another estimate of total wheat production[13]. We call this simple model as 'Method 3'. The results are presented in Table XII.

The actual production in the two years for the three districts lies less than 2 standard error of estimate from the estimated production by Methods 1 and 2. However, the percentage difference between any of the three estimates and the actual production are quite high. Method 1 is relatively better for predictions than the other two methods. In five out of six predictions, the difference between the actual and estimated production is less than 7 per cent while for the other two methods only 3 out of 6 predictions lie less than 7 per cent away from the actual production.

The prediction of wheat output on the basis of the studied relationship between production, acreage and rainfall, though not a correct estimate of production in any year, is useful as it approximates the actual production more

[12] The acreage and the maximum-effective rainfall during January to March for 1961/62 and 1962/63 for the three districts is shown below:

WHEAT ACREAGE AND MAXIMUM-EFFECTIVE RAINFALL IN THREE DISTRICTS: 1961/62 and 1962/63

District	1961/1962		1962/1963	
	Acreage (thousand acres)	Rainfall (inches)	Acreage (thousand acres)	Rainfall (inches)
Rawalpindi	339.2	5.68	290.1	5.22
Jhelum	363.1	3.56	355.6	2.74
Campbellpur	637.7	3.00	582.9	2.99

[13] The long-run yield per acre of wheat is taken to be the average yield realized during the period from 1931/32 to 1960/61. The yields for districts Rawalpindi, Jhelum and Campbellpur were 0.228, 0.242 and 0.180 tons per acre respectively.

TABLE XII

ACTUAL AND ESTIMATED WHEAT PRODUCTION: 1961/62 and 1962/63

Wheat production \ Districts		1961/1962			1962/1963		
		Rawalpindi	Jhelum	Campbellpur	Rawalpindi	Jhelum	Campbellpur
Actual production (thousand tons)		85.400	84.900	139.200	46.700	80.100	111.700
Estimated production as per cent of actual production	Method 1	— 5.88	+ 6.87	— 7.31	— 0.53	+17.68	— 4.39
	Method 2	—14.21	— 8.94	—15.25	— 4.94	+ 3.88	— 3.46
	Method 3	— 9.44	— 7.41	—17.70	— 2.23	+ 7.43	— 6.07

closely than other simple methods of estimation. However, further research work is needed to take account of other determinants of wheat production, as the rainfall and acreage could explain only 60 per cent of the variance in wheat production. Such broad models would presumably be more accurate in prediction.

VII. SUMMARY AND CONCLUSIONS

The main conclusions of the study have been listed at each stage of the analysis. It is, however, useful to restate the broad conclusions and point out some of the policy suggestions emerging from the analysis.

Rainfall during the presowing and sowing periods is an important determinant of wheat acreage in any cropping season. Sowing-period rainfall is relatively more important in districts where the average rainfall during October to December is generally adequate for proper seed germination. The presowing-period rainfall becomes crucial for districts where the average rainfall during the sowing season is so low that soil moisture from early rains has to be preserved for the proper germination of wheat plant.

The wheat production in any cropping season is heavily influenced by the quantity and distribution of rainfall in the presowing, sowing and the growing periods. Presowing- and sowing-period rainfall are relatively more crucial for wheat production in Jhelum and Campbellpur while the growing-period rains are more important for production in Rawalpindi.

There are some important implications of our results for the agricultural sector in the economy. *First,* the estimated relationships between acreage, rainfall and wheat production give us a fairly reliable estimate of wheat production every year by mid-April whereas the official estimates are available by the first week of September. The three districts account for 8 per cent of the total wheat production in West Pakistan but their behaviour can be reasonably good indicator of wheat production in the remaining *barani* areas. This way we get an estimate for about 24 per cent of the total wheat production in West Pakistan. Since the *barani* wheat production accounts for a substantial portion of the variability in wheat production in West Pakistan, our results are useful in improving government policies regarding foodgrain imports, storage, prices, *etc.*

Secondly, the fact that the performance in the agricultural sector is significantly and measurably influenced by weather conditions is important and should be taken note of in assessing the impact of investment in agricultural sector in any development plan. The estimated relationship between production and rainfall in different periods gives us the estimated production levels in different plan years. If the actual production is away by more than 2 standard errors of estimate from the estimated production for the plan years in a row, it would be reasonable to presume that the investment in agriculture is bearing fruit. Since for the first two years of Second Five Year Plan, the wheat production in three districts was not significantly different from the predicted production, it can be said that the development expenditure in the agricultural sector in the three districts was not effective. *Thirdly*, the estimated relationships between rainfall, acreage and production have at best explained only 60 per cent of the variance in production and still lower in acreage. A follow-up study of using prices as the explanatory variable may yield some interesting results. *Finally*, the fact that the influence of weather is measurable and relatively stable indicates that the sort of analysis followed here could be profitably applied to other important crops and the results used for planning process and for the evaluation of plan.

Appendix A

TABLE A-1

SCHEDULE OF MAXIMUM-EFFECTIVE RAINFALL

Monthly rainfall increment	Estimated effective rainfall	
	Per cent (inches)	Accumulated (inches)
1	95	0.95
2	90	1.85
3	82.5	2.68
4	65	3.32
5	45	3.78
6	25	4.02
over 6	5	

Note: This schedule has been worked out on the basis of the procedure developed by the U.S. Bureau of Reclamation.

TABLE A-2

RAWALPINDI: MAXIMUM-EFFECTIVE RAINFALL AS PERCENTAGE OF ACTUAL RAINFALL

Year[a]	Actual rainfall	Maximum effective rainfall	Col. (2) as per cent of Col. (1)
	(........inches	........)	
	(1)	(2)	(3)
1931/32	38.34	20.49	53.44
1932/33	28.08	17.70	63.03
1933/34	32.33	16.55	51.19
1934/35	34.18	19.35	56.61
1935/36	36.19	21.49	59.38
1936/37	33.46	21.71	64.88
1937/38	25.32	17.73	70.02
1938/39	34.28	20.47	59.71
1939/40	19.32	16.46	85.20
1940/41	28.67	16.76	58.46
1941/42	33.08	22.19	67.08
1942/43	31.74	19.34	60.93
1943/44	31.71	22.28	71.90
1944/45	36.59	21.31	58.24
1945/46	33.85	19.03	56.22
1946/47	29.70	17.61	59.29
1947/48	38.85	22.61	58.20
1948/49	47.49	23.25	48.96
1949/50	32.83	20.57	62.66
1950/51	41.71	20.40	48.91
1951/52	23.79	16.90	71.04
1952/53	28.72	15.45	53.80
1953/54	38.91	22.23	57.13
1954/55	27.56	17.82	64.66
1955/56	38.34	21·08	54.98
1956/57	44.35	21.01	47.37
1957/58	29.88	22.11	74.00
1958/59	45.62	26.49	48.07
1959/60	51.50	26.32	51.11
1960/61	33.94	20.55	60.55

Sources: *i)* For the period 1931/32 to 1946/47, *Monthly Rainfall Bulletins*, Government of India, Metereological Department, Delhi.

ii) Since 1947/48, *Monthly Rainfall Bulletins*, Government of Pakistan, Meteorological Department, Karachi.

a) The year is defined from July to March corresponding to the wheat season.

TABLE A-3

JHELUM: MAXIMUM-EFFECTIVE RAINFALL AS PERCENTAGE OF ACTUAL RAINFALL

Year[a]	Actual rainfall	Maximum effective rainfall	Col. (2) as per cent of Col. (1)
	(.........inches.........)		
	(1)	(2)	(3)
1931/32	15.37	12.07	78.53
1932/33	17.08	12.24	71.66
1933/34	24.19	12.25	50.64
1934/35	17.75	13.44	75.72
1935/36	20.76	15.28	73.60
1936/37	16.18	13.35	82.51
1937/38	14.43	9.98	69.71
1938/39	15.21	12.58	82.71
1939/40	12.41	10.94	88.15
1940/41	18.44	12.68	68.76
1941/42	20.91	17.33	82.88
1942/43	21.61	13.88	64.17
1943/44	22.54	16.46	73.02
1944/45	24.96	14.87	59.58
1945/46	16.05	11.56	72.02
1946/47	12.26	10.40	84.83
1947/48	18.87	15.45	81.88
1948/49	31.48	15.90	50.51
1949/50	20.56	16.44	79.96
1950/51	20.99	13.77	65.60
1951/52	19.44	12.75	65.59
1952/53	13.40	10.29	76.79
1953/54	19.53	16.24	83.15
1954/55	15.39	12.50	81.22
1955/56	22.57	15.24	67.52
1956/57	25.64	15.15	59.08
1957/58	15.30	12.84	88.92
1958/59	22.25	17.80	80.00
1959/60	35.93	20.87	58.08
1960/61	24.82	13.46	54.23

Sources: i) For the period 1931/32 to 1946/47, *Monthly Rainfall Bulletins*, Government of India, Metereological Department, Delhi.

ii) Since 1947/48, *Monthly Rainfall Bulletins*, Government of Pakistan, Metereological Department, Karachi.

a) The year is defined from July to March corresponding to the wheat season.

TABLE A-4

CAMPBELLPUR: MAXIMUM-EFFECTIVE RAINFALL AS PERCENTAGE OF ACTUAL RAINFALL

Year*a*	Actual rainfall (...........inches.........) (1)	Maximum effective rainfall (2)	Col. (2) as per cent of Col. (1) (3)
1931/32	14.81	13.02	87.91
1932/33	16.66	10.89	67.81
1933/34	23.65	13.58	57.42
1934/35	19.64	13.51	68.77
1935/36	19.11	14.87	77.81
1936/37	14.31	12.35	86.30
1937/38	17.33	12.72	73.40
1938/39	19.47	13.52	74.58
1939/40	14.53	13.35	91.88
1940/41	15.92	12.45	78.20
1941/42	18.18	16.06	88.34
1942/43	22.34	15.50	69.38
1943/44	20.18	15.19	75.28
1944/45	21.84	14.64	67.03
1945/46	17.11	13.33	77.91
1946/47	15.05	11.73	77.94
1947/48	15.48	13·57	87.60
1948/49	23.59	16.61	70.41
1949/50	15.73	12.56	79.85
1950/51	20.91	13.48	64.47
1951/52	15.59	12.46	79.92
1952/53	11.81	9.41	79.68
1953/54	18.36	15.36	83.66
1954/55	10.88	9.75	89.52
1955/56	15.15	12.64	83.43
1956/57	26.31	17.21	65.15
1957/58	14.14	12.70	89.82
1958/59	26.75	21.06	78.73
1959/60	29.52	19.32	65.11
1960/61	16.73	14.43	86.25

Sources: *i)* For the period 1931/32 to 1946/47, *Monthly Rainfall Bulletins*, Government of India, Metereological Department, Delhi.

ii) Since 1947/48, *Monthly Rainfall Bulletins*, Government of Pakistan, Metereological Department, Karachi.

a) The year is defined from July to March corresponding to the wheat season.

TABLE A-5

ACREAGE FOR THREE DISTRICTS

Year	Rawalpindi	Jhelum	Campbellpur
	(..............000 acres	....	)
1931/32	238.37	337.33	591.50
1932/33	227.51	322.65	421.28
1933/34	238.69	349.62	560.59
1934/35	246.34	331.91	538.59
1935/36	246.94	345.04	585.73
1936/37	260.02	348.32	590.01
1937/38	259.44	339.77	650.51
1938/39	263.52	332.58	517.11
1939/40	248.89	310.16	562.55
1940/41	235.42	344.53	592.54
1941/42	244.17	343.49	585.31
1942/43	236.00	354.00	598.30
1943/44	237.26	327.14	496.44
1944/45	243.05	340.38	584.10
1945/46	238.84	341.60	592.40
1946/47	247.43	316.74	590.75
1947/48	253.35	309.52	547.53
1948/49	240.01	316.96	621.34
1949/50	251.32	350.01	621.34
1950/51	242.48	359.39	614.96
1951/52	273.32	337.00	635.38
1952/53	253.39	289.35	539.25
1953/54	243.91	315.30	581.55
1954/55	259.57	329.24	643.76
1955/56	253.34	329.24	533.40
1956/57	257.75	353.17	660.90
1957/58	267.30	359.80	691.00
1958/59	285.00	360.00	642.00
1959/60	280.00	371.00	641.00
1960/61	267.00	353.00	612.00

Sources: *i)* For 1931/32 to 1958/59, A. Rab, *Acreage, Production and Prices of Major Agricultural Crops of West Pakistan (Punjab), op. cit.*

ii) For 1959/60 and 1960/61, Final estimates of Agricultural Department, West Pakistan.

TABLEA-6

PRODUCTION OF WHEAT IN RAWALPINDI, JHELUM, AND CAMPBELLPUR DISTRICTS

Year	Rawalpindi	Jhelum	Campbellpur
	(..............000	acres	...............)
1931/32	46.3	76.2	101.4
1932/33	44.4	73.2	65.4
1933/34	37.6	75.2	106.8
1934/35	50.01	80.7	80.7
1935/36	54.6	83.4	83.4
1936/37	69.4	91.3	111.8
1937/38	62.1	71.5	146.7
1938/39	60.6	69.1	103.5
1939/40	55.1	57.2	121.5
1940/41	39.3	90.2	111.8
1941/42	63.0	84.1	112.3
1942/43	65.2	102.3	124.4
1943/44	48.4	62.8	86.6
1944/45	62.7	88.9	121.7
1945/46	48.5	58.6	112.1
1946/47	45.8	54.4	81.3
1947/48	56.3	70.0	103.9
1948/49	66.4	93.0	141.6
1949/50	69.4	98.5	134.5
1950/51	80.5	107.8	162.3
1951/52	60.6	70.5	120.5
1952/53	35.0	35.9	47.2
1953/54	63.06	86.6	115.6
1954/55	53.7	62.0	53.5
1955/56	64.3	102.0	134.2
1956/57	60.2	104.7	134.2
1957/58	62.4	106.7	131.3
1958/59	66.6	109.1	155.9
1959/60	66.2	107.1	133.2
1960/61	64.4	94.9	144.9

Source : Same as for Table A-5.