LACIE-00503
JSC-11700

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

E79-10139
CR-158148

LARGE AREA CROP INVENTORY EXPERIMENT

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(E79-10139) LARGE AREA CROP INVENTORY EXPERIMENT (LACIE). THE Z-INDEX AND SUBITANEOUS EVENTS AS VARIABLES FOR ESTIMATING WHEAT YIELDS IN ARGENTINA (National Oceanic and Atmospheric
HC A03/MF A01
N79-18404
Unclas
G3/43 00139

NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

SEPTEMBER 1977

CENTER FOR CLIMATIC AND

ENVIRONMENTAL ASSESSMENT

Technical Note 76-4

The Z-Index and Subitaneous Events as Variables for Estimating Wheat Yield in Argentina

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November, 1976

CCEA TECHNICAL NOTE 76-4

The Z-Index and Subitaneous Events as Variables for Estimating Wheat Yield in Argentina

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INTRODUCTION

The use of monthly temperature and precipitation into a moisture anomaly index called "Z" is described. The Z-index together with subitaneous events, often not weather-related, that impacts on the wheat farmer over a short period of time are used in a wheat yield model for five provinces in Argentina.

Sakamoto and Jensen (1975), in their study involving the impact of climatic change on wheat production in Argentina, compared three indices in a yield prediction model: soil moisture, the ratio of evapotranspiration to potential evapotranspiration, and the Z-index together with temperature departures were used in regression models. It was found that the Z-index explained the greatest variability of yield among the three indices compared. The Z-index is a moisture anomaly index, the value of which has the same relative meaning for each month of the year as well as with varied climatic regions.

Others (Baier and Robertson, 1968, and Nix and Fitzpatrick, 1969) have used similar derived indices for estimating wheat yields from meteorological data. They found that these indices were better estimators of yield than the use of raw meteorological variables such as precipitation and temperature.

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THE Z-INDEX

Monthly temperature and precipitation are used in an algorithm that derives the Z-index. This is defined as:

$$Z = dk \tag{1}$$

where:

$$d = P - \hat{P} \tag{2}$$

and P is the observed precipitation while $\hat{P}$ is the "climatically appropriate" precipitation. $\hat{P}$ is further estimated by:

$$\hat{P} = \widehat{ET} + \hat{R} + \widehat{RO} - \hat{L}. \tag{3}$$

Evapotranspiration $\widehat{ET}$, recharge $\hat{R}$, runoff $\widehat{RO}$, and loss $\hat{L}$ are obtained by multiplying its potential value (PET, PR, PRO, PL) by the coefficient which is the ratio of average $\overline{ET}$, $\overline{T}$, $\overline{RO}$ or $\overline{L}$ by its average potential values; that is, $\alpha = \overline{ET/PET}$, $\beta = \overline{R/PR}$, $\gamma = \overline{RO/PRO}$, $\sigma = \overline{L/PL}$. Climatically appropriate evapotranspiration, recharge, runoff, and loss are then determined as: $\widehat{ET} = \alpha \cdot PET$, $\hat{R} = \beta \cdot PR$, $\widehat{RO} = \gamma \cdot PRO$, and $\hat{L} = \sigma \cdot PL$, respectively.

Soil moisture depletion is based on evapotranspiration (ET) estimates and is determined by the following:

$$(ET)_n = \frac{(S)_{n-1}}{AWC} \{(PET)_n - (P)_n\} + (P)_n \tag{4}$$

where:

$(ET)_n$ = "actual" evapotranspiration,

$(S)_{n-1}$ = available moisture at end of n-1 months,

AWC = maximum water holding capacity,

$(P)_n$ = precipitation for month n,

$(PET)_n$ = potential evapotranspiration for month n.

Determination of recharge, runoff and loss is through a hydrologic accounting procedure developed by Palmer (1965). Briefly, this procedure utilizes a two-layer soil profile and assumes that the surface layer holds one inch of water and the lower layer holds the remaining amount. Moisture is lost at a potential rate from the surface layer until all moisture is lost in that layer; i.e.,

$$L_s = (PET - P) \text{ or } S'_s \tag{5}$$

where:

L_s = soil moisture loss from surface layer,

S'_s = stored available moisture in surface layer.

After all the surface moisture is lost, moisture is extracted from the lower layer as a percent of available soil moisture (see Figure 1). Precipitation adds to the top layer until field capacity is reached before the lower layer is recharged. Runoff is assumed to occur only after both layers have reached field capacity, although this assumption may not be entirely satisfactory.

The amount of moisture lost from the underlying layer is determined by the following relationship:

$$L_u = (S_u/AWC)\ (PET - P - L_s) \tag{6}$$

where:

L_u = soil moisture loss from underlying (lower) layer,

S_u = available soil moisture in the lower layer at the beginning of the month,

AWC = water holding capacity (combined layers),

PET = potential evapotranspiration based on Thornthwaite's (1948) procedure,

P = precipitation for the month,

L_s = soil moisture loss from upper (surface) layer.

In the accounting procedure, if the soil moisture content in both layers is zero, evapotranspiration, ET, is assumed to be equal to precipitation; i.e., ET = Γ. The potential values, including potential evapotranspiration PET, potential recharge PR, potential runoff PRO, and potential loss PL are used in the water balance procedure and are defined as follows:

$$PR = AWC - S' \tag{7}$$

where:

PR is the amount of moisture required to bring the soil to field capacity and AWC is the available water capacity. S' is the amount of available moisture in the two layers at the beginning of the period.

$$PL = PL_s + PL_u \tag{8}$$

where:

PL is the potential loss; i.e., the amount of moisture that could be lost from the surface (s) and underlying profile (u) provided precipitation is zero. It is further defined as PL_s = PE or S'_s whichever is smaller and PL_u is the potential loss from the underlying layer and is defined as:

$$PL_u = (PE - PL_s)\ S'_u/AWC.$$

In general, potential runoff PRO is equal to precipitation minus the amount that could be added to the soil or P-(AWC-S'). However, precipitation is not introduced for the development of potential runoff. For lack of a better way to handle this problem, potential runoff is defined as a function of soil moisture, the reason being that if soil moisture is high, potential runoff is likely to be large and vice versa. This reasoning seemed to have worked fairly well, according to Palmer (1965).

$$PRO = AWC - PR = S'. \tag{9}$$

Potential evapotranspiration is determined by the procedures developed by Thornthwaite (1948). To estimate potential evapotranspiration by Thornthwaite's procedure requires temperature and the heat index. The duration of daylight is used to adjust potential evapotranspiration as a portion of 12 hours. The basic equation is:

$$PET = (10T/I)^a \tag{10}$$

where:

I = heat index, which is the sum of the 12 monthly index i where $i = (T/5)^{1.514}$,

T = monthly temperature (^oC),

a = an empirical exponent,

$= 6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.79 \times 10^{-2}I + 0.49.$

The heat index I can alternately be estimated from the mean annual temperature t by the following relationship:

$$\ln I = 0.06798(t) + 3.199 \tag{11}$$

where t is in ^oC. The above relationship has been estimated from the data of Palmer nd Havens (1958).

The variable k is the average demand and supply coefficient which varies with the local climate. It is a measure of the local significance of the moisture departures. It is initially estimated by an empirical relationship for month i by:

$$k_i' = 1.5 \log \{(\frac{\overline{PE_i} + \overline{R_i} + \overline{RO_i}}{\overline{P_i} + \overline{L_i}} + 2.80)/\overline{D_i}\} + 0.50 \tag{12}$$

where:

$\overline{D_i} = (\sum_{d=1}^{j} |d_{ij}|)/j$ for month i where j = number of year, i = 1 = January, 12 = December.

The final k is estimated by:

$$k_i = \frac{17.67\,(k_i')}{\sum_{i=1}^{12} (\overline{D}_i k_i')} \tag{13}$$

k_i is therefore a weighting factor and has been derived from a range of climate including North Dakota in the north to Texas and Tennessee in the south and from Kansas in the west to Pennsylvania in the east. When used with d, the Z-index provides a comparable measure of moisture anomaly, the departure of the moisture climate from the average of the month.

SUBITANEOUS EVENTS

A subitaneous event is defined as an event that impacts rapidly on wheat production in Argentina and manifests itself from the effects of weather (episodal events) or decline in the economy. This decline is in turn the result of political instability. Examples of weather related subitaneous events include flood, hail, windstorm, damage from plant disease or insects. An example of a non-weather subitaneous event is a political disorder. It is well known that Argentina has had a turbulent political history. Government coups seem to be a frequent occurrence and often arise following an economic decline. The economic stability of Argentina depends heavily on world trade, particularly on the world wheat market which fluctuates with the tide of international and national relationships.

A major factor leading to economic instability in Argentina is the attitude that economic laws that govern the world do not apply in that country (Aizcorbe, 1975). Peronist law proponents follow "imports substitution," which takes away part of the farmer's income, to pay for the import duties of raw material needed in industry. The theory behind this action is that since raw materials do not pay import taxes, it will cost industry less. This, in turn, would encourage export. As an example, if a dollar is 10 pesos, the farmer receives 5 pesos per dollar based on the sale of wheat, at say 50 percent of the international price. If Argentina wants the peso to be raised to 15 and, further, should the price of wheat increase on the international market, the farmer will still receive 5 pesos (Aizcorbe, 1975). The remaining 10 pesos will be used by the government to subsidize industry. With this subsidy by the farmer, the assumption is that Argentina industrial products would be cheaper. However, the Central Bank of Argentina must now pay 15 pesos for each dollar, where it previously had paid 10 pesos. This import substitution may work for a short time. Eventually, inflation occurs and the agriculture sector losses because of price control. This leads to reduction in production.

Argentina's current or anticipated wheat trade balance has a significant effect on the response of the wheat farmer and his efforts to achieve maximum yield and production. If the economic situation appears dismal, he may elect not to apply costly fertilizer to his field, or purchase improved seeds which cost more, or apply herbicides, or fallow practices - all leading to potential yield increases. The farmer may not harvest at all or harvest only part of his field should a field be damaged by weather related factors and he determines that it will not be beneficial because of low economic return.

An example of a political event that impacted on wheat production in Argentina is the signing of the Declaration of Reciprocal Assistance and Cooperation for the Defense of the American Nations in 1940. The signing was preceded by the German invasion of Poland in 1939. Since Argentina depended almost entirely on its trade with the European market prior to

1940, the signing of the agreement lead to a trade reduction, and consequently, large wheat surplus (Paz and Ferrari, 1966). This meant a low return for the farmer and discouraged him from applying the latest technology.

Some events have positive effects on the farmer in his decision to improve yield. For example, following the decline of the gold reserve and declining agricultural prices in the early 1950's that led to importation of wheat, President Peron sought economic union with other South American countries, which led to the signing of the Declaration of Buenos Aires in 1953. The pact involved a series of agreements that produced reduced tariff, coordination of exchange, etc. This effort raised the hopes of the farmer for a better price on his wheat and other crops.

Admittedly, the assignment of a year as being "subitaneous" is very subjective. This is further made difficult because the outlying provinces from Buenos Aires may not all respond simultaneously because of local interests and events. However, the role of agriculture, especially the farmer and his part in the economy of his nation, has been quite different than those of the United States. In Argentina, factors other than weather play a dominant role on annual wheat yield. Table 1 is a list of events that are hypothesized as having an economic impact on Argentina and consequently, on wheat production in that country.

DESCRIPTION OF THE PAMPAS

The agricultural region known as the Pampas produces approximately 90 percent of Argentina's grain. A portion of five provinces made up this area. These provinces are Buenos Aires, Cordoba, Entre Rios, La Pampa and Santa Fe (see Figure 1).

Table 1. Suggested Subitaneous Events and Hypothesized Effect on Production (and Yield) in Argentina

Year	Event	Effect
1932	Uprising in Entre Rios. Conspiracy against President Uriburu in February 1932 ended dictatorship of Uriburu. General Justo inaugurated.	+ (Entre Rios)
1933	Uprising in province of Santa Fe between factions of General Justo and radicals. From December 16, 1932 to mid-1933 the radical party was banned from operation. In December 1933, coup to overthrow government began in Santa Fe and Corrientes.	− (Santa Fe) 1932-1933
1933-1935	Roca-Runciman Treaty signed in May and renewed in 1935 served as basis for Justo's program for economic recovery. Treaty provides provision for maintaining import quotas into United Kingdom, reduced tariff for imports. Government fixed minimum prices for grain. This action helped the farmer. In 1934, government control of economy further enlarged by the creation of a central bank.	+ 1934
1940	Signing of the Declaration of Reciprocal Assistance and Cooperation for the Defense of the American Nations. Reduction of trade with Europe following invasion of Poland in 1939. Creation of large wheat surplus.	−
1941	Commercial agreement with United States. In January 1941, a regional conference that included South American countries as well as the United States met to discuss development of regional trade among themselves. This was done to ease the loss of trade with Europe. In October, an agreement was signed between the United States and Argentina, the first of its kind in 90 years. Both countries reduced their tariff and Argentina reduced its surpluses including meat and wheat.	+
1943	Revolution of 1943. Peron takes power - geared to the transformation of Argentina into a regimented industrial society at the expense of the agrarian community.	−
1944	June 6. Import duties of raw material raised as much as 50 percent to stimulate industry. Free trade of wheat industry with Europe reversed.	−
1945	Declaration of war against Germany. Diplomatic relations were terminated. The Act of Chapultepec united the South American countries and the United States. With a dwindling European market and an accompanying buildup of wheat surplus, the period near the end of World War II was difficult for Argentina.	−
1947-1948	Foreign Assistance Act (Marshall Plan). Argentina saw this Plan as a way to reduce the surplus. Hope for the farmer was also raised by the creation of the Argentina Institute for the Promotion of Trade (IAPI) (Goldwert, 1972). IAPI provided for heavy government spending, including higher wages for all working class in Argentina.	+

Table 1 (Continued)

Year	Event	Effect
1950	Declining agricultural prices, declining value of peso. Importation of wheat. Agricultural production declined, discouraged by policies of IAPI. By 1949, the economic situation in Argentina began to deteriorate under Peron's Five-Year Plan (1947-1951).	-
1952	Declining agricultural prices; devaluation of peso; severe drought. Attempted coup on Peron. Importation of wheat. IAPI paid 50 pesos per 100 kilos of wheat while receiving 180 pesos/100 kilos. 130 pesos went to Banco Central.	-
1953	Declaration of Buenos Aires passed in August to attract foreign investment. A series of agreements with South American countries to reduce tariff, coordination of exchange, etc. raised the hopes of the farmer.	+
1955	June-September Peron overthrown.	+
1961	Rise in cost of living to 323 percent. Drop in agricultural export. President Frondizi established the free convertibility policy of the peso with the U.S. dollar.	-
1965	Economic conditions under new President Illia improved and trade surplus was on hand. However, with continued inflation and continuous printing of money to remain "solvent" only temporarily eased the situation.	+
1966	Collapse of Illia's regime with military coup.	-
1969	Solid economic progress was made after 1966 during Onaganis regime. Labor, however, was divided with wage freeze in 1968 to curb inflation. Labor was to bear the cost of economic development. Student and labor unrest lead to violence (in Cordoba).	-
1970	On June 8, 1970, Onaganis was deposed by the military.	+
1971	Under Levingston, inflation soared again. To keep cost of living from soaring, Levingston increased taxes on ranchers. The country's cattle herd dropped. Cattle prices soared because beef is the staple of Argentina's diet.	-

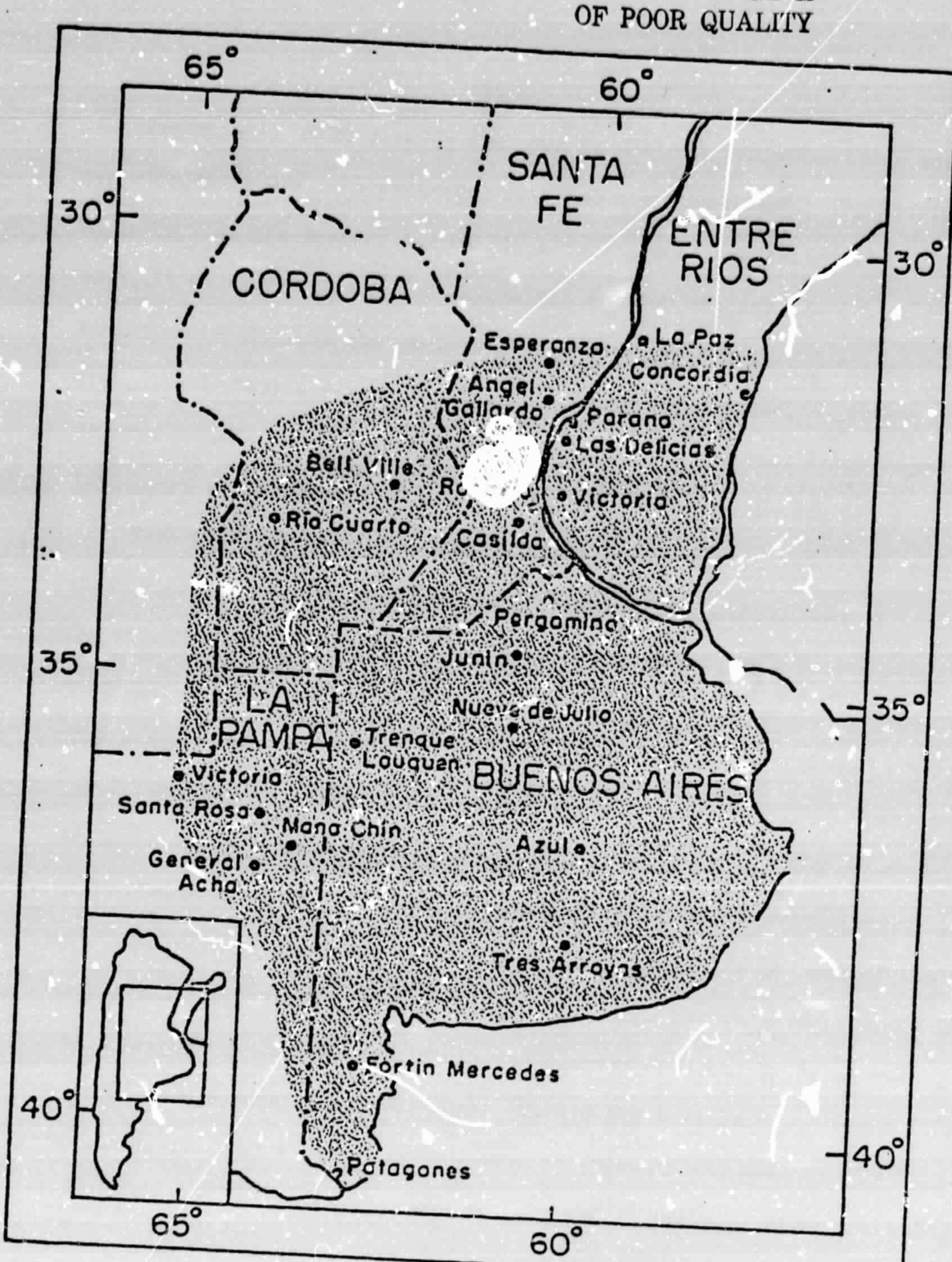

Figure 1. Five major wheat growing provinces in Argentina including Buenos Aires, Cordoba, Entre Rios, La Pampa and Santa Fe. The names indicated within each province are locations for which weather information was used. The darkened area shows the major wheat growing area in Argentina.

Argentina's wheat growing area can be divided for convenience into two climatic zones, the semi-arid west and the humid east. The provinces of Entre Rios and eastern Buenos Aires in the east are relatively humid. Rainfall in these provinces averages 635 to 1000 millimeters (25 to 40 inches). Rainfall in the semi-arid west averages 450 to 800 millimeters (18 to 31 inches) a year. Physically, the towering Andes, on Argentina's western border, and the waters of the Atlantic to the east exert major influences on the country's temperature and precipitation regime.

Each province has its unique climatic problems that tend to reduce wheat yields. Drought and high winter temperatures affect wheat yield in the more northern provinces of Santa Fe, Cordoba and Entre Rios. Entre Rios' wheat yields are also affected by excessive moisture in addition to high winter temperatures. The more western provinces, including La Pampa, are affected by cooler spring temperatures and occasional late frosts which can occur as late as November. The growing season in La Pampa is about a month shorter than Buenos Aires province (Pascale and Damario, 1961).

The soils of the Pamas are typically diverse, although most of the area has a deep, black, friable layer. The soils become more sandy toward the western Argentina border, including western Cordoba, La Pampa and southwestern Buenos Aires provinces. Toward the northeast, in Entre Rios province, the soil texture becomes heavier (Pascale and Damario, 1961).

Spring or semi-winter growth habit wheat is grown in Argentina. Seeding is begun in the south in April or May and proceeds northward by June, July or early August. Consequently, autumn or early winter is the usual planting period in Argentina. Harvest begins in the north in late November and proceeds southward through December and - times into January.

DATA REQUIREMENTS

The basic meteorological inputs required to calculate the Z-index include monthly temperature and precipitation. These are used in the hydrologic accounting procedure described earlier. The soil moisture budget also requires an estimate of the available water holding capacity of the two layer profile. These were estimated by the general characteristics of the soils of the Pampas. For the five provinces, the values were as follows: Buenos Aires, 1 and 4 inches; Córdoba, 1 and 3 inches; Entre Rios, 1 and 5 inches; La Pampa, 1 and 3 inches; and Santa Fe, 1 and 4 inches. The initial soil water was estimated to be at field capacity on January 1931 as rainfall was plentiful during the summer months. The soil water holding capacities are based on an assumed wheat root zone of about four feet.

The initial soil water content must be known. In practice, however, this may not be known. Therefore, an estimate must be entered to start the model so that once field capacity is reached in the accounting procedure, the moisture status of the soil can be considered as reflecting the "current" situation. One could also start on a month subsequent to a rainy period as was done in this study.

Daylength, as a fraction of 12 hours, is used to adjust potential evapotranspiration calculations in accordance with the Thornthwaite procedure. These are inputed directly in the program but can be calculated internally given the latitude and Julian date.

DATA SOURCE

Monthly meteorological data, including temperature and precipitation, for the period 1931-70 were obtained from the Servicio Meteorological

Nacional in Argentina (Jensen, et al., 1974; private communication, 1976). The station data were analyzed to provide mean monthly temperature and precipitation aggregated for each of the five provinces. To minimize bias because of station concentration, greater weights were given to those stations that were located in the high density wheat growing area. The stations used in the data base, together with their weights are shown in Table 2.

Harvested yield data were also obtained for each of the five provinces in Argentina (private communication, 1974). The average yield and standard deviation for the five provinces and the period 1931-60 are shown in Table 3. The average yield for the period 1961-70 is approximately as follows: Buenos Aires, 1450 kgm/ha; Cordoba, 1250 kgm/ha; Entre Rios, 1100 kgm/ha; La Pampa, 850 kgm/ha; and Santa Fe, 1500 kgm/ha. The plot of the harvested yield data series through 1970-71 are shown in Figures 2 through 6.

YIELD MODEL

Description of Model

Z-indices for selected months as well as temperature departures from the 1931-70 base period were used as meteorological variables in a multiple regression model. Subitaneous events, in accordance with Table 1, are quantized by dummy weights of 1. Since harvest, and consequently yield, could be hampered by precipitation, precipitation departure from normal was also entered as a variable (usually for November or December).

Technological contribution has been very evident in some states in Argentina. These contributions include increasing use of modern machinery, increasing use of improved seeds and herbicides, bulk handling of grains, and improved soil tillage methods. It is difficult to predict technology

Table 2. Location, elevation and meteorological weights for selected meteorological sites in Argentina

Province	Station	Latitude(S)	Longitude(W)	Elevation(m)	Weight
BUENOS AIRES	Azul	36°44'	59°50'	132	1
	Fortin Mercedes	39°31'	62°38'	25	1
	Junin	34°35'	60°56'	80	2
	Nueve de Julio	35°27'	60°53'	76	2
	Patagones	40°48'	62°59'	40	2
	Pergamino	33°56'	60°33'	65	2
	Trenque Lauquen	35°58'	62°44'	95	2
	Tres Arroyos	38°20'	60°15'	115	1
CORDOBA	Bell Ville	32°38'	62°41'	130	1
	Rio Cuarto	33°05'	65°16'	421	2
ENTRE RIOS	Concordia	31°23'	58°02'	38	1
	La Paz	30°45'	59°39'	37	1
	Las Delicias	31°56'	60°25'	105	1
	Parana'	31°47'	60°29'	79	1
	Victoria	32°37'	60°11'	29	1
LA PAMPA	General Acha	27°22'	64°35'	230	2
	Macachin	37°08'	63°41'	142	1
	Santa Rosa	36°34'	64°16'	190	2
	Victoria	36°14'	65°26'	312	1
SANTA FE	Angel Gallardo	31°37'	60°41'	18	1
	Casilda	33°03'	61°09'	72	1
	Esperanza	31°27'	60°56'	40	1
	Rosario	32°55'	60°44'	22	1

Table 3. Mean and Standard Deviation of Harvested Yield at Five Provinces in Argentina (1931-1960).

Province	Kilogram/hectare		Bushels/acre*	
	Mean	Std. Dev.	Mean	Std. Dev.
Buenos Aires	1109	192	16.5	2.8
Cordoba	1097	314	16.3	4.7
Entre Rios	925	244	13.7	3.6
La Pampa	710	301	10.6	4.5
Santa Fe	1257	319	18.7	4.7

*1 kilogram/hectare = .01487 bushels/acre
1 bushel/acre x 67.25 = kilograms/hectare

Figure 2. Wheat Yield for Buenos Aires Province, Argentina (1930-31 to 1972-73).

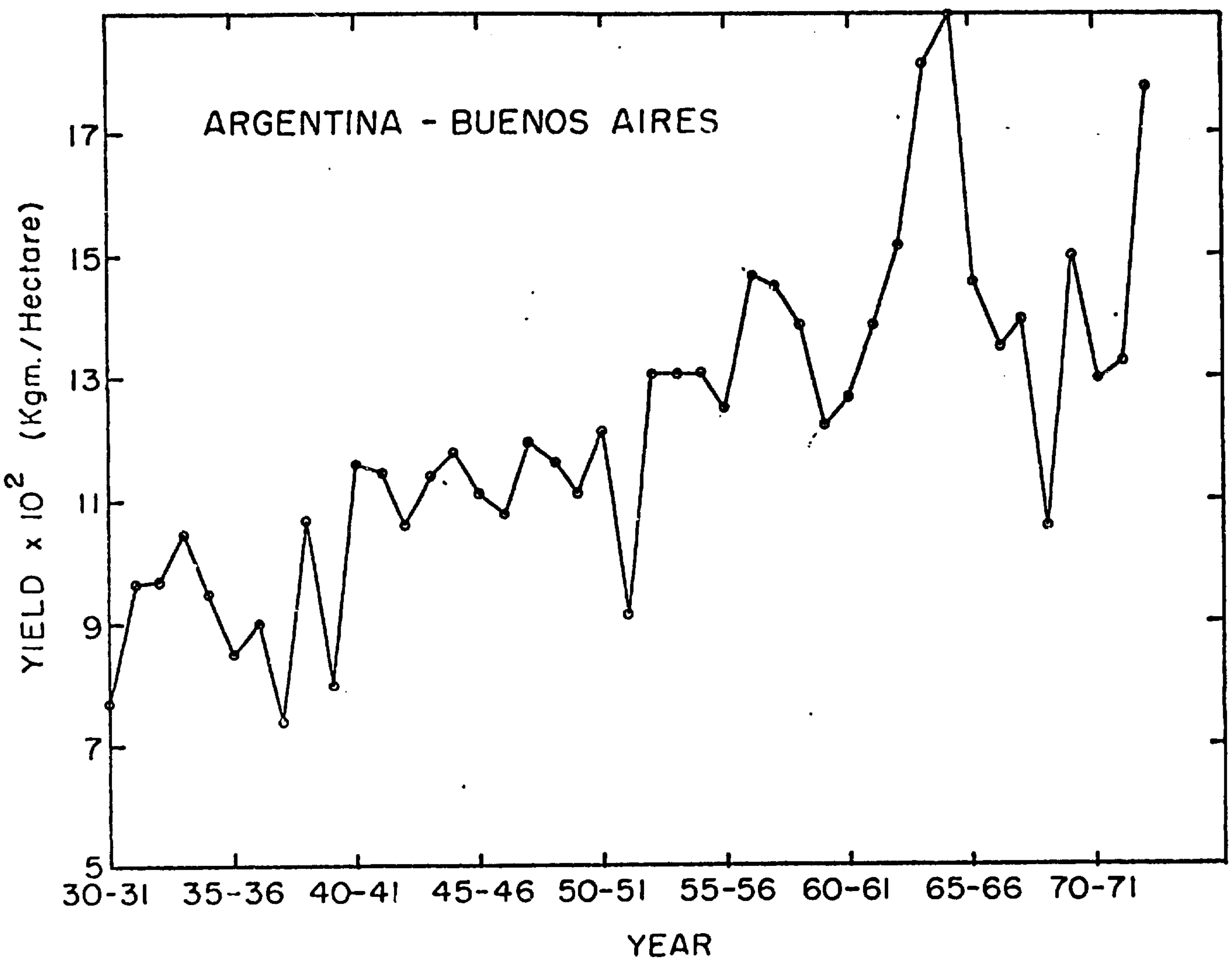

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Figure 3. Wheat Yield for Cordoba Province, Argentina (1930-31 to 1972-73).

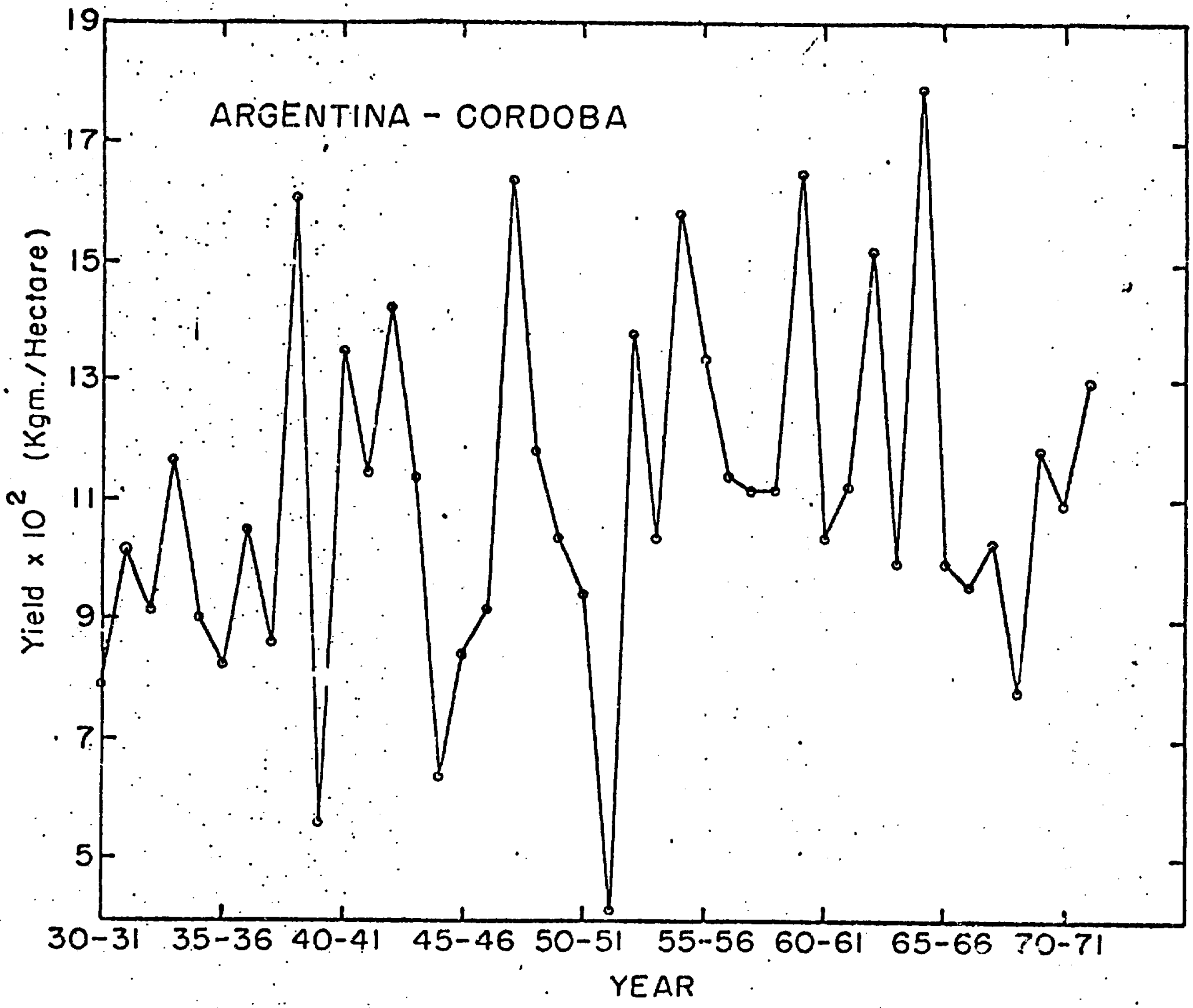

Figure 4. Wheat Yield for Entre Rios Province, Argentina (1930-31 to 1972-73).

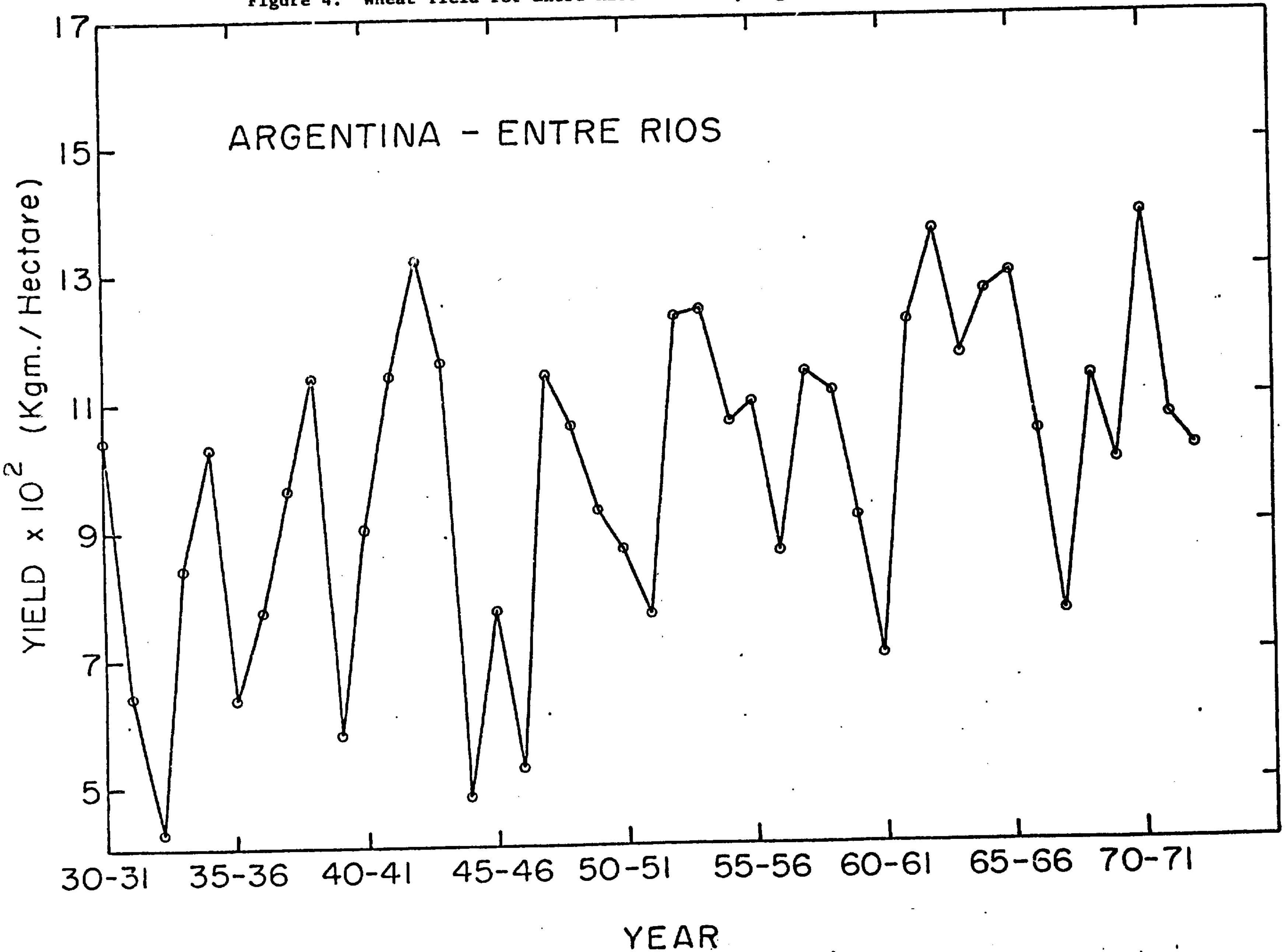

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Figure 5. Wheat Yield for La Pampa Province, Argentina (1930-31 to 1972-73).

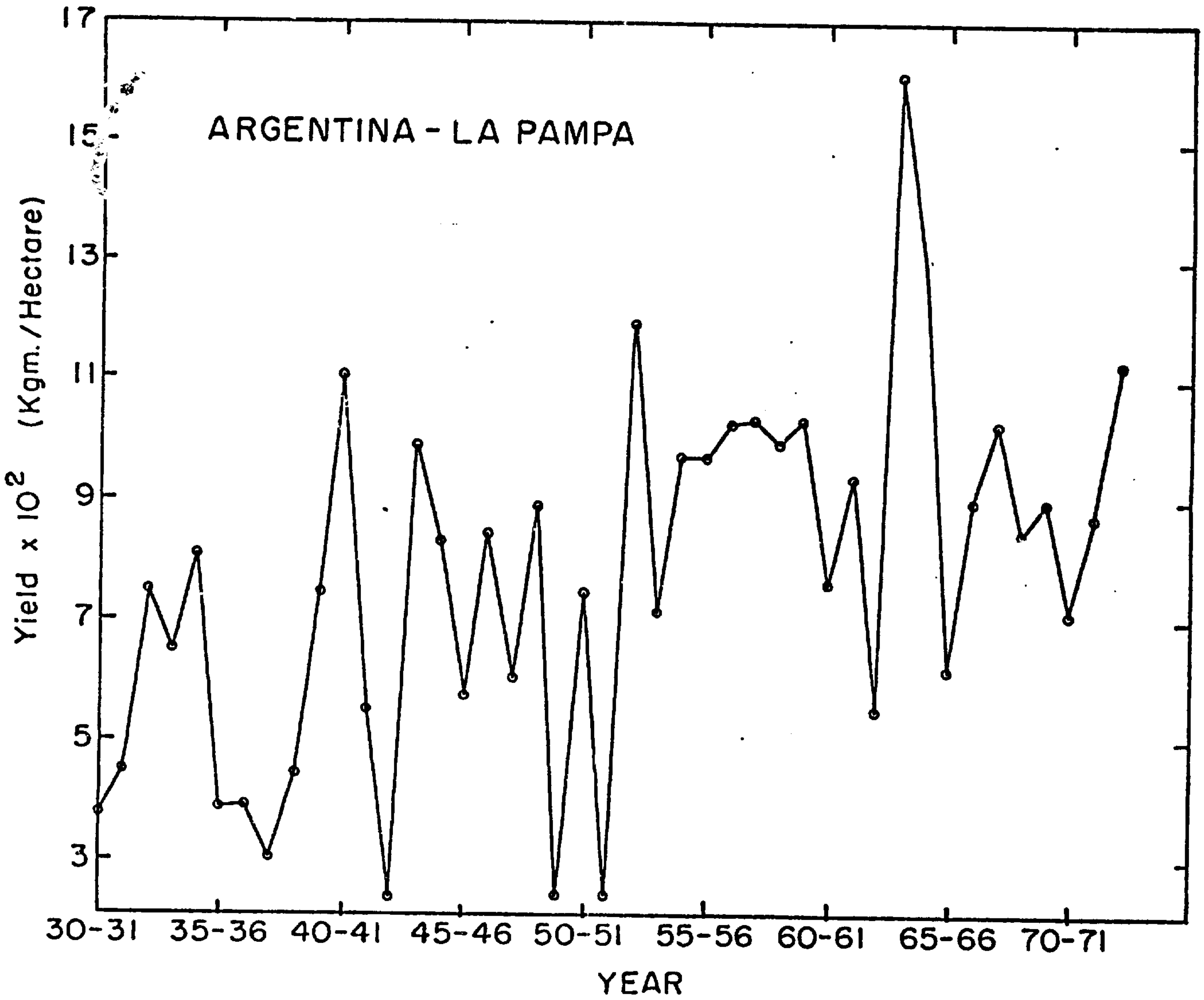
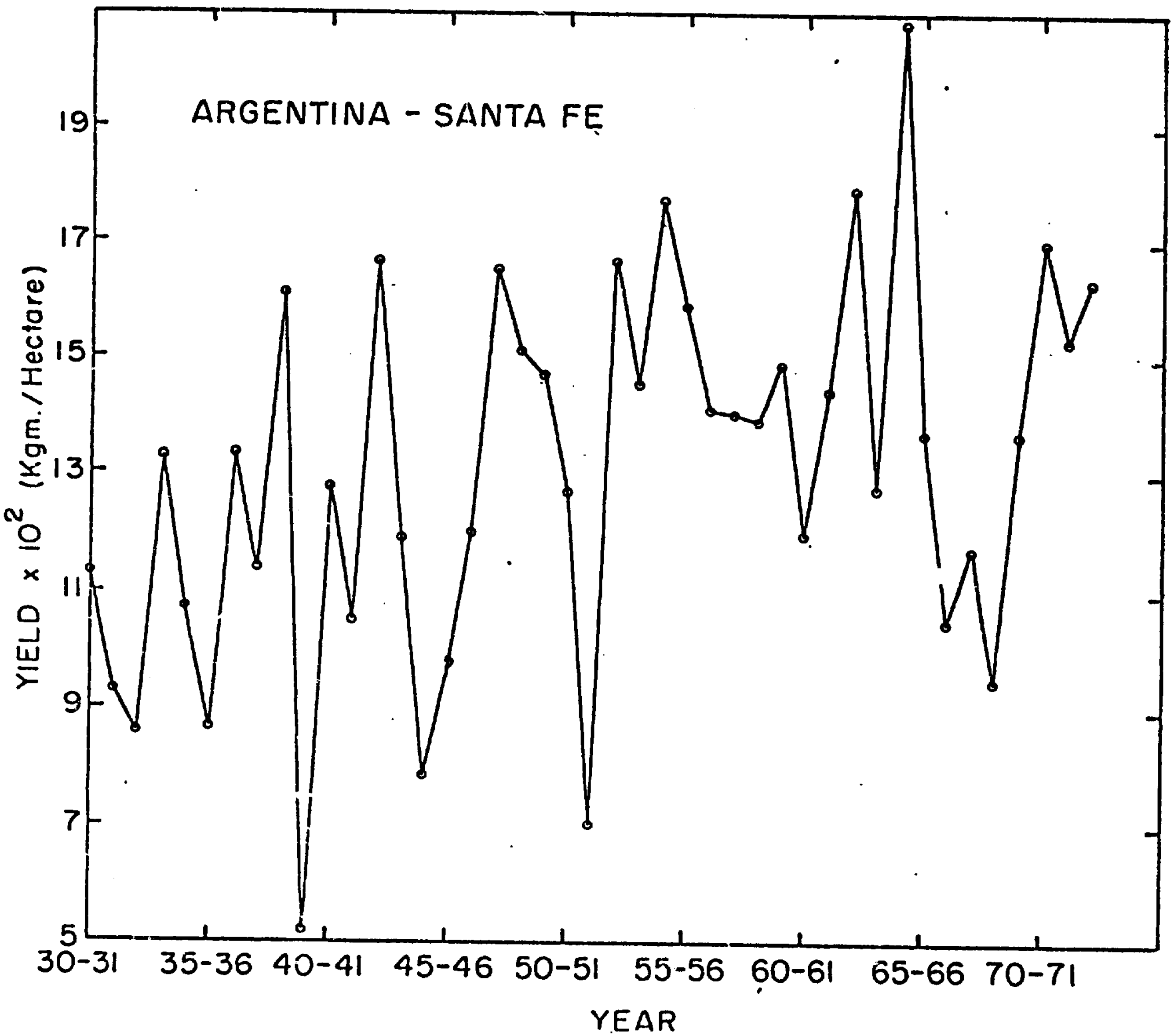


Figure 6. Wheat Yield for Santa Fe Province, Argentina (1930-31 to 1972-73).



into the future and this must be handled cautiously in yield predictions. New dwarf varieties were introduced in the early 1970's but the effects may not begin to show until after the mid-1970's (Hutchinson, et al., 1972). Fertilizer could potentially contribute to technological increases in yield, but the cost to most Argentine farmers is still prohibitive in relation to expected economic returns. Consequently, fertilizer has not been a significant factor affecting wheat production in Argentina.

Technology was represented by linear trend of years. For Cordoba, Entre Rios, Santa Fe, and La Pampa, it was estimated by inspection that a linear trend to 1954 and a constant trend thereafter would probably depict the best estimate of "technology" with time in those provinces. For Buenos Aires, the linear trend would also apply with 1931=1, 1932=2, ..., 1960=30, 1961=31, ..., 1970=31. Introduction of high yielding varieties since 1970 would suggest, however, that another linear trend needs to be added to the model. This is suggested to the user of this model, particularly in the province of Buenos Aires.

The Z-values were combined in some areas so that the effect of moisture was aggregated over a period greater than one month. This also permitted the treatment of this effect as a single variable. For example, Z-values for August, September, and October may have been combined by a weighted average procedure with the greatest weight assigned to October, the usual heading stage in Australia. Weights are assigned to the months from June through November (Figure 7) as a percent of water required at heading. The weights have been estimated from the work of Richardson (Callaghan and Millington, 1957). The weighting procedure revealed a better relationship with plots of yield than with linear averaging. Bauer (1972) has also determined that soil moisture deficiency at heading and flowering leads to the largest reduction in yield when compared with other growth stages.

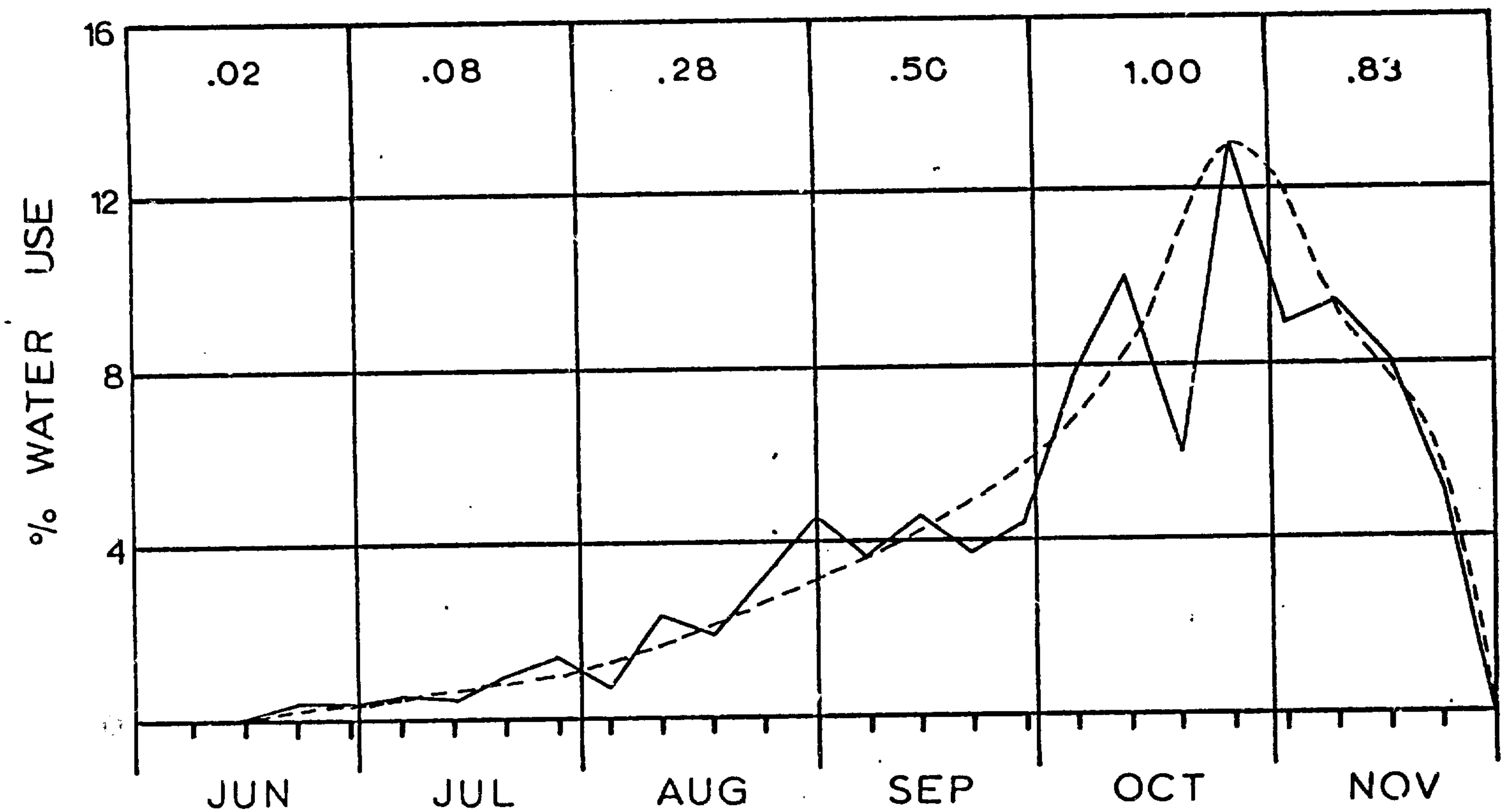


Figure 7

The form of the equation is:

$$\hat{y} = \alpha + \beta_1 T + \beta_2 S_d + \beta_3 S_a$$

$$+ \beta_4 \left(\frac{\sum_{i=1}^{n} Z_i \cdot W_i}{\sum_{i=1}^{n} W_i}\right) + \beta_5 \left(\frac{\sum_{i=1}^{n} Z_i \cdot W_i}{\sum_{i=1}^{n} W_i}\right)^2 \qquad (14)$$

$$+ \sum_{j=1}^{m} \gamma_j D_j + \sum_{j=1}^{m} \sigma_j D_j^2 + \sum_{j=1}^{k} \eta_j P_j + \varepsilon$$

where:

$\hat{y}$ = estimated yield

α = constant

T = linear trend 1931=1, 1932=2, ..., 1970=40 (for Buenos Aires)

S_d = subitaneous event that depreciates yield

S_a = subitaneous event that appreciates yield

Z_i = Z-index for i number of months, i=1, 2, ..., n

W_i = weight for month i to n (June through November only)

D_j = temperature departure from normal for month j, j=1 to m months

P_j = precipitation departure from normal for month j=1 to k months

β_1, β_2, β_3, β_4, β_5, γ_j, σ_j, η_j = coefficients of variables

ε = unexplained error.

The model for each province was a variation of equation (14). If the signs of the coefficient seemed unrealistic the quadratic term was omitted from the model. The variables and signs of the coefficients were selected after consideration of the growth stage or activity, such as harvesting, and the reasonableness of the coefficients with known agronomic response of the wheat crop to weather. The reader is reminded that one of the constraints of the model was the use of monthly temperature and precipitation.

The Z-index and temperature departure D could be either positive or negative. If climatic conditions are close to "climatically appropriate" for a given area, Z and D will be close to zero. Large positive Z-values suggest wet conditions while larger negative Z-index indicate anomalously dry conditions.

Truncation

Since it is desirable to estimate yield as early as possible prior to harvest, truncated models, usually beginning in May, have been developed. This assumes that the Z and D values for subsequent months are zero. ? Further, subitaneous dummy values should be entered if it is determined that this is a factor.

The models are shown in the Appendix.

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CONSTANTS AND COEFFICIENTS FOR TRUNC D MODEL AT: BUENOS AIRES, ARGENTINA
December, 1976

Variable		Trend	Sub	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Constant	17.9	12.0	12.0				12.4		12.1	12.3	13.0
Trend		.301	.303				.295		.304	.292	.290
Subitaneous (A)			1.882				1.843		1.881	1.754	1.571
Subitaneous (D)			-1.781				-1.632		-1.813	-2.009	-1.857
Aug D (35)							.202		.190	.198	.091
D^2 (36)							- .039		- .050	- .049	- .067
Oct D (43)									.217	.189	.232
D^2 (6)									.058	.068	.043
Oct-Nov Z (77)										.466	
Dec Prec DFN (48)											.714
SDFN (9)											- .162
S	3.86	2.38	2.13				2.13		2.11	2.11	1.92
R^2		.63	.72				.74		.75	.76	.81

NORMALS

August Temperature = 49.1°F
October Temperature = 58.5°F
December Precipitation = 3.28 inches

NOTES: Suggest linear trend term after 1970
Meteorological and yield data base period: 1931-70 Trend: 1931=1, 1932=2,...,1960=30, 1961=31,...,1970=31*
Units: Precipitation (inches), Temperature (°F), Yield (Bu/A) Subitaneous A = Appreciation on Yield
D = Temperature departure from long-term averages; Z = Moisture Anomaly D = Depreciation on Yield
*Effect of high-yielding varieties will alter this term in the mid-1970's

CONSTANTS AND COEFFICIENTS FOR TRUNCATED MOD AT: CORDOBA, ARGENTINA
December, 1976

Variable			Trend	Sub	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Constant		16.5	14.1	13.9		14.0	13.8	14.3	14.4	14.6		14.4
Trend			.143	.142		.150	.166	.146	.133	.130		.137
Subitaneous (A)				5.02		4.45	4.21	3.52	4.00	4.13		4.29
Subitaneous (D)				-3.19		-3.53	-3.80	-4.17	-3.87	-4.12		-3.84
Jun Z	(25)					.147						
Jun D	(27)					.470	.519	.478	.492	.692		.702
Jun-Jul Z	(64)						.519	.795	.663	.623		.574
Aug Z	(33)							- .628				
Aug-Sep Z	(69)								- .385	- .596		- .533
Oct D	(43)									.270		.238
Oct Z	(41)									.888		.853
Oct Z^2	(12)									- .027		- .024
Dec Prec DFN.	(48)											- .125
S		4.57	4.48	3.72		3.58	3.46	3.41	3.47	3.00		3.03
R^2			.05	.38		.46	.50	.53	.51	.67		.67

NORMALS

June Temperature = 50.1°F
October Temperature = 61.6°F
December Precipitation = 4.83 inches

NOTES: Trend: 1931=1, 1932=2,...,1954=24, 1955=24,...,1970=24
Meteorological and yield data base period: 1931-70
Units: Precipitation (inches), Temperature (°F), Yield (Bu/A)
D = Temperature departure from long-term averages; Z = moisture anomaly

December Precipitation Average = 4.90 inches
Subitaneous A = Appreciation on Yield
D = Depreciation on Yield

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CONSTANTS AND COEFFICIENTS FOR TRUNCA MODEL AT: ENTRE RIOS, ARGENTINA

December, 1976

Variable		Trend	Sub	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Constant	14.8	12.1	12.6					13.0	13.0	12.9	
Trend		.154	.158					.129	.133	.141	
Subitaneous (A)			.719					.492	.452	.353	
Subitaneous (D)			-3.07					-2.69	-2.63	-2.55	
Aug Z (33)								.211	.333	.415	
Sep Z (37)								- .655	- .624	- .680	
Sep D (39)								.247	.265	.288	
Oct Z (41)									- .250	- .343	
Oct D (43)									.102	.154	
Nov Z (45)										- .342	
Nov D (47)										- .259	
S	3.27	3.08	2.84					2.74	2.78	2.79	
R^2		.13	.31					.44	.43	.47	

NORMALS

September Temperature = 59.8°F

October Temperature = 64.7°F

November Temperature = 70.0°F

NOTES:

Meteorological and yield data base period: 1931-70

Subitaneous A = Appreciable Effect

D = Depreciable Effect

Units: Precipitation (inches), Temperature (°F), Yield (Bu/A)

D = Temperature departure from long-term averages; Trend: 1931=1, 1932=2,...,1954=24, 1955=24,...,1970=24

CONSTANTS AND COEFFICIENTS FOR TRUNC.) MODEL AT: LA PAMAP, ARGENTINA
December, 1976

Variable			Trend	Sub	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Constant		11.4	6.42	6.49		6.40		6.68	7.14	7.24	8.63	
Trend			.293	.283		.289		.286	.289	.286	.273	
Subitaneous (A)				4.35		4.28		3.62	3.52	3.26	2.10	
Subitaneous (D)				-2.60		-2.64		-3.08	-3.16	-3.38	-4.32	
Jun D	(27)					.198		.162	.174	.196	.264	
Jul Z	(29)									.297	.385	
Aug D	(35)							.600	.781	.876	.905	
Sep Z	(37)								.397	.410		
Sep D	(39)								.713	.770	.694	
D^2	(13)								- .113	- .102	- .091	
Oct-Nov Z	(74)										.539	
Z^2	(75)										- .314	
S		4.72	4.17	3.59		3.59		3.39	3.25	3.27	3.30	
R^2			.24	.47		.48		.55	.62	.63	.64	

NORMALS

June Temperature = 46.5°F

August Temperature = 48.7°F

September Temperature = 53.5°F

NOTES:

Meteorological and yield data base period: 1931-70 Trend: 1931=1, 1932=2,...,1954=24, 1955=24,...,1970=24

Units: Precipitation (inches), Temperature (°F), Yield (Bu/A) Subitaneous A = Appreciable Effect

D = Temperature departure from long-term averages; Z = moisture anomaly D = Depreciable Effect

CONSTANTS AND COEFFICIENTS FOR TRUNC.) MODEL AT: SANTA FE, ARGENTINA
December, 1976

Variable		Trend	Sub	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Constant	19.1	14.7	15.0	15.1		14.3	15.5	15.3	15.0	14.7	14.6
Trend		.260	.243	.242		.254	.233	.238	.250	.292	.296
Subitaneous (A) (4)			4.17	4.14		4.32	3.72	3.81	3.45	3.08	3.32
Subitaneous (D) (5)			-3.19	-3.30		-3.10	-4.01	-3.70	-4.93	-5.97	-5.77
Mar-May Z (79)				.164		.209	.198	.112	.167	.301	.292
Z^2 (80)										- .023	- .031
Jun-Jul Z (64)						- .344					
Z^2 (65)						.295					
Jun-Aug Z (67)							- .718	- .900	-1.09	-1.218	-1.225
Sep D (39)								- .442	- .530	- .546	- .603
Sep Z (37)								- .289			
Oct D (43)									.439	.564	.569
D^2 (6)									.105	.167	.188
Nov D (47)										- .361	- .390
Dec Prec DFN (48)											- .295

NORMALS

September Temperature = 58.1°F
October Temperature = 63.4°F
November Temperature = 68.8°F
December Precipitation - 4.15 inches

		Trend	Sub	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S	4.79	4.39	3.76	3.79		3.85	3.73	3.64	3.58	3.58	3.54
R^2		.18	.43	.44		.45	.47	.53	.56	.59	.61

NOTES:
Meteorological and yield data base period: 1931-70
Units: Precipitation (inches), Temperature (°F), Yield (Bu/A)
D = Temperature departure from long-term averages; Z = moisture anomaly

Subitaneous A = Appreciable Effect
D = Depreciable Effect

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