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WEATHER AND GRAIN YIELDS IN THE SOVIET UNION

Padma Desai

September 1986

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FOREWORD

The International Food Policy Research Institute has pioneered in the analysis of variability in food production. First, Shakuntla Mehra drew attention to the relation between the green revolution in India and variability in foodgrain production in *Instability in Indian Agriculture in the Context of the New Technology*, Research Report 25. Then, in *Instability in Indian Foodgrain Production*, Research Report 30, Peter Hazell documented the importance of an increased tendency for fluctuations between crops and between regions to be coordinated with a consequent overall increase in fluctuation. Padma Desai adds to that line of inquiry with a detailed analysis of the Soviet Union. The task was exceedingly difficult, requiring new analytical and estimating procedures and scrutiny and adjustment of large amounts of data. The findings are of unusual importance because of the dominant presence the Soviet Union has in world grain markets, so that whatever affects Soviet grain production can have major effects on developing country exporters and importers.

The finding that policy variables have a major part in the explanation of increased variability in Soviet grain yields has important implications to developing countries, which often intercede in markets for fertilizer and face constraints on supplies of foreign exchange, electricity, and other key inputs for agriculture. The findings that weather-caused variability in one large subarea of the Soviet Union can be offset in another also suggests the value of regional agreements among smaller countries, as suggested in another IFPRI research report, by Ulrich Koester, *Regional Cooperation to Improve Food Security in Southern and Eastern African Countries*, Research Report 53.

IFPRI will continue to publish studies dealing with food supply variability and security as part of its particular concern for the very poor people who are forced by loss of employment and by escalating prices to make the bulk of the adjustment to fluctuations in their society's food supply.

John W. Mellor
September 1986

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1

SUMMARY

Because the grain belt of the Soviet Union lies far to the north, summers there are short and winters, long. The Atlantic has some moderating influence on temperatures and brings some rain, but these influences are reduced as one moves south and east. The consequences of the location of the Soviet grain belt can magnify weather's effects on Soviet grain yields. The purpose of this report is to determine how much these yields are affected by weather, and how much by factors more susceptible to manipulation by policy, such as the flow of inputs into agriculture, or by "systemic" factors, which affect the structure of incentives for agricultural production.

The focus of the analysis is the Soviet grain belt; 95 percent of Soviet cultivated area can be found in the four republics that contain this belt, the Ukraine, Belorussia, Kazakhstan, and the Russian Republic (the R.S.F.S.R., the Russian Soviet Federated Socialist Republic). The unit of analysis is the oblast, because sustained time-series data on grain yield are available for oblasts from Soviet sources.

Oblasts from the four republics were selected for study to meet two criteria. First, the distribution of sown area between winter and spring crops in these oblasts equaled the distribution in the Soviet Union as a whole. Second, the distribution of grain-sown area in the oblasts selected from a republic relative to total grain-sown area in all selected oblasts equaled the distribution of grain-sown area in the republic relative to grain-sown area in the four republics. With these criteria met, the report focuses on 14 oblasts: Altay kray, Moscow, Omsk, Rostov, Stavropol kray, Tatar Autonomous Soviet Socialist Republic (A.S.S.R.), and Voronezh from the R.S.F.S.R.; Kharkov, Kiev, Lvov, and Odessa from the Ukraine; Minsk from Belorussia; and Karaganda and Kustanay from Kazakhstan. (The two krays and the Tatar A.S.S.R. are similar in size to the oblasts, and so can be treated in the same manner.)

Weather-yield models were estimated for each oblast, using grain yields from 1950 to 1975 and the precipitation and temperatures in the critical months of the crop cycle. These models serve as the basis for the rest of the analysis.

They are used in estimations of the weather variability of yield—the variability of yield attributable to the deviation of the actual weather in a year from the mean weather in the oblast. These estimates show that when aggregate yields were good, in 1973 and 1978 for example, weather was better than average in most oblasts, and when aggregate yields were poor, in 1963 and 1975 for example, weather was worse than average in most oblasts. These estimations also show that in 10 of the 14 oblasts weather was better than average as often as it was worse than average in the period studied.

The correlation coefficients show that the variability of weather is generally correlated between oblasts in the western part of the U.S.S.R. The same can be said of the weather of oblasts further to the east. However, the weather variability of the western oblasts is not correlated with the weather variability of the eastern oblasts. The absence of this correlation means that the effect of variations in the weather on aggregate Soviet grain yields is dampened; poor yields in the west of the grain belt because of poor weather may be offset by better yields in the east because of better weather there.

When the oblasts are ranked according to how bad their weather is, it can be confirmed that weather tends to worsen as one moves south and east in the grain belt, that is, oblasts such as Minsk and Lvov have better weather than such oblasts as Karaganda and Kustanay. The estimates show that the contribution of weather fluctuations to the explained yield variance ranges from between 9 and 22 percent—in Lvov, Kiev, and

Odessa—to more than 90 percent—in Omsk, Altay kray, and Karaganda.

The weather-yield equations for the oblasts and the actual grain yields from 1958 to 1975 were used to estimate the weather variability of yield for the country as a whole for the period 1955–82. These estimates show that occasionally large variations in yield can be attributed to weather. In 1963, when the weather was bad, yields were 2.8 centners per hectare lower than they would have been had the weather been average. This translates into a reduction of output of 36 million tons and is a third of the actual yield, 8.3 centners per hectare. Similarly, when the weather was good in 1970, yields were 3.2 centners per hectare higher than they would have been had the weather been average. This was 20 percent of the actual yield, 15.6 centners per hectare, and raised output about 38 million tons.

But these are extremes. The standard deviation of the weather variability of yield is much smaller, 1.58 centners per hectare. This is only 13.3 percent of the mean yield for 1955–82, 12.8 centners per hectare. This translates into 19.8 million tons of output.

Taken as a whole, weather variation contributed 52 percent of the explained variance of yield. The remaining 48 percent was contributed by variations in inputs. This and the low standard deviation of the weather variability of yield suggest that weather has had only a moderately large effect on yield variation.

Soviet grain harvests between 1979 and 1982 were poor. Yet the estimates of the weather variabilities of yield and output for those years were small. In fact, had weather been average for all four years, output would have been only 13 million tons greater.

When the estimated variations in yield and output attributable to weather are subtracted from actual yield and output and the resulting trends are given the appropriate statistical tests, yield is found to have varied to a significantly greater extent between 1968 and 1982 than between 1955 and 1967. With weather removed from the trend, this means that policy and systemic effects on yield became larger in the later period. This suggests that the massive injection of resources into agriculture that took place during the Brezhnev years may have increased agriculture's organizational problems. A sharp increase in the application of fertilizer on grain without a matching use of better seed varieties, pesticides, water, and weed control could have contributed to yield variability. These results show that Soviet planners face serious problems in coping with the increased variability of yield. They point to the need to introduce suitable incentives and to decentralize decisionmaking in agricultural management and production.

Partly because of the large fluctuations in Soviet grain output, the Soviets began to import huge amounts of grain in the early 1970s. On the one hand, these imports and the evident Soviet desire to diversify their sources of these imports provide a good opportunity for developing countries with grain surpluses. The emergence of Argentina as a major supplier of grain to the Soviet Union attests to this.

On the other hand, an unpredicted shortfall in grain output that leads to massive imports could cause problems for grain-deficit countries. It is less likely to cause problems for China and India now than a decade ago, but the needs of poor countries in Africa and elsewhere must be protected.

2

INTRODUCTION

In 1926, the Soviet economist Chayanov emphasized that Soviet grain yield was influenced by meteorological factors that could not be fully controlled by state policies. Therefore, it should be treated with awe and addressed as "Monsieur" yield. His publisher thought otherwise. Marxist dialectics and state policies, according to him, were needed to resolve the question of grain yield and convert it into "Comrade" yield.

The debate between Chayanov and his publisher was part of the larger debate on the Soviet economy that marked the turbulent years preceding the Stalinist industrialization drive.[1] More than half a century later, the issue is still disputed.

This report is undertaken in the hope of throwing meaningful light on the dichotomy posed by Chayanov and his publisher. Its aims are to measure the effect of weather on Soviet grain yields and to assess how "systemic" factors and policies affect weather-adjusted yields. The latter include the ways inputs such as the farm capital stock, labor, and fertilizers are used and the division of Soviet farms into state and collective farms. Also included are such systemic elements as the absence of incentives, which inhibits efficient allocation of resources and innovations in farming methods. Appropriate methodologies are devised for analyzing several critical issues.

The influence of policy and systemic factors on Soviet grain yields cannot be assessed and separated from yields unless the effect of weather is measured first. For this purpose, the question is asked: if weather were to deviate from the average, by how much would yield vary in a year? A further step is to measure the contribution of weather fluctuations to yield variation. These two concepts—the deviation of weather from average, measured in terms of yield, and the contribution of variations in weather to variations in yield—are rigorously defined and incorporated in the methodology of this report.

The effect of weather on Soviet grain yield variation would be accentuated if bad weather in one place were not offset by good weather elsewhere. The association between the weather of different parts of the grain belt is examined, as is the question whether weather deteriorates as one moves south and east in the grain belt.

Finally, variations in yield, among other factors, have led to the importation of increasing amounts of grain by the Soviets, making Soviet grain demand critically important to world grain markets. A discussion of how this affects Third World countries forms the last part of the analysis.

[1] The debate between Chayanov and his publisher is cited at length in Stephen G. Wheatcroft, "The Significance of Climatic and Weather Change in Soviet Agriculture (With Particular Reference to the 1920s and 1930s)," Paper No. 11, Soviet Industrialization Project Series, Center for Russian and East European Studies, University of Birmingham, Birmingham, U.K., 1977.

3

FEATURES OF CLIMATE, SOIL, AND VEGETATION, AND THE CHOICE OF OBLASTS

The general characteristics of climate, soil, and vegetation that influence Soviet grain cultivation are important criteria for developing a weather-yield model for the selected oblasts. The criteria used to select oblasts are given in this chapter.

General Features of Climate

A distinction important for this report is between "climate" and "weather."[2] Weather is a short-term phenomenon that influences the yearly variations in yields of crops. Climate is the long-term trend of weather in a region, which influences the types of crops that can be grown and their maximum attainable yields.

Two factors determine the climate of the Soviet Union: its high latitude and extreme continentality.[3] Soviet agriculture continuously battles the environmental hazards these two elements produce.

The north-south boundaries of the Soviet Union stretch for almost 5,000 kilometers. The southern boundary lies within 12 degrees of the tropics; the northern one comes within 12 degrees of the Pole.

The consequences of these high latitudes for growing grain are many. One is the "asymmetrical annual regime of temperature": winters are long and cold; summers are short and hot. Winter is by far the longest season, with temperatures becoming extremely cold for three or four months on average. In summer, temperatures peak in the middle, becoming high for short periods. The transitional seasons of autumn and spring are brief. In fact, spring is practically nonexistent, so that by the time the snow has melted and the water has evaporated, temperatures rise sharply, affecting the growth and harvesting of winter crops and the planting of spring seeds.

The brief period between the last frost in spring and the first freezing days in autumn restricts grain growing in most areas, just as the cold, long winters do. Most crops require a frost-free season of at least three months, with two successive crops requiring at least six months. "The growing season in the mildest region of western Georgia can be as short as 180 days. On the European Plain the minimum length of growing season ranges from about 150 days in the southern Crimea to less than 90 days near Moscow and less than 30 days on the Arctic coast. The frost-free period can be as short as 180 days on the southern boundary of Central Asia, and 75 days in southwestern Siberia. Only the southern steppes and the western borderlands of the U.S.S.R., including much of Belorussia and the Baltic Republics, can be sure of no frosts in July and August."[4] As a result, the growing season is too short in some areas even for one crop and in large areas with arable land, for two crops.

Because of the high latitude, some precipitation is received as snow. Snow cover, rather than snowfall itself, is important for winter crops because they need to be insulated from the extreme fluctuations of winter

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[2] For more on this distinction, see S. Leung, W. Reed, S. Cauchois, and R. Howitt, *Methodologies for Valuation of Agricultural Crop Yield Changes: A Review*, EPA-600/5-78-018 (Corvallis, Ore.: Office of Research and Development, U.S. Environmental Protection Agency, 1978), p. 11, and G. Stanhill, "Quantifying Weather-Crop Relations," in *Environmental Effects on Crop Physiology*, ed. J. J. Landsberg and C. V. Cutting (London: Academic Press, 1977), p. 23.

[3] The discussion in this and the next section relies on Paul E. Lydolph, *Geography of the U.S.S.R.* (Elkhart Lake, Wisc.: Misty Valley Publishing, 1979).

[4] Ibid., p. 76.

surface temperatures.[5] "About 30 centimeters of snow is an ideal insulating layer. If it is thinner, the ground experiences deep freezing and frequent fluctuation of temperature; if it gets too thick, crops tend to rot from lack of ventilation."[6] In the southern zones of the European U.S.S.R., snow cover is inadequate, averaging only 10 centimeters. In western Siberia, it averages about 40 centimeters. Thus much of the grain-growing area lacks ideal snow cover. "Therefore, the Soviets usually sustain extensive winter kill in portions of the country every year. This is one of the primary problems of agriculture."[7]

Among the consequences of high latitude, then, is that winters are long and severe and summers are short, and the transitional seasons of autumn and spring are short. The effective growing season is less than ideal because the chances that there will be a late frost in spring or an early frost in autumn are high. The snow cover to insulate the winter crops from the freezing, fluctuating temperatures is again less or more than required in much of the grain belt.

The Consequences of Continentality

From west to east the Soviet Union extends for almost 10,000 kilometers, encompassing 11 time zones. The topography of this massive land mass complicates its climate.

Its geographical location and rugged mountain barriers preclude maritime influence except from the Atlantic. The mountain ranges along the southern periphery, and the lands of Southern Asia, the Arabian Peninsula, and Africa insulate the Soviet Union from the warm, moist flow of air from the Indian Ocean. The flow of air from west to east precludes maritime influence from the Pacific except for monsoon-type rains on the eastern periphery of Siberia. The Arctic Ocean is frozen most of the year so that it produces little moisture by evaporation. "About the only extensive maritime influence on the Soviet Union comes from the Atlantic in the west, and this is far removed from much of the Soviet Union. Atlantic maritime air must cross the entirety of Europe before reaching the U.S.S.R. Nevertheless, because of the prevailing westerly winds the influences of the Atlantic are carried far eastward well into Siberia and Central Asia, especially during summer. Except in the Soviet Far East, much of the precipitation that falls in the Soviet Union is derived initially from the Atlantic and its bordering seas."[8]

One consequence of the maritime air flow is that temperatures on the Soviet European plain are lower in the summer and warmer in the winter than in other places on comparable latitudes. This has a favorable effect on grain-growing in that region. However, the difference between winter and summer temperatures increases as one moves eastward. For example, winters are warmer and summers are cooler in Lvov oblast than in Kharkov oblast, which is further to the east (Figure 1). As for precipitation, it falls off sharply in the southeasterly direction both in the summer and the winter. It declines as one moves east and south because the maritime airs in the summer get dry as they travel inland. (The nearly dry air can generate rains from adiabatic cooling only on the highest mountain slopes.) As already indicated, with severe winters inland, the cold air has low capacity to hold moisture. There-

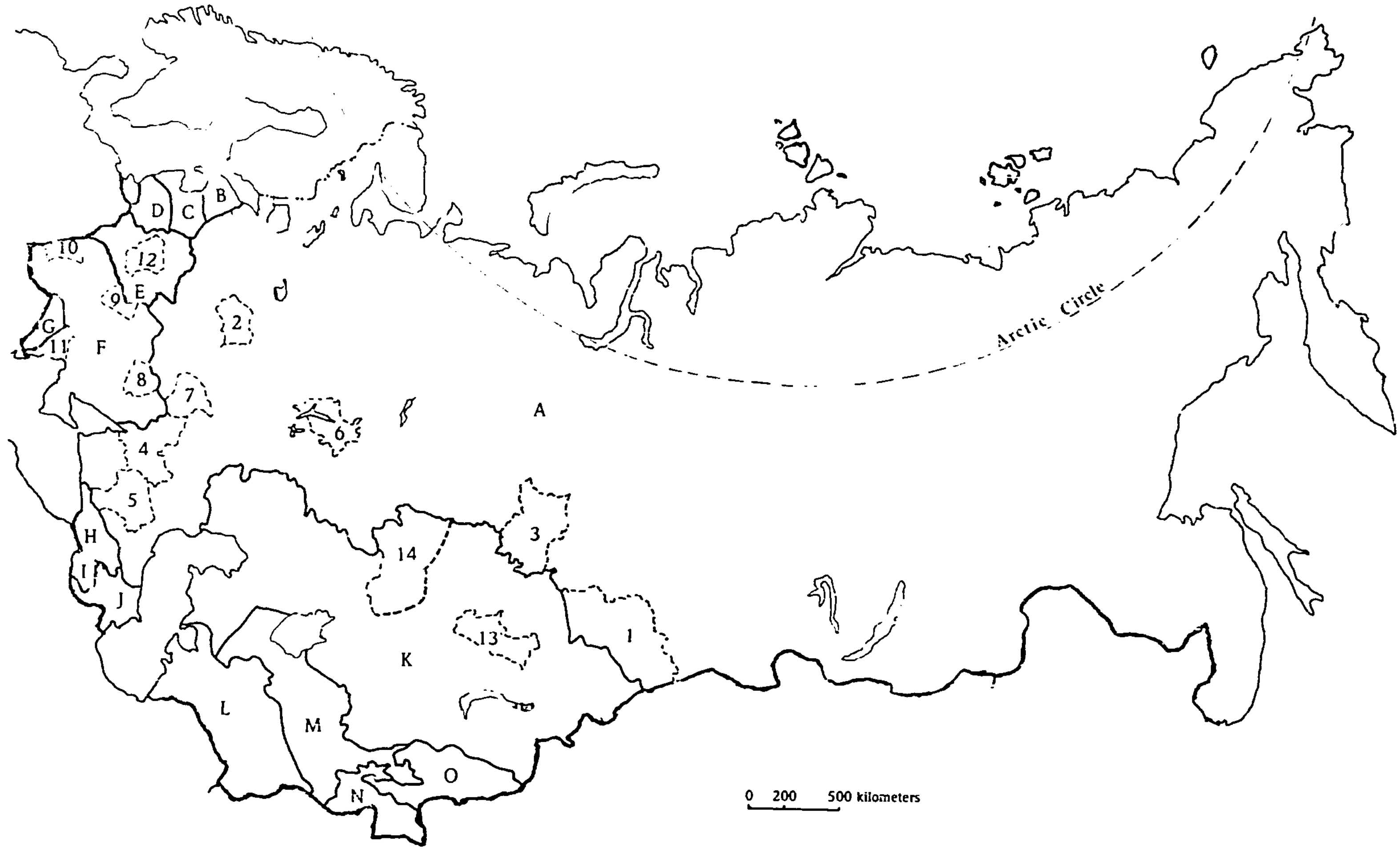
[5] The Soviet grain belt receives modest to meager snowfall during the winter: the air at high latitudes is exceedingly cold and has low capacity to hold moisture. However, the amount of snow retained varies in different parts of the grain-growing region. In the southern half of the grain belt, in western Ukraine, Belorussia, and the Baltic republics, winter thaws occur frequently, and during the 10 days of winter with maximum snow cover, the depth may average about 20 centimeters. This depth increases eastward to more than 50 centimeters in Moscow and 80 centimeters on the eastern slopes of the Urals.

[6] Lydolph, *Geography of the U.S.S.R.*, p. 90.

[7] Ibid. During the 1970s, 85 percent of the area sown in the autumn was actually harvested in the spring of the following year. For details, see Paul E. Lydolph, Gail Martell, and Robert H. Ericksen, "Recent Weather and Agriculture in the Soviet Union," n.p., 1984 (mimeographed).

[8] Lydolph, *Geography of the U.S.S.R.*, pp. 57-58.

Figure 1—Republics and selected oblasts



Republics

A Russian Soviet Federated Socialist Republic
B Estonian S.S.R.
C Latvian S.S.R.
D Lithuanian S.S.R.
E Belorussian S.S.R.
F Ukrainian S.S.R.
G Moldavian S.S.R.
H Georgian S.S.R.
I Armenian S.S.R.
J Azerbaydzhan S.S.R.
K Kazakh S.S.R.
L Turkmen S.S.R.
M Uzbek S.S.R.
N Tadzhik S.S.R.
O Kirghiz S.S.R.

Selected Oblasts

1 Altay Kray
2 Moscow Oblast
3 Omsk Oblast
4 Rostov Oblast
5 Stavropol Kray
6 Tatar A.S.S.R.
7 Voronezh Oblast
8 Kharkov Oblast
9 Kiev Oblast
10 Lvov Oblast
11 Odessa Oblast
12 Minsk Oblast
13 Karaganda Oblast
14 Kustanay Oblast

fore, precipitation declines east and south in the winters, too.

Across the plain of the European U.S.S.R., precipitation decreases sharply in a southeasterly direction from the Baltic to the Caspian Sea and into Central Asia. Most of the grain-growing area receives between 200 to 600 millimeters of precipitation annually (Figure 2). (Only in parts of the extreme northwest, including the Baltic republics and most of Belorussia, can it be as high as 1,000 millimeters.) As a result, the potential evapotranspiration increases in the southeasterly direction and the area gets dry very quickly. This area also corresponds roughly to the grain-growing triangle of the Soviet Union (Figure 3).

Soil and Vegetation Zones in the Arable Lands

The limitations of climate are further reflected in and aggravated by the shortcomings of soil and vegetation in the arable lands. These lands, which are favorable for grain cultivation, form a triangular wedge that tapers eastward into Asia (Figure 3). This area, roughly a million square miles, is one-eighth of Soviet territory. Its dominant vegetation types are mixed-forest, forest-steppe, steppe, and semidesert.[9]

The vegetation-soil region of mixed forest in the west stretches eastward from the Baltic coast (Figure 4). The forests are primarily coniferous evergreen in the north and broadleafed deciduous in the south. Minsk and Moscow oblasts, part of Kiev oblast, and the Tatar Autonomous Soviet Socialist Republic (A.S.S.R.) (all included in this report) are located in this region. Much of the area in the mixed-forest zone has been put into cultivation. "In Moscow Oblast, for instance, forests still occupy about one-third of the territory. Much of the rest is in cultivation. . . . This region [of mixed forest] has the advantage of slight drought hazard as compared to the better soils in the steppes to the south."[10]

The forest-steppe zone lies between the mixed forests of the north and the steppe. It is the northern part of the famous chernozem belt of the Soviet Union with black topsoil. "The chernozems are the best soils in the world, and the wooded-steppe zone has about the best combination of moisture and heat resources in the Soviet Union. . . . Although the zone is subject to drought, it is not as prone as the steppes and deserts to the south, and it has much better heat resources than the forest zones of the north. Thus, while it does not have the maximum amount of heat in the Soviet Union nor the maximum amount of moisture, it has the best combination of the two. This with the excellent soil makes this the potentially best agricultural region in the country, adapted to a wide variety of crops. . . ."[11] However, windblown soil erosion is a serious problem in this zone. Much of the original vegetation has been plowed up and the land put into cultivation. Lvov, Kharkov, parts of Kiev and Odessa oblasts in the Ukraine, parts of Voronezh oblast and the Tatar A.S.S.R., Omsk oblast, and parts of Altay kray in Western Siberia, all included in this report, are located in this zone.

The open steppes of the southern plains include parts of Odessa oblast in the Ukraine, Rostov oblast, Stavropol kray, the southwestern territory of Voronezh oblast in the central chernozem region, and Kustanay oblast in Kazakhstan. "Like the chernozems, steppe soils are well drained, well

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[9] The "tundra" in the extreme north and the "taiga" below it are not considered in this report because grain cannot be grown in these two zones except where the taiga borders the mixed forest zone in the European U.S.S.R. In the "tundra," which is the treeless, infertile marshy plain of the extreme north, no month has an average temperature above 10°C (50°F). The ground is permanently frozen; the absence of subsurface drainage results in swamps everywhere. Vegetation cannot grow in such conditions. The "taiga" to its south are the vast coniferous forests of Siberia. However, much of the land in this zone is devoid of trees because of poor drainage and has been overtaken by marsh, grass, and bushes. The soils of the zone are infertile, waterlogged podzolic types that preclude agriculture.

Also omitted from consideration are the desert, subtropical, and mountain zones where almost no grain is grown.

[10] Lydolph, *Geography of the U.S.S.R.*, p. 99.

[11] Ibid., p. 100.

Figure 2—Precipitation in the grain belt

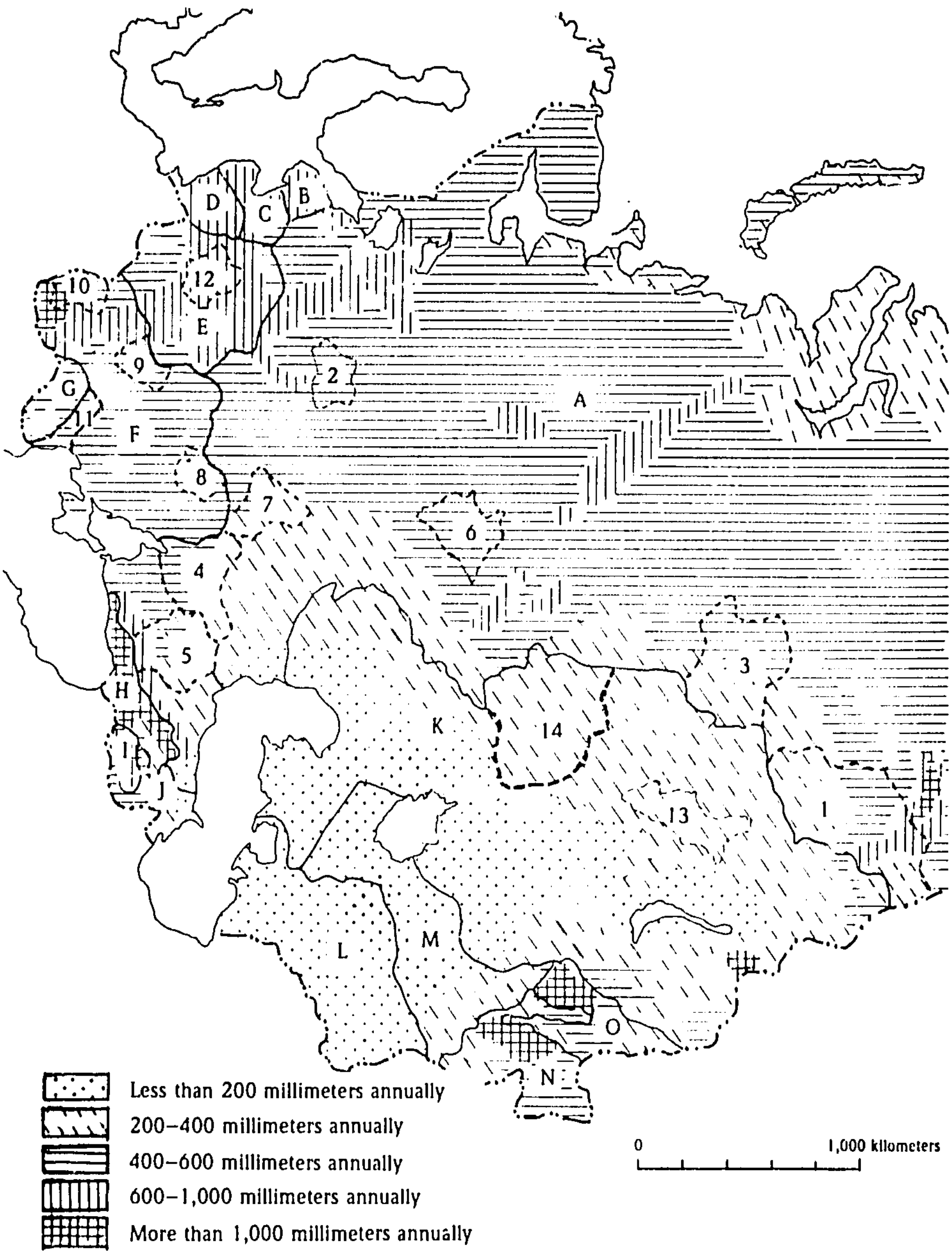


Figure 3—Distribution of sown area

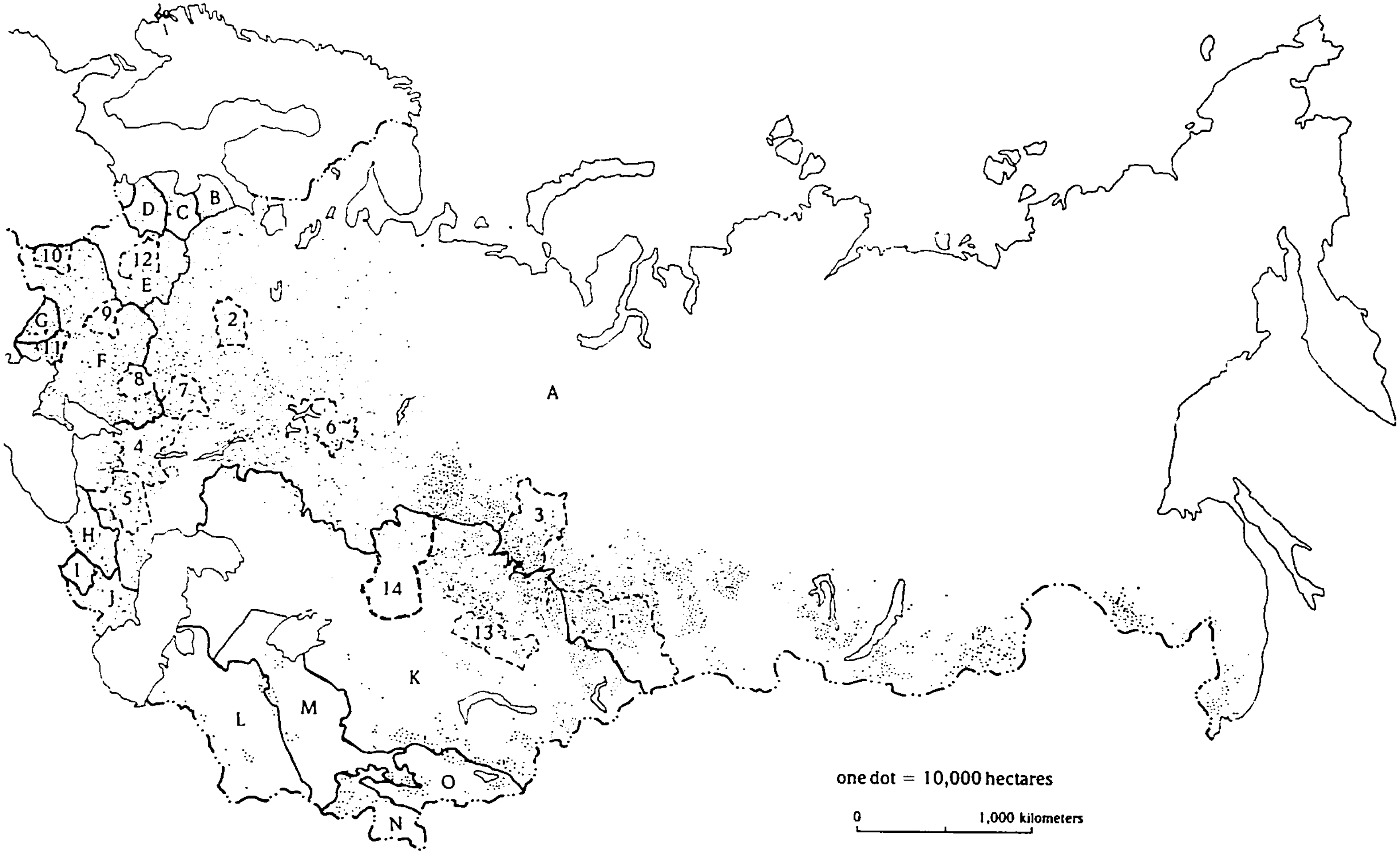
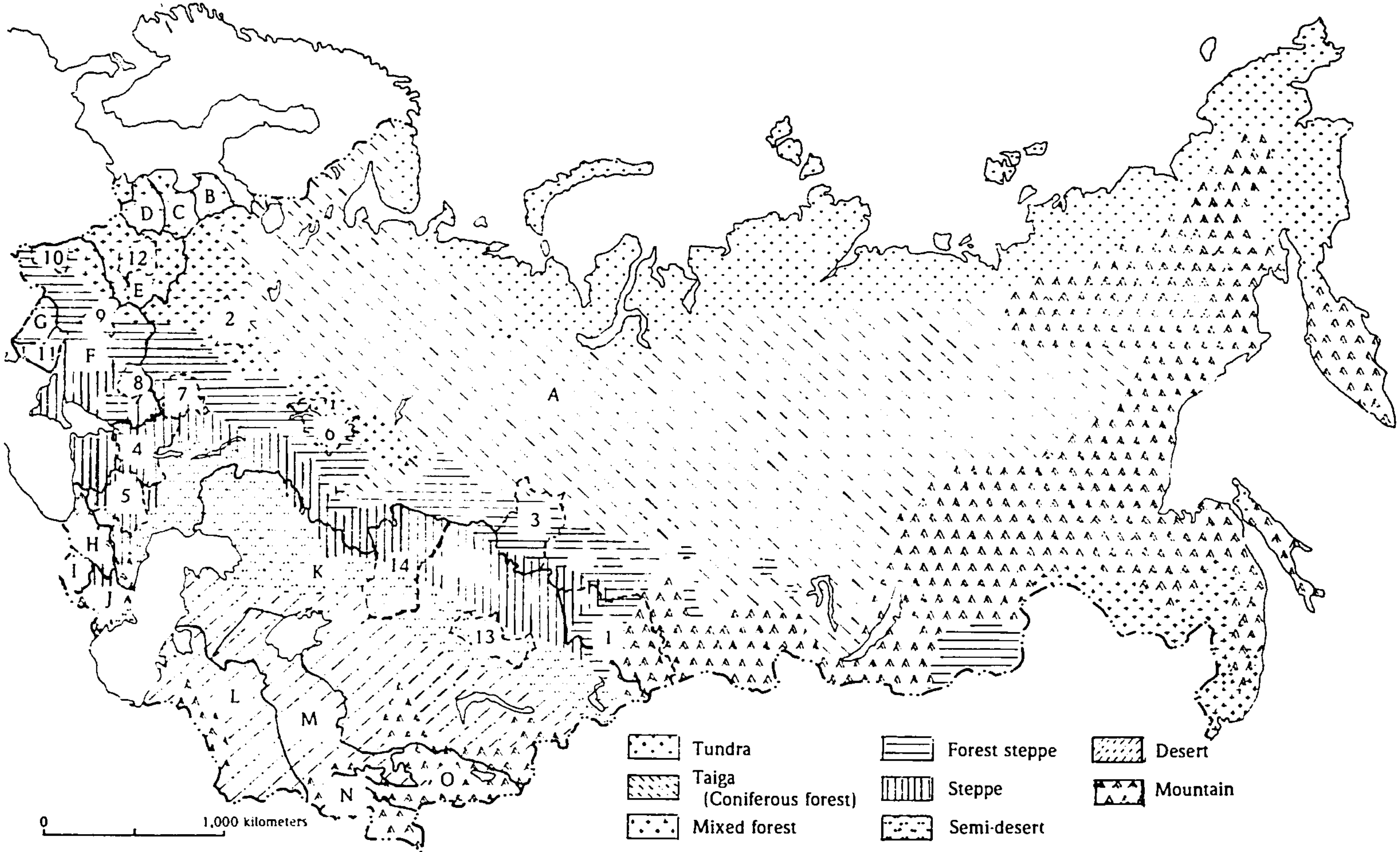


Figure 4—Vegetation zones



structured, and easy to cultivate. Heat resources in this zone are greater than anything to the north, but the moisture supply becomes less and less the farther south one goes. Therefore, crop combinations are somewhat more limited in the steppe zone than in the wooded-steppe zone. The steppe zone is well suited to the raising of wheat and sunflowers. Maize has been introduced rather heavily since the mid 1950s although it finds neither optimum moisture nor optimum heat supplies here. The steppe zone is even more susceptible to wind erosion than is the wooded-steppe to the north. . . ."[12]

The semidesert zone to the south of the steppes is the final zone under consideration. Karaganda oblast is located here. As can be expected, moisture deficiency is a constant problem in this region. "The soils here are high in mineral content but low in humus. With proper irrigation, they can be made quite productive for certain crops."[13]

It is clear from the brief discussion of climate, soil, and vegetation characteristics of the Soviet grain-growing area that heat resources increase as one travels southeastward across the region but precipitation declines sharply. The forest-steppe zone that straddles the middle of the grain-growing area eastward from north to south has the best combination of heat and moisture resources and the most fertile chernozem soils.

Choice of Oblasts

To separate the effects of weather from Soviet grain yield and output, weather must be measured accurately. This is a formidable task in view of the wide variety of climate and soil-vegetation patterns. Indeed, these features are so complex and diverse that using their average measure for the U.S.S.R. to estimate the effect of weather is unsatisfactory. A disaggregated approach that emphasizes this complexity in the grain belt is called for.[14] However, a detailed investigation of all the oblasts in the grain-growing region is not possible. Oblasts that represent weather, soil, and vegetation of the Soviet grain belt must be selected.[15]

The oblast is the basic unit of analysis in this report because it is the smallest unit for which sustained time-series data of grain yield are available in Soviet sources. The Tatar A.S.S.R. and Altay and Stavropol krays are also included.[16] Time-series data for yields are not available for rayons, administrative units smaller than the oblast, kray, and A.S.S.R. On the other hand, yield data generally from 1950 to 1975, are available for the republics, but the republic is often a much larger unit and can include a wider variety of climate, soil, and vegetation.

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[12] Ibid.

[13] Ibid., p. 101

[14] A further complication arises from the organization of agricultural activity, including grain cultivation, into state and collective farms. In other words, two oblasts that are identical in their weather, soil, and vegetation may nevertheless have different grain yields because their institutional arrangements differ. This complication is not included in the analysis of this report.

[15] By contrast, an "aggregated" model is adopted by the CIA and Ambroziak and Carey to separate the effects of weather and technology from yield (U.S. Central Intelligence Agency, *U.S.S.R.: The Impact of Recent Climatic Change on Grain Production*, ER 76-10577 U [Washington, D.C.: U.S. Central Intelligence Agency, October 1976]; and Russell A. Ambroziak and David W. Carey, "Climate and Grain Production in the Soviet Union," in U.S. Congress, Joint Economic Committee, *Soviet Economy in the 1980s. Problems and Prospects* [Washington, D.C.: U.S. Government Printing Office, 1982], 2: 109-123). Data on grain, winter wheat, and spring wheat yields and weather variables from 1962 to 1974 for all the 17 crop regions of the Soviet grain belt are pooled to estimate a single weather-yield equation, which is then used to estimate yields for any and all regions.

[16] "The oblast is purely an administrative subdivision that contains no significant nationality group other than the titular nationality of the union republic within which it is located. The A.S.S.R. administratively serves the same function as the oblast, but its boundaries have been drawn to give political recognition to an important minority nationality group. A kray is a kind of combination of the other two. Its boundaries have been laid out rather arbitrarily, primarily for administrative facility, but it contains within it lesser political subdivisions that are based on nationality groups--autonomous oblasts (A.O.) or autonomous okrugs or both." For details, see Lydolph, *Geography of the U.S.S.R.*, pp. 22-23.

Criteria for Selection of Oblasts

The oblasts are the building blocks of this report, and are to be selected by climate, soil, and vegetation. Because soil determines vegetation, the two can be treated together. If the grain belt can be divided into climatic zones, and the relative distribution of these zones among the oblasts in the grain belt is ascertained, the oblasts can be selected to represent that distribution. But while there are sources that categorize Soviet territory by climate, it has not been possible to find a source categorizing grain-sown area by climate and by oblast. Nor are data available for the distribution of grain-sown area by soil and vegetation by oblast.[17] Even if both categorizations were available, it would still be difficult to select a set of oblasts that would provide a sample that met both criteria adequately: an oblast may fall in a given climate zone but may straddle two soil and vegetation zones. Though rayons might satisfy both criteria, sustained grain yield data are not available for them. This impossibility of selecting a representative sample of oblasts is the major limitation of this report. It must be emphasized that this limitation arises because the data needed are not available.

It has therefore been necessary to select oblasts so that they fulfill the following two criteria: since grain-growing is concentrated in a few republics, the cultivated area in an oblast from a given republic as a proportion of cultivated area in the selected oblasts should equal the cultivated area in that republic as a proportion of cultivated area in the four republics. Grain-growing is concentrated in a few republics because of favorable combinations of climate, soil, and vegetation. Therefore, this criterion seeks to capture these combinations for U.S.S.R. grain-growing in the area of the selected oblasts. Next, the relative distribution of cultivated area of the selected oblasts between winter and spring crops should equal their relative distribution in the whole country. Whether an oblast is predominantly a winter or a spring cultivating area, again, depends on its climate.

Relative Distribution of Republic and Oblast Cultivated Areas

To begin with, grain-growing in the Soviet Union is concentrated in the four republics of the Russian Soviet Federated Socialist Republic (R.S.F.S.R.), the Ukraine, Belorussia, and Kazakhstan. Official data on sown area between 1960 and 1975 indicate that the average sown area of 116.7 million hectares in the four republics constituted 95 percent of the total sown area of 122.8 million hectares (Table 1). Therefore the representative oblasts should be selected from these four republics, and it should be made certain that they are in the grain-growing area. The information in Table 1 further indicates that, on average, sown area in the R.S.F.S.R., the Ukraine, Belorussia, and Kazakhstan made up 63.80, 13.45, 2.50, and 20.25 percent of the total sown area of the four. The sown area of the oblasts selected from each republic as a proportion of sown area of selected oblasts should equal these percentages.

The problems of meeting this requirement are two. First, quite a few oblasts are large, so that only limited fine tuning of selection is possible. Second, weather data collected from a centrally located weather station in the oblast grain belt must be avail-

[17] A list of articles on agricultural regions and their climate, soil, and vegetation features is available in *Vestnik Sel'skokhozyaystvennoi Nauki*, 1966, pp. 55-72. Another source is A. I. Manelya et al., *The Dynamics of Agricultural Yield in the R.S.F.S.R.* (Moscow: Statistika, 1972). However, it has not been possible to trace a source with the climate, soil, and vegetation features of the oblasts in the grain belt. By contrast, sources are readily available where climate, soil, and topographic features at district levels are incorporated in weather-yield models in North America. Examples are W. Hopkins, "Protein Content of Western Canadian Hard Red Spring Wheat in Relation to Some Environmental Factors," *Agricultural Meteorology* 9 (No. 5, 1968): 411-431; T. W. Peters, "Relationships of Yield Data to Agroclimates, Soil Capability Classification and Soils of Alberta," *Canadian Journal of Soil Science* 57 (August 1970): 341-347; Marsha Sheppard and G. D. V. Williams, "Quantifying the Effects of Great Soil Groups on Cereal Yields in the Prairie Provinces," *Canadian Journal of Science* 56 (November 1976): 511-516; and the works by G. D. V. Williams listed in the bibliography.

Table 1—Area sown with grain, by republic

Republic	1960	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
						(million hectares)							
R.S.F.S.R.	71.372	77.594	76.102	74.872	74.290	73.511	72.689	71.801	73.131	76.623	76.486	77.023	74.625
Ukraine	13.729	16.495	15.836	15.501	15.111	15.867	15.518	15.503	15.288	16.648	16.692	16.540	15.727
Belorussia	2.590	2.890	2.832	2.856	2.725	2.718	2.505	5.537	2.659	2.621	2.603	2.603	2.928
Kazakhstan	21.932	24.320	23.680	22.686	23.090	24.556	22.603	22.407	23.154	24.778	25.441	25.568	23.685
Total	109.623	121.299	118.450	115.915	115.216	116.652	113.315	115.248	114 232	120.670	121.222	121.734	116.965
U.S.S.R. Total	115.537	128.024	124.810	122.170	121.470	122.719	119.260	117.937	120.158	126.738	127.187	127.920	122.828

Sources: The data for 1960 and 1968 are from Soyuz Sovetskikh Sotsialisticheskikh Respublik (SSSR), Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov (TsSU), *Narodnoye khozyaystvo SSSR 1969* (Narkhoz 1969) (Moscow: Statistika, 1969), p. 314. The data for 1965 and 1970–75 are from SSSR, TsSU, *Narkhoz 1975* (Moscow: Statistika, 1975), p. 352; and the data for 1966 and 1967 are from SSSR, TsSU, *Narkhoz 1967* (Moscow: Statistika, 1967), p. 335.

Note: The R.S.F.S.R. is the Russian Soviet Federated Socialist Republic.

able for the years from 1950 to 1982.[18]

Keeping these limitations in mind, the following 11 oblasts, two krays, and one A.S.S.R. are selected from the four republics: Altay kray, Moscow, Omsk, Rostov, Stavropol kray, Tatar A.S.S.R., and Voronezh from the R.S.F.S.R.; Kharkov, Kiev, Lvov, and Odessa from the Ukraine; Minsk from Belorussia; and Karaganda and Kustanay from Kazakhstan. (To simplify things, these will all be referred to as oblasts hereafter.) Their mean sown area of 26.416 million hectares is 22.6 percent of the average sown area of 116.965 million hectares of the four republics and 21.5 percent of the total average U.S.S.R. sown area of 122.826 million hectares (Table 1 and Appendix 1, Table 16).

As already stated, the proportion of sown area of the oblasts selected from a republic in the total sown area of all selected oblasts should conform to the proportion of sown area of that republic in the total sown area of the four republics. For example, the share the oblasts of the R.S.F.S.R. have in the total sown area of all 14 selected oblasts is 67.7 percent; this is close to the R.S.F.S.R.'s share in the total sown area of the four republics, 64 percent (Table 2). Similarly, the share the four oblasts of the Ukraine have in the total sown area of the 14 selected oblasts is 11 percent, close to the share of the Ukraine in the sown area of the four republics, 13.5 percent. The shares of Belorussia and Kazakhstan are also very close.

This procedure implies that the cultivated area of each republic has an equal share in the selected grain area. In other words, the ratios of the sown area of the oblasts selected from a republic to the sown area in that republic must be roughly equal for all republics. These ratios in the final column of Table 2 are close, ranging from 18.5 percent for the Ukraine to 24 percent for the R.S.F.S.R. Given that the sown areas in the oblasts are large, complete equality cannot be assured.

Relative Distribution of Winter and Spring Sown Area in the Selected Oblasts

The other criterion is the correspondence of the distribution of winter and spring area between the selected oblasts and the U.S.S.R. To ensure this correspondence, the oblasts must, first, be divided into winter and spring types. The necessary information for this is presented in Table 3.[19]

Grain in Altay kray and Omsk in the R.S.F.S.R., and Karaganda and Kustanay in Kazakhstan is almost wholly grown in the spring. The severe winters in these regions rule out winter crops except for small amounts of winter rye in Altay kray and Omsk and millet in Karaganda and Kustanay. On the other hand, Stavropol kray in the R.S.F.S.R. and Lvov in the Ukraine are largely winter areas, with sown area in the spring being only 35.1 percent in Stavropol kray and 29.1 percent in Lvov. (Small amounts of spring oats are grown in Stavropol kray and some spring barley and pulses are grown in Lvov.) The rest of the oblasts are mixed, with mean sown area in the spring ranging from 44 percent in Odessa

[18] Average monthly temperature and precipitation for about 60 weather stations in the European U.S.S.R. (including about 40 in the grain belt) and 10 in the grain belt of the Asian republics are available from the *World Weather Records* of the U.S. Department of Commerce. The complete data set from 1950 to 1982 can be put together from this source for about 28 weather stations in the grain belt. The weather data used in this report were obtained from the National Oceanic and Atmospheric Administration (NOAA).

Soviet sources report detailed information on U.S.S.R. weather. The *U.S.S.R. Meteorological Monthly*, published every month (and received by NOAA), reports daily information on the average temperature and precipitation (including their maximum and minimum values) for about 200 weather stations in the Soviet Union. Average monthly temperature and precipitation for each oblast capital in the recent period is also available in L. G. Konyukova, V. V. Orlova, and Ts. A. Shver, *Klimaticheskiye Kharakteristiki SSSR po Mesyatsam* (Leningrad: Gidrometeorizdat, 1971).

[19] The information was put together from scores of republic statistical handbooks and other sources, most of which are available in the Center for International Research of the Bureau of the Census. Complete data for winter and spring area from 1958 to 1970 are available only for Tatar A.S.S.R. and Kiev oblast. They are not generally available after 1970.

Table 2—Shares of grain-sown area in selected oblasts in the grain-sown area of their republics, all selected oblasts

Republic	Selected Oblasts	Republic Sown Area as a Proportion of Total Sown Area of the Four Republics	Sown Area of Selected Oblasts in a Republic as a Proportion of Total Sown Area of Selected Oblasts	Sown Area of Selected Oblasts in a Republic as a Proportion of Sown Area in that Republic
			(percent)	
R.S.F.S.R.	Altay kray, Moscow, Omsk, Rostov, Stavropol kray, Tatar A.S.S.R., Voronezh	63.80	67.7	24.0
Ukraine	Kharkov, Kiev, Lvov, Odessa	13.45	11.0	18.5
Belorussia	Minsk	2.50	2.0	18.3
Kazakhstan	Karaganda, Kustanay	20.25	19.3	21.5

Sources: Soyuz Sovetskikh Sotsialisticheskikh Respublik, Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov, *Narodnoye khozyaystvo SSSR*, various issues (Moscow: Statistika, various years); and statistical handbooks from the republics available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census.

Note: These ratios are computed from mean sown area for 1960–75. The R.S.F.S.R. is the Russian Soviet Federated Socialist Republic

to 65.3 percent in Tatar A.S.S.R.[20]

The data for sown area in the spring derived for the period 1958–1970 from the spring sown-area ratios of Table 3 indicate that 19.378 million hectares, 73.4 percent of the area in the selected oblasts, 26.416 million hectares, was sown in the spring. The spring-winter sown-area ratio for the U.S.S.R. as a whole is 75:25 (Table 4). As intended, the two ratios are close.

Relative Distribution of Sown Area in the Climate, Soil, and Vegetation Zones

Because the required information is difficult to locate in available Soviet sources, the best that can be done to ensure that the distribution of area in the selected oblasts corresponds to the distribution of overall area by identifiable climate categories and soil and vegetation types, is to use the scattering of the selected oblasts in the Soviet grain belt and the grain-sown area of each republic (shown in Figure 3).

This scattering implies that 11 percent of Soviet grain-sown area has the climate, soil, and vegetation of the Ukraine. It cannot be ensured that the oblasts selected will reflect the distribution of these characteristics within the Ukraine precisely. But an effort to capture this distribution is made by selecting oblasts from all parts of the grain-growing region of the Ukraine. Accordingly, 3.8 percent of Soviet grain-sown area has the climate, soil, and vegetation of Odessa oblast. This is to imply that 3.8 percent of Soviet grain-sown area is in the forest-steppe vegetation zone (Figure 4) and has annual precipitation between 400 and 600 millimeters (Figure 2).[21]

[20] Should not Tatar A.S.S.R., with 65 percent spring-sown area, be classified as a spring area just as Stavropol kray, with 65 percent winter area, is designated as a winter area? The reason for designating Tatar A.S.S.R. as a mixed crop area is that it is the only area where the spring sown area has steadily risen from 54.4 percent of total area in 1958 to 78.7 percent in 1970. In other words, Tatar A.S.S.R. was a mixed oblast in the fifties and the early sixties. By contrast, the distribution of spring- and winter-sown area in Stavropol kray has fluctuated around a mean proportion of spring-sown area of 35.1 percent.

[21] The distribution of the varieties of soils (chernozem [black], nonchernozem [nonblack], and so forth) in the selected oblasts can be traced by superimposing oblast territories on a soil map. The procedure, not attempted here, would give the soil distribution through the sample area.

Table 3—Share of grain-sown area cultivated in the spring and estimated mean spring grain-sown area, by oblast, 1958–70

Year	Altay Kray	Moscow	Omsk[a]	Rostov	Stavropol Kray[b]	Tatar A.S.S.R.	Voronezh	Kharkov	Kiev	Lvov	Odessa	Minsk	Karaganda	Kustanay
							(percent)							
1958	n.a.	51.9	n.a.	40.5	36.5	54.4	50.5	55.8	42.0	28.7	34.1	45.8	84.7	93.4
1959	n.a.	n.a.	n.a.	40.3	n.a.	54.9	45.4	40.0	36.3	32.4	n.a.	45.7	82.5	92.2
1960	99.5	55.0	98.3	59.7	42.6	57.7	55.8	n.a.	71.7	35.6	57.2	43.7	n.a.	n.a.
1961	n.a.	58.0	n.a.	42.7	n.a.	60.4	47.5	55.2	48.6	n.a.	n.a.	45.8	n.a.	n.a.
1962	n.a.	41.8	n.a.	40.2	37.1	62.9	56.2	74.8	48.3	n.a.	n.a.	n.a.	n.a.	n.a.
1963	n.a.	51.8	n.a.	52.2	39.6	65.7	87.1	15.7	56.0	n.a.	n.a.	n.a.	n.a.	n.a.
1964	n.a.	48.7	n.a.	n.a.	35.2	64.3	60.3	58.4	65.6	n.a.	n.a.	n.a.	n.a.	n.a.
1965	98.4	41.5	97.6	63.8	25.9	46.8	63.6	62.9	38.7	27.2	33.4	n.a.	n.a.	n.a.
1966	97.8	48.3	96.7	61.8	29.1	65.6	61.9	46.5	40.2	27.1	46.3	n.a.	n.a.	n.a.
1967	98.6	45.8	98.5	n.a.	34.9	69.4	n.a.	65.2	41.5	27.3	39.5	n.a.	n.a.	n.a.
1968	98.5	44.1	98.0	n.a.	n.a.	70.1	n.a.	69.3	45.4	26.9	44.5	n.a.	n.a.	n.a.
1969	98.7	50.9	98.3	n.a.	n.a.	79.4	n.a.	n.a.	36.8	n.a.	38.8	n.a.	n.a.	n.a.
1970	98.5	n.a.	98.5	56.2	n.a.	78.7	68.2	n.a.	58.5	n.a.	58.3	n.a.	n.a.	n.a.
Mean	98.6	48.9	98.0	50.8	35.1	65.3	59.7	53.4	48.4	29.3	44.0	45.3	83.6	92.8
Estimated mean spring sown area (1,000 hectares)	5,336.3	195.1	2,597.2	1,724.9	803.8	1,576.2	952.3	470.8	319.9	94.6	439.4	248.3	921.4	3,697.6

Sources: Statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census.

Notes: Where "n.a." appears, the data are not available. The mean percentages are used to estimate spring grain-sown area for these years. Mean spring grain-sown area is estimated by applying the spring sown area ratios to the sown area for the oblasts from 1958 to 1970 given in Appendix 1, Table 16, and averaging the results.

[a] The ratio includes small amounts of winter wheat and barley.

[b] The ratio includes small amounts of winter barley.

Table 4—Distribution of winter and spring grain-sown area, 1960 and 1965–75

Season	1960	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Average	Share
							(million hectares)							(percent)
Winter	29.4	37.2	34.9	33.4	32.8	24.5	29.8	31.5	24.4	26.7	29.8	29.3	30.3	24.7
Spring	86.2	90.8	89.9	88.8	88.7	98.2	89.5	86.4	95.7	100.0	97.4	98.6	92.5	75.3
Total	115.6	128.0	124.8	122.2	121.5	122.7	119.3	117.9	120.1	126.7	127.2	127.9	122.8	100.0

Sources: The data for 1965–75 are from Soyuz Sovetskikh Sotsialisticheskikh Respublik (SSSR), Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov (TsSU), *Narodnoye khozyaystvo SSSR (Narkhoz 1975)* (Moscow: Statistika, 1975), p. 348. The data for 1960, 1968, and 1969 are from SSSR, TsSU, *Narkhoz 1979* (Moscow: Statistika, 1979), p. 308; and the data for 1966 and 1967 are from SSSR, TsSU, *Narkhoz 1967* (Moscow: Statistika, 1967), p. 340.

Table 5—Distribution of oblast grain-sown area among vegetation zones of the grain belt

Zone/ Oblast	Grain-Sown Area	Share of Grain-Sown Area in Zone	Area in Zone
	(1,000 hectares)	(percent)	(1,000 hectares)
Mixed forest			
Moscow	405.3	100	405.3
Tatar A.S.S.R.	2,410.7	33	795.5
Minsk	535.2	100	535.2
Total	. . .	. . .	1,736.0
Forest-steppe			
Altay kray	5,231.9	67	3,505.4
Omsk	2,559.8	100	2,559.8
Tatar A.S.S.R.	2,410.7	67	1,615.2
Voronezh	1,616.4	50	808.2
Kharkov	896.4	50	448.2
Kiev	671.7	100	671.7
Lvov	325.1	100	325.1
Odessa	1,016.6	50	508.3
Total	. . .	. . .	10,441.9
Steppe			
Altay kray	5,231.9	33	1,726.5
Rostov	3,395.5	100	3,395.5
Stavropol kray	2,264.8	100	2,264.8
Voronezh	1,616.4	50	808.2
Kharkov	896.4	50	448.2
Odessa	1,016.6	50	508.3
Kustanay	3,984.5	100	3,984.5
Total	. . .	. . .	13,136.0
Semi-desert			
Karaganda	1,102.3	100	1,102.3
Total	. . .	. . .	1,102.3

Sources: The grain-sown area data are mean acreages found in statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. The shares of grain-sown area in the vegetation zones are estimated from Figure 4; when the entire territory of an oblast is in a given zone, the share is 100 percent.

Similarly, it is possible to indicate roughly the vegetation and precipitation characteristics of the sample area by locating each oblast on a map showing vegetation or precipitation zones. If the entire territory of an oblast is in one zone, the oblast area is assigned fully to it. For example, Minsk, with an average sown area of 535.2 thousand hectares (Appendix 1, Table 16), is located in the mixed-forest zone (Figure 4) and its annual precipitation ranges between 600 and 1,000 millimeters (Figure 2). Similarly, Karaganda, with an average sown area of 1,102.3 thousand hectares, is in the semi-desert zone with annual precipitation of between 200 and 400 millimeters. But how does one assign the sown area of Altay kray? It straddles the forest-steppe and steppe zones, and two precipitation ranges, 200 to 400 millimeters and 400 to 600 millimeters. The mountain territory in the south of the kray is omitted by a rule-of-thumb procedure and two-thirds of the remaining territory is assigned to the forest-steppe zone and one-third to the steppe zone (Figure 4). Similarly, two-thirds of the kray territory (excluding the mountains) is included in the annual precipitation range of 200 to 400 millimeters and the remaining one-third in the 400 to 600 millimeter range (Figure 2).

These fractions derived from the oblast territory are approximate and are applied to average sown area (Appendix 1, Table 16) and not to the oblast territory, to derive esti-

Table 6—Distribution of oblast grain-sown area among precipitation zones of the grain belt

Zone/ Oblast	Grain-Sown Area	Share of Grain-Sown Area in Zone	Area in Zone
	(1,000 hectares)	(percent)	(1,000 hectares)
Precipitation of 200–400 millimeters			
Altay kray	5,231.9	67	3,505.4
Omsk	2,559.8	50	1,279.9
Rostov	3,395.6	50	1,697.8
Stavropol kray	2,264.8	75	1,698.6
Voronezh	1,616.4	67	1,083.0
Karaganda	1,102.3	100	1,102.3
Kustanay	3,984.5	100	3,984.5
Total	...	...	14,351.5
Precipitation of 400–600 millimeters			
Altay kray	5,231.9	33	1,726.5
Moscow	405.3	100	405.3
Omsk	2,559.8	50	1,279.9
Rostov	3,395.6	50	1,697.8
Stavropol kray	2,264.8	25	566.2
Tatar A.S.S.R.	2,410.7	100	2,410.7
Voronezh	1,616.4	33	533.4
Kharkov	896.4	100	896.4
Kiev	671.7	100	671.7
Lvov	325.1	67	217.8
Odessa	1,016.6	100	1,016.6
Total	...	...	11,422.3
Precipitation of 600–1,000 millimeters			
Lvov	325.1	33	107.3
Minsk	535.2	100	535.2
Total	...	...	642.5

Sources: The grain-sown area data are mean acreages found in statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. The shares of grain-sown area in the precipitation zones are estimated from Figure 2; when the entire territory of an oblast is in a given zone, the share is 100 percent.

mates of the distribution of the sample area among the precipitation and vegetation zones. These estimates of the sample area are given in Table 5. They indicate that 6.6, 39.5, 49.7, and 4.2 percent of the sample area is located in the mixed-forest, forest-steppe, steppe, and semidesert vegetation zones, which implies a similar distribution for overall grain area. Again, 54.3, 43.2, and 2.4 percent of the sample area has annual precipitation ranges of 200 to 400, 400 to 600, and 600 to 1,000 millimeters, implying a similar precipitation distribution in the Soviet grain area (Table 6).

It must be emphasized that the choice of oblasts in this report is not unique. The choices were made after rejecting alternatives and in full recognition that a set that fully meets even the simple criteria adopted here is difficult to get.

A different set of oblasts would change the sample distribution of precipitation, soil, and vegetation. For example, Smolensk could have been selected instead of Moscow in the R.S.F.S.R.; like Moscow, it is in the mixed-forest zone, but unlike Moscow, which has 400 to 600 millimeters annual precipitation, Smolensk has 600 to 1,000 millimeters annual precipitation in the north and west. However, there are no data from the Smolensk weather station for 1971 to 1978. Again, Orenberg could have been selected instead of Tatar A.S.S.R.: the oblast, slightly to the north, is in the mixed-forest and forest-steppe zones. The oblast also has less annual precipitation than Tatar A.S.S.R. However, no weather data are available for Orenberg. Finally, the choice of Novosibirsk instead of Omsk, both in Western Siberia in the R.S.F.S.R., would have kept the sample relative distribution of vegetation and precipitation almost unchanged. But there is no suitable weather station for Novosibirsk.

4

OBLAST WEATHER-YIELD MODELS

The yield of a given crop is influenced not only by the effects of temperature and precipitation on plant growth, but also by a complex process of interaction between climate, soil, vegetation, and topography, from the planting of seeds to the harvesting of crops. Equally important are inputs such as labor, capital, and fertilizers. The manner in which they are combined, in fact, the way in which grain cultivation is organized, is critical. Models that estimate and predict grain yield must include all these factors.[22]

A caveat must be introduced at the very outset about the types of weather-yield models used here.[23] They are empirical-statistical exercises that employ regression techniques relating grain yield statistics from different areas to weather data from roughly the same areas. The causal or physiological approach that requires a detailed inquiry into the biological-physical process of interaction between the plant-soil system and the immediate atmosphere-soil environment of the plant is eschewed.[24] While critical stages in the crop cycle are included in the models, the "exact biological clock" of the stages of crop development from seeding to maturity is not.

Considerations in Choosing the Oblast Weather-Yield Models

What considerations are relevant in selecting the oblast weather-yield models? First, the oblasts must be classified as winter, spring, or mixed. This was done in the preceding chapter. Next, inputs such as capital, labor, and fertilizers are assumed to be included in the time trend of the oblast specification.[25] Time series data of input use by oblast are not available. The parameter of the time trend can be used to measure the contribution to yield of the inputs representing a given state of farming technology. In the Soviet case, they also represent state policies of input allocations implying centralized decisionmaking and the absence of incen-

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[22] Martin H. Yeh, "Yield Predictions for 1965 Wheat, Oats, and Barley in Manitoba," *Canadian Journal of Agricultural Economics* 13 (No. 2, 1979): 405–417, distinguishes among four factors that influence yield: resources (R), such as land, labor, and capital; technology (T), which includes innovation in mechanization and management and improved farming practices; weather (W), which includes the direct influences of rainfall and temperature and indirect influences such as insect damage and plant disease; and residuals (e), which include all other factors.

In this report, W does not include the "indirect" influences.

[23] For an illuminating discussion of the classification of such models, see W. Baier, "Note on Terminology of Crop-Weather Yields," *Agricultural Meteorology* 20 (April 1979): 137–145; and Felix N. Kogan, "Large Area U.S.S.R. Barley-Yield Models: Development and Evaluation," Statistical Reporting Service, Statistical Research Division, U.S. Department of Agriculture, Washington, D.C., February 1983.

[24] A mixed, cause-and-effect and empirical-statistical model, where the biological growth rates of spring wheat are regressed on weather variables, and yields are regressed on the estimated plant growth index and weather variables, is used in J. R. Haun, "Prediction of Spring Wheat Yields from Temperature and Precipitation Data," *Agronomy Journal* 66 (May-June 1974): 405–409.

[25] This is the standard method of incorporating factor inputs in the weather-yield models. One of the earliest studies of the impact of rainfall on wheat yield used the time trend in the equation (R. A. Fisher, "The Influence of Rainfall Distribution on the Yield of Wheat Crop," *Philosophical Transactions of the Royal Society* [Series B], No. 213, 1924, pp. 89–142). So did Thompson in his analysis of the impact of weather on the yields of wheat, corn, soybeans, and sorghum. Other studies that use the time trend to approximate the application of inputs are Orlan Buller and Wuu-Long Lin, "Measuring the Effect of Weather on Crop Production," *Canadian Journal of Agricultural Economics* 17 (February 1969): 91–98; and Sheppard and Williams, "Quantifying the Effects of Great Soil Groups," pp. 511–516. Factor inputs are generally represented by the time trend in the Soviet weather-yield models summarized in Felix N. Kogan, *Grain Production in the U.S.S.R.: Present Situation, Perspectives for Development and Methods for Prediction*, in cooperation with the Atmospheric Science Department of the University of Missouri, Staff Report No. AGES 810904 (Washington, D.C.: U.S. Department of Agriculture, 1981).

tives.[26] Variations in all these elements, including erratic input supplies, are assumed to be included in the error term of the equation.[27]

Another problem is the definition of the weather variables to be incorporated in the weather-yield models. The most extensive and sustained time-series of weather data for the oblasts included here are average monthly precipitation and temperature. Indeed, the availability of such data was one of the criteria of oblast selection. The monthly temperature and precipitation are averages of daily data broadcast by weather stations in the oblasts. Most of the stations are located in the cities having the same name as the oblast (Moscow, for example). The station in the Tatar A.S.S.R. is in Kazan, Stavropol kray's station is in Piatigorsk, and Altay kray's station is in Barnaul.

The major limitation of monthly temperature and precipitation as weather variables is that they do not represent the effective weather acting on a plant to produce yield. Indexes of evapotranspiration and soil moisture derived from temperature and precipitation data are generally more effective.[28] But because of the lack of data and the difficulties of deriving these weather indexes for the Soviet grain belt with the methodologies available, they have not been constructed for this report (see Appendix 2 for a discussion of alternative methodologies and their limitations).[29]

Equally complicated is the problem of selecting the relevant months for which temperature or precipitation should be included in the weather-yield models. The paramount consideration is that the effects of weather in these months should be agronomically relevant in the stages of the crop cycle.[30] In other words, spurious association between yield and weather must be avoided.[31] The dates of planting, emergence, heading, and maturing of the crops are needed to establish a connection between the advancing stages of the crop

[26] By contrast, in a market economy, farm input use can change in response to input prices. Indeed, in contrast to the Soviet practice where crop plantings are determined by planned targets, the choice of crops will vary depending on the expectations of future prices. These market responses are absent in Soviet grain-growing.

[27] The use of an input, such as fertilizer, will fluctuate because of production shortfalls and inefficient supply systems. Such variations will be measured in the weather-yield models by the error term.

[28] For example, the inclusion of potential evapotranspiration (PE), in addition to precipitation, in the regression improves the regression equations analyzing Canadian prairie wheat yields during 1952–67 in G. D. V. Williams, "Weather and Prairie Wheat Production," *Canadian Journal of Agricultural Economics* 17 (February 1969): 99–109. Following W. Baier and G. W. Robertson, "The Performance of Soil Moisture Estimates as Compared with the Direct Use of Climatological Data for Estimating Crop Yields," *Agricultural Meteorology* 9 (No. 5, 1968): 17–31, Williams estimates monthly PE from monthly averages of daily maximum and minimum temperatures and mid-month solar radiation. The author suggests that the model could be simplified further and improved by combining the precipitation and PE variables into a single soil moisture index.

[29] The weather indexes employed in the Soviet weather-yield models are discussed in Kogan, *Grain Production in the U.S.S.R.*

[30] Such relevance would be shown if the estimated parameter had the correct sign and size. It must be emphasized that the primary aim of the weather-yield models here is not to identify and measure the influence of each independent weather variable, but, rather, to use them to estimate oblast yields for the years 1950 to 1975 and predict them beyond 1975. Relevance, therefore, implies that the parameter must have the sign suggested by agronomic considerations. For example, high July temperature after the planting of the spring crop deprives the germinating seeds of soil moisture and, therefore, reduces spring yields. The sign of the estimated parameter must be negative.

It is not unusual to identify the critical stages of the crop growth cycle in terms of months. For example, Buller and Lin, "Measuring the Effect of Weather on Crop Production," pp. 91–98, use drought severity indexes of October (of the preceding year), April, and June to represent the planting or pregrowing, growing, and heading stages in their analysis of wheat yields in Northwestern Kansas from 1932 to 1965. Neil V. Weber, "Modelling Predictive Indexes for Indiana Corn Production: 1960–69," Professional Paper No. 10, Department of Geography and Geology, Indiana State University, Terre Haute, Ind., 1978, includes direct weather variables of monthly rainfall from April to August (along with growing degree days plus a slope variability index) to predict Indiana corn production. Richard W. Katz, "Sensitivity Analysis of Statistical Crop-Weather Models," *Agricultural Meteorology* 20 (August 1979): 291–300, uses monthly weather variables, with linear and quadratic terms, for modeling wheat yields for the three westernmost crop districts of Kansas.

[31] The procedure adopted here differs from the stepwise estimation method. The latter is often used when the data set is massive and includes a large number of crop districts with a variety of soil characteristics and weather variables. In such instances, it is difficult to derive each equation from a priori reasoning about the effect of the weather variables on crop yields. Instead, the search for the predictor variables proceeds by sequentially introducing those that improve the value of R^2 till a

(continued)

cycle and monthly temperature and precipitation in the oblast. The exact dates are not available for use in this report. The choice was, therefore, made on the basis of an approximate timetable of the stages of the crop cycle for the winter, spring, and mixed oblasts.[32]

The crop cycle for winter oblasts usually begins in mid-August when sowing begins and ends in May or early June of the next year when the crop is harvested. The soil moisture before, during, and immediately after the planting should be adequate and the temperature should be seasonable. The dormant months are approximately November to February. The snow cover during that period should be deep enough to protect the sprouts from freezing and fluctuating temperatures but not too deep or they will rot. March to May are the seasonally active months of the crop calendar: sometime in April, the cereal develops from the heading to the milk and dough stages. Moisture is necessary for the process. The final days of crop maturity and harvesting should be cool and dry.

The crop cycle for spring oblasts is more difficult to define. In the four spring oblasts of Altay kray, Omsk, Karaganda, and Kustanay, spring planting can begin only after the winter snow has thawed and the water has evaporated. If the planting is delayed because there is too much snow, the harvesting will also be delayed till late October. Temperatures in June and July should not be too high; otherwise the germinating seeds and sprouts can wither. Precipitation too should be enough in these months to ensure that the soil is moist. September and October, during which the crops mature and are harvested, should be cool and dry.

Finally, the relevant months in the crop cycles of both the winter and spring crops must be incorporated in line with the above reasoning in the weather-yield models of the mixed oblasts.

The approach in formulating the oblast weather-yield models is to include the temperature, the precipitation, or both of the months that are critical in the crop cycle. Such a selective approach clearly differs from the alternative procedure in which each month in the crop cycle is regarded as equally important. Indeed, it can be argued that in moisture-deficient oblasts, soil moisture at seeding time depends on its accumulation during several presowing months. The decisive arguments in favor of the selective approach are two. First, the climate of the Soviet grain-growing region, as already indicated, is generally characterized by long, severe winters, short summers with peak temperatures, and brief transitional seasons of autumn and spring. The onset and duration of autumn, when spring crops are harvested and winter crops are sowed, and of spring, when winter crops begin to mature, are therefore critical. So the weather variables of September and March are included in the initial formulations of the models. Also included are precipitation in September and October, especially for Altay kray and Omsk oblast in Western Siberia and

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(footnote 31 continued)
specified number of predictors—the number depending on the sample size—are included. For example, the first 10 independent predictors, which include the time trend, the weather, topography, and soil texture, are included in G. D. V. Williams, M. A. Joynt, and P. A. McCormick, "Regression Analysis of Canadian Prairie Crop-District Cereal Yields, 1961–1972, in Relation to Weather, Soil and Trend," *Canadian Journal of Soil Science* 55 (February 1975): 43–53. The search procedure consists in first introducing the trend, then the soil texture and topographic characteristics and, finally, the weather variables. The procedure is also employed in Baier and Robertson, "The Performance of Soil Moisture Estimates"; Buller and Lin, "Measuring the Effect of Weather"; G. D. V. Williams, "Geographical Variations in Yield-Weather Relationships over a Large Wheat Growing Region," *Agricultural Meteorology* 9 (Nos. 3/4, 1972): 265–283; Daniel W. Bridge, "A Simultaneous Model Approach for Relating Effective Climate to Winter Wheat Yields on the Great Plains," *Agricultural Meteorology* 17 (September 1976): 185–194; Sheppard and Williams, "Quantifying the Effects of Great Soil Groups"; and Weber, "Modelling Predictive Indices."

It is possible that the stepwise regression procedure may pick up a predictor variable that raises the R^2 but has no agronomic relationship to yield. For a discussion of the problem of predictors with an inconsistent or spurious relationship to yield and the need for a priori knowledge of yield response to climate, see Clarence M. Sakamoto, "The Z-Index as a Variable for Crop Yield Estimation," *Agricultural Meteorology* 19 (August 1978): 311.

[32] The critical element in determining the crop cycle is the date of sowing. The approximate dates of sowing are given for each oblast in the discussion of the individual weather-yield models. These dates could be obtained for the mixed oblasts only for the winter cycle.

Karaganda and Kustanay oblasts in Kazakhstan where the spring crop is often harvested in wet cloudy weather.[33] Again, given that summers are short with peak temperatures usually occurring in June and July, the temperature variables of these months are included in the spring weather-yield models to measure their adverse effects on yields.

The second argument is that adverse weather events such as *sukhovey*, which can damage the ripe winter crops, droughts in the summer months with their adverse effects on the spring plantings, and an early frost, which can destroy the winter plantings, have a high probability of occurring.[34] Where the approximate timing of these events can be identified in the relevant oblasts, the relevant monthly temperature variables are again included.

The preliminary models resulting from the above procedure can be adjusted to account for specific statistical problems.[35] For example, the precipitation and temperature of a given month are often highly correlated. High temperatures in the winter months may be associated with high precipitation. High temperatures in the summer months are likely to be associated with low precipitation.[36] In such cases, the final choice of the weather variable is made after a careful investigation of the signs and t values of the estimated parameters of both variables in the initial formulation.

Another possibility is that the temperature of a given month may be positively correlated with that of the preceding month. This problem is handled by averaging the temperature of two or more months. The temperature, the precipitation, or both is also averaged when this improves the equation statistically, even when they are not correlated over two or more months.

The models adopted here are, with a few exceptions, linear. The exceptions support the hypothesis that grain yield rises with a weather variable up to a maximum and then declines. This quadratic formulation is tried when a few observations of the weather variable measured on the horizontal axis of the scatter diagram (with yield measured on the vertical axis) are in the southeast corner.

Oblast Weather-Yield Models

The models for each oblast are given below. The reasons why each is specified as it is are discussed. The estimated parameters are interpreted and their effects on yield indicated. The square of the correlation coefficient (R^2), the Durbin-Watson statistic (D.W.), and the standard error of the regression (SER) are given under each equation. The t values of the parameters are in parentheses under each estimate. The weather variables are numbered according to the month. For example, PREP4 represents April precipitation and TEMP6, June temperature. LPREP10 is October precipitation with a lag of one year: the crop cycle for the winter crop begins in the autumn of the preceding year. $(TEMP4)^2$ denotes the squared value of the April temperature. T in each equation represents the time trend.[37] Parameters marked with an asterisk are not significant at the 5 percent level.

Altay Kray

Altay kray in the R.S.F.S.R. is one of the largest of the selected oblasts, with an aver-

[33] For a discussion of the problems of the two-stage harvesting in the Soviet grain belt generally in wet, cloudy conditions, see Lydolph, Martell, and Ericksen, "Recent Weather and Agriculture," p. 6.

[34] *Sukhovey* are dry, hurricane-force winds that blow across the southern plain, which includes the desert of Central Asia, eastern Ukraine, and the lower Volga region, generally in the late spring and early summer. They have a devastating impact on mature crops.

[35] The sequence of equations from the initial formulation to the final choice is not reproduced here. They are available from the author on request.

[36] The matrix of R^2 of the 24 weather variables for each oblast is used to determine such positive or negative correlation among the weather variables.

[37] Oblast yields, which are available from 1950 to 1975, have missing values that differ in each set. Therefore the time trend in each equation is not identical. It is, however, represented by T for simplicity.

age of 5,231.9 thousand hectares sown with grain. The territory in the north and the west is steppe and forest-steppe whereas mountains dominate the remaining half. Grain cultivation is concentrated in the northern steppes. Precipitation in the area under cultivation is generally low, with an annual range between 200 and 400 millimeters. The highest precipitation, averaging between 49 and 62 millimeters, occurs in June, July, and August. June and July are the hottest months with mean temperatures of 18°C and 20°C. The main crops are spring wheat and oats. Marginal amounts of maize are also grown. Spring sowing is done between late April and early June.

The kray is treated as a spring producer. Variables included in the initial formulation were March and April temperatures, which contribute to timely spring conditions, April and May precipitation, which is important for soil moisture for spring sowing, June and July temperatures, and September precipitation (harvesting begins then). The final equation is

$$\begin{aligned} Y_{AL} = {} & \underset{(6.8700)}{46.5540} + \underset{(1.5271)}{0.0808T^*} \\ & \underset{(2.3526)}{0.0660PREP4} - \underset{(2.7705)}{0.6994TEMP6} \\ & - \underset{(5.9103)}{1.2349TEMP7} \\ & - \underset{(3.2460)}{0.0713\ PREP9} + e_{AL}; \end{aligned} \qquad (1)$$

$R^2 = 0.8344$, D.W. = 1.9360, SER = 1.7990, number of observations = 26.

(The equation worsens when TEMP6 and TEMP7 are averaged, with the estimates of R^2 and D.W. declining to 0.8133 and 1.8016, and the SER rising to 1.8639.)

High precipitation in April contributes to soil moisture and has a positive impact on spring plantings. High temperatures in June and July have a negative effect on yield. Finally, September rains interfere with the harvesting of spring crops; hence the negative sign.

Moscow Oblast

Moscow oblast was formed in 1929. The oblast is heavily industrialized, and farming, especially grain cultivation, plays a minor role. An average 405.3 thousand hectares is sown with grain. Fodder crops occupy over half the arable land. The oblast is in the interior but is affected by the Baltic: winter temperatures are low without being extreme and summer temperatures are generally moderate. Precipitation is adequate, with an annual range of between 400 and 600 millimeters. Of the summer and autumn months, precipitation has the widest range in October with a minimum of 7 millimeters in 1961. Winter barley and rye and spring oats are the main crops. Winter crops are planted between August 10 and 25.

The oblast is treated as a winter-spring crop producer. Given the moderate climate, the critical variables are precipitation in October after winter sowing, precipitation and temperature in June when the winter grain is harvested and the spring crop is planted, and precipitation in September when the spring crop is harvested. The initial formulation also included May temperatures, which are important for the winter plant growth, and July and August temperatures, which are important for the spring crop. The equation resulting after some trial and error is

$$\begin{aligned} Y_{MO} = {} & \underset{(2.3763)}{-71.9353} + \underset{(12.1359)}{0.8841T} \\ & + \underset{(4.3201)}{0.0524LPREP10} + \underset{(2.3452)}{0.0564PREP4} \\ & + \underset{(2.3954)}{9.0514TEMP6} \\ & - \underset{(2.5645)}{0.2961(TEMP6)^2} \\ & - \underset{(1.6243)}{0.0249^*PREP9} + e_{MO}; \end{aligned} \qquad (2)$$

$R^2 = 0.9681$, D.W. = 2.2613, SER = 1.5862, number of observations = 21.

(The first-order serial correlation correction coefficient is statistically not significant. Therefore, equation (2) can be accepted without correction.)

High precipitation in October provides moisture to the winter seeds (this is important because October precipitation can be as low as 7 millimeters). Hence the positive sign. High precipitation in April increases yields because it contributes to winter plant growth. Temperatures in June higher than 15.3°C are harmful for spring sowing. Therefore, the sign of the quadratic term is negative. September rains interfere with the harvesting of the spring crop, so September precipitation has a negative sign.

Omsk Oblast

Omsk in Western Siberia in the R.S.F.S.R. is another large oblast, with an average grain-sown area of 2,559.8 thousand hectares. The oblast is in the forest-steppe zone, and much of the land was brought under the plow in the Virgin Land campaign of the 1950s. The southern steppe has rich soil, which is cultivated intensively. The climate is severe, with cold, harsh winters and hot summers. Precipitation throughout the year is low, with an annual range of between 200 and 400 millimeters. The hottest month is July with a chance of *sukhovey* occurring. Agriculture dominates the economy with spring wheat as the main crop. Spring grain is sown between late April and early June.

Omsk is a spring oblast. April to July precipitation, June to August temperatures, and September precipitation were included in the initial formulation. The final formulation is

$$Y_{OM} = \underset{(6.9797)}{29.7647} + \underset{(1.7907)}{0.0877*T} - \underset{(2.9830)}{0.4736TEMP5} + \underset{(2.2409)}{0.0454PREP5} + \underset{(4.9835)}{0.0658PREP6} - \underset{(5.1307)}{1.0421TEMP7} + e_{OM}; \quad (3)$$

R^2 = 0.8412, D.W. = 1.7356, SER = 1.6572, number of observations = 25.

(When PREP5 and PREP6 are kept separate and TEMP5, TEMP6, and TEMP7 are averaged, the equation is worse with an R^2 of 0.7286 and a D.W. of 1.0742. Equation (3) is also slightly better than the alternative formulation in which PREP5 and PREP6 are averaged.)

High May and July temperatures with chances of *sukhovey* in July reduce spring plantings. High precipitation in May and June provides soil moisture during sowing and subsequently aids seed germination. Therefore, these variables appear with a positive sign.

Rostov Oblast

The average grain-sown area in Rostov oblast in the southwestern R.S.F.S.R. is 3,395.6 thousand hectares. Most of the oblast is a low, rolling plain formed by the wide flood plains of the Donets and Don rivers. The natural vegetation of steppe grass on the fertile soil has been almost entirely replaced by farming. Precipitation is moderate but variable around monthly averages. June is one of the hottest months, with an average temperature of 21°C. *Sukhovey* in May and June may occur as often as four times a year. The oblast produces winter wheat and barley, which are planted between August 25 and September 20, and some spring wheat.

The oblast is treated as a winter-spring producer. March to May precipitation, March to August temperatures, and September precipitation were included in the initial formulation. The final equation is

$$Y_{RV} = \underset{(4.8653)}{68.7044} + \underset{(1.3979)}{0.1624*T} + \underset{(3.0645)}{1.0810} \times \left(\frac{TEMP3 + TEMP4}{2}\right) + \underset{(2.2517)}{0.0432PREP5} - \underset{(3.8866)}{1.3661TEMP6} - \underset{(1.2289)}{0.5458*TEMP7} - \underset{(2.3908)}{1.0250TEMP8} + e_{RV}; \quad (4)$$

R^2 = 0.8521, D.W. = 1.4561, SER = 2.3291, number of observations = 19.

(When TEMP6, TEMP 7, and TEMP8 are averaged, the R^2 deteriorates slightly and the D.W. improves to 1.6005 but the t value of the trend parameter worsens to 0.9099.)

High temperatures in March help melt the snow. In April they promote winter plant growth. Therefore, the sign of the average temperature variable is positive. Precipitation in May provides moisture for spring sowing. By contrast, high temperatures in June, July, and August reduce the spring crop.

Stavropol Kray

Stavropol kray is located in the northern Caucasus in the southwestern R.S.F.S.R. The arable lands are mostly fertile steppe soils and are cultivated intensively. Winters are dry with low precipitation (averaging 20 millimeters in January, 27 millimeters in February, and 25 millimeters in March), and moderately low temperatures, averaging −3°C in January and −2°C in February. Summers are hot with June temperature averaging 19°C (with a low standard deviation of 1°C). In fact, the crops can be devastated by dust storms and heat waves in June. Winter wheat and maize are the main crops and are planted between September 25 and October 5. Grain is sown on an average 2,264.8 thousand hectares.

Stavropol kray is treated as a winter producer. February to June temperatures and precipitation were included in the initial formulation. February is the critical month: February precipitation is low (averaging 27 millimeters) with the highest variability (indicated by a standard deviation of 27 millimeters). February temperature also has the highest variability among the winter months, with a mean of −2°C. The final equation is

$$\begin{aligned} Y_{ST} = {} & \underset{(4.3752)}{35.0441} + \underset{(2.9880)}{0.2668T} \\ & + \underset{(4.1940)}{0.7726TEMP2} + \underset{(1.0491)}{0.0469^{*}PREP2} \\ & - \underset{(3.0682)}{1.3030TEMP6} + e_{ST}; \qquad (5) \end{aligned}$$

$R^2 = 0.7471$, D.W. = 1.5122, SER = 2.1606, number of observations = 18.

Temperatures in February are generally below freezing; precipitation is also low. Low precipitation with freezing temperature implies that there will be too little snow cover for the winter sprouts. By contrast high February temperatures along with high precipitation indicate that the snow cover is probably adequate. Therefore February precipitation and temperature have positive signs. Finally, the negative sign of high June temperature shows the adverse effects that high June temperatures have on the winter crops.

Rostov and Stavropol are adjacent to each other and the initial formulations are similar, but the models turn out to be different. March and May precipitation is included in Rostov's equation but not in Stavropol's. It is more variable in the former and has lower minimum values. By contrast, precipitation in Stavropol is less variable and has a substantially higher minimum value.

Tatar A.S.S.R.

The average grain-sown area of the Tatar A.S.S.R in the east-central R.S.F.S.R. is 2,410.7 thousand hectares. The territory in the forest-steppe zone has podzolized black earth soil. The climate is continental: winters are long and severe, and summers are hot. Precipitation is adequate, ranging between 400 and 600 millimeters annually, but highly variable around monthly averages. The maximum rainfall occurs in July and August. The main crop is spring wheat, but marginal amounts of maize and winter wheat are also grown. Spring crops are planted between late April and early June.

The oblast is a winter-spring crop producer. Temperatures and precipitation from April to July, and precipitation in September, when the spring crop is harvested, were included in the initial formulation. The following equation is the final result; April temperatures appear with a quadratic term:

$$\begin{aligned} Y_{TA} = {} & \underset{(3.4028)}{14.5208} + \underset{(7.2700)}{0.3574T} \\ & + \underset{(5.1949)}{2.3623TEMP4} - \underset{(5.8593)}{0.2444(TEMP4)^2} \\ & - \underset{(2.2373)}{0.0212PREP6} \\ & - \underset{(2.6673)}{0.5564TEMP7} \\ & - \underset{(1.8530)}{0.0247^{*}PREP9} + e_{TA}; \qquad (6) \end{aligned}$$

$R^2 = 0.8878$, D.W. = 1.5172, SER = 1.2662, number of observations = 20.

High temperatures in April up to 4.8°C help melt the snow and establish suitable conditions for winter plant growth. June precipitation interferes with the harvesting of the winter crop. Therefore, the parameter has a negative sign. High July temperatures reduce spring plantings. Finally, September precipitation interferes with the harvesting of the spring crop, so both parameters have negative signs.

Voronezh Oblast

Voronezh oblast is situated in western R.S.F.S.R. It bisects the basin of the middle Don River in a north-south direction. The oblast lies in the forest-steppe and steppe zone with alternating vegetation of oak forest and grass steppe. The soil is exceptionally rich but intensive plowing has caused soil erosion. Agriculture in the oblast is highly developed and is dominated by the cultivation of wheat, maize, and other grains, which are sown on an average 1,616.4 thousand hectares. This is one of the few areas of the Soviet Union with a climate suitable for maize. Voronezh is located next to Kharkov, yet the climate is different. It is drier than Kharkov, with annual precipitation between 200 and 400 millimeters, and has a lower mean precipitation throughout the year. It resembles Rostov in that its monthly precipitation is extremely variable with high standard deviations. The oblast is susceptible to cold spells in winter and *sukhovey* in summer. Temperatures can be as high as 22°C between June and August. Spring and winter grains are grown in approximately a 40:60 ratio.

The formulation of a weather-yield model for Voronezh is complicated by the inclusion of maize in the crop sequence because maize must be left in the field long enough to ripen fully. This delays the harvesting of the spring crop and the planting of winter wheat in the autumn, which then becomes susceptible to winter-kill from freezing November temperatures. If winter-kill is excessive, the ground may simply be plowed up the next spring for the spring crop. If the maize harvest is delayed excessively, winter wheat may not be planted at all. In that case, spring wheat will be planted, with maize, the next year.

Winter wheat planted after the spring crop is harvested can be assumed to be in place in October. With freezing November temperatures, November precipitation must be large enough to provide snow cover for the germinating seeds. Therefore, November precipitation was included in the initial formulation. Temperatures from February to April were also included to measure the influence of the severe cold spells on the winter crop. Similarly, temperatures from June to August were included because they affect spring plantings and their growth.

The final equation is

$$
\begin{aligned}
Y_{VZ} = {} & \underset{(5.0892)}{36.4547} + \underset{(2.8395)}{0.2707T} \\
& + \underset{(2.0623)}{0.0470LPREP11} + \underset{(2.5943)}{0.4261TEMP2} \\
& - \underset{(3.2012)}{1.2208} \times \left(\frac{TEMP6 + TEMP7 + TEMP8}{3}\right) \\
& + e_{VZ}; \qquad (7)
\end{aligned}
$$

$R^2 = 0.7923$, D.W. = 2.3321, SER = 2.1864, number of observations = 19.[38]

High November precipitation provides adequate protection from freezing temperatures to the germinating seeds. Therefore, the estimated parameter has a positive sign. February is the coldest month with the temperature averaging −15.8°C. Precipitation in February, with a mean of 29.7 and a low of 3 millimeters, is the lowest in the year. Therefore, high February precipitation associated with high temperature, with the R^2 of 0.4746, raises the probability that snow cover will be adequate. Hence, the positive sign of the estimated parameter of February temperature. High temperatures in June, July, and August can damage the growing

[38] The first-order serial correlation correction coefficient is statistically not significant. Therefore, equation (7) can be accepted without correction.

spring crop, as can the *sukhovey* that might occur. Therefore, the parameter has a negative sign.

Kharkov Oblast

Kharkov oblast, in the eastern Ukraine, has an average 896.4 thousand hectares sown with grain. Much of the area is forest-steppe with fertile soils, intensive farming, and a relatively high population density despite a steady decline of inhabitants. Kharkov is colder in the winter and warmer in the summer than Kiev and Lvov. Precipitation is also lower and monthly observations extremely variable. The major crops are winter wheat and maize and spring wheat. Winter grains are planted between September 5 and 25.

Kharkov is a winter-spring producer. March to June temperatures and precipitation were included in the initial formulation. Also considered were July and August temperatures, which influence spring crops. The final equation is

$$\begin{aligned} Y_{KH} = & \underset{(0.0478)}{-0.7716^*} + \underset{(3.3843)}{0.4940T} \\ & + \underset{(1.5559)}{3.5606^*TEMP4} - \underset{(1.5296)}{0.1995^*(TEMP4)^2} \\ & + \underset{(2.3623)}{0.5211PREP4} \\ & - \underset{(2.4710)}{0.0080(PREP4)^2} + \underset{(1.7962)}{0.1473^*PREP5} \\ & - \underset{(1.4173)}{0.0008^*(PREP5)^2} \\ & - \underset{(1.2766)}{0.6751^*TEMP8} + e_{KH}; \qquad (8) \end{aligned}$$

$R^2 = 0.7734$, D.W. = 2.1100, SER = 2.9605, number of observations = 20.

(When TEMP4, PREP4, and PREP5 are included without the quadratic terms and TEMP8 is retained, R^2 drops to 0.5978.)

High temperatures in April (up to 8.9°C) promote winter plant growth. High precipitation in April (up to 32.6 millimeters) and in May (up to 92 millimeters) contributes not only to winter plant growth but also to soil moisture for spring plantings. High temperatures in August reduce the spring crop.

Kiev Oblast

Most of Kiev oblast lies on the low, flat plain of the Dnieper and the lower Pripyat in the Ukraine. The oblast is colder in winter than Odessa but the precipitation is higher and less variable around monthly averages. Precipitation is higher also in the summer months. The main crops are winter wheat, maize, and barley, and spring wheat. Grain is sown on an average of 671.7 thousand hectares. Winter crops are planted between August 20 and September 10.

The oblast is a mixed winter-spring producer. With precipitation throughout the year generally adequate, the initial formulation was specified with March to August temperatures. The final equation, in which the temperatures of March and April and of May, June, and July are averaged, is

$$\begin{aligned} Y_{KV} = & \underset{(4.9645)}{37.8226} + \underset{(11.4052)}{0.7121T} \\ & + \underset{(2.4740)}{0.5730}\left(\frac{TEMP3 + TEMP4}{2}\right) \\ & - \underset{(4.1212)}{1.7675} \times \\ & \left(\frac{TEMP5 + TEMP6 + TEMP7}{3}\right) \\ & + e_{KV}; \qquad (9) \end{aligned}$$

$R^2 = 0.9056$, D.W. = 1.8128, SER = 1.9037, number of observations = 22.[39]

Rising temperatures in March and April increase the growth of winter crops. High May, June, and July temperatures, in contrast, reduce both winter and spring crops.

---

[39] When TEMP3, TEMP4, TEMP5, TEMP6, and TEMP7 are adopted individually, the parameters of TEMP4 and TEMP7 are not statistically significant. When TEMP3 and TEMP4 are averaged but TEMP5, TEMP6, and TEMP7 are kept separate, the estimate of TEMP7 is, again, statistically not significant. Nor is the estimate of TEMP4 statistically significant when TEMP5, TEMP6, and TEMP7 are averaged but TEMP3 and TEMP4 are kept separate. The R^2 and D.W. statistic of these three equations are only slightly different from those of equation (9) adopted here.

The contrast between the Kharkov and Kiev models must be emphasized. Kharkov is drier in the spring. The Kharkov model, therefore, includes precipitation in April and May—both with positive signs (but negative signs in the quadratic terms).

Lvov Oblast

Lvov oblast in northwestern Ukraine is one of the smallest of the selected oblasts, with an average grain-sown area of 325.1 thousand hectares. The southern half was Drogobych oblast until 1958. Lvov is warmer in winter and cooler in summer than Kharkov and Kiev in the southeast. Annual precipitation, between 400 and 600 millimeters, is higher than in Kiev and Kharkov and is generally adequate. It tends, however, to vary widely around monthly averages. For example, precipitation in October ranges between 2 and 171 millimeters and has a higher standard deviation relative to its mean than any other month. The major crops are winter wheat and rye and spring wheat. Winter crops are planted between September 1 and September 15.

The oblast is modeled as a winter producer. Precipitation in October, after the winter crop is sown, and precipitation in June, when the winter crop is harvested, were included in the initial formulation. Temperatures in March, April, and May were also included. The final equation is

$$
\begin{aligned}
Y_{LV} = {} & \underset{(2.7316)}{3.9263} + \underset{(10.0415)}{0.7809t} \\
& + \underset{(2.3162)}{0.0691LPREP10} \\
& - \underset{(4.0979)}{0.0007(LPREP10)^2} \\
& + \underset{(1.7621)}{0.3172{*}TEMP3} \\
& - \underset{(1.4214)}{0.0149{*}PREP6} + e_{LV}; \qquad (10)
\end{aligned}
$$

$R^2 = 0.9047$, D.W. $= 1.4192$, SER $= 1.7263$, number of observations $= 20$.

(When LPREP10 is adopted without the quadratic term, R^2 declines drastically to 0.7904, and the t values of the estimates of TEMP3 and PREP6 decline to 1.3621 and 0.2339.)

The equation emphasizes the positive effect of October precipitation, which provides moisture after spring sowing. If it exceeds 49.4 millimeters, its effect is negative. As March temperatures rise, they help melt the snow and promote plant growth. Therefore, the variable has a positive sign. June precipitation has a negative sign because it reduces the harvesting of the winter crop.

Odessa Oblast

All of Odessa oblast lies in the Ukrainian steppe, and the fertile soils are plowed intensively. The average area sown with grain is 1,016.6 thousand hectares. The climate is dry and there is little surface water because all but the largest rivers dry out in the summer. Indeed, the average precipitation throughout the year is among the lowest. The main crops are winter wheat and barley and spring wheat. Winter crops are planted between September 5 and 25.

The model is formulated to include the basic features of the oblast's climate, low precipitation in the spring and dry, hot summers. The initial formulation included precipitation from March to May, the spring months of plant growth, and temperatures in June, July, and August, which influence the spring crop. The final equation is

$$
\begin{aligned}
Y_{OD} = {} & \underset{(2.9606)}{40.6308} + \underset{(8.8424)}{0.6188T} \\
& + \underset{(2.6739)}{0.0818} \left(\frac{PREP4 + PREP5}{2}\right) \\
& - \underset{(2.4040)}{1.5104} \times \left(\frac{TEMP6 + TEMP7 + TEMP8}{3}\right) \\
& + e_{OD}; \qquad (11)
\end{aligned}
$$

$R^2 = 0.8551$, D.W. $= 1.3722$, SER $= 2.2456$, number of observations $= 22$.[40]

[40] The first-order serial correlation correction coefficient is statistically not significant. Therefore, equation (11) can be retained.

(When all the weather variables are adopted individually in the formulation, the estimates of TEMP7, TEMP 8, and PREP4 are statistically not significant. When the temperature variables are averaged but the precipitation variables are kept separate, the estimate of TEMP7 proves to be statistically not significant and the D.W. drops to 1.2605. When the precipitation variables are averaged but the temperature variables are kept separate, the estimates of the temperature variables are statistically not significant.)

High precipitation in April and May promotes winter plant growth and contributes to soil moisture for the spring plantings. Therefore, the sign is positive. By contrast, high temperatures in June, July, and August lead to evapotranspiration, dry the soil, and adversely affect the spring crop. Therefore, the sign is negative.

Minsk Oblast

Minsk oblast in central Belorussia has an average grain-sown area of 535.2 thousand hectares. It gets rain almost throughout the year so the precipitation is adequate, and, indeed, occasionally excessive. Winter and summer temperatures are on the whole moderate. The oblast is located in the mixed forest zone. The oblast is a major producer of winter barley. Other major crops are winter rye, buckwheat, and spring wheat. Winter grains are planted between August 25 and September 15.

The oblast is treated as a mixed producer. Given the moderate climate, only the critical weather variables are included in the initial formulation. These include temperatures and precipitation in September and October, during and after winter planting; temperature and precipitation in June, during spring planting; and temperature and precipitation in August, during the harvesting of the spring crop. The final equation is

$$
\begin{aligned}
Y_{MK} = {} & \underset{(1.3779)}{9.1940^*} + \underset{(11.0743)}{0.8499T} \\
& - \underset{(4.8987)}{1.4832LTEMP10} \\
& + \underset{(2.5447)}{0.0475LPREP10} \\
& - \underset{(2.7250)}{0.6995TEMP6} \\
& - \underset{(1.5470)}{0.5214^*TEMP8} + e_{MK}; \qquad (12)
\end{aligned}
$$

$R^2 = 0.9590$, D.W. $= 2.0025$, SER $= 1.6154$, number of observations $= 19$.

Low temperature and high precipitation in October increase the yields of winter crops. The temperature in October is not high in absolute terms. But precipitation in October can be as low as 3 millimeters. The combination of high precipitation and low temperature results in low evapotranspiration and sufficient moisture for the winter plantings and high yield. High temperatures in June reduce the spring plantings. By contrast, high temperatures in August increase yields. They imply low precipitation with an R^2 of -0.6033, and they ensure a dry environment for the maturing crop.

Karaganda Oblast

Karaganda oblast is in the dry semidesert zone in east-central Kazakhstan. The climate is dry and continental. Winters are severe with hurricane-force winds and prolonged snowstorms. Summers are hot—June and July temperatures average 18.5°C and 20.6°C—and dust storms are frequent. Precipitation is low, between 200 and 400 millimeters. July is the hottest and wettest month. The oblast is a spring grain producer, with spring wheat the main crop. Grain is sown on an average 1,102.2 thousand hectares and is planted between late April and early June.

Most important in formulating a weather-yield model is the low and variable precipitation of the winter months. Precipitation must accumulate through the winter so that the soil is moist enough when spring sowing begins. And the snow must melt on time for spring sowing to begin on schedule. Therefore, precipitation for each month alone, January through May, and in combinations of two or three with their corresponding averages, and temperatures for March and April were included in the initial formulations. Also included were the temperatures for June and July, which influence the spring crop.

The final equation is

$$Y_{KG} = \underset{(5.1288)}{36.8844} + \underset{(1.3871)}{0.0828^{*}T} + \underset{(2.1549)}{0.0977PREP2} + \underset{(1.8935)}{0.0619^{*}PREP4} - \underset{(4.9165)}{1.8185}\left(\frac{TEMP6 + TEMP7}{2}\right) + e_{KG}; \quad (13)$$

$R^2 = 0.7015$, D.W. = 2.1326, SER = 1.9682, number of observations = 22.

(When TEMP6 and TEMP7 are included individually in the equation, R^2 goes up slightly to 0.7173 but the D.W. statistic increases sharply to 2.4323.)

High precipitation in February and April adds to soil moisture for the spring plantings and, therefore, increases yields. High temperatures in June and July reduce spring plantings and yields.

Kustanay Oblast

The average area sown with grain in Kustanay oblast in northern Kazakhstan is 3,984.5 thousand hectares. The oblast has a wide fertile black earth belt in the north that changes into dry steppe in the south. As in Karaganda oblast, the climate is dry and continental with long severe winters and hot summers. Precipitation is low, in the range of 200 to 400 millimeters each year. Spring wheat, the main crop, is planted between late April and early June.

Kustanay is a spring oblast. The initial formulation included the same weather variables as in Karaganda—January to May precipitation, March and April temperatures, and June and July temperatures. The final equation is

$$Y_{KT} = \underset{(8.1354)}{48.4862} + \underset{(2.3348)}{0.0980T} + \underset{(2.7186)}{0.1118} \times \left(\frac{PREP3 + PREP4 + PREP5}{3}\right) - \underset{(7.7068)}{2.2271}\left(\frac{TEMP6 + TEMP7}{2}\right) + e_{KT}; \quad (14)$$

$R^2 = 0.8130$, D.W. = 1.9613, SER = 1.7456, number of observations = 26.[41]

High precipitation in March, April, and May provides soil moisture for spring plantings and, therefore, contributes positively to the yield. As in Karaganda, high temperatures in June and July reduce spring plantings and yields.

It is not surprising that both oblasts in Kazakhstan have highly fluctuating yields and so give low trend parameters (this is also true of Altay kray and Omsk oblast in Western Siberia). Given the extreme climate, it is also possible to identify the weather variables easily and estimate them confidently. The results are also well-estimated because both are spring oblasts with a single crop, wheat. Both models might be improved if

---

[41] When the weather variables are included separately in the formulation, the estimates of PREP3 and PREP4 are statistically not significant. When the precipitation variables are kept separate but the temperature variables are averaged, the estimates of PREP3 and PREP4 are again statistically not significant. However, when the precipitation variables are averaged but the temperature variables are kept separate, the results are slightly better:

$$Y_{KT} = \underset{(8.3488)}{47.9276} + \underset{(2.5037)}{0.1012T} + \underset{(2.8419)}{0.1124}\left(\frac{PREP3 + PREP4 + PREP5}{3}\right) - \underset{(7.1653)}{1.3134TEMP6} - \underset{(4.8385)}{0.9045TEMP7} + e_{KT};$$

$R^2 = 0.8350$, D.W. = 1.9285, SER = 1.6785, number of observations = 26.

However, note that neither the estimated yields nor the weather variability resulting from this equation would be different than in equation (14). The constant term here is slightly lower than in equation (14) but the estimate of T is slightly higher. The combined parameter of TEMP6 and TEMP7 here adds up to −2.2179, which is only marginally different from the estimated parameter for (TEMP6 + TEMP7)/2 in equation (14), −2.2271.

more effective weather variables, such as soil moisture indexes, were used. However, the difficulties of building such indexes must be weighed against the availability of the data for the average monthly weather variables used. The results from the remaining oblasts must be interpreted similarly. One major improvement (though not for Altay kray and Omsk, which are both spring regions) would be to separate the crops into winter and spring, in order to derive separate winter and spring weather-yield models. Here again, the problem is that sufficiently long time-series data on winter and spring crop yields are unavailable.

5

THE WEATHER PATTERN IN THE GRAIN BELT

The weather pattern in the grain belt presents two questions that will be addressed here. First, does good weather in one oblast or set of oblasts offset bad weather in another? If so, of course, the variability of yield attributable to weather will be dampened. Second, does weather worsen as one moves southeast in the grain belt? This, too, would have its implications for yield variability, with the weather fluctuations affecting yields more in the more southeasterly oblasts.

Weather Association in the Oblasts

To answer the first question, the weather variability of yield for each oblast is defined and separated from each equation. Weather variability, measured as yield in centners per hectare, is the estimated deviation of observed weather from mean weather. It can be positive or negative. These estimates of the oblast weather variability series from 1951 to 1982 are given in Table 7. A positive or negative association of weather variability between two oblasts would then be indicated by a statistically significant positive or negative correlation between the estimated weather variability series of the two oblasts. A positive correlation implies that weather tends to be similar in the two oblasts. Therefore, the variability of their combined yield attributable to weather would be large. By contrast, a negative correlation coefficient would suggest an offsetting weather pattern and a dampening of the yield variability attributable to weather.[42] Finally, if no significant correlation of weather variability is found, the variability of their combined yield attributable to weather is neither large nor small but in between. The estimates of the correlation coefficients on the basis of which the association of weather variability in the oblasts is classified in these three possibilities are presented in Tables 8 and 9.

To estimate the correlation of weather variability between oblasts, the yearly weather variability in an oblast is defined and estimated using the following equation:

$$Y_i = \hat{\alpha}_i + \hat{\beta}_i T + \hat{\gamma}_i TEMP3_i + \hat{\theta}_i PREP4_i + e_i, \quad (15)$$

where Y_i is the grain yield, in centners per hectare, of oblast i, $TEMP3_i$ is the March temperature in degrees Celsius and $PREP4_i$ is the April precipitation in millimeters, T is the time trend, and e_i is the estimated error term. For simplicity, March temperature and April precipitation are assumed to be the only weather variables. $\hat{\alpha}_i$, $\hat{\beta}_i$, $\hat{\gamma}_i$, and $\hat{\theta}_i$ are the estimated parameters. The time subscript t is omitted for convenience.

Equation (15) is transformed to estimate the weather variability of yield in the i^{th} oblast and written as

$$Y_i = (\hat{\alpha}_i + \hat{\beta}_i T + \hat{\gamma}_i \overline{TEMP3}_i + \hat{\theta}_i \overline{PREP4}_i) + \{\hat{\gamma}_i(TEMP3_i - \overline{TEMP3}_i) + \hat{\theta}_i(\overline{PREP4}_i - PREP4_i)\} + e_i, \quad (16)$$

where $\overline{TEMP3}_i$ and $\overline{PREP4}_i$ are the mean March temperature and April precipitation during the sample period in the i^{th} oblast.

The first expression in parentheses on the right-hand side of equation (16) is defined as the input component of grain yield and the expression in curved brackets is the weather variability component. The former measures

[42] Lydolph, Martell, and Ericksen, "Recent Weather and Agriculture," suggest that the weather patterns of the Ukraine and Kazakhstan might be opposed to each other, showing the opposite pattern of yields in the two regions in five of the ten reporting years between 1971 and 1980—1971, 1972, 1973, 1979, and 1980

Table 7—Estimated weather variabilities of oblast yields, 1951–82

Year	Altay Kray	Moscow	Omsk	Rostov	Stravropol Kray	Tatar A.S.S.R.	Voronezh	Kharkov	Kiev	Lvov	Odessa	Minsk	Karaganda	Kustanay
							(centners per hectare)							
1951	-3.67	-1.82	-1.31	0.07	-1.88	-2.57	-4.24	-1.06	0.66	1.11	-3.67	0.89	-5.57	-2.31
1952	-1.13	-3.26	-7.44	0.44	3.36	-2.89	0.58	-1.57	0.58	-1.13	0.07	4.04	-1.03	-5.28
1953	-4.52	-0.71	-2.43	-5.90	0.61	0.93	-4.25	1.45	-2.03	0.70	-1.08	0.98	-0.54	2.00
1954	0.94	-4.26	0.04	-9.27	-9.23	-0.74	-8.82	-0.50	-3.13	0.51	-2.44	-3.57	3.52	-0.75
1955	-4.78	4.96	-4.52	-1.87	1.44	1.88	3.11	1.23	-0.05	-0.37	1.87	3.16	-2.58	-4.51
1956	2.01	-6.80	2.24	-2.39	-3.50	4.00	-6.02	3.08	-0.76	-0.83	2.06	-5.09	0.02	3.82
1957	2.36	-0.36	-0.80	-1.65	0.16	0.48	1.88	-1.07	-0.15	1.82	-2.22	1.25	-1.13	-2.57
1958	4.78	-0.47	-0.44	2.06	2.45	1.11	2.25	3.52	-1.41	-0.48	1.23	-0.99	5.33	-0.08
1959	1.18	1.36	-1.77	-4.37	-1.24	0.79	-2.52	-1.13	-1.04	1.43	-1.81	-2.64	3.12	1.36
1960	1.57	-4.44	3.50	-2.38	1.58	0.13	-2.43	-0.20	-1.94	0.16	0.29	1.26	2.26	3.59
1961	-0.09	-1.26	-0.71	0.25	-0.62	0.25	2.01	3.83	1.06	1.74	2.05	0.42	2.37	0.77
1962	-3.96	-2.28	-2.95	2.02	0.57	0.82	0.37	-2.61	2.71	-0.39	0.70	-2.02	-3.04	-2.72
1963	-4.04	-0.66	-3.93	-3.25	2.62	-2.39	-0.39	-7.90	-3.90	-0.49	-3.26	-1.03	-4.57	-4.17
1964	-0.63	-4.26	0.84	2.55	-2.58	-1.38	0.63	4.74	-2.41	0.31	-0.26	-3.63	0.15	-0.04
1965	-4.70	-2.06	-7.18	-2.48	-1.74	-1.16	-0.23	0.13	1.71	0.12	1.56	-0.40	-3.51	-3.24
1966	1.26	-[illegible].32	3.12	4.48	5.32	-0.25	2.55	-2.08	1.51	-0.28	-0.91	-1.19	-0.09	0.40
1967	-1.65	0.65	-4.55	0.70	-0.88	1.71	-1.29	-1.84	-0.76	0.32	-1.93	-2.87	-0.63	1.59
1968	1.39	-1.82	1.31	0.50	2.39	2.89	0.42	-1.20	1.01	1.38	-1.13	-4.96	-1.43	5.19
1969	-4.71	2.61	-1.28	-2.11	-6.11	2.60	-1.09	0.22	0.22	-1.50	1.71	3.50	-1.91	3.12
1970	2.65	2.91	3.69	7.64	3.90	0.53	1.70	1.93	0.70	0.81	4.09	0.23	-1.58	4.49
1971	4.40	3.74	2.94	-1.72	-0.69	-1.07	-0.63	0.08	0.20	0.62	-0.58	4.23	-0.90	-1.12
1972	7.72	0.22	4.91	-7.21	-5.86	-1.01	-5.70	-1.67	-1.27	1.49	-2.70	0.33	5.11	5.86
1973	0.03	0.84	4.89	7.95	3.64	1.22	6.95	5.33	1.59	1.13	3.64	1.88	0.78	1.70
1974	-5.15	2.67	0.74	3.45	-0.91	1.34	4.51	5.02	3.91	0.95	2.38	4.69	-3.46	-2.09
1975	1.32	1.42	-2.01	-2.16	-3.15	-5.95	-2.86	-2.76	-2.02	-8.79	-3.08	2.21	-3.31	-2.76
1976	-1.37	1.43	0.84	6.26	-3.13	1.33	-0.34	3.71	4.53	-0.61	3.03	1.61	1.10	2.96
1977	4.30	1.44	-0.50	5.69	4.28	1.45	1.14	6.34	1.96	2.21	5.58	6.56	-5.93	-1.26
1978	2.11	-1.63	1.56	11.27	5.72	-3.30	1.37	1.95	4.99	0.70	1.50	-0.13	-1.36	-1.61
1979	-0.70	-0.69	2.65	-2.86	0.67	-7.24	-1.28	-1.46	-0.03	1.55	0.80	-1.53	1.21	3.18
1980	-1.10	-2.24	0.99	2.86	-5.05	1.27	0.48	5.56	3.80	-0.53	2.34	3.13	-1.46	-1.34
1981	-1.11	-7.22	0.82	-5.73	0.41	-3.45	1.12	3.50	0.00	1.53	0.00	1.71	-0.37	0.00
1982	-0.44	2.18	-1.22	5.30	-0.04	0.99	4.00	0.58	1.88	-1.20	-0.96	-1.84	-4.45	-1.90
Number of Years with Negative Variability	17	19	16	15	16	13	15	14	14	12	15	14	21	17

(continued)

Table 7—Continued

Year	Altay Kray	Moscow	Omsk	Rostov	Stravropol Kray	Tatar A.S.S.R.	Voronezh	Kharkov	Kiev	Lvov	Odessa	Minsk	Karaganda	Kustanay
						(centners per hectare)								
Standard Deviation	3.21	2.87	3.12	4.69	3.47	2.45	3.26	3.10	2.16	1.90	2.30	2.85	2.82	2.94
Minimum	−5.15	−7.22	−7.44	−9.27	−9.23	−7.24	−8.82	−7.90	−3.90	−8.79	−3.67	−5.09	−5.93	−5.28
Maximum	7.72	4.96	4.91	11.27	5.72	4.00	6.95	6.34	4.99	2.21	5.58	6.56	5.33	5.86

Source: Calculated from oblast grain yield data collected from statistical yearbooks from the republics and weather data obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Notes: The estimates were made from the oblast weather yield models on the basis of $\hat{\gamma}_i\,(TEMP3_i - \overline{TEMP3}_i) + \hat{\theta}_i\,(PREP4_i - \overline{PREP4}_i)$, where $\overline{TEMP3}_i$ and $\overline{PREP4}_i$ are the mean March temperature and April precipitation in the ith oblast.

Table 8—Correlation of the weather variability of yield between oblasts

Oblast/ Statistic	Altay Kray	Moscow	Omsk	Rostov	Stavropol Kray	Tatar A.S.S.R.	Voronezh	Kharkov	Kiev	Odessa	Minsk	Karaganda	Kustanay
Moscow													
Correlation coefficient	n.s.	. . .											
Probability	. . .	. . .											
Omsk													
Correlation coefficient	0.5780	n.s.	. . .										
Probability	0.0005	. . .	. . .										
Rostov													
Correlation coefficient	n.s.	n.s.	n.s.	. . .									
Probability	. . .	. . .	. . .	. . .									
Stavropol kray													
Correlation coefficient	n.s.	n.s.	n.s.	0.5570	. . .								
Probability	. . .	. . .	. . .	0.0009	. . .								
Tatar A.S.S.R.													
Correlation coefficient	n.s.	n.s.	n.s.	n.s.	n.s.	. . .							
Probability	. . .	. . .	. . .	. . .	. . .	. . .							

Voronezh													
Correlation coefficient	n.s.	0.3639	n.s.	0.6868	0.6230	n.s.	...						
Probability	...	0.0406	...	0.0001	0.0001	...	...						
Kharkov													
Correlation coefficient	n.s.	n.s.	0.3265*	0.4246	n.s.	0.3541	0.3532	...					
Probability	...	...	0.0681	0.0154	...	0.0468	0.0474	...					
Kiev													
Correlation coefficient	n.s.	n.s.	n.s.	0.7065	n.s.	n.s.	0.5139	0.4506	...				
Probability	...	...	...	0.0001	...	...	0.0026	0.0097	...				
Odessa													
Correlation coefficient	n.s.	n.s.	n.s.	0.5739	n.s.	0.3605	0.4881	0.7427	0.5717	...			
Probability	...	...	...	0.0006	...	0.0426	0.0045	0.0001	0.0006	...			
Minsk													
Correlation coefficient	n.s.	0.4331	n.s.	n.s.	n.s.	n.s.	0.3265*	0.3125*	0.3243*	0.3813	...		
Probability	...	0.0133	...	...	...	...	0.0682	0.0816	0.0702	0.0313	...		
Karaganda													
Correlation coefficient	0.4917	n.s.	0.4031	n.s.	n.s.	n.s.	n.s.	n.s.	−0.2985*	n.s.	−0.3215*	...	
Probability	0.0043	...	0.0222	...	...	...	...	...	0.0971	...	0.0728	...	
Kustanay													
Correlation coefficient	0.3925	n.s.	0.6589	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	−0.3346*	0.5348	...
Probability	0.0263	...	0.0001	...	...	...	...	...	...	...	0.0612	0.0016	...

Source: Calculated from oblast grain yield data collected from statistical yearbooks from the republics and weather data obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Notes: The correlation coefficient (r) is calculated using the following formula:

$$r = \left[\sum_{t=1}^{n=32} (AM_{it} - \overline{AM}_i)(AM_{jt} - \overline{AM}_j)\right] / \left[\sum_{t=1}^{n=32} (AM_{it} - \overline{AM}_i)^2 \quad \sum_{t=1}^{n=32} (AM_{jt} - \overline{AM}_j)^2\right]$$

where AM_{it} and AM_{jt} are the time series of estimated weather variabilities in oblasts i and j, with $i \neq j$, and $\overline{AM}_i$ and $\overline{AM}_j$ are their means.
The probabilities are the significance probabilities. For example, if the probability is 0.0005, then the probability of rejecting the null hypothesis that the true correlation coefficient is zero when it is in fact zero is 0.0005, or 0.05 percent. Therefore the null hypothesis is rejected at the 5 percent level of significance. The estimates marked with an asterisk are statistically significant at a significance level between 5 and 10 percent. No estimate of the correlation coefficient between the weather variability of Lvov and that of another oblast is statistically significant. Where n.s. appears, the significance probabilities exceed 0.10.

Table 9—Correlation of the weather variability of yield between groups of oblasts

	Western Oblasts		Eastern Oblasts		
Oblast Group/ Statistic	**Kharkov, Kiev, Lvov, and Odessa**	**Kharkov, Kiev, Lvov, Odessa, and Minsk**	**Karaganda and Kustanay**	**Karaganda, Kustanay, Omsk, and Altay Kray**	**Karaganda, Kustanay, Omsk, Altay Kray, and Tatar A.S.S.R.**
Western oblasts					
Rostov, Stavropol kray, and Voronezh					
Correlation coefficient	0.5397	0.5294	−0.1880[b]	−0.0240[b]	. . .
Probability	0.0014	0.0018	0.3027	0.8964	. . .
Moscow, Rostov, Stavropol kray, and Voronezh					
Correlation coefficient	0.5362	0.5301	. . .	. . .	. . .
Probability	0.0016	0.0018	. . .	. . .	. . .
Minsk					
Correlation coefficient	. . .	. . .	−0.3623	. . .	. . .
Probability	. . .	. . .	0.0416	. . .	. . .
Kharkov, Kiev, Lvov, and Odessa					
Correlation coefficient	. . .	. . .	0.1039[b]	0.1280[b]	. . .
Probability	. . .	. . .	0.5716	0.4851	. . .
All western oblasts[a]					
Correlation coefficient	. . .	. . .	. . .	. . .	0.0247[b]
Probability	. . .	. . .	. . .	. . .	0.8931
Eastern oblasts					
Altay Kray and Omsk					
Correlation coefficient	. . .	. . .	0.5692	. . .	. . .
Probability	. . .	. . .	0.0007	. . .	. . .
Altay Kray, Omsk, and Tatar A.S.S.R.					
Correlation coefficient	. . .	. . .	0.6158	. . .	. . .
Probability	. . .	. . .	0.0002	. . .	. . .

Source: Calculated from oblast grain yield data collected from statistical yearbooks from the republics and weather data obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Notes: To estimate the correlation coefficient (r) between groups of oblasts, the oblast weather variabilities are weighted by the proportion each oblast has in the total grain-sown area of the selected oblasts.

The correlation coefficient (r) is calculated using the following formula:

$$r = [\Sigma_{t=1}^{n=32} (\Sigma_{i=1} s_{it} AM_{it} - \Sigma_{i=1} s_{it} \overline{AM}_i)(\Sigma_{j=1} s_{jt} AM_{jt} - \Sigma_{j=1} s_{jt} \overline{AM}_j)] \ / $$

$$[\Sigma_{t=1}^{n=32} (\Sigma_{i=1} s_{it} AM_{it} - \Sigma_{i=1} s_{it} \overline{AM}_i)^2 \quad \Sigma_{t=1}^{n=32} (\Sigma_{j=1} s_{jt} AM_{jt} - \Sigma_{j=1} s_{jt} \overline{AM}_j)^2],$$

where AM_{it} and AM_{jt} are the time series of estimated weather variabilities in oblasts i and j, with $i \neq j$, $\overline{AM}_i$ and $\overline{AM}_j$ are their means, and s_{it} is the share of grain-sown area of oblast i in year t in the total grain-sown area of the selected oblasts in that year.

The probabilities are the significance probabilities. For example, if the probability is 0.0005, then the probability of falsely rejecting the null hypothesis that the true correlation coefficient is zero when it is in fact zero is 0.0005, or 0.05 percent. Therefore the null hypothesis is rejected at the 5 percent level of significance. Where ellipses (. . .) appear, the estimate was not meaningful or not significant.

[a] These oblasts are Moscow, Rostov, Stavropol kray, Voronezh, Kharkov, Kiev, Lvov, Odessa, and Minsk.
[b] These estimates are not significant at the 5 percent level.

the contribution to yield of the trend term T and mean weather, with T representing the application of inputs such as capital, labor, and fertilizers. Because the contribution of the inputs in T must be positive, the estimated input contribution to yield cannot be negative. The weather variability component measures the estimated deviation, in centners per hectare, of actual weather from mean weather. It can be positive or negative with a positive value suggesting above-average weather and a negative value, below-average weather. For example, an estimated weather variability of 2 centners per hectare in a given year suggests that yield would have been lower by 2 centners in that year if the weather had been average. By contrast, a weather variability of -2 centners implies that yield would have been higher by 2 centners if the weather had been average. Note that mean or average weather (the two terms are used interchangeably in this report) is defined so that the sum of the estimated weather variabilities in each oblast over the sample period equals zero.

The estimated components of oblast weather variability, AM_i, from 1951 to 1982 are presented in Table 7 and plotted in Figures 5-18. They reveal an interesting pattern. First, Soviet grain yields (and output) in 1963 and 1975 were exceptionally poor: the estimated weather variability for 1963 is negative in all the oblasts except Stavropol kray. For 1975, it is negative everywhere except in Altay kray, and Moscow and Minsk oblasts. Yields (and harvests) were exceptionally good in 1973 and 1978: the weather variability for 1973 is positive in all the oblasts whereas for 1978 it is negative for Moscow, Tatar A.S.S.R., Minsk, Karaganda, and Kustanay. In other words, exceptionally good or bad grain yields are associated either with similar weather in the entire grain belt or in some portions of the grain belt. The implied association of weather between two oblasts or two groups of oblasts will be analyzed rigorously below.

Second, during the 32-year period, there were as many years of negative as positive weather variability in all oblasts except Moscow, which had 19 years of positive variability, Minsk, which had 21 years, Tatar A.S.S.R., with 13 years of negative variability, and Lvov, which had 12.[43] Finally, the average volatility of oblast weather can be assessed from the estimated standard deviation of the variability in Table 7. The standard deviation is lowest in Lvov, 1.9 centners per hectare, and highest in Rostov, 4.7 centners per hectare. When the extreme negative weather variability of -8.79 centners in 1975 is omitted, the standard deviation of weather variability in Lvov drops to 1.00 centner. This low standard deviation of the weather variability in Lvov implies that the estimated weather is less volatile (Figure 14); whereas a large standard deviation, as in Rostov, implies great weather variability (Figure 8). If all the oblasts were like Lvov, the weather variability of their aggregate yield would be small; by contrast, if they were all like Rostov, it would be large.

How similar or dissimilar is weather in the selected oblasts? To answer this question, the correlation coefficients of the weather variability series for oblast pairs are computed, using the following equation:

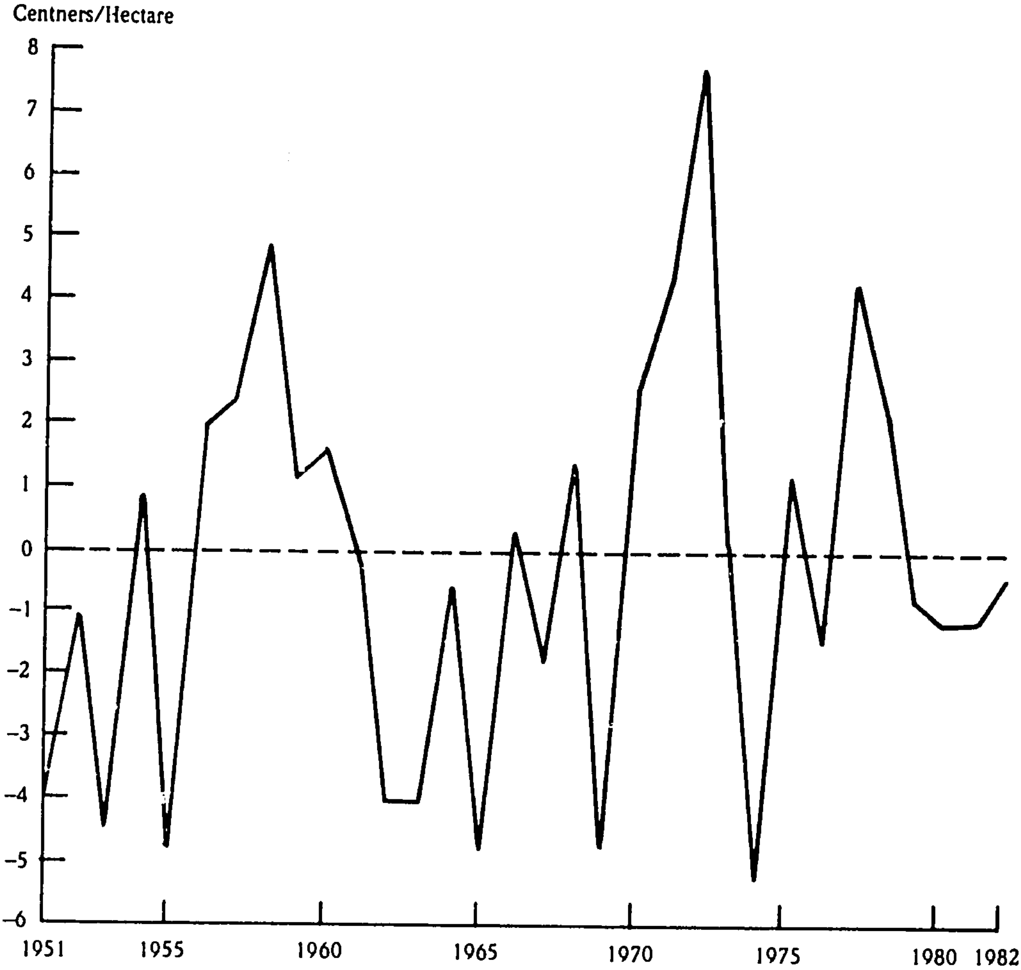
$$r = \sum_{t=1}^{32} (AM_{it} - \overline{AM}_i)(AM_{jt} - \overline{AM}_j) \;/\; \{\sum_{t=1}^{32} (AM_{it} - \overline{AM}_i)^2 \times \sum_{t=1}^{32} (AM_{jt} - \overline{AM}_j)^2\}, \quad (17)$$

where AM_{it} and AM_{jt} are the time series of estimated weather variabilities in oblasts i and j with $i \neq j$, and $\overline{AM}_i$ and $\overline{AM}_j$ are their respective means. These estimated coefficients are presented in Table 8. A positive coefficient indicates that the weather variability in two oblasts follows a similar pattern whereas a negative value suggests an opposite weather pattern.[44] Only the esti-

[43] In the aggregate, there may be as many negative as positive years of weather variability. This is analyzed in Chapter 6.

[44] Clearly, the extent of the similarity or dissimilarity of weather depends on the value of r: the higher the absolute value of r, the greater the association. In the analysis that follows, a statistically significant value of r higher than 0.50 is accepted as evidence of positive weather association. The only statistically significant, negative value of r in Table 9 is -0.36, suggesting that the weather between Minsk in Belorussia, and Karaganda and Kustanay in Kazakhstan is mildly dissimilar.

Figure 5—Weather variability of yield in Altay kray, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

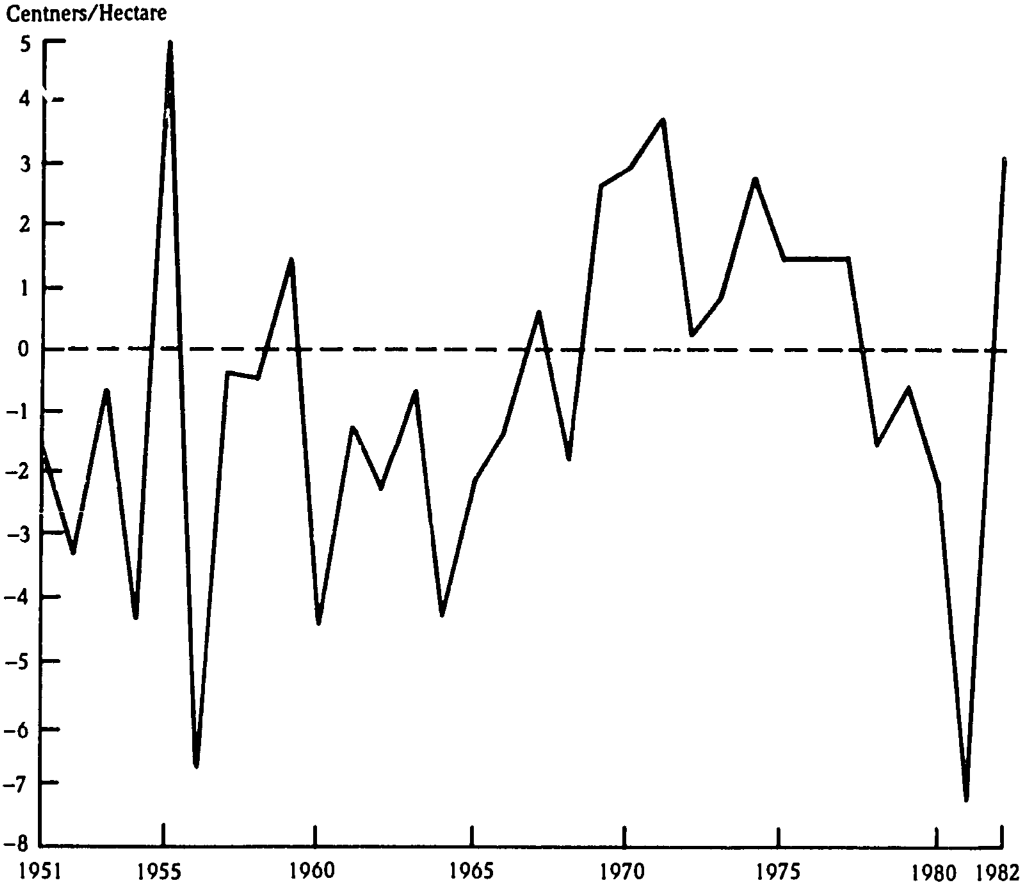
mates that are statistically significant at the 5 percent level of significance are interpreted in this manner, although those estimates that can be accepted with a significance level between 5 and 10 percent are reported.[45]

The weather pattern indicated by these estimated r's between the weather variabilities of pairs of oblasts has several features. First, the highest positive association of weather, with an r of 0.7427, is between Kharkov and Odessa. Good and bad weather in these two oblasts is highly correlated; when the weather is good in Kharkov, it is likely to be good in Odessa.

Second, as can be expected, oblasts that are close to each other have similar weather. Thus, Altay kray and Omsk, Omsk and Kustanay, and Kustanay and Karaganda tend to have similar weather, with r exceeding 0.50 for all three pairs. The correlation co-

[45] These are marked with an asterisk in Table 8. The remaining values are available from the author.

Figure 6—Weather variability of yield in Moscow oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

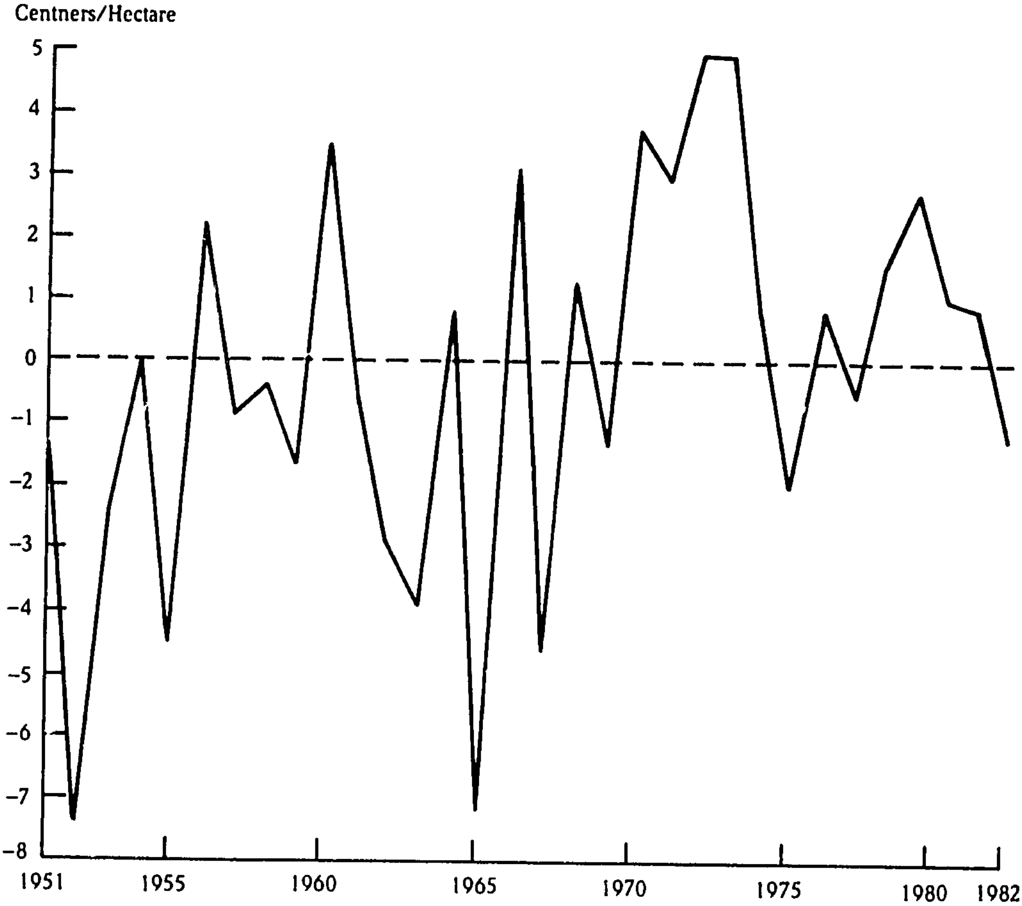
efficients between Rostov, Stavropol, and Voronezh are all larger than 0.50. Positive correlations exceeding 0.50 are also noted between the oblasts of the Ukraine—between Odessa and Kharkov as already noted, and Kiev and Odessa. Furthermore, high correlations are also found between Ukrainian oblasts and oblasts just outside the Ukraine, between Kiev and Voronezh, and Odessa and Rostov, for example.

Third, Moscow and Tatar A.S.S.R. have no correlation of weather variability exceeding 0.50 with any oblast, and Lvov is the only oblast that does not have a single estimate of r that is statistically significant.[46] Finally, none of the negative correlations, between Minsk and Karaganda and Minsk and Kustanay, for example, are statistically significant.

In conclusion, the high positive correlation of weather between oblasts in a given location suggests that these oblasts might be grouped into subsets with similar weather. For example, the oblasts of the Ukraine might form one group and Rostov oblast and Stavropol kray, both in northern Caucasus,

[46] That Lvov is unique is also indicated by its standard deviation of the estimated weather variability, which is lower than for any other oblast. As will be shown below, it also has the lowest relative contribution of weather variation to yield variation.

Figure 7—Weather variability of yield in Omsk oblast, 1951-82

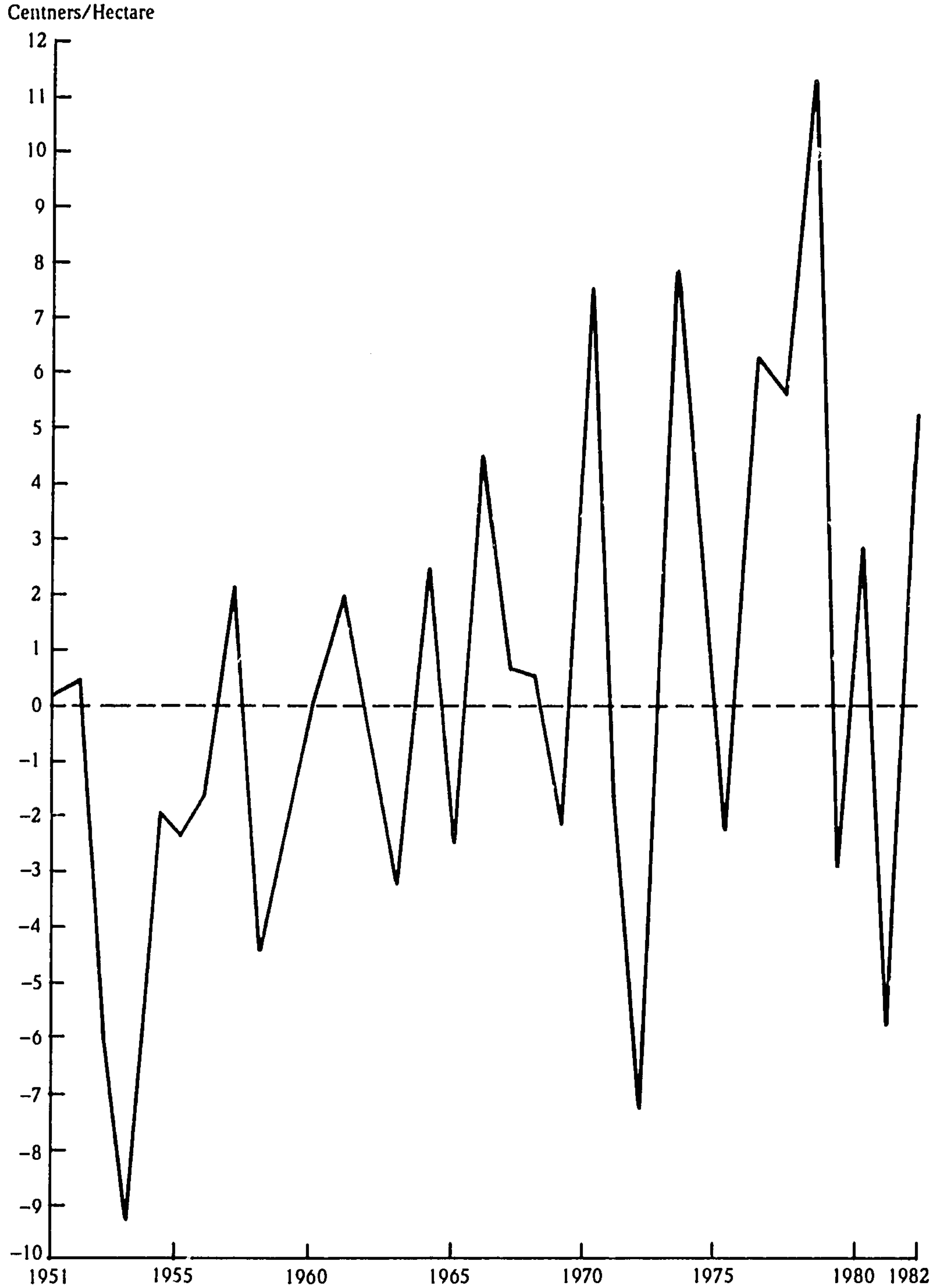


Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

might be joined to neighboring Voronezh to form another. The four oblasts of Western Siberia in the R.S.F.S.R. and Kazakhstan could form a third. A possible negative correlation between the weather variabilities of Minsk in the northwest and Karaganda and Kustanay, both in Kazakhstan, is also examined by combining the latter two oblasts.

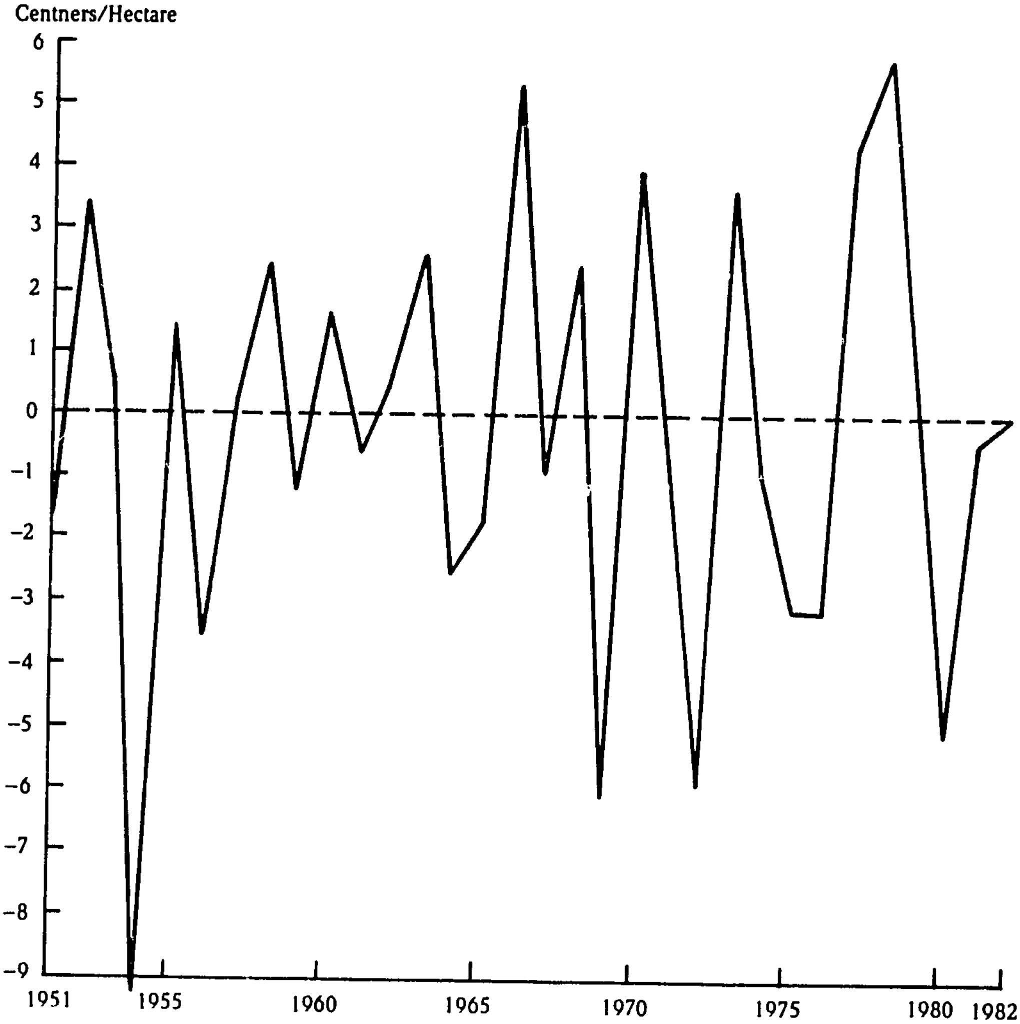
The r's are estimated between oblast subsets that are grouped in this manner (Table 9). The weather variabilities are weighted by the proportion each oblast has in the total sown area of the selected oblasts. The weights are calculated from data in Appendix 1, Table 16. The resulting estimates of r indicate the pattern of weather association between major areas of the Soviet grain belt. Thus in Table 9, the estimated r of 0.54 between the group of Rostov, Stavropol kray, and Voronezh and the group of Kharkov, Kiev, Lvov, and Odessa suggests that the weather in the two groups is similar. When Moscow, northeast of the northern Caucasus, is included in the former subset, and Minsk, northeast of the Ukraine, is included in the latter, r is 0.53 and statistically significant. Weather is also somewhat similar between Altay kray and Omsk in Western Siberia, and Karaganda and Kustanay in Kazakhstan with an r of 0.57. It goes up to 0.62 when Tatar A.S.S.R. is included with Altay kray and Omsk. The correlation between Minsk in

Figure 8—Weather variability of yield in Rostov oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

Figure 9—Weather variability of yield in Stavropol kray, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

Belorussia, and Karaganda and Kustanay in Kazakhstan is −0.36 and statistically significant.[47] Thus, weather in Belorussia and Kazakhstan seems to be dissimilar: the r of −0.36 is negative and statistically significant but low. Beyond this, there is no weather association between the Ukraine and Kazakhstan, between the Ukraine and Western Siberia including Kazakhstan, between the northern Caucasus with Voronezh and Kazakhstan, and between the northern Caucasus with Voronezh and Western Siberia plus Kazakhstan: none of these r's are statistically significant and the hypothesis of zero correlation between these subsets cannot be rejected. Finally, if the grain belt is divided on an east-west line, with Moscow included in the west and Tatar A.S.S.R. in the east,

[47] As already noted, precipitation in Minsk can be excessive whereas precipitation in Kazakhstan is generally low. When precipitation in Minsk is excessive (and, therefore, the weather variability is negative), above-average precipitation can be expected in Kazakhstan (and, therefore, the weather variability would be positive).

Figure 10—Weather variability of yield in Tatar A.S.S.R., 1951-82

Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

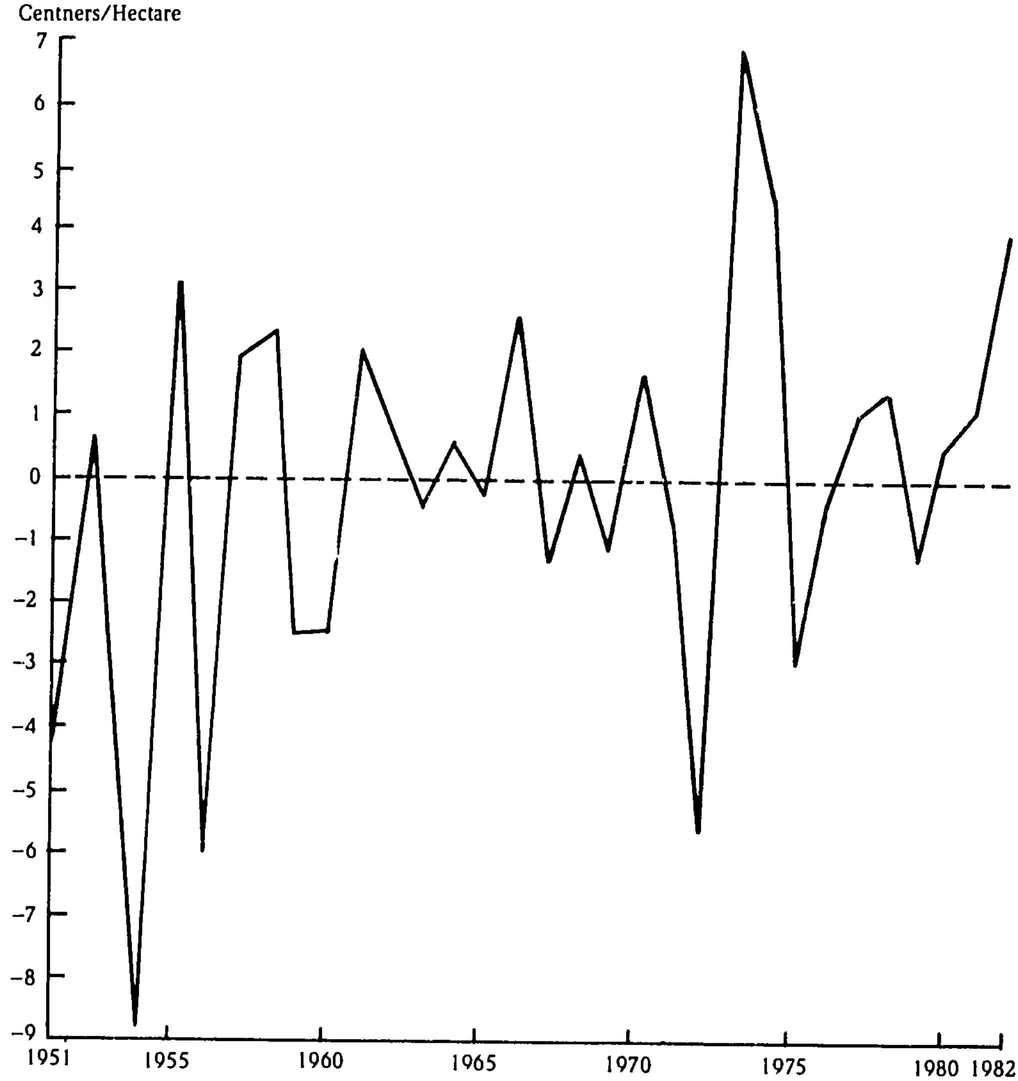
there is no association of weather between the area to the west—including Moscow, the Ukraine, the northern Caucasus, Voronezh and Belorussia, and the area to the east—Tatar A.S.S.R., Kazakhstan, and Western Siberia: r is again statistically not significant.

The major indication of the analysis here is that, whereas weather is somewhat similar within the west and within the east, there is no association of weather between the west and east. In other words, if the weather of the east were duplicated in the west of the grain area and vice versa, the weather variability of aggregate Soviet grain yield would be massive. However, that is not so. This variability is dampened by the absence of weather association between the west and the east. (The variability would be even less if the weather correlation between the west and the east were negative.)

Weather Pattern in the Grain Belt

Does weather worsen in the southeasterly direction of the Soviet grain belt? The analytical framework used to answer this question follows from the influence that fluctuating weather has on oblast yield variations. The contributions to yield variation of the variations in inputs and of the set of weather variables are estimated to analyze the weather pattern in the Soviet grain belt. The former is the estimated covariance between oblast yield and the trend weighted by the corresponding parameter. The latter is the sum of the estimated covariances between oblast yield and the weather variables, each weighted by the corresponding parameter. The larger the ratio of the weighted

Figure 11—Weather variability of yield in Voronezh oblast, 1951-82



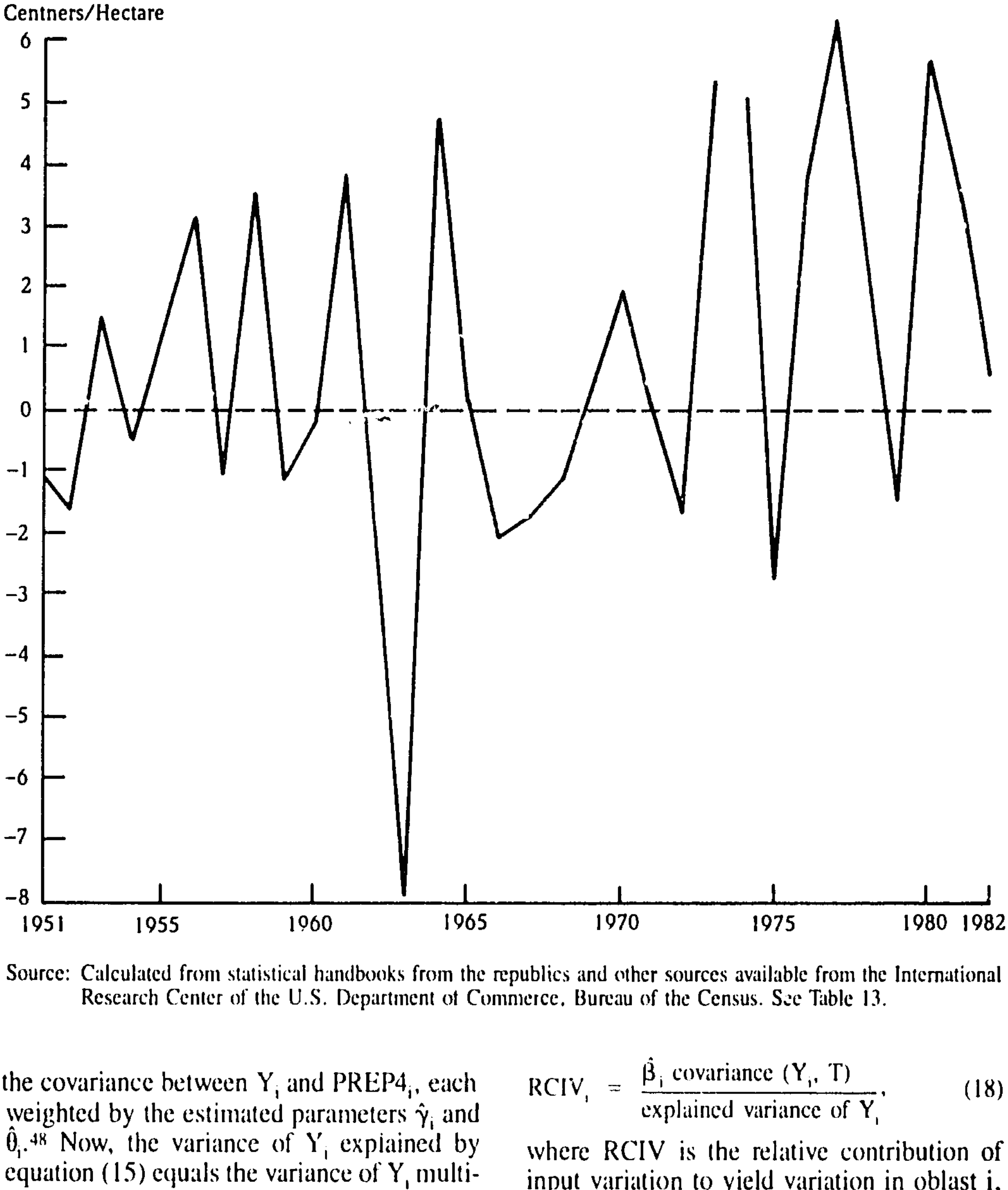
Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

covariance between yield and the weather variables and the explained yield variance, the worse the weather.

The crucial assumption of the methodology is that, whereas weather and input fluctuations influence yield variation, there is no interaction between weather and inputs. For example, increased applications of labor and machines take place when weather is better than average. Such interaction is excluded from the analysis.

With this assumption, the contribution of variation in input use to yield variation in oblast i is measured by the covariance between the yield Y_i and the time trend T, weighted by the estimated parameter β_i in equation (15). Similarly, the contributions to the variation in yield of the weather variables, $TEMP3_i$ and $PREP4_i$, are measured by the covariance between Y_i and $TEMP3_i$ and

Figure 12—Weather variability of yield in Kharkov oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

the covariance between Y_i and $PREP4_i$, each weighted by the estimated parameters $\hat{\gamma}_i$ and $\hat{\theta}_i$.[48] Now, the variance of Y_i explained by equation (15) equals the variance of Y_i multiplied by its R^2. This explained variance equals the sum of the covariances between Y_i on the one hand and T, $TEMP3_i$, and $PREP4_i$ on the other, each weighted by the corresponding parameter (see Appendix 3). Therefore,

$$RCIV_i = \frac{\hat{\beta}_i \text{ covariance } (Y_i, T)}{\text{explained variance of } Y_i}, \tag{18}$$

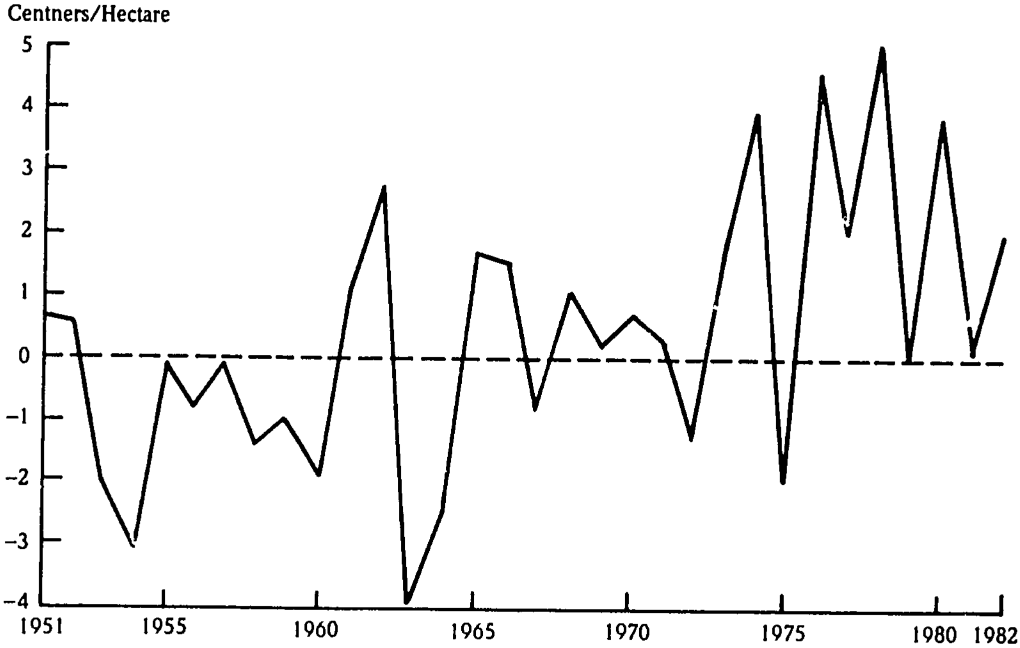
where RCIV is the relative contribution of input variation to yield variation in oblast i, and

$$RCWV_i = [\hat{\gamma}_i \text{ covariance } (Y_i, TEMP3_i) + \hat{\theta}_i \text{ covariance } (Y_i, PREP4_i)] / \text{explained variance of } Y_i \tag{19}$$

where $RCWV_i$ is the relative contribution of

[48] The purpose here is not to measure the contribution of the variation of each weather variable to yield variation. Therefore, the estimates of the covariances between Y_i and the individual weather variables are not given here. They are available from the author. For the same reason, the stepwise method of measuring the additional contribution of each weather variable to the explained variance of Y_i is also not used here.

Figure 13—Weather variability of yield in Kiev oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

weather variation to yield variation in oblast i. The sum of the covariance ratios of equations (18) and (19) equals 1. Also, the larger the oblast estimate of equation (19), the worse the weather. The oblasts can therefore be ranked using the estimates from equation (19).

These estimates are given in Table 10. The oblasts are first ranked on the basis of their location in the grain belt (Figure 3): an oblast to the north or west of another can be presumed to have better weather and is ranked ahead of the latter: as already noted, weather worsens in the southeasterly direction of the grain belt. This ranking of worsening oblast weather is then matched with the ranking associated with the covariance ratios of equation (19).

However, the rank oblasts should have by virtue of their location is not always clear. For example, should Lvov be followed by Minsk in the east or Odessa in the south? The annual range of precipitation (Figure 2) can be used to resolve such conflicts: the oblast with higher precipitation is ranked ahead.[49] Annual precipitation ranges are wide, however, with a spread of 200 millimeters in each range and may fail to provide a reliable indication. For example, Odessa and Moscow are in the same annual precipitation range but Odessa is generally drier than Moscow. In that case, the mean monthly precipitation is examined to settle the choice (Appendix 1, Table 17).

With this caveat, the oblasts are ranked by location as follows: Lvov is ranked first, followed by Minsk. Minsk has a higher precipitation range, between 600 and 800 millimeters, but is not ranked ahead of Lvov because precipitation there can be excessive, suggesting that the weather is worse in Minsk. How should Kiev, Moscow, Odessa, and Kharkov, all with a precipitation range between 400 and 600 millimeters, be ranked? Odessa is somewhat drier than Moscow; therefore it follows Moscow in the

[49] The summer and winter temperatures, preferably at their long-term mean values, could be used as well. But their inclusion would complicate the ranking procedure and is not considered.

Figure 14—Weather variability of yield in Lvov oblast, 1951-82

Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

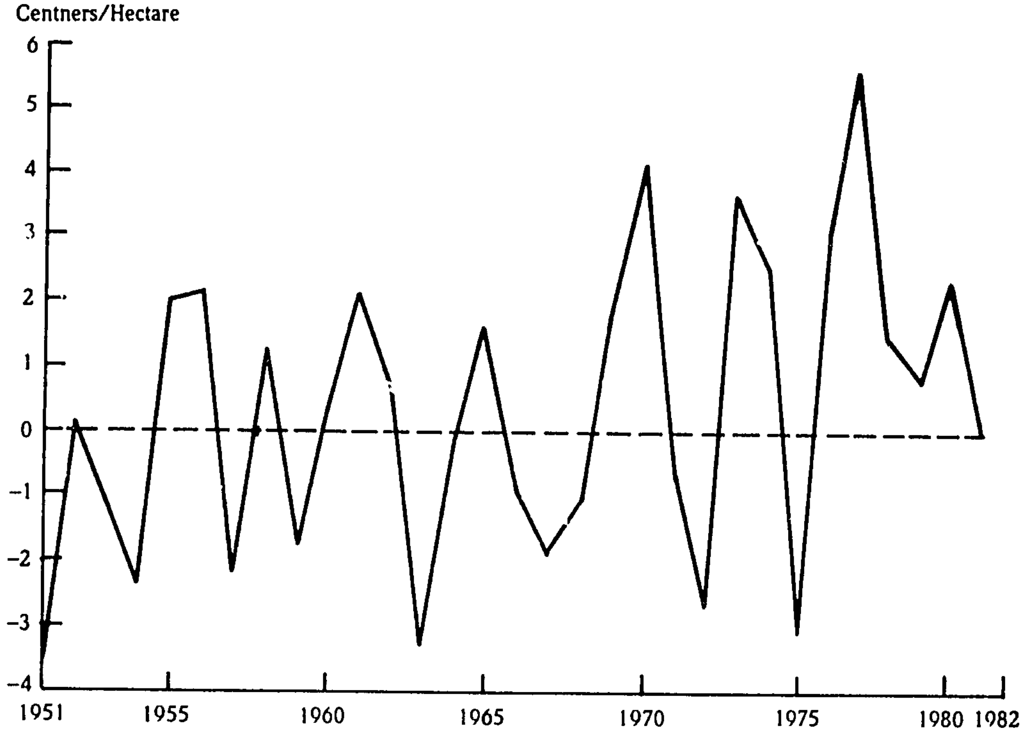
ranking. The ranking of the subset thus becomes Kiev, Moscow, Odessa, and Kharkov. Tatar A.S.S.R. is to the east of Voronezh. But because it has a higher precipitation range it is ranked before. For the same reason, Omsk is ranked before Kustanay and Altay kray is ranked ahead of Karaganda.

The comparison of the ranking by location with the ranking associated with the relative contribution of weather variation to yield variation indicates that weather does worsen in the southeasterly direction of the Soviet grain triangle: the contribution of fluctuating weather is 9.4 percent in Lvov at the top and 98.3 percent in Karaganda at the bottom, both measured relative to their explained yield variances. In between, the covariance ratios show a rising trend indicating that the weather worsens in the southeasterly direction.

The estimates have several striking features. The lowest contribution of fluctuating weather is in the three oblasts of Lvov (9 percent), Kiev (16 percent), and Odessa (22 percent) in the Ukraine followed by Moscow (23 percent) and Tatar A.S.S.R. (37 percent). The contribution of weather in Kharkov, in the southeast of the Ukraine, is 49 percent, and in neighboring Voronezh, it is 72 percent. In all the remaining oblasts, the contribution exceeds 85 percent. In other words, at least 85 percent of the explained variance of yield in these oblasts is attributed to weather fluctuations.

How does one interpret this statement? For example, the variance of Stavropol yield is 14.1 centners per hectare, and the R^2 of the estimated equation is 0.7471. Therefore, the weather-yield model, including the time trend and the weather variables, accounts for the yield variance of 10.5 centners. As much as 9 centners of this variance, that is, 85.9

Figure 15—Weather variability of yield in Odessa oblast, 1951-82



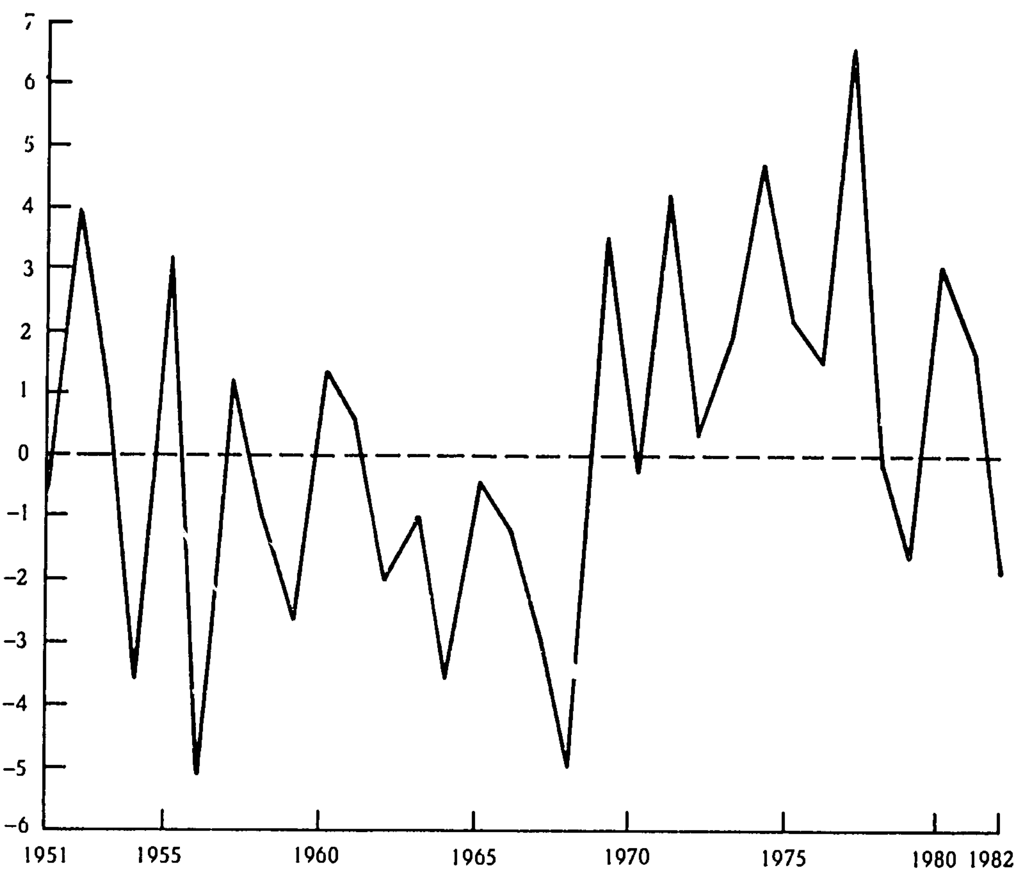
Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

percent, is explained by weather fluctuations. The remaining 1.5 centners is accounted for by the variation of inputs represented by the time trend.

It must be noted that the acceptability of the criterion of equation (19) devised here for estimating the contribution of weather fluctuations must be assessed in terms of the R^2 of the oblast equation. In general, the lower the R^2, the less acceptable the criterion. In other words, if the yield variance explained by the oblast R^2 is low, a measure of the contribution of weather fluctuation, which is itself a proportion of the explained variance of yield, should not be devised. (Note that for a given variance, the higher the R^2, the higher the explained variance.) In the majority of the estimates of Table 6, the oblast R^2 explains over 80 percent of the yield variance.

The major conclusions of the analysis of this chapter are two: the correlation between the estimated weather variability of the oblasts indicates that the weather in the oblasts located in the west is somewhat similar and so is the weather in the oblasts located in the east of the grain belt. But there is no weather association between the west and the east. Second, weather in the Soviet grain belt, measured in terms of the relative contribution of oblast weather variation to yield variation, worsens in the southeasterly direction.

Figure 16—Weather variability of yield in Minsk oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

Table 10—Relative contributions of variations in weather and inputs to variations in oblast grain yields

Oblast	Relative Contribution of Weather Variation	Relative Contribution of Input Variation	R^2 of the Oblast Weather-Yield Equation	Variance of Oblast Yield
	(percent)			(centners/hectare)
Lvov	9.4	90.6	0.9047	23.0
Minsk	27.9	72.1	0.9590	46.0
Kiev	16.0	84.0	0.9056	35.0
Moscow	23.1	76.9	0.9681	55.2
Odessa	21.5	78.5	0.8551	29.8
Kharkov	49.2	50.8	0.7734	22.4
Tatar A.S.S.R.	37.5	62.5	0.8878	9.8
Voronezh	72.4	27.6	0.7923	17.9
Rostov	89.2	10.8	0.8521	24.3
Stavropol kray	85.9	14.1	0.7471	14.1
Omsk	92.2	7.8	0.8412	13.7

(continued)

Table 10—Continued

Oblast	Relative Contribution of Weather Variation	Relative Contribution of Input Variation	R^2 of the Oblast Weather-Yield Equation	Variance of Oblast Yield
	(percent)			(centners/hectare)
Kustanay	87.1	12.9	0.8130	14.3
Altay kray	94.2	5.8	0.8344	15.6
Karaganda	98.3	1.7	0.7015	10.6

Sources: Yield data are from statistical handbooks for each republic. Temperature and precipitation are from data obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Notes: The relative contribution of weather variation (RCWV) to grain yield variation is

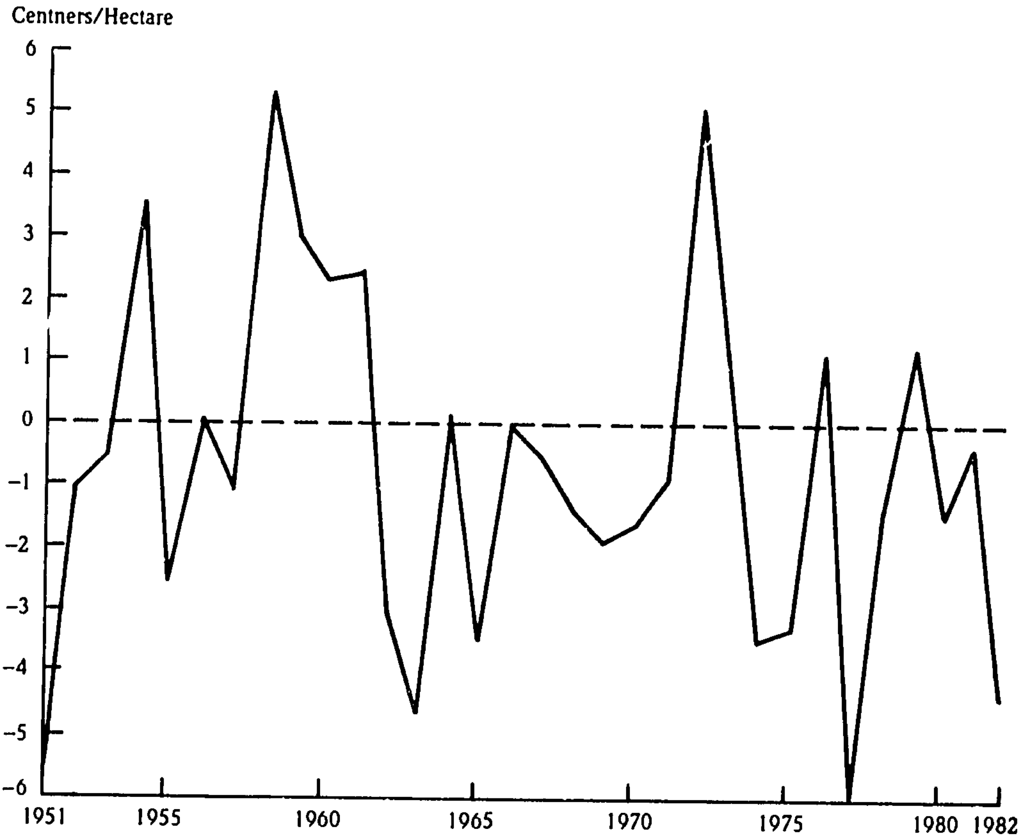
$$RCWV = [\hat{\gamma}_i \text{ covariance } (Y_i, TEMP3_i) + \hat{\theta}_i \text{ covariance } (Y_i, PREP4_i)] / \text{explained variance of } Y_i,$$

where Y_i is the grain yield of oblast i, and $TEMP3_i$ and $PREP4_i$ are the temperature in March and precipitation in April in oblast i. The relative contribution of input variation (RCIV) to grain yield variation is calculated as

$$RCIV = [\hat{\beta}_i \text{ covariance } (Y_i, T)] / \text{explained variance of } Y_i,$$

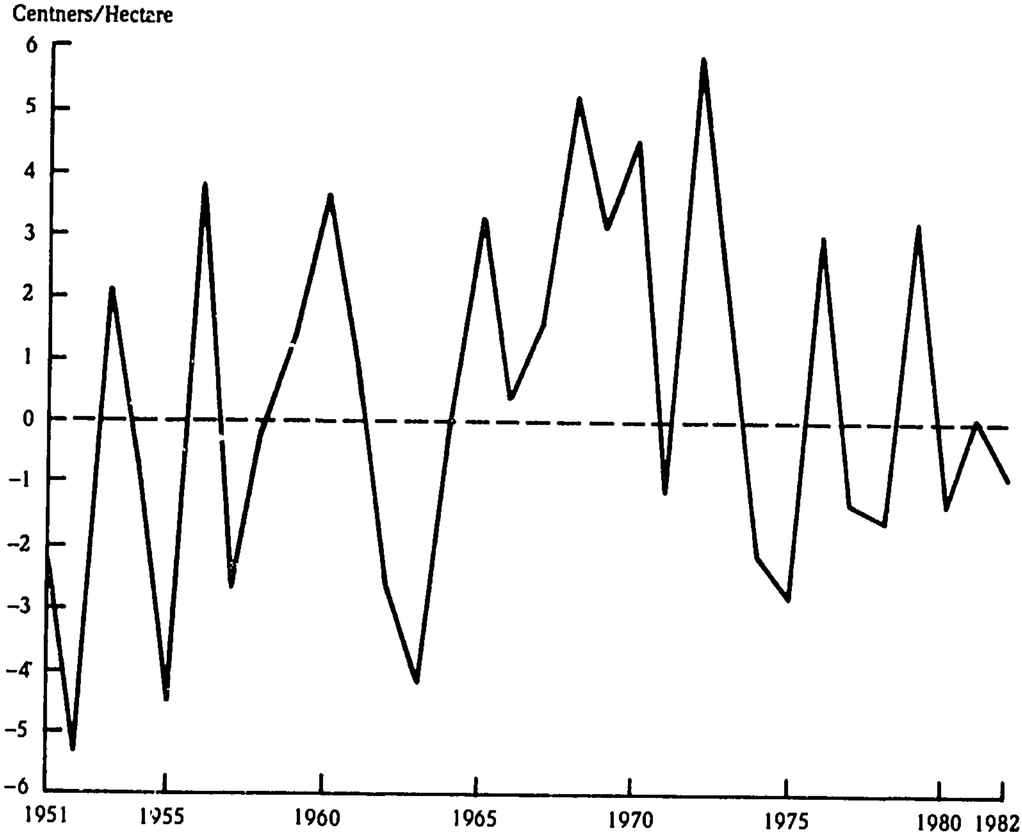
where T is the time trend representing input use.

Figure 17—Weather variability of yield in Karaganda oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

Figure 18—Weather variability of yield in Kustanay oblast, 1951-82



Source: Calculated from statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census. See Table 13.

6

WEATHER VARIABILITY AND THE CONTRIBUTION OF WEATHER FLUCTUATIONS TO SOVIET GRAIN YIELD VARIATION

Estimates of the variability of Soviet grain yield and output are presented in this chapter. The contribution of weather fluctuations to yield variation is also measured and analyzed.

Aggregate Weather-Yield Equation for Estimating the Weather Variability of Soviet Grain Yield

The aggregate weather-yield equation is derived by regressing observed Soviet grain yields on oblast yields estimated from the oblast weather-yield equations in Chapter 4. The estimated yields rather than the observed oblast yields are used as independent variables because the latter are not available after 1975 (see Appendix 1, Table 18). However, oblast yields after 1975 can be predicted using the oblast weather-yield models and the required weather data.

The estimated oblast yields are weighted by the share of each oblast in the total sown area of the selected oblasts, and U.S.S.R. grain yield is regressed on the weighted sum. Finally, the regression equation is estimated for the period 1958–75. Whereas oblast yields can be estimated from 1950, the area weights before 1958 are not reliable: until 1958, the oblast territories were changing and the pre-1958 territory and area data are not comparable with the post-1958 data.[50]

The equation is defined as

$$Y_{USSR,t} = \hat{a} + \hat{b} \sum_{i=1}^{14} (s_{it} \hat{Y}_{it}) + e_{USSR,t} \quad (20)$$

where $\hat{b} > 0$, $Y_{USSR,t}$ is observed Soviet grain yield in centners per hectare from 1958 to 1975, $\hat{Y}_{it}$ is the estimated yield of oblast i in year t, $s_{it} = A_{it}/\Sigma_{i}^{14} A_{it}$, where A_{it} is the observed sown area in thousand hectares in oblast i in year t, and $e_{USSR,t}$ is the estimated error term in year t.

The estimated equation is

$$Y_{USSR} = \underset{(62.1980)}{0.9694} \sum_{i=1}^{14} s_i \hat{Y}_i + e_{USSR}; \quad (21)$$

$R^2 = 0.9908$, D.W. = 2.5933, SER = 0.8668, number of observations = 18.[51]

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[50] Peter R. Craumer, "Areas of Secondary and Tertiary Administrative Units of the U.S.S.R., 1949–1983," Department of Geography, Columbia University, New York, 1984 (mimeographed), gives a complete list of the territories of Soviet oblasts from 1955. A sharp change in the area of an oblast between two consecutive years would suggest that its territory changed during one of the years.

[51] The equation below with the intercept is rejected because the estimate of the intercept is statistically not significant:

$$Y_{USSR} = \underset{(0.2499)}{-0.3031} + \underset{(10.7244)}{0.9922} \Sigma_{i=1}^{14} (s_i \hat{Y}_i) + e_{USSR};$$

$R^2 = 0.8779$, D.W. = 2.6945, SER = 0.8917, number of observations = 18.

The D.W. statistic, d, is approximately equal to $2(1-\rho)$ where ρ is the first-order autoregressive coefficient in $u_t = \rho u_{t-1} + e_t$. The range of d is from 0 to 4 with the range being 0 to 2 for $\rho > 0$, and 2 to 4 for $\rho < 0$. If $d > 2$ (as in equation [21]), the test of the hypothesis of serial correlation refers to $\rho = 0$ against $\rho < 0$. For this purpose, the value of (4-d) is estimated and the hypothesis of $\rho = 0$ is tested against the hypothesis of positive autocorrelation. Here $(4\text{-}d) = 1.4067$ is larger than $d_U = 1.39$ with $n = 18$ and $k = 1$, where d_U is the critical 5 percent upper limit of the D.W. statistic, n is the sample size, and k refers to the number of explanatory variables. Therefore, the hypothesis of no autocorrelation cannot be rejected. For details of the procedure of applying the test, see G. S. Maddala, *Econometrics* (New York: McGraw-Hill Book Company, 1977), pp. 284–285.

Equation (21) is used to separate the weather variabilities of Soviet grain yields and outputs in the period 1955–82. For this purpose, it is restated below with the required components from equations (16) and (21):

$$
\begin{aligned}
Y_{USSR} = 0.9694\ & [\{(\sum_{i=1}^{14} s_i \hat{c}) \\
& + (\sum_{i=1}^{14} s_i \hat{\beta}_i T) + (\sum_{i=1}^{14} s_i \hat{\gamma}_i \overline{TEMP3_i} \\
& + \sum_{i=1}^{14} s_i \hat{\theta}_i \overline{PREP4_i})\} \\
+ \{(\sum_{i=1}^{14} & s_i \hat{\gamma}_i TEMP3_i + \sum_{i=1}^{14} s_i \hat{\theta}_i PREP4_i) \\
- (\sum_{i=1}^{14} & s_i \hat{\gamma}_i \overline{TEMP3_i} + \sum_{i=1}^{14} s_i \hat{\theta}_i \overline{PREP4_i})\}] \\
& + e_{USSR} . \qquad (22)
\end{aligned}
$$

Note that the component in the first curled bracket of equation (22), multiplied by 0.9694, is the estimated yield from the inputs and mean weather. (In the remainder of this chapter, it is referred to as estimated yield with mean or average weather.) The component in the second curled bracket, multiplied by 0.9694, is the estimated weather variability of yield. Indeed, the only difference between equation (16) of Chapter 5 and equation (22) is that the former is for the oblasts, whereas the latter is for the entire U.S.S.R.

The estimates of grain yield with mean weather, and the weather variability of Soviet grain yields from 1955 to 1982, are given in Table 11.[52] Several important conclusions follow from these estimates. First, there are 15 years of positive and 13 years of negative weather variability during the 28-year period.[53] Second, the largest negative weather variability of yield, 2.8 centners, is for 1963; the next largest is 2.7 centners for 1965. The largest positive variability, 3.2 centners, is for 1970; the next largest is 3 centners for 1973. (The negative variability of 2.8 centners for 1963 implies that yield would have been higher by 2.8 centners if the weather had been average; similarly, the positive variability of 3.2 centners in 1970 implies that yield would have been lower by 3.2 centners if the weather had been average.)

Third, the ranking for the positive weather variability changes when expressed in terms of output rather than yield: 1973 becomes the best weather year with a positive variability of 38.6 million tons against 37.9 million tons in 1970.[54] The change occurs because grain area in 1973 was almost 7.5 million hectares higher than in 1973. The ranking for negative weather variability is, however, unaltered.

Fourth, the weather-related variability, positive and negative, of yield can be large: the highest negative variability, for 1963, is 33.7 percent of the actual yield of 8.7 centners. The highest positive variability, for 1970, is 20.4 percent of the actual yield of 15.6 centners. The critical issue, however, is the size of the average weather variability of yield around the zero mean. The standard deviation of yield variability during 1955–82 is 1.58 centners.

---

[52] It must be emphasized that the weather variability of output is estimated by multiplying the estimated yield variability by the sown area. In other words, the estimated weather variability of yield is spread over the area sown. Therefore, the weather variability of yield relative to actual yield is identical to the weather variability of output relative to actual output.

[53] However, for the longer period 1951–82, the 17 negative years are larger than the 15 positive years. This longer period of 32 years is compatible with the earlier analysis of Chapter 5 where the years with positive and negative weather variability were given for oblasts. The shorter period of 1955–82 is adopted because the time series data for grain-sown area begin only in 1955.

[54] This implies that, instead of the estimated 194.6 million tons in 1970 with observed weather, output would have been 156.7 million tons. In this context, estimated grain output with actual weather in a year must be distinguished from actual grain output: the former is the sum of the estimated grain output with mean weather and weather variability. Actual grain output can be more or less than estimated grain output with actual weather in a year. For, in addition to the contribution of the two explanatory variables of the time trend (representing inputs) and the weather, actual output is influenced by other factors that are not adopted as explanatory variables but are included in the error term of the models. For example, actual grain output is influenced by inputs varying in response to weather. Similarly, estimated yield, the sum of the estimated yield with mean weather and weather variability, should be distinguished from actual yield.

Table 11—Weather variability in Soviet grain yield and output, 1955–82

Year	Actual Grain Yield	Estimated Grain Yield: Actual Weather[a]	Estimated Grain Yield: Mean Weather[b]	Estimated Weather Variability of Grain Yield[c]	Share of Estimated Weather Variability in Actual Grain Yield	Sown Area	Estimated Grain Output with Mean Weather[d]	Estimated Weather Variability of Grain Output[e]	Estimated Grain Output with Weather Variability[f]	Actual Grain Output
	(centners/hectare)				(percent)	(million hectares)	(million tons)			
1955	8.4	8.1	9.7	−1.6	−19.0	123.461	119.6	−20.1	99.5	103.7
1956	9.9	10.4	9.9	0.5	5.1	125.605	124.6	6.4	131.0	125.0
1957	8.4	9.9	10.1	−0.2	−2.4	122.005	123.8	−2.0	121.8	102.6
1958	11.1	12.2	10.3	1.9	17.1	121.417	125.5	23.0	148.5	134.7
1959	10.4	10.2	10.5	−0.3	−2.9	114.522	120.0	−4.0	116.0	119.5
1960	10.9	11.7	10.7	1.0	9.2	115.537	123.0	11.9	134.9	125.5
1961	10.7	11.6	11.1	0.5	4.7	122.243	135.9	6.5	142.4	130.8
1962	10.9	10.0	11.3	−1.3	−11.9	128.676	145.3	−16.4	128.9	140.2
1963	8.3	8.7	11.5	−2.8	−33.7	129.980	150.0	−36.4	113.6	107.5
1964	11.4	11.8	11.8	−0.04	−0.4	133.321	157.3	−0.5	156.8	152.1
1965	9.5	9.3	12.0	−2.7	−28.4	128.024	153.2	−34.7	118.5	121.1
1966	13.7	13.9	12.2	1.7	12.4	124.807	152.0	20.7	172.7	171.2
1967	12.1	11.9	12.5	−0.6	−5.0	122.172	152.2	−7.6	144.6	147.9
1968	14.0	14.1	12.6	1.5	10.7	121.472	153.5	17.9	171.4	169.5
1969	13.2	11.8	12.8	−1.0	−7.6	122.703	157.3	−12.0	145.3	162.4
1970	15.6	16.3	13.1	3.2	20.5	119.261	156.7	37.9	194.6	186.8
1971	15.4	14.0	13.4	0.6	3.9	117.937	157.9	6.8	164.7	181.2
1972	14.0	14.6	13.6	1.0	7.1	120.158	163.9	11.5	175.4	168.2
1973	17.6	16.9	13.9	3.0	17.0	126.738	176.2	38.6	214.8	222.5
1974	15.4	14.0	14.1	−0.02	−0.1	127.187	179.7	−0.2	179.5	195.7
1975	10.9	12.2	14.3	−2.1	−19.3	127.920	183.2	−26.6	156.6	140.1
1976	17.5	15.8	14.5	1.3	7.4	127.760	184.9	16.7	201.5	223.8
1977	15.0	17.0	14.7	2.3	15.3	130.344	191.6	29.4	221.0	195.7
1978	18.5	17.1	14.9	2.2	11.9	128.465	191.7	27.6	219.3	237.4
1979	14.2	14.8	15.2	−0.4	−2.8	126.351	191.5	−5.4	186.1	179.2
1980	14.9	15.5	15.4	0.1	0.7	126.608	194.7	1.1	195.8	189.1
1981	12.7	14.6	15.6	−1.0	−7.9	125.559	196.0	−12.7	183.3	160.0
1982	14.6	16.1	15.8	0.3	2.1	123.012	194.8	4.1	198.9	180.0

(continued)

Sources: The actual grain yields for 1955–75 are from Soyuz Sovetskikh Sotsialisticheskikh Respublik (SSSR), Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov (TsSU), *Narodnoye khozyaystvo SSSR 1975* (*Narkhoz 1975*) (Moscow: Statistika, 1975), p. 312; those for 1976–82 are from U.S. Department of Agriculture (USDA), Economic Research Service (ERS), *U.S.S.R. Outlook and Situation Report*, RS-84-4 (Washington, D.C.: USDA, 1984), p. 22. The sown area data for 1955–74 are from USDA, ERS, *U.S.S.R. Grain Statistics: National and Regional, 1955–75*, Statistical Bulletin No. 564 (Washington, D.C.: USDA, 1977), p. 10; those for 1975 are from USDA, ERS, *U.S.S.R. Review of Agriculture in 1981 and Outlook for 1982*, Supplement 1 to WAS 27 (Washington, D.C.: USDA, 1982), p. 20; and those for 1976–82 are from USDA, ERS, *U.S.S.R. Outlook and Situation Report*, RS-84-4, p. 22. The actual grain output data for 1955–75 are from SSSR, TsSU, *Narkhoz 1975*, pp. 310–311; those for 1976–82 are from USDA, ERS, *U.S.S.R. Situation Report*, RS-84-4, p. 22. Temperature and precipitation data were obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

[a] This series is estimated on the basis of $Y_{USSR} = 0.9694 \sum_{i=1}^{n=14} s_i \hat{Y}_i + \hat{e}_{USSR}$

[b] These estimates are derived on the basis of $[(\sum_{i=1}^{n=14} s_i \hat{\alpha}_i) + (\sum_{i=1}^{n=14} s_i \hat{\beta}_i T) + (\sum_{i=1}^{n=14} s_i \hat{\gamma}_i \overline{TEMP3}_i + \sum_{i=1}^{n=14} s_i \hat{\theta}_i \overline{PREP4}_i)]$, multiplied by 0.9694, where T is the time trend representing input use and $\overline{TEMP3}_i$ and $\overline{PREP4}_i$ are the mean temperature in March and precipitation in April in oblast i.

[c] These figures are estimated on the basis of $[(\sum_{i=1}^{n=14} s_i \hat{\gamma}_i TEMP3_i + \sum_{i=1}^{n=14} s_i \hat{\theta}_i PREP4_i) - (\sum_{i=1}^{n=14} \hat{\gamma}_i s_i \overline{TEMP3}_i + \sum_{i=1}^{n=14} s_i \hat{\theta}_i \overline{PREP4}_i)]$, multiplied by 0.9694.

[d] These figures are calculated by multiplying the estimated grain yield with mean weather in each year by sown area.

[e] These figures are calculated by multiplying the estimated weather variability of grain yield by sown area.

[f] These figures are calculated by adding the estimates of grain output with mean weather and the weather variability of output.

This implies that, on average, yield varies by 1.58 centners when weather deviates from its mean. This is 12.3 percent of the mean yield of 12.8 centners.

Finally, because Soviet grain harvests of the six consecutive years from 1979 have been poor, the weather variability of grain yield and output of those years must be assessed. Unfortunately, official statistics of output after 1980 are not available, and 1983 and 1984 could not be included in the analysis because the weather data are not available. Nonetheless, the estimated weather variability of both yields and output in the four years from 1979 is small. Indeed, it is positive in 1980 and 1982, albeit by small amounts. The highest negative variability, 1 centner per hectare in 1981, implies a variability in output of only 12.7 million tons. If the weather had been average, grain output in the four years would have gone up by only 12.9 million tons.

Aggregate Weather-Yield Equation for Measuring the Contributions of Input and Weather Fluctuations in Yield Variation

Since inputs (represented by the time trend) and weather are the only explicit variables influencing yield in the models adopted here, the fluctuations of inputs and weather must contribute to the fluctuations of yield explained by the models. The covariance procedure of Chapter 5 is extended here to estimate the contribution of each to the explained variance of yield.

In equation (23) below, actual Soviet grain yields, again from 1958 to 1975, are regressed on time trend T and weather $\hat{W}_i$, estimated from the oblast weather-yield equations. In this specification, both T and the weather variables $TEMP3_i$ and $PREP4_i$ are weighted not only by the share of oblast area in the total area of the selected oblasts, s_i, but also by the coefficients $\hat{\beta}_i$, $\hat{\gamma}_i$, and $\hat{\theta}_i$ of the oblast weather yield in equation (19).[55] That is,

$$Y_{USSR,t} = \hat{p} + \hat{q} \sum_{i=1}^{14} s_{it} \hat{\beta}_i T + \hat{r} \sum_{i=1}^{14} s_{it} (\hat{\gamma}_i TEMP3_i + \hat{\theta}_i PREP4_i)_t + e_{USSR,t}. \quad (23)$$

The estimated weather, $\hat{W}_i$, in equation (23) is ($\hat{\gamma}_i TEMP3_i + \hat{\theta}_i PREP4_i$). The estimated equation is

$$Y_{USSR} = \underset{(9.3750)}{32.6539} + \underset{(7.2480)}{1.1813} \times \sum_{i=1}^{14} s_i \hat{\beta}_i T + \underset{(7.5080)}{0.8566} \times \sum_{i=1}^{14} s_i \hat{W}_i + e_{USSR}; \quad (24)$$

$R^2 = 0.8919$, D.W. = 2.5250, SER = 0.8665, number of observations = 18.

The parameters of equation (24) are used to measure the contribution of weather fluctuations to Soviet grain yield variation through the covariance procedure of Chapter 5. The yield variance explained by equation (24) is its R^2 of 0.8919 multiplied by the yield variance of 6.13 centners (per hectare), that is, 5.47 centners. The relative contribution of input variation to this variance is

$$\frac{\hat{q} \text{ covariance } (Y_{USSR}, \sum_{i=1}^{14} s_i \hat{\beta}_i T)}{\text{explained variance of } Y_{USSR}}; \quad (25)$$

[55] Alternatively, the time trend T can be specified without the weights $\sum_{i=1}^{14} s_{it} \hat{\beta}_i$. That is

$$Y_{USSR_t} = p' + q'T + r' \sum_{i=1}^{14} s_{it} (\hat{\gamma}_i TEMP3_i + \hat{\theta}_i PREP4_i)_t + e'_{USSR_t}$$

Since the 14 oblasts represent grain-growing in the grain belt, the weather variables and their measured effects are from these oblasts (and not from the grain area as a whole). By the same token, the time trend T in the aggregate equation, representing input application and its estimated effect on yield, must also be for the 14 oblasts. $\sum_{i=1}^{14} s_{it} \hat{\beta}_i T$ in equation (23) is this required measure of the effect of inputs in the oblasts. By contrast, the unweighted T in the equation above represents input use in the entire grain belt. Therefore, equation (23) is the preferred specification, and its parameters are used to estimate the contribution of fluctuating weather to variations in aggregate grain yield.

and the relative contribution of weather variation is

$$\frac{\hat{r}\ \text{covariance}\ (Y_{USSR},\ \sum_{i=1}^{14} s_i\ \hat{W}_i)}{\text{explained variance of}\ Y_{USSR}}. \qquad (26)$$

Note that $\hat{q}$ and $\hat{r}$ are the estimated parameters of equation (23).

The covariance of $(Y_{USSR}, \Sigma_{i=1}^{14} s_i\ \hat{\beta}_i T)$ is 2.24 centners and, of $(Y_{USSR}, \Sigma_{i=1}^{14} s_i\ \hat{W}_i)$ is 3.29 centners. Multiplied by the corresponding estimated parameters, these become 2.65 and 2.82 centners, which are 48 and 52 percent of the yield variance of 5.47 centners. The contribution of weather fluctuations to yield variation is thus large, 52 percent of the total, but not dramatic.

This estimate is clearly influenced by the adoption of the time trend instead of the inputs in the oblast equations. The input data for deriving the estimate are simply not available. Again, it is not possible to locate a study that uses this covariance procedure to estimate the contribution of weather fluctuations to grain yield variation for say, the United States. In the United States, changes in area associated with governmental farm subsidy programs and the resulting fluctuations in input use—and not weather fluctuations—can be presumed to have a decisive influence on yield variation.

Johnson and Brooks compare the trend, level, and variability of Soviet grain yields with those in the climatically analogous areas of North America. "The comparisons indicate that grain yields in the USSR have been increasing at essentially the same rate as in the climatically similar areas. The comparisons of the levels of grain yields indicate that yields in the USSR, when maize is excluded in the comparison areas, are at a reasonable level." However, yield differences are small or do not exist because crops such as grains and cotton have received high priority. The implication is that in the planned Soviet system, the size of yields can be brought in line with those in climatically analogous areas of North America. This is not to suggest that the policies have led to efficient allocation of resources for growing grain, because ". . . the resources devoted to agriculture in the Soviet Union produce approximately half as much as the same bundle of resources would produce in climatically similar areas in North America."[56]

As for the variability of yields attributable to weather: "It is clear that climatic variability can and does significantly affect crop output, not only from one year to the next but for periods as long as five years. This variability makes it difficult for Soviet officials to make concrete plans and for those who study Soviet agriculture to put great confidence in short run projections."[57]

In view of the different methodology adopted by Johnson and Brooks in assessing the effect of weather on grain yield variability, their assessment cannot be compared with the result reported here.

The conclusions of this chapter portray the role of weather in Soviet yields and outputs during 1955–82 as modest. The average weather variability of yields and outputs is 12.3 percent of mean yield and output, although it can occasionally be substantial. For example, in 1963, grain output would have gone up by 36.4 million tons, that is, 33.8 percent of the actual output if the weather had been average. The contribution of weather fluctuation to yield variation estimated at 52 percent of the explained yield variance of 5.47 centners is large but not dramatic. Finally, the weather variability of yield and output between 1979 and 1982 is small.

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[56] D. Gale Johnson and Karen McConnell Brooks, *Prospects for Soviet Agriculture in the 1980s* (Bloomington, Ind.: Indiana University Press, 1983), p. 78.

[57] Ibid., p. 196.

7

VARIABILITY OF WEATHER-ADJUSTED GRAIN YIELD

What pattern does Soviet grain yield have when weather variability is removed? The impact of the "systemic" and policy factors on Soviet grain yield cannot be assessed unless this question is answered.

Net grain yields and outputs are derived by subtracting the estimated weather variability of yields and outputs from actual yields and outputs. The time series required are those in Table 11. The weather-adjusted series are given in Table 12 and plotted in Figures 19 and 20. The graphs show that the weather variability component fluctuates and is more or less random and that the absolute fluctuations between 1958 and 1967 are smaller than between 1968 and 1982.

Are the oscillations in the second period higher because weather became more volatile in the second period? Probably not. The entire period under consideration is too short for a dramatic shift of the weather. It would seem, therefore, that the higher yield and output variability in the second period, if statistically significant, has to be explained by erratic input supplies and systemic and policy factors.[58]

The statistical test of whether net yield and output are more variable in the second period is performed by first specifying the trend equation:

$$Y_{SU,t} = AB^t u_{SU,t} \qquad (27)$$

where $u_{SU,t}$ is stochastic with mean μ_u and variance σ_u^2 and where the variance of the dependent variable, yield (Y_{SU}), is an increasing function of time.[59] Equations were fitted in the log-linear form for yield and output (O_{SU}) in the periods 1958–82, 1958–67, and 1968–82.[60]

$$1958\text{–}82:\ \ln Y_{SU} = \underset{(53.5420)}{2.2083} + \underset{(8.8960)}{0.0173t} + \ln u_{Y_{SU}}; \qquad (28)$$

$R^2 = 0.7825$, $\rho_1 = 0.2344$, SSR = 0.1568, number of observations = 25.

ρ_1 is the first-order serial correlation correction coefficient. The D.W. statistic in the uncorrected equation is 2.5490.

$$1958\text{–}82:\ \ln O_{SU} = \underset{(123.7330)}{6.9946} + \underset{(7.1620)}{0.0190t} + \ln u_{O_{SU}}; \qquad (29)$$

$R^2 = 0.6904$, D.W. = 2.0420 SSR = 0.2114, number of observations = 25.

$$1958\text{–}67:\ \ln Y_{SU} = \underset{(25.9300)}{2.0268} + \underset{(5.0050)}{0.0305t} + \ln u_{Y_{SU}}; \qquad (30)$$

$R^2 = 0.7579$, D.W. = 3.1920, SSR = 0.0245, number of observations = 10.

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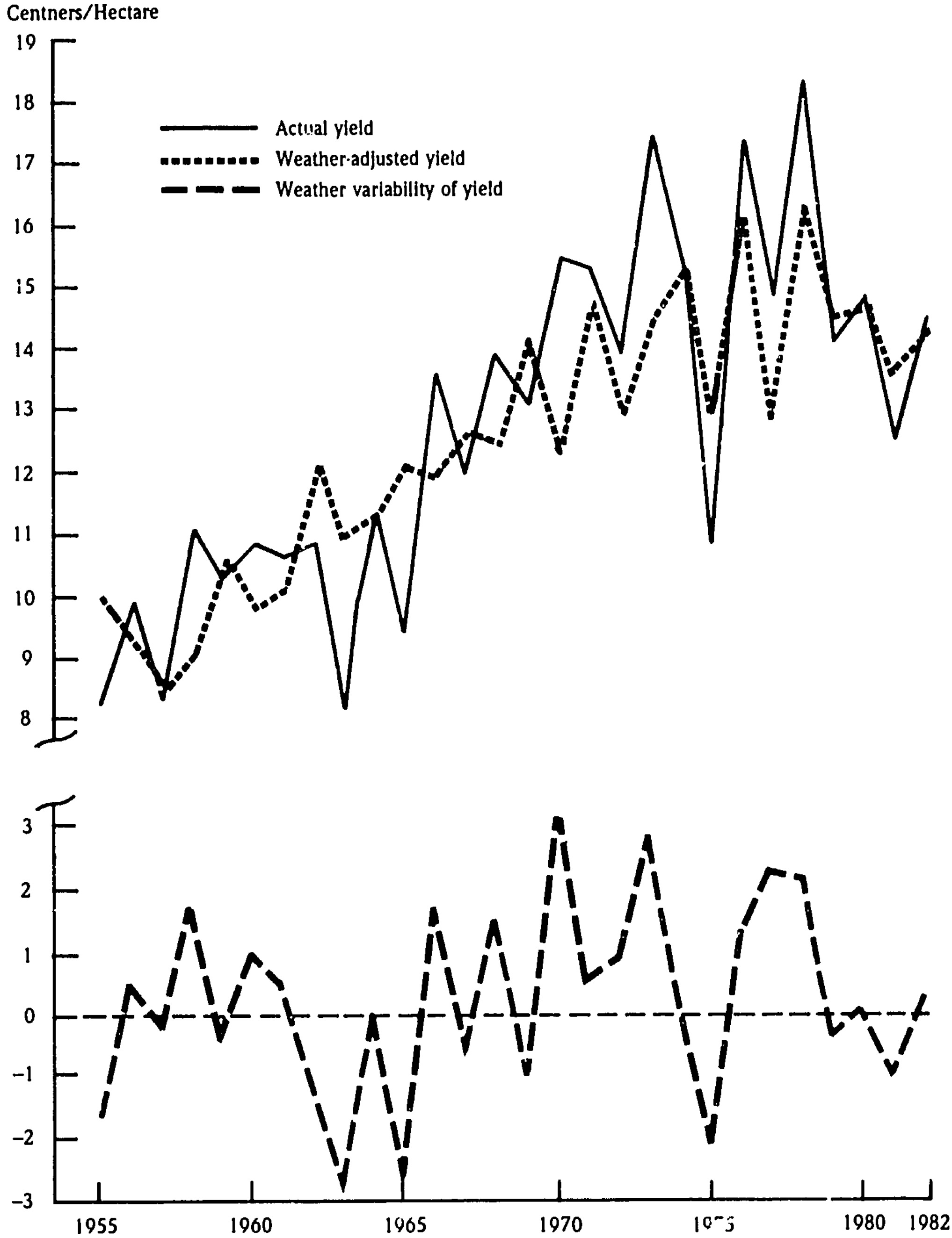
[58] Net yield here, with weather variability taken out, includes a trend term, which rises linearly; average weather, which is a constant; and an error term. As stated earlier, the trend term represents input use indicating not only a given state of farming methods but also the planners' decisions about how to allocate farm inputs. Also, input use will vary from year to year, perhaps because of supply shortfalls. Therefore, the increased variability of net yield between 1968 and 1982 can be attributed to the erratic effect of all these elements, including deviations in input use from the trend line.

[59] The variance of (Y_{SU}), $V(Y_{SU}) = (AB^t)^2\sigma_u^2$. For details, see Shakuntla Mehra, *Instability in Indian Agriculture in the Context of the New Technology*, Research Report 25 (Washington, D.C.: International Food Policy Research Institute, 1981).

[60] Equations were also fitted for the subperiods 1955–67 and 1968–82 but the statistical test for increased variability did not work.

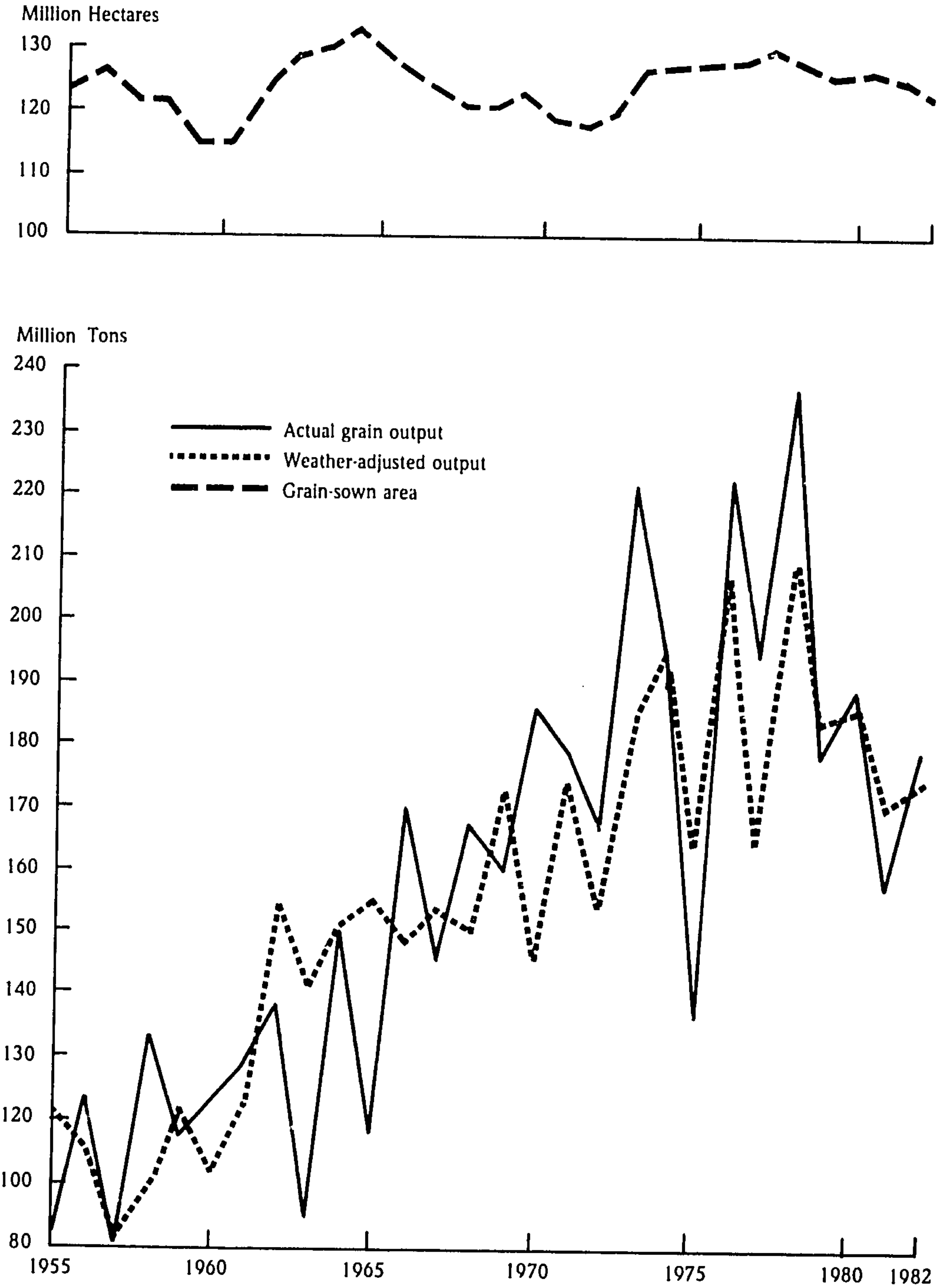
Figure 19—Actual and weather-adjusted grain yield, and weather variability of grain yield, 1955-82



Sources: The actual grain yields for 1955-75 are from Soyuz Sovetskikh Sotsialisticheskikh Respublik (SSSR), Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov, *Narodnoye khozyaystvo SSSR 1975*, (Moscow: Statistika, 1975), p. 312; those for 1976-82 are from U.S. Department of Agriculture, Economic Research Service, *U.S.S.R. Outlook and Situation Report*, RS-84 4 (Washington, D.C.: USDA, 1984), p. 22. The weather variability of yield figures are the estimates found in Table 11.

Note: The weather adjusted yield is derived by subtracting the estimated weather variability of grain yield given in Table 11 from actual yield.

Figure 20—Grain-sown area, actual grain output, and weather-adjusted grain output, 1955-82



(continued)

Figure 20—Continued

Sources: The sown area data for 1955-74 are from U.S. Department of Agriculture (USDA), Economic Research Service (ERS), *U.S.S.R. Grain Statistics: National and Regional, 1955-75,* Statistical Bulletin No. 564 (Washington, D.C.: USDA, 1977), p. 10; those for 1975 are from USDA, ERS, *U.S.S.R. Review of Agriculture in 1981 and Outlook for 1982,* Supplement 1 to WAS 27 (Washington, D.C.: USDA, 1982), p. 20; and those for 1976-82 are from USDA, ERS, *U.S.S.R. Outlook and Situation Report,* RS-84-4, p. 22. The actual grain output data for 1955-75 are from Soyuz Sovetskikh Sotsialisticheskikh Respublik, Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov, *Narodnoye khozyaystvo SSSR 1975* (Moscow: Statistika, 1975), pp. 310-311; those for 1976-82 are from USDA, ERS, *U.S.S.R. Outlook and Situation Report,* RS-84-4, p. 22. Temperature and precipitation data were obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Note: The weather-adjusted output is derived by subtracting the estimated weather variability of grain output given in Table 11 from actual output.

Table 12—Weather-adjusted grain yield and output, 1955–82

Year	Weather-Adjusted Yield	Weather-Adjusted Output
	(centners/hectare)	(million tons)
1955	10.0	123.8
1956	9.4	118.6
1957	8.6	104.6
1958	9.2	111.7
1959	10.7	123.5
1960	9.9	113.6
1961	10.2	124.3
1962	12.2	156.6
1963	11.1	143.9
1964	11.4	152.6
1965	12.2	155.8
1966	12.0	150.5
1967	12.7	155.5
1968	12.5	151.6
1969	14.2	174.4
1970	12.4	148.9
1971	14.8	174.4
1972	13.0	156.7
1973	14.6	183.9
1974	15.4	195.9
1975	13.0	166.7
1976	16.2	207.1
1977	12.7	166.3
1978	16.3	209.8
1979	14.6	184.6
1980	14.8	188.0
1981	13.7	172.7
1982	14.3	175.9

Sources: The actual grain yields for 1955–75 are from Soyuz Sovetskikh Sotsialisticheskikh Respublik (SSSR), Tsentral'noye Statisticheskoye Upravleniye pri Sovete Ministrov (TsSU), *Narodnoye khozyaystvo SSSR 1975* (*Narkhoz 1975*) (Moscow: Statistika, 1975), p. 312; those for 1976–82 are from U.S. Department of Agriculture (USDA), Economic Research Service (ERS), *U.S.S.R. Outlook and Situation Report,* RS-84-4 (Washington, D.C.: USDA, 1984), p. 22. The actual grain output data for 1955–75 are from SSSR, TsSU, *Narkhoz 1975,* pp. 310–311; those for 1976–82 are from USDA, ERS, *U.S.S.R. Outlook and Situation Report,* RS-84-4, p. 22. Temperature and precipitation data were obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Notes: Weather-adjusted yield is derived by subtracting the estimated weather variability of grain yield given in Table 11 from actual yield. Weather adjusted output is derived by subtracting the estimated weather variability of grain output given in Table 11 from actual output.

1958–67: $\ln O_{SU} = \underset{(65.2880)}{6.7374} + \underset{(4.8760)}{0.0392t} + \ln u_{O_{SU}}$; (31)

$R^2 = 0.7483$, D.W. = 1.8500, SSR = 0.0427, number of observations = 10.

1968–82: $\ln Y_{SU} = \underset{(18.9240)}{2.4697} + \underset{(1.3860)}{0.0071t} + \ln u_{Y_{SU}}$; (32)

$R^2 = 0.1287$, D.W. = 3.4250, SSR = 0.0963, number of observations = 15.

1968–82: $\ln O_{SU} = \underset{(50.2410)}{7.2009} + \underset{(1.9330)}{0.0109t} + \ln u_{O_{SU}}$; (33)

$R^2 = 0.2233$, D.W. = 2.8380, SSR = 0.1162, number of observations = 15.

Before conducting the F-test for the hypothesis that yield and output variability increased in the second period, the D.W. statistics in equations (30), (32), and (33) must be corrected for serial correlation. ρ_2 and ρ_3 are the second- and third-order serial correlation correction coefficients.[61]

1958–67: $\ln Y_{SU} = \underset{(60.1030)}{2.0359} + \underset{(11.2910)}{0.0300t} + \ln u_{Y_{SU}}$; (34)

$R^2 = 0.9623$, $\rho_1 = \underset{(2.3276)}{0.7329}$, $\rho_2 = \underset{(1.6585)}{0.5743}$, $\rho_3 = \underset{(0.2927)}{-0.0922}$,

SSR = 0.0089, number of observations = 10.

1968–82: $\ln Y_{SU} = \underset{(33.7730)}{2.4861} + \underset{(2.2600)}{0.0066t} + \ln u_{Y_{SU}}$; (35)

$R^2 = 0.3172$, $\rho_1 = \underset{(2.2818)}{0.5855}$,

$\rho_2 = \underset{(0.4321)}{-0.1109}$,

SSR = 0.0511, number of observations = 15.

1968–82: $\ln O_{SU} = \underset{(71.0390)}{7.2016} + \underset{(2.7530)}{0.0110t} + \ln u_{O_{SU}}$; (36)

$R^2 = 0.3871$, $\rho_1 = \underset{(1.7307)}{0.2357}$,

SSR = 0.0947, number of observations = 15.

F-tests were conducted on the coefficient of variation of yields based on equations (34) and (35), and outputs based on equations (31) and (36).[62] At the 5 percent level of significance, the coefficient of variation of yield is significantly greater in the second period. However, the test does not support the hypothesis that the variation of output increased.[63]

What kind of hypotheses can be formulated to explain the higher net yield variability in the period 1968–82? Note that

[61] The serial correlation correction is carried out until the final coefficient is statistically not significant.

[62] It is not meaningful to conduct a statistical test on changes in the variance of Y_{SU} or $V(Y_{SU})$ between the two periods because $V(Y_{SU})$ is specified to be an increasing function of time. But suppose $v_t = \ln u_{SU,t}$ is distributed according to a normal distribution with $\mu_v = 0$ and variance σ_v^2. This implies that $u_{SU,t}$ has a log-normal distribution with

$$\mu_u = e^{1/2\,\sigma_v^2} \text{ and } \sigma_u^2 = e^{\sigma_v^2}(e^{\sigma_v^2} - 1).$$

The coefficient of variation of v_t is then $(e^{\sigma_v^2} - 1)^{1/2}$, which is also the coefficient of variation Y_{SU}. Tests for increases in the coefficient of variation of Y_{SU} then reduce to tests about increases in $e^{\sigma_v^2} - 1$, or, because this is a monotonically increasing function in σ_v^2, about tests of increases in σ_v^2. Because it has been assumed that v_t is normally distributed, standard F-tests are applicable. For details, see Mehra, *Instability in Indian Agriculture*.

[63] The critical 5 percent value of the F ratio with 13 degrees of freedom in the numerator and 8 in the denominator is about 3.2. The respective ratios for yield and output are 0.0511/0.0089 = 5.7416 and 0.0947/0.0427 = 2.2178.

these years coincide roughly with the increasingly massive injections of investments in Soviet agriculture that accompanied the decision to raise the standard of living of the Soviet people by steadily raising their consumption of livestock products. These massive injections of resources, coupled with a lack of genuine incentives in the farm economy, could have intensified the organizational problems there. For example, the problems of increasing labor shortages in the farm sector could have been aggravated.[64] Fertilizer use rose dramatically perhaps without a balancing increase in the use of complementary inputs of pesticides, water, and weed control. Agricultural mechanization, in particular with continuing problems of spare parts, especially at harvesting time, may have become more problematic. The introduction of new varieties of seeds for certain crops could also have accentuated the attendant problems of pest control, inadequate water supplies, and so on. Increased yield variation can also result from the policy decision to introduce barley (which has greater variations in yield) into the spring crop of the oblasts of the Ukraine and the northern Caucasus.

The analysis of net yield variability, suggesting increased variability, needs to be strengthened by distinguishing between crops such as spring wheat, winter wheat, and barley, and by using different weather indexes.

In conclusion, the finding of increased variability of weather-adjusted grain yield poses serious problems for the Soviet planners. In particular, it points to the urgent need to introduce suitable incentives in the management of the farm economy to reduce the variability of weather-adjusted grain yields.

[64] A list of sources that discuss problems in Soviet grain production is given in Felix N. Kogan, "Soviet Grain Production: Resources and Prospects," *Soviet Geography: Review and Translation*, November 1983, pp. 631–661. The problems created by the increasing labor shortages in agriculture are discussed in A. I. Zdorovtsev, "Resources of Agriculture" (in Russian), *Ekonomika Sel'skogo Khozyaystva*, 1981, no. 11: 3–6; V. S. Golovin, A. N. Lifanchikov, and I. P. Ul'yanov, "The Development of the APK in the Nonchernozem Zone" (in Russian), *Voprosy Ekonomiki*, 1982, no. 9: 100-111; I. Gridasov and B. Andreyeva, "The Basis of Fertility" (in Russian), *Sel'skaya Zhizn'*, June 20, 1982; and A. A. Sergeyev, "Principal Trends for Capital Investments During the 11th Five-Year Plan" (in Russian), *Planirovaniye: Uchet v Sel'skokhozyaystvennikh Predpriyatiyakh*, 1982, no. 1: 2–6.

The increasingly complex and unsatisfactory fertilizer situation is discussed in V. V. Tokarev and I. A. Potashov, "Improving Mineral Fertilizer Effectiveness" (in Russian), *Zemledeliye*, 1980, no. 9: 19–26; A. Gol'tsov, "Growth in the Production of Grain—A Most Important Task of the 11th Five-Year Plan" (in Russian), *Planovoye Khozyaystvo*, 1981, no. 4: 90-96; V. Golikov, "The Central Problem of the Five-Year Plan" (in Russian), *Kommunist*, 1982, no. 13: 22–31; Golovin, Lifanchikov, and Ul'yanov, "The Development of the APK"; Gridasov and Andreyeva, "The Basis of Fertility"; and B. Istomin, "Notes from a Scientific Conference" (in Russian), *Sel'skaya Zhizn'*, July 8, 1982.

Farm equipment problems are treated at length in V. A. Domanskiy, "On Supplying Agriculture with Equipment and the Use of Such Equipment" (in Russian), *Vestnik Statistiki*, 1981, No. 4, pp. 23–31, and Z. Gerasimova, "On the Prices for Agricultural Equipment" (in Russian), *Ekonomika Sel'skogo Khozyaystva*, 1981, No. 3, pp. 40–42.

The increasing problems, especially with new varieties of winter wheat, are discussed in Gol'tsov, "Growth in the Production of Grain"; and "Effectiveness of Scientific Research, Report on the 1982 Annual Meeting of the Academy of Agricultural Sciences" (in Russian), *Sel'skaya Zhizn'*, April 27, 1982.

8

IMPLICATIONS FOR DEVELOPING COUNTRIES

The role of "systemic" and policy factors in the fluctuation of Soviet grain yields became more pronounced between 1968 and 1982. When yields vary from year to year and grain output falls short of requirements, imports must fill the gap. The fluctuations in Soviet grain yields and the imports they engender affect the developing countries as importers and suppliers of grain in world markets.

Three aspects of relevance to the analysis are discussed below. The most relevant is the massive and increasing Soviet grain imports dating from 1971/72.[65] Also important is the emergence of Argentina as a large grain supplier to the Soviet Union. The third aspect discussed is the possible conflict between Soviet grain demand and the import needs of the developing countries.

Weather Variability and Soviet Grain Imports

The weather variability of Soviet grain output after 1970 was substantially negative only in 1975/76 and in 1981/82. It was only marginally negative in 1979/80, close to zero in 1974/75, and positive in eight years. Imports, by contrast, have grown steadily and were a massive 142 million tons in the four years from 1979/80 to 1982/83 (Table 13). The combined negative weather variability of output in the four years was 12.9 million tons. Fluctuations in output attributable to factors other than below-average weather seem to have contributed to large imports beginning from 1971/72, assuming that nothing else changed. If, as a result, they continue to be large in the future, and if they are not predicted in advance, they can have serious implications for the grain-surplus and the grain-deficit developing countries of the world.

Soviet Grain Import Requirements and Developing-Country Grain Suppliers

Table 14 shows that the U.S. share of grain exports to the Soviet Union declined drastically to 23 percent in 1980/81, a result of the grain embargo imposed by the Carter Administration in January 1980. Argentina emerged as a major supplier of grain at that time.[66] Argentina's shares in Soviet grain imports have continued to be large with the 1983 share, 27 percent, exceeding the U.S. share, 22 percent, and matching the Canadian share.[67]

Supply prices show that international grain trade, in recent years, has been competitive, with Argentina able to compete in both wheat and maize. Argentine wheat prices fell below the prices of U.S., Canadian, and Australian suppliers in several years between 1975 and 1981, and averaged U.S. $154 per metric ton over the whole period, less than the Canadian average (U.S. $162) and not far above the averages for the United States and Australia (both U.S.

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[65] The years referred to here are consumption years starting from July 1 and ending on June 30 of the next year. Imports are net of exports.

[66] Argentina also supplied 39 and 55 percent of Soviet purchases of soybeans in 1982 and 1983. Brazil's share of Soviet purchases of soybean meal was 62 and 55 percent in 1982 and 1983. The data are from U.S. Department of Agriculture (USDA), Economic Research Service (ERS), *U.S.S.R. Outlook and Situation Report*, RS-84-4 (Washington, D.C.: USDA, 1984), p. 29; and USDA, ERS, *U.S.S.R. Outlook and Situation Report*, RS-85-4 (Washington, D.C.: USDA, 1985), p. 21. These commodities are not considered in this report.

[67] These shares include Soviet purchases of grain and grain products in tons in the calendar years. For details, see USDA, ERS, *U.S.S.R. Outlook*, RS-84-4, p. 29, and USDA, ERS, *U.S.S.R. Outlook*, RS-85-4, p. 21.

Table 13—Net grain imports and the estimated weather variability of output, 1971/72–1982/83

Year	Net Grain Imports[a]	Estimated Weather Variability of Grain Output
	(million tons)	
1971/72	1.4	6.8
1972/73	21.0	11.5
1973/74	5.2	38.6
1974/75	0.4	−0.2
1975/76	25.4	−26.6
1976/77	7.7	16.7
1977/78	16.8	29.4
1978/79	12.8	27.6
1979/80	29.7	−5.4
1980/81	34.3	1.1
1981/82	45.5	−12.7
1982/83	32.0	4.1

Sources: The net import data from 1971/72 to 1975/76 are from U.S. Department of Agriculture (USDA), Economic Research Service (ERS), *World Agriculture: Outlook and Situation*, WAS 29 (Washington, D.C.: USDA, 1982), p. 21; the data from 1976/77 to 1982/83 are from USDA, ERS, *U.S.S.R. Outlook and Situation Report*, RS-85-4 (Washington, D.C.: USDA, 1985), p. 6. The estimates of the weather variability of grain output are found in Table 11.

Note: Each year is the grain consumption year beginning July 1 and ending June 30 of the next year.

$148). Similarly, Argentine maize prices fell below U.S. maize prices between 1976 and 1979, and averaged only slightly more than U.S. prices between 1975 and 1981 (U.S. $121 per metric ton compared to U.S. $117).[68]

The Soviets have shown a desire to reduce their dependence on U.S. supplies and to diversify their sources of purchase, which can be financed by barter of, say, oil in exchange for grain. Grain-producing developing countries can take advantage of this opportunity if they can generate exportable surpluses at the prevailing international prices.

Soviet Grain Import Requirements and Grain-Importing Developing Countries

Rising Soviet shares of imports of coarse feedgrains in world trade, including maize, will conflict with the increasing needs of middle-income developing countries for these commodities to satisfy rising demands for livestock products as incomes grow and living standards improve (Table 15). This may be less likely to happen with wheat. In 1972, large and secret wheat purchases by the Soviet Union from the United States raised the wheat prices paid by wheat importers such as India and China abnormally high. The wheat import requirements of India and China are now marginal and occasional. They can be met through long-term agreements with supplier countries such as those China has made or through commercial transactions such as India made in 1983. Soviet long-term grain agreements with the United States, Canada, and Argentina would also minimize these problems. These import requirements can create severe problems only if sustained droughts in India or China coincide with massive harvest failures in the Soviet Union. The grain needs of African lands, some of them severely drought-stricken, and of poor countries such as Bangladesh, are more in need of adequate protection. A harvest failure in the Soviet Union, however massive, cannot and should not be allowed to exacerbate the consequences of a drought in Africa.

[68] USDA, ERS, *U.S.S.R. Review of Agriculture in 1981 and Outlook for 1982*, Supplement 1 to WAS-27 (Washington, D.C.: USDA, 1982), p. 7.

Table 14—Soviet imports of grain by country of origin, 1971/72–1983

	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1982	1983
					(percent)							
Wheat												
U.S.	. . .	60.9	60.0	35.7	40.0	63.0	50.0	56.9	32.8	n.a.	n.a.	n.a.
Canada	80.0	26.9	36.0	10.7	32.0	26.1	25.8	39.2	17.6	n.a.	n.a.	n.a.
Australia	14.3	5.8	2.2	28.6	12.0	8.7	4.5	2.0	22.7	n.a.	n.a.	n.a.
Argentina	. . .	. . .	. . .	25.0	12.0	2.2	16.7	. . .	16.8	n.a.	n.a.	n.a.
European Community	2.9	4.5	. . .	. . .	. . .	. . .	. . .	. . .	5.0	n.a.	n.a.	n.a
Others	2.9	1.9	2.2	. . .	4.0	. . .	3.0	2.0	5.0	n.a.	n.a.	n.a.
Total												
(million metric tons)	3.5	15.6	4.5	2.8	10.0	4.6	6.6	5.1	11.9	n.a.	n.a.	n.a.
Coarse grains												
U.S.	67.4	60.9	81.3	48.1	64.7	81.8	78.0	83.0	61.6	n.a.	n.a.	n.a.
Canada	4.7	13.0	3.1	. . .	8.5	4.0	1.7	1.0	7.0	n.a.	n.a.	n.a.
Australia	. . .	. . .	. . .	3.7	5.2	2.0	. . .	. . .	7.0	n.a.	n.a.	n.a.
Argentina	2.3	1.4	4.7	40.7	1.3	4.0	13.6	14.0	16.2	n.a.	n.a.	n.a.
European Community	. . .	17.4	7.8	3.7	3.3	4.0	1.7	2.0	1.1	n.a.	n.a.	n.a.
Others	25.6	7.2	3.1	3.7	17.0	5.0	5.1	. . .	7.0	n.a.	n.a.	n.a.
Total												
(million metric tons)	4.3	6.9	6.4	2.7	15.3	5.5	11.8	10.0	18.5	n.a.	n.a.	n.a.
Total												
U.S.	37.2	60.8	72.5	44.2	54.9	73.3	67.9	74.2	50.2	23.5	31.0	22.0
Canada	38.5	22.7	16.5	. . .	17.8	13.9	10.3	13.9	11.1	20.0	24.0	27.0
Australia	6.4	4.0	1.0	17.3	7.9	5.0	1.6	0.7	13.1	8.5	5.0	3.0
Argentina	1.3	0.4	2.8	34.6	5.5	3.0	14.7	9.3	16.7	32.6	22.0	27.0
European Community	1.3	8.4	4.6	1.9	2.0	2.0	1.1	1.3	2.6	3.5	1.0	12.0
Others	15.4	3.6	2.8	1.9	11.9	3.0	4.3	0.7	6.2	11.8	17.0	9.0
Total												
(million metric tons)	7.8	22.5	10.9	5.2	25.3	10.1	18.4	15.1	30.5	34.0	40.3	33.9

Sources: Except for 1982 and 1983, the figures are calculated from U.S. Department of Agriculture (USDA), Economics, Statistics, and Cooperative Service, *The Washington Sales Suspension and Soviet Agriculture, An October Assessment*, Supplement 1 to WAS 23 (Washington, D.C.: USDA, 1981). The percentages for 1982 and 1983 are given in USDA, Economic Research Service (ERS), *U.S.S.R. Outlook and Situation Report*, RS-84-4 (Washington, D.C.: USDA, 1984); and USDA, ERS, *U.S.S.R. Outlook and Situation Report*, RS-85-4 (Washington, D.C.: USDA, 1985). The original data are based on reports of the exporting countries.

Notes: Ellipses (. . .) mean that less than 50,000 tons were imported. The years are from July 1 to June 30 except for 1982 and 1983, which are calendar years. n.a. stands for not available.

Table 15—Shares of developing countries and the Soviet Union in world imports of cereals and coarse grains, 1969–84

Year	Cereals			Coarse Grains		
	World	Share of Developing Countries	Share of Soviet Union	World	Share of Developing Countries	Share of Soviet Union
	(1,000 metric tons)	(percent)		(1,000 metric tons)	(percent)	
1969	97,168	36.7	1.3	35,210	8.8	1.4
1970	112,117	37.4	2.5	41,271	11.3	0.7
1971	118,438	36.8	3.4	43,294	11.3	2.2
1972	131,418	33.8	12.3	54,082	12.0	13.5
1973	157,653	36.6	15.5	60,672	15.8	12.0
1974	150,826	40.5	5.1	62,840	16.7	5.9
1975	156,433	37.8	10.6	65,359	15.9	10.3
1976	170,856	34.0	12.5	77,087	12.1	18.0
1977	162,571	39.3	7.3	68,812	18.7	6.1
1978	187,670	40.1	12.5	84,329	19.8	16.2
1979	201,288	41.2	13.3	91,025	23.3	17.3
1980	218,912	44.0	14.3	95,934	27.6	13.1
1981	233,056	43.4	18.7	99,890	26.0	19.4
1982	223,977	44.8	17.9	88,869	29.2	15.9
1983	219,223	49.9	14.7	87,996	35.9	8.5
1984	233,828	48.0	18.5	92,159	35.8	15.0

Source: Food and Agriculture Organization of the United Nations, *Trade Yearbook* (Rome: FAO, 1975–85).
Notes: Included in the coarse grains data are barley, maize, and oats. Developing countries include all developing market economies and the Asian centrally planned economies.

9

CONCLUSIONS

The weather variability of Soviet grain yield during 1955–82 is suitably defined and measured in this report on the basis of a representative sample of 14 oblasts. It is estimated as the deviation of observed from average weather expressed in terms of yield. These estimates provide several conclusions.

First, the weather variability of aggregate yield can occasionally be large but its standard deviation is not. For example, the highest negative yield variability, 2.8 centners in 1963, which suggests that yield would have been higher by 2.8 centners if the weather had been average, is 33.7 percent of the actual yield of 8.3 centners in that year. Similarly, the highest positive weather variability, 3.2 centners in 1970, is 20.4 percent of the actual yield of 15.6 centners. (The estimates also suggest that the 1963 grain output would have been larger by 36.4 million tons and the 1973 output smaller by 38.6 million tons if the weather had been average.) By contrast, the weather variability of yield between 1979 and 1982 is small despite poor harvests in each of these years. Indeed, grain output in the four years would have gone up only 12.9 million tons if the weather had been average. Overall, the standard deviation of yield variability is 1.58 centners, implying that, on average, above-average or below-average weather will raise or lower yields by 1.58 centners. This standard deviation is 12.3 percent of the mean yield of 12.8 centners during 1955–82. Thus, yields (and therefore, output) can be excessively high or low because weather deviates from the mean, but the standard deviation is by no means large. This phenomenon can be explained by lack of an association between weather in the west and the east of the Soviet grain belt: the correlation coefficient between the series of estimated weather variabilities of the oblasts in the west and the east of the grain belt is statistically not significant. As a result, the weather variability of aggregate yield is dampened.

The second major conclusion of the report is that the contribution of weather fluctuations to variations of yield in the aggregate is modest. The covariance between yield and the weather variables in the weather-yield model is weighted by the estimated parameters of the weather variables in the model, aggregated and divided by the yield variance explained by the model. The 14 oblast covariance ratios show a rising trend in the southeasterly direction of the grain belt, suggesting a deterioration of weather in that direction. The covariance ratio is 9.41 percent for Lvov oblast in the northwest and 98.33 percent for Karaganda oblast in the southeast. This covariance ratio for aggregate yield is 52 percent, implying that 52 percent of the explained yield variance is accounted for by weather fluctuations, with the remaining 48 percent accounted for by input variations.

This raises the question of the role of policy and systemic factors in yield. When the weather variability component is subtracted from the actual yields of the period 1958–82, the weather-adjusted yield shows increased variability for the 1968–82 period. This period coincides roughly with the years in which massive investments were pumped into agriculture. But these investments were not accompanied by new incentives or decentralized decisionmaking. While fertilizer use increased, it was not matched by an adequate supply of matching inputs such as pesticides, new seed varieties, and water supply. Increasing shortages of labor and machinery spare parts could also have contributed to the variability of grain yields.

Finally, a word of caution. The estimates and conclusions need to be strengthened by further research. In particular, grain yield must be separated into yields of winter and spring wheat and of coarse grains. The weather variables adopted here, monthly temperature and precipitation, must be refined.

APPENDIX 1—SUPPLEMENTARY TABLES

Table 16—Area sown with grain in selected oblasts, 1958–75

	Russian Soviet Federated Socialist Republic								Ukraine					Belo-russia	Kazakhstan			All Selected Oblasts
Year	Altay Kray	Moscow	Omsk	Rostov	Stravropol Kray	Tatar A.S.S.R.	Voronezh	Total	Kharkov	Kiev	Lvov	Odessa	Total	Minsk	Karaganda	Kustanay	Total	
								(thousand hectares)										
1958	5,753.0	428.0	2,612.0	3,152.0	2,263.0	2,327.0	1,496.0	18,031.0	896.2	712.3	389.3	1,025.0	3,022.8	531.9	1,018.2	4,001.9	5,020.1	26,613.0
1959	5,792.0	382.0	2,666.0	2,59[illegible].0	1,831.0	2,220.0	1,254.0	16,743.0	719.9	650.5	317.9	1,120.0	2,808.3	528.1	965.8	3,666.7	4,632.5	24,711.9
1960	5,788.0	298.0	2,780.0	2,801.0	2,082.0	2,306.0	1,364.0	17,419.0	785.4	615.2	273.7	884.1	2,558.4	513.3	967.4	3,943.5	4,910.5	25,401.6
1961	5,885.0	374.0	2,744.0	3,343.0	2,443.0	2,395.0	1,640.0	18,824.0	991.0	701.1	330.4	1,064.7	3,087.2	533.9	966.2	3,780.7	4,745.9	27,192.0
1962	5,988.0	362.0	2,887.0	3,533.0	2,402.0	2,515.0	1,747.0	19,434.0	912.2	683.5	318.4	1,016.3	2,930.4	521.5	1,107.6	3,780.7	4,888.3	27,774.2
1963	5,095.0	369.0	2,644.0	3,522.0	2,772.0	2,546.0	1,415.0	18,363.0	964.8	666.1	349.8	1,058.9	3,039.6	573.6	1,214.6	3,877.1	5,091.7	27,067.9
1964	5,721.0	438.0	2,793.0	4,020.0	2,492.0	2,647.0	1,821.0	19,932.0	1,003.3	701.2	341.7	991.6	3,037.8	594.0	1,167.8	3,973.4	5,141.2	28,705.0
1965	5,611.0	416.0	2,696.0	3,577.0	2,460.0	2,549.0	1,664.0	18,973.0	900.9	684.0	330.1	1,036.8	2,951.8	567.1	1,154.0	3,973.4	5,127.4	27,619.3
1966	5,314.0	412.0	2,675.0	3,630.0	2,390.0	2,470.0	1,702.0	18,593.0	871.0	633.7	317.3	971.6	2,793.6	562.6	1,182.9	3,907.8	5,090.7	27,039.9
1967	4,875.0	432.0	2,461.0	3,547.0	2,265.0	2,394.0	1,644.0	17,618.0	882.5	637.1	298.8	938.5	2,756.9	574.2	1,127.4	3,816.3	4,943.7	25,892.8
1968	4,902.0	410.0	2,502.0	3,464.0	2,242.0	2,369.0	1,720.0	17,609.0	842.9	646.2	322.2	928.6	2,739.9	526.4	1,137.5	4,006.2	5,143.7	26,019.0
1969	4,960.0	444.0	2,541.0	3,425.0	1,997.0	2,336.0	1,637.0	17,340.0	898.3	671.5	301.4	986.9	2,858.1	545.4	1,229.0	4,190.0	5,419.0	26,162.5
1970	4,679.0	439.0	2,457.0	3,333.0	2,165.0	2,317.0	1,612.0	17,002.0	785.9	638.3	314.5	1,000.1	2,738.8	512.8	1,080.4	3,878.1	4,958.5	25,212.1
1971	4,625.0	423.0	2,270.0	3,225.0	2,106.0	2,347.0	1,602.0	16,598.0	863.8	642.8	316.8	971.5	2,794.9	504.1	1,040.7	3,926.3	4,967.0	24,864.0
1972	4,704.0	427.0	2,308.0	3,209.0	2,123.0	2,352.0	1,635.0	16,758.0	915.5	651.1	328.6	1,028.9	2,924.1	522.6	1,046.1	4,032.0	5,078.1	25,282.8
1973	4,884.0	425.0	2,408.0	3,558.0	2,247.0	2,413.0	1,769.0	17,704.0	973.8	698.1	329.9	1,104.6	3,106.4	507.8	1,126.5	4,216.0	5,342.5	26,660.7
1974	4,797.0	401.0	2,291.0	3,580.0	2,204.0	2,441.0	1,732.0	17,446.0	982.5	722.9	331.2	1,048.6	3,085.2	497.1	1,139.2	4,249.5	5,388.7	26,417.0
1975	4,802.0	415.0	2,341.0	3,603.0	2,282.0	2,449.0	1,642.0	17,534.0	945.2	735.8	339.0	1,121.6	3,141.6	510.0	1,169.8	4,501.2	5,671.0	26,856.6
Mean	5,231.9	405.3	2,559.8	3,395.6	2,264.8	2,410.7	1,616.4	17,884.5	896.4	671.7	325.1	1,016.6	2,909.8	535.2	1,102.3	3,984.5	5,086.8	26,416.2

Source: Statistical handbooks from the republics and other sources available from the International Research Center of the U.S. Department of Commerce, Bureau of the Census.
Note: Only the years for which data are available for all the oblasts are included.

Table 17—Minimum, maximum, and mean values and standard deviations of temperature and precipitation of the selected oblasts, by month, 1950–82

Oblast/ Month	Temperature				Precipitation			
	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum
	(degrees Celcius)				(millimeters)			
Altay kray								
January	−16.20	3.91	−23.70	−8.80	−24.15	13.19	4.00	60.00
February	−15.60	3.63	−25.40	−9.10	22.54	12.32	4.00	51.00
March	−8.18	2.91	−12.80	−3.10	23.77	10.02	9.00	54.00
April	2.57	2.22	−1.70	6.10	28.04	15.40	6.00	59.00
May	11.79	2.10	7.80	15.80	40.38	21.98	9.00	86.00
June	17.95	1.56	14.80	20.60	49.31	25.91	10.00	117.00
July	19.95	1.88	15.60	23.80	61.96	32.05	4.00	138.00
August	16.84	1.37	14.20	19.50	58.12	32.82	3.00	116.00
September	11.02	1.83	7.00	15.50	28.73	17.37	5.00	69.00
October	2.34	1.91	−2.60	5.50	43.31	23.41	11.00	108.00
November	−7.94	4.16	−17.00	−0.80	37.88	21.90	2.00	90.00
December	−14.80	4.32	−26.60	−9.00	30.13	17.31	1.00	61.00
Karaganda								
January	−13.92	2.97	−20.90	−7.90	17.67	12.70	2.00	49.00
February	−13.50	3.05	−19.10	−7.60	18.82	9.78	8.00	40.00
March	−6.96	4.03	−14.50	4.10	17.95	9.73	4.00	49.00
April	4.48	2.39	−1.40	8.40	24.36	14.32	0.00	61.00
May	12.82	2.63	8.20	18.60	33.00	27.71	4.00	100.00
June	18.25	1.54	15.20	21.80	43.41	20.03	3.00	84.00
July	20.05	1.86	16.60	23.80	44.32	32.07	5.00	116.00
August	17.47	1.43	15.50	20.50	30.86	21.17	0.00	72.00
September	11.68	1.95	8.10	15.10	18.29	12.52	0.00	40.00
October	2.52	2.07	−3.50	5.10	27.76	14.44	1.00	60.00
November	−1.46	22.87	−12.60	99.99	22.38	9.06	4.00	42.00
December	−12.40	3.56	−20.60	−6.90	18.18	10.59	2.00	42.00
Kharkov								
January	−6.53	3.92	−15.00	−1.50	44.32	33.61	4.00	126.80
February	−5.71	2.70	−9.80	−0.50	35.80	14.95	6.00	60.00
March	−1.09	2.25	−6.00	3.30	29.27	13.72	10.00	51.00
April	8.76	2.48	4.90	13.50	28.62	14.83	6.00	60.50
May	15.84	1.73	12.80	18.90	42.38	29.55	8.00	136.80
June	19.35	1.73	17.00	23.10	46.44	22.81	6.00	85.00

July	21.52	1.61	18.80	25.00	47.07	33.43	3.10	114.00
August	19.94	1.49	17.60	24.10	55.23	38.00	3.90	151.00
September	14.19	1.67	10.90	16.90	36.05	21.85	6.00	79.00
October	7.49	1.75	4.00	10.90	31.77	25.04	7.40	95.00
November	1.21	2.69	−4.00	7.00	38.18	25.86	4.00	104.40
December	−3.29	2.95	−8.20	2.90	45.47	27.63	7.00	132.20
Kiev								
January	−5.85	3.61	−13.80	0.40	43.64	22.36	12.00	84.00
February	−3.62	2.54	−7.40	0.60	43.50	26.27	7.00	112.00
March	0.13	2.32	−4.20	3.80	33.47	23.37	4.00	100.00
April	8.68	2.17	4.90	12.90	36.57	17.89	13.00	69.80
May	15.06	1.83	12.50	19.00	52.95	25.87	15.00	106.30
June	18.43	1.66	16.30	22.30	50.67	27.84	7.40	105.80
July	20.16	1.49	17.40	23.40	77.40	49.64	5.00	210.00
August	18.76	1.12	16.40	20.90	74.05	32.65	16.00	158.00
September	13.77	1.62	10.70	16.90	41.16	36.29	2.00	132.00
October	8.09	1.54	5.40	11.50	42.45	30.59	5.30	139.00
November	1.72	2.28	−3.20	5.70	52.61	34.53	5.00	127.00
December	−2.32	2.47	−7.00	2.90	49.22	28.27	5.00	105.00
Kustanay								
January	−17.74	4.53	−29.00	−11.10	13.41	8.24	0.00	31.00
February	−16.78	3.94	−26.80	−9.10	12.92	8.14	0.00	30.00
March	−9.61	3.56	−14.20	−3.10	14.72	15.56	1.00	81.00
April	4.90	3.05	−1.40	10.80	23.24	14.21	2.00	65.00
May	13.87	2.31	8.80	17.80	24.00	18.16	2.00	72.00
June	18.88	1.82	16.10	22.60	34.64	19.50	6.00	82.00
July	20.46	1.91	16.70	23.70	44.64	30.59	7.00	140.00
August	17.91	1.48	16.00	20.60	28.04	22.28	1.00	77.00
September	12.03	2.38	7.60	17.70	26.12	21.13	0.00	74.00
October	2.40	2.26	−5.00	6.60	25.36	13.91	3.00	56.00
November	−6.37	3.26	−16.20	−0.70	21.32	11.36	6.00	44.00
December	−13.62	3.95	−22.80	−8.20	17.52	9.95	1.00	42.00
Lvov								
January	−4.79	2.90	−12.10	1.20	37.69	18.29	8.00	74.90
February	−2.72	2.64	−7.50	1.50	47.60	34.81	8.00	154.00
March	0.69	2.66	−3.90	4.40	33.05	19.47	3.00	81.80
April	7.48	1.73	4.20	10.10	48.66	20.91	17.10	101.00
May	12.79	1.70	10.20	15.80	73.60	30.08	22.70	133.00
June	16.44	1.50	14.10	20.60	93.29	43.78	22.40	171.40

(continued)

Table 17—Continued

Oblast/ Month	Temperature				Precipitation			
	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum
	(degrees Celcius)				(millimeters)			
July	17.91	1.29	15.50	20.40	110.93	40.72	51.70	177.00
August	17.05	0.99	15.00	19.50	86.08	40.15	19.50	152.00
September	12.90	1.59	10.30	16.50	49.06	28.73	4.20	113.00
October	7.93	1.57	5.40	11.90	50.74	40.29	2.30	171.00
November	2.99	1.90	−1.20	6.40	48.31	20.01	11.00	89.40
December	−1.94	2.59	−6.80	2.90	54.75	22.84	8.00	96.80
Minsk								
January	−7.28	3.68	−13.80	−0.60	33.89	17.83	11.00	69.00
February	−5.69	2.78	−9.40	−1.20	32.68	17.59	6.00	65.00
March	−2.06	2.93	−7.00	2.00	35.47	19.77	4.00	84.00
April	5.73	1.29	2.80	8.10	40.63	15.82	9.00	87.00
May	12.68	1.99	8.70	16.30	62.12	28.38	19.00	120.00
June	16.47	1.58	13.70	19.80	73.26	37.38	21.00	154.00
July	17.82	1.51	15.20	20.80	78.68	59.32	20.00	280.00
August	16.62	1.23	14.80	19.20	69.11	32.03	13.00	132.00
September	11.68	1.46	9.10	14.90	44.63	20.05	18.00	77.00
October	6.29	1.31	4.30	9.40	46.63	26.73	3.00	102.00
November	0.59	1.84	−3.70	3.40	52.26	19.92	16.00	85.00
December	−3.83	2.89	−8.60	1.40	41.47	19.63	12.00	95.00
Moscow								
January	−10.05	4.13	−16.20	−3.50	38.06	20.45	5.00	75.60
February	−8.11	3.25	−14.00	−1.50	36.87	21.58	5.00	93.80
March	−2.72	2.67	−9.40	0.40	33.81	17.32	13.30	87.50
April	5.65	1.95	2.50	10.10	39.28	17.95	11.00	85.20
May	12.88	1.99	9.70	17.00	56.41	26.84	16.70	120.00
June	16.31	1.88	13.50	19.20	67.31	34.00	14.20	128.00
July	18.56	1.81	15.70	22.40	82.78	37.22	24.00	139.70
August	16.58	1.40	14.50	20.60	72.46	37.01	23.40	163.00
September	10.80	1.62	7.60	13.70	56.37	24.43	20.00	98.80
October	4.66	2.31	−1.00	9.00	57.85	29.32	6.90	114.90
November	−1.62	2.58	−8.00	1.80	51.03	27.16	21.80	140.00
December	−6.23	3.82	−41.50	0.90	43.66	22.32	14.00	94.70

Odessa								
January	−1.91	3.20	−9.40	2.40	43.55	31.67	0.80	139.00
February	−0.57	1.93	−3.80	3.40	39.32	32.71	5.00	[illegible]
March	2.25	1.66	−0.60	5.40	25.17	15.06	1.00	57.00
April	8.98	1.74	5.00	11.20	28.03	18.76	7.00	70.00
May	15.14	1.52	13.00	17.60	42.40	29.94	4.00	128.40
June	19.60	1.36	17.30	21.90	34.16	21.38	2.00	80.00
July	22.10	1.30	19.90	24.80	46.55	37.33	2.00	142.60
August	21.45	1.06	19.60	23.00	33.70	[illegible]	2.90	137.40
September	16.81	1.38	13.80	19.40	39.91	37.79	1.40	166.00
October	11.30	1.89	7.90	14.80	18.28	14.75	3.00	57.00
November	5.91	2.06	1.00	9.20	42.52	28.42	4.40	91.00
December	1.45	2.17	−2.00	6.90	45.92	28.64	4.00	111.50
Omsk								
January	−18.90	4.54	−30.00	−11.80	15.24	10.95	2.00	44.00
February	−17.51	3.89	−25.30	−10.90	11.28	8.29	0.00	40.00
March	−9.92	3.35	−17.00	−4.40	12.00	6.10	2.00	27.00
April	2.97	2.61	−3.30	8.10	18.80	11.62	0.00	43.00
May	11.82	2.29	7.50	16.50	30.56	19.77	3.00	80.00
June	17.58	1.66	14.90	21.20	51.72	31.05	2.00	110.00
July	19.42	1.82	16.10	22.40	62.80	34.02	2.00	175.00
August	15.92	1.34	13.00	18.20	53.80	24.16	5.00	112.00
September	10.56	2.17	6.70	14.60	27.16	14.28	3.00	55.00
October	1.60	1.97	−4.60	5.10	27.96	15.74	1.00	80.00
November	−8.40	4.02	−19.00	−2.50	22.32	12.32	3.00	47.00
December	−15.63	3.83	−25.00	−9.00	15.20	7.90	1.00	36.00
Rostov								
January	−4.65	3.58	−13.40	0.60	45.43	34.50	4.00	114.90
February	−3.37	2.96	−8.80	1.80	40.62	25.30	2.00	89.00
March	1.17	2.11	−1.80	4.60	36.48	20.28	8.50	90.00
April	10.47	2.34	6.30	15.20	32.89	20.97	5.40	83.00
May	17.13	1.67	14.80	20.30	49.55	32.31	0.00	125.00
June	21.24	1.65	19.00	25.20	59.06	33.15	6.00	134.00
July	23.51	1.35	21.20	25.60	55.11	33.23	0.00	102.70
August	22.41	1.48	19.60	25.70	36.29	28.55	3.20	112.00
September	16.27	1.89	13.10	19.30	29.10	23.32	0.00	69.00
October	9.38	2.10	4.90	14.20	36.85	20.82	7.00	87.00
November	3.13	2.65	−4.10	5.90	43.29	33.95	4.00	119.70
December	−1.24	2.48	−6.20	3.00	63.72	42.29	2.00	141.80
Stravropol kray								
January	−3.72	3.20	−12.10	0.90	19.29	9.14	6.00	37.30
February	−2.62	3.15	−9.00	2.60	19.73	12.19	3.00	44.00

(continued)

Table 17—Continued

Oblast/ Month	Temperature Mean	Temperature Standard Deviation	Temperature Minimum	Temperature Maximum	Precipitation Mean	Precipitation Standard Deviation	Precipitation Minimum	Precipitation Maximum
	(degrees Celcius)				(millimeters)			
March	1.00	2.20	−2.70	6.10	26.80	12.03	12.00	52.00
April	8.85	1.97	5.30	13.30	53.55	18.27	29.70	100.00
May	14.96	0.97	13.40	17.30	71.64	27.58	42.00	158.70
June	18.73	1.29	16.60	21.00	69.76	37.21	8.00	121.20
July	20.99	1.25	19.20	22.90	83.51	54.78	38.00	248.00
August	20.24	1.26	18.20	23.10	54.96	38.96	10.00	150.30
September	14.70	1.39	12.30	17.40	38.51	21.84	8.10	77.50
October	8.92	1.95	5.10	12.60	30.76	22.89	6.00	92.00
November	3.20	2.20	−3.30	5.20	22.34	11.90	8.00	52.00
December	−1.24	2.03	−5.00	2.00	21.82	8.75	9.00	35.40
Tatar A.S.S.R.								
January	−13.70	4.49	−22.00	−6.20	25.41	11.41	5.20	45.50
February	−12.18	2.96	−18.80	−8.10	25.62	16.55	4.70	82.70
March	−5.76	3.01	−13.40	−0.90	22.74	17.06	5.80	75.20
April	4.83	2.65	0.90	10.80	31.48	19.83	4.00	82.60
May	12.89	2.03	8.00	16.00	30.70	22.26	2.30	87.00
June	17.10	1.46	13.90	19.70	55.58	36.61	13.00	152.70
July	19.55	1.51	16.60	21.80	60.43	27.98	7.00	116.00
August	17.38	1.91	14.80	23.10	66.47	36.14	6.30	135.20
September	11.01	2.57	4.40	14.60	40.28	25.15	5.00	103.00
October	3.58	1.95	0.80	8.10	41.11	16.97	4.70	72.00
November	−3.70	2.30	−8.60	0.30	36.53	18.64	8.00	71.50
December	−9.12	3.30	−15.40	−3.60	30.89	12.36	14.00	57.00
Voronezh								
January	−9.01	4.02	−15.80	−3.70	34.95	24.59	9.00	88.00
February	−8.31	3.45	−14.20	−1.70	29.74	16.90	3.00	65.00
March	−3.02	2.52	−7.90	1.70	30.63	15.70	8.00	67.00
April	7.51	2.62	3.50	13.10	39.58	17.56	11.00	70.00
May	14.86	2.09	12.30	19.10	47.26	31.96	9.00	134.00
June	18.38	1.87	15.90	22.00	46.37	26.65	6.00	118.00
July	20.19	1.64	17.30	23.50	63.47	30.53	12.00	122.00
August	18.64	1.83	16.50	25.00	53.21	23.91	4.00	97.00
September	12.86	1.61	9.90	15.80	47.26	36.88	13.00	139.00
October	6.23	1.90	2.70	10.40	32.32	18.28	6.00	76.00
November	−0.56	2.38	−4.70	3.20	45.63	27.98	8.00	10[illegible].00
December	−5.18	3.09	−10.60	0.60	47.11	27.03	14.00	118.00

Source: Calculated from data obtained from U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Table 18—Actual and estimated yields of the selected oblasts, 1950–82

Year	Altay Kray		Karaganda		Kharkov		Kiev		Kustanay		Lvov		Minsk		Moscow		Odessa		Omsk		Rostov		Stravropol Kray		Tatar A.S.S.R.		Voronezh	
	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.	Actual	Esti.
	(centners/hectare)																											
1950	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.	n.a.	n.e.
1951	n.a.	5.7	n.a.	0.0	n.a.	11.3	n.a.	10.8	4.6	4.4	n.a.	6.0	n.a.	1.9	n.a.	0.6	n.a.	9.3	n.a.	7.5	n.a.	12.7	n.a.	8.2	n.a.	3.7	n.a.	8.2
1952	n.a.	8.3	n.a.	4.6	n.a.	11.2	n.a.	11.5	3.4	1.5	n.a.	4.6	n.a.	5.9	n.a.	0.0	n.a.	13.6	n.a.	1.5	n.a.	13.3	n.a.	13.7	n.a.	3.7	n.a.	13.3
1953	4.9	5.0	6.8	5.2	12.1	14.8	8.2	9.6	9.6	8.9	7.8	7.2	4.8	3.7	4.9	3.4	12.8	13.1	7.9	6.6	6.8	7.1	8.9	11.2	7.4	7.9	n.a.	8.7
1954	15.3	10.5	9.9	9.3	n.a.	13.3	n.a.	9.2	7.6	6.2	n.a.	7.8	n.a.	0.0	n.a.	0.8	n.a.	12.4	10.2	9.1	n.a.	3.9	n.a.	1.6	n.a.	6.6	7.4	4.4
1955	5.2	4.9	4.6	3.3	18.7	15.5	12.6	13.0	2.1	2.6	7.2	7.7	n.a.	7.6	n.a.	10.9	18.6	17.3	4.5	4.6	n.a.	11.4	n.a.	12.6	n.a.	9.6	n.a.	16.6
1956	13.5	11.7	6.0	6.0	n.a.	17.9	n.a.	13.0	13.8	11.0	n.a.	8.0	n.a.	0.2	n.a.	0.0	n.a.	18.1	12.8	11.5	n.a.	11.1	n.a.	7.9	n.a.	12.0	n.a.	7.7
1957	11.7	12.2	5.9	4.9	15.9	14.2	14.2	14.3	3.9	4.7	12.0	11.4	n.a.	7.4	n.a.	7.3	14.5	14.5	8.2	8.5	n.a.	12.0	n.a.	11.8	n.a.	8.9	n.a.	15.9
1958	13.0	14.7	12.3	11.5	20.4	19.3	15.0	13.7	5.9	7.3	11.2	9.9	6.7	6.0	7.1	8.1	18.8	18.5	10.5	9.0	17.0	15.9	16.2	14.4	8.0	9.9	15.5	16.6
1959	9.8	11.2	7.8	9.4	14.9	15.1	17.0	14.8	9.3	8.8	13.5	12.6	7.2	5.2	11.5	10.8	17.4	16.1	10.3	7.7	10.0	9.6	9.8	11.0	10.0	9.9	11.9	12.1
1960	11.0	11.6	6.6	8.6	14.9	16.6	15.0	14.6	8.3	11.2	12.1	12.1	9.1	9.9	8.2	5.9	19.2	[illegible]	9.8	13.1	14.4	11.7	16.9	14.1	10.1	9.6	16.4	12.4
1961	9.8	10.0	5.9	8.8	20.4	21.1	20.8	18.3	5.5	8.4	13.9	14.5	8.7	9.9	7.8	10.0	19.5	[illegible]	9.1	9.7	13.8	14.5	12.4	12.1	9.1	10.1	16.1	17.1
1962	6.4	6.3	5.8	3.4	14.8	15.1	19.8	20.7	5.9	5.1	11.5	13.1	7.9	8.4	10.1	9.8	19.0	20.5	7.2	6.8	18.3	16.5	16.2	13.6	10.6	11.0	17.4	15.8
1963	3.4	6.3	1.1	2.0	9.8	10.3	13.6	14.8	3.8	3.7	12.1	13.8	8.7	10.2	10.3	12.3	14.2	17.1	3.1	5.9	10.4	11.4	16.4	15.9	8.0	8.2	10.6	15.3
1964	9.9	9.8	9.2	6.8	19.9	23.5	16.7	17.0	10.3	7.9	13.8	15.4	7.6	8.4	9.6	9.6	17.7	20.7	10.7	10.8	16.8	17.3	8.9	11.0	9.4	9.5	18.2	16.6
1965	5.5	5.8	1.6	3.2	16.9	19.4	24.6	21.8	3.7	4.8	16.1	16.0	12.3	12.5	12.5	12.7	24.0	23.2	2.8	2.9	9.6	12.5	10.8	12.1	10.1	10.1	16.2	16.0
1966	12.6	11.8	8.2	6.7	21.8	17.6	23.2	22.4	13.0	8.6	17.2	16.4	11.3	12.6	12.6	14.3	24.1	21.3	13.1	13.2	20.1	19.6	17.2	19.4	10.9	11.4	[illegible]	19.0
1967	7.1	9.0	3.3	6.3	19.4	18.4	19.7	20.8	9.7	9.9	17.8	17.8	12.3	11.8	16.2	17.2	22.1	20.9	4.1	5.7	[illegible]	16.0	14.1	13.5	14.4	13.7	14.1	15.5
1968	10.5	12.1	3.9	5.5	18.8	19.5	19.4	23.3	8.6	13.6	20.5	19.6	11.7	10.5	16.8	15.6	21.1	22.3	10.7	11.6	14.3	15.9	14.8	17.0	15.6	15.2	17.9	17.4
1969	8.9	6.1	5.4	5.2	23.0	21.4	23.4	23.2	10.0	11.6	18.9	17.5	17.7	19.8	22.7	20.9	27.7	25.8	9.7	9.1	10.9	13.5	9.1	8.8	16.4	15.3	17.8	16.2
1970	13.4	13.5	3.2	5.6	24.6	23.6	20.1	24.4	13.1	13.0	19.7	20.6	18.0	17.4	22.4	22.1	29.9	28.8	13.4	14.2	21.1	23.4	20.0	19.0	14.8	13.6	21.9	19.3
1971	15.8	15.3	5.3	6.3	25.6	22.3	25.5	24.6	9.1	7.5	25.1	21.2	22.7	22.2	23.6	23.8	26.2	24.8	14.9	13.5	17.0	14.2	20.7	14.7	14.3	12.3	17.5	17.2
1972	19.9	18.8	13.9	12.4	17.3	21.0	25.5	23.8	13.9	14.6	24.1	22.8	18.4	19.2	19.3	21.2	26.6	23.2	16.7	15.6	11.2	8.9	12.8	9.8	10.9	12.8	12.9	12.4
1973	12.5	11.1	7.3	8.2	30.0	28.5	29.6	27.4	10.2	10.5	21.4	23.3	23.2	21.6	23.8	22.7	32.0	30.2	15.3	15.6	26.3	24.2	21.0	19.6	13.9	15.3	24.8	25.3
1974	5.7	6.0	1.9	4.0	27.8	28.7	29.7	30.4	6.7	6.9	21.5	23.9	28.1	25.3	25.2	25.4	24.1	29.6	9.6	11.6	21.5	19.8	14.9	15.3	16.1	15.8	22.8	23.2
1975	12.7	12.6	4.3	4.2	19.6	21.4	25.4	25.2	2.7	6.3	14.9	14.9	21.9	23.6	24.8	25.0	23.4	24.7	8.2	8.9	13.0	14.4	10.6	13.3	8.9	8.9	13.3	16.0
1976	11.0	10.0	9.8	8.7	n.a.	28.4	n.a.	32.5	14.4	12.1	n.a.	23.9	n.a.	23.9	27.8	25.9	n.a.	31.5	13.6	11.8	n.a.	23.0	n.a.	13.6	n.a.	16.5	n.a.	18.8
1977	14.0	15.7	3.8	1.8	n.a.	31.5	n.a.	30.6	8.1	8.0	n.a.	27.5	n.a.	29.7	26.3	26.8	n.a.	34.6	12.1	10.6	n.a.	22.6	n.a.	21.3	n.a.	17.0	n.a.	20.6
1978	n.a.	13.6	9.1	6.4	n.a.	27.6	n.a.	34.4	10.1	7.7	n.a.	26.7	n.a.	23.8	n.a.	24.6	n.a.	31.2	n.a.	12.7	n.a.	28.3	n.a.	23.0	n.a.	12.6	n.a.	21.1
1979	n.a.	10.9	n.a.	9.1	n.a.	24.7	n.a.	30.1	14.0	12.6	n.a.	28.4	n.a.	23.3	n.a.	26.4	n.a.	31.1	n.a.	13.9	n.a.	14.3	n.a.	18.2	n.a.	9.0	n.a.	18.7
1980	n.a.	10.6	n.a.	6.5	n.a.	32.2	n.a.	34.6	14.0	8.2	n.a.	27.1	n.a.	28.8	n.a.	25.8	n.a.	33.2	n.a.	12.3	n.a.	20.2	n.a.	12.8	n.a.	17.9	n.a.	20.7
1981	n.a.	10.6	n.a.	7.7	n.a.	30.6	n.a.	31.5	9.5	9.6	n.a.	29.9	n.a.	28.2	n.a.	21.7	n.a.	31.5	n.a.	12.3	n.a.	11.8	n.a.	18.5	n.a.	13.5	n.a.	21.6
1982	n.a.	11.4	n.a.	3.7	n.a.	28.2	n.a.	34.1	n.a.	7.8	n.a.	28.0	n.a.	25.5	n.a.	32.0	n.a.	31.2	n.a.	10.3	n.a.	23.0	n.a.	18.3	n.a.	18.3	n.a.	24.8
Mean	10.42	n.e.	6.66	n.e.	18.94	n.e.	19.55	n.e.	8.05	n.e.	16.23	n.e.	13.59	n.e.	16.36	n.e.	21.11	n.e.	10.00	n.e.	15.06	n.e.	13.94	n.e.	11.27	n.e.	16.42	n.e.
Standard																				n.a.								
deviation	3.95	n.e.	[illegible]	n.e.	4.73	n.e.	5.92	n.e.	3.79	n.e.	4.80	n.e.	6.78	n.e.	7.43	n.e.	5.46	n.e.	3.70	n.e.	4.93	n.e.	3.76	n.e.	3.13	n.e.	4.23	n.e.
Minimum	3.40	n.e.	1.10	n.e.	9.80	n.e.	8.20	n.e.	2.10	n.e.	7.20	n.e.	4.80	n.e.	4.90	n.e.	12.80	n.e.	2.80	n.e.	6.80	n.e.	8.90	n.e.	6.40	n.e.	7.40	n.e.
Maximum	9.90	n.e.	13.90	n.e.	30.00	n.e.	29.70	n.e.	14.40	n.e.	25.10	n.e.	28.10	n.e.	27.80	n.e.	32.00	n.e.	16.70	n.e.	26.30	n.e.	21.00	n.e.	16.40	n.e.	24.80	n.e.

Sources: Statistical handbooks for each republic and the U.S. Department of Agriculture. The estimated yields were derived from weather-yield equations calculated for each oblast.

Notes: Where n.a. appears, the data were not available. Where n.e. appears, the statistic was not estimated. The mean and standard deviations are calculated only for those years included in the sample for the oblast. Estimates of yields beyond the sample period for the oblast use the mean values of temperature and precipitation when the actual value values are not available.

APPENDIX 2—WEATHER INDEXES

Weather indexes must directly incorporate the soil moisture that is available to plants as they mature. The weather variables of monthly temperature and precipitation adopted in this report do not provide such direct measures of soil moisture. However, soil moisture indexes are difficult to construct and require a massive amount of information about soil types, their capacity to retain moisture at various depths, precipitation from rainfall and irrigation, moisture loss through evapotranspiration, the critical phases of plant growth, and so on. These indexes are constructed by meteorologists, soil scientists, and agronomists with the result that the relevant literature is highly technical. The purpose of this Appendix is to indicate the difficulties of constructing weather indexes to the nonspecialist reader.

Concepts and Definitions

Rain and irrigation are two sources of moisture for plants. This moisture is held in the soil, which is invaded by plant roots.[69] The maximum amount of available soil moisture cannot exceed the moisture storage capacity or field capacity, which varies with soil type.[70] A minimum amount of moisture is available when the plant wilts irretrievably. Technically, therefore, drought occurs when the soil moisture is depleted to the permanent wilting point.[71] The range of available soil moisture is between the permanent wilting point and field capacity—both defined in terms of soil moisture.

Not all water from rain or irrigation is available to plants as moisture. Some of it runs off while some percolates in the soil beyond the roots. Again, moisture is lost through evaporation from the soil caused by atmospheric factors such as temperature, and transpiration from the plants. The total loss of moisture from the process is defined as evapotranspiration. The soil moisture available to plants from rainfall, irrigation, and so forth is the moisture left in the soil after actual evapotranspiration (ET_a).[72] It is possible to calculate soil moisture availability during a given period by the Versatile Budgeting Method. Rainfall during the day is added to the available soil moisture at the beginning of the day and ET_a is subtracted.[73]

Two formidable problems must be resolved before this apparently simple procedure can be used. First, a method must be found to estimate ET_a and second, the available soil moisture must be estimated at several depths. Clearly, a depth close to the surface is important when seeds are germinating, whereas a lower depth is important during the maximum growth phase of the plant.

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[69] Moisture may be expressed in percentages relative to the dry weight of soil. It is generally converted into inches or centimeters. For a discussion of the method of conversion, see J. R. Thomas, T. J. Army, and E. L. Cox, *Relationship of Soil Moisture and Precipitation to Spring Yields in the Northern Great Plains*, Production Research Report No. 56 (Washington, D.C.: USDA, 1962), p. 3.

[70] With regard to moisture storage capacity, note the following statement in Jen-Hu Chang, *Climate and Agriculture: An Ecological Survey* (Chicago: Aldin Publishing Company, 1968), pp. 198–199: "In his study of global water balance, Thornthwaite . . . assumed a storage capacity of ten centimeters for a normal soil, which he subsequently raised to 30 centimeters. . . . Such standard values are at best crude. Soils developed on recent lava may have such a small moisture capacity that even an annual rainfall of 100 inches can support only xerophytic plants. On the other hand, some deep alluvial soils may have a storage capacity well over 40 centimeters. Therefore, for practical agricultural purposes, the storage capacity of a soil should be determined on the spot. . . . In general, the total amount of usable water for plant growth is greater for clay than for coarse-textured soils."

[71] The permanent wilting point varies with the type of soil. For example, the moisture content at the permanent wilting point is greater for clay than for sand.

[72] Here, the moisture availability depends also on how much moisture the soil has before the advent of rain.

[73] For a numerical example and discussion of this method, see Chang, *Climate and Agriculture*, Chapter 19.

Measuring Actual Evapotranspiration

The soil moisture available to plants is the residual moisture after actual evapotranspiration ET_a. In order to measure ET_a, the soil moisture required by plants is first defined. The maximum or potential soil moisture loss or evapotranspiration under ideal conditions—a land area covered with vegetation that receives adequate moisture at all times—depends on the soil moisture required by the plant. This is defined as potential evapotranspiration (ET_p). ET_p is more or less constant for a given soil and stage of plant growth.[74] ET_p is calculated from either an empirical or a physical formula. ET_a is estimated on the basis of assumed relationships between ET_p, ET_a, and available soil moisture.

A widely used formula for estimating ET_p is attributed to Thornthwaite. It is an empirical formula based on an observed relationship between evaporation and temperature in the temperate, continental climate of North America.[75] It is "an exponential function of the mean monthly air temperature":

$$E = 1.6\,(10T/I)^a, \qquad (37)$$

where "E is the unadjusted (30 days—each a twelve-hour day) potential evapotranspiration in centimeters, T is the mean monthly temperature in degrees C., a is a constant that varies from place to place, and I is the annual heat index."[76] The following equation produces a:

$$a = 0.000000675\,I^3 - 0.0000771\,I^2 + 0.01792\,I + 0.49239. \qquad (38)$$

I is the sum of 12 monthly heat indexes, i, which are defined as

$$i = (T/5)^1\,0.514 \qquad (39)$$

E is corrected by the actual daylength of hours and days in a month to give the adjusted potential evapotranspiration. This adjusts E for season and latitude. Thornthwaite omitted other meteorological factors, justifying this by stressing "that they vary together with air temperature."[77]

While the formula can be used readily to derive ET_p from temperature data, its limitations arise from its exclusion of other relevant and even critical explanatory variables such as radiation and wind velocity.

The relationship between ET_p, ET_a, and the available soil moisture can be shown using a simple Versatile Budgeting Method that incorporates all these concepts to simulate the available soil moisture.

The Versatile Budgeting Method

The purpose here is to calculate the soil moisture available to plants (SM) during a certain period with a simple bookkeeping method. Thus, assuming that the soil moisture available at the beginning of the first day equals the moisture storage capacity $\overline{SM}$, the soil moisture available at the beginning of the second day is

$$\overline{SM} + R - ET_a, \qquad (40)$$

where R is the rainfall during the first day

[74] Details are in Andres C. Ravelo and Wayne L. Decker, "The Probability Distribution of a Soil Moisture Index," *Agricultural Meteorology* 20 (1979): 302.

[75] It differs from physical formulae, such as the Penman formula, which are based on an understanding of the "physics of the evaporation process" (Edward T. Linacre, "A Simple Formula for Estimating Evaporation Rates in Various Climates, Using Temperature Data Alone," *Agricultural Meteorology* 18 (1977): 410). These are more accurate in predicting evaporation rates but require more information. According to Linacre, the Penman formula requires information on ". . . four climatic elements, i.e., the net-radiation intensity, the atmospheric humidity, the wind speed and temperature. Not all of them are commonly available. In practice, the only data may be daily maximum and minimum temperatures and the rainfall, often tabulated as monthly values." Linacre, therefore, develops an approximation to the Penman formula based on temperature measurements alone.

[76] This derivation of the Thornthwaite formula is from Chang, *Climate and Agriculture*, p. 149.

[77] For a discussion of the effects of these factors on ET_p, see Chang, *Climate and Agriculture*, pp. 149–151.

and ET_a is the actual evapotranspiration.[78]

A few bookkeeping rules are used to estimate ET_a:

- If the initial available soil moisture, SM, is 0 and the rainfall during the day R exceeds the estimated ET_p, then ET_a is set at ET_p.
- If SM is 0 but R is less than the estimated ET_p, then ET_a is set at R.
- If R is 0 but SM exceeds ET_p, then ET_a is set at ET_p.
- If R is 0 but SM is less than ET_p, then ET_a is set at SM.
- Finally, if both SM and R are 0, then ET_a is set at 0.

In the more sophisticated versions of the budgeting exercise, SM is simulated by assuming a linear relationship between it and ET_a/ET_p.[79]

If the assessment of the effect of soil moisture on plant growth is to be realistic, the availability of soil moisture must be measured at appropriate depths.

Soil Moisture and Soil Depths

During the initial phase of planting-emergence and emergence-tillering of a plant, only the top layers of soil are critical for moisture availability whereas in the final phases of milk-soft dough and soft dough-hard dough, moisture must be available in the lower layers of the soil as well. Appropriate weights should be attached to the soil moisture available at each depth when deriving the soil moisture index.[80]

The daily index of available soil moisture, DMI, is:

$$DMI_i = \sum_{j=1}^{4} k_j S_i j \qquad (41)$$

where

> "DMI is the index of available soil moisture on the ith day, k_j is a weighing coefficient . . . for the jth depth, and S_ij is the moisture store within the jth depth on the ith day."[81]

The rooting zone of the crop must be divided into specific depths, each with a moisture capacity and the crop development divided into intervals corresponding to a given phase of plant maturity—a difficult task indeed.

In a full-blown model, Baier and Robertson regressed Canadian wheat yields from 39 plantings during five seasons on soil moisture indexes estimated for six soil depths and five crop-maturing intervals.[82] The yields were also regressed on simple climatological variables such as minimum and maximum temperatures and rainfall in the relevant months. The authors conclude

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[78] Note that SM and $\overline{SM}$ are stocks whereas ET_a, ET_p, and R are flows. Also, the soil moisture available at any one time cannot exceed $\overline{SM}$. It is prudent to begin the exercise assuming that the available soil moisture at the beginning of the first day is $\overline{SM}$. The choice of the first day may thus be determined by adequate rainfall the previous night.

[79] According to Augustine Y. M. Yao, "Agricultural Potential Estimated from the Ratio of Actual to Potential Evapotranspiration," *Agricultural Meteorology* 13 (No. 3, 1974): 409–410, "Baier compared five different types of relationships between available soil moisture and AE/PE (where AE is E_t [ET_a] and PE is E_p [ET_p]). He found . . . that the observed and estimated soil moisture means are all significantly different except for his type-C curve which assumes a linear relationship between available soil moisture and AE/PE. This relationship holds for subsoil moisture as well. In conclusion, Baier has stated that if soil moisture observations are not available for comparison, the type-C curve appears to be a realistic assumption for the linear relationship between AE/PE and available soil moisture. It has been recommended as a good starting point for most soils and crops when estimating soil moisture by the Versatile Budget Method."

A linear relationship between the rate of moisture loss and moisture availability is also assumed in J. Lewin and J. Lomas, "A Comparison of Statistical and Soil Moisture Modeling Techniques in a Long-Term Study of Wheat Yield Performance under Semi-Arid Conditions," *Journal of Applied Ecology* 11 (December 1974): 1081–1090, in their analysis of wheat yield performance in the semiarid conditions of three Israeli settlements.

[80] The weights k_j are available in L. A. Heapy et al., "Development of a Barley Yield Equation for Central Alberta: 2, Effects of Soil Moisture Stress"; Baier and Robertson, "The Performance of Soil Moisture Estimates," p. 21; and W. Baier, "An Agroclimatic Probability Study of the Economics of Fallow-Seeded and Continuous Spring Wheat in Southern Saskatchewan," *Agricultural Meteorology* 9 (Nos. 5/6, 1971/72): 308.

In Heapy et al., "Development of a Barley Yield Equation," p. 251, the rooting zone is divided into four depths, each with a moisture capacity of 2.5 cm and the plant growth timetable is divided into seven intervals.

[81] Heapy et al., "Development of a Barley Yield Equation," p. 251.

[82] Baier and Robertson, "The Performance of Soil Moisture Estimates," pp. 17–31.

that the yield-soil moisture model had the highest coefficients of correlation and the lowest standard errors of estimate.

However, as the discussion here suggests, soil moisture indexes are difficult to construct. In any case, the required information is not available for use in this report. While it is possible to estimate monthly potential evapotranspiration for the oblasts of the report on the basis of, for example, the Thornthwaite formula, its applicability to the climatic conditions of the Soviet grain belt is doubtful. All in all, the weather variables of monthly temperature and precipitation adopted here, with occasional averaging and introduction of quadratic terms where applicable, are not only convenient but perhaps the only available alternative.[83]

[83] This is not to suggest that Soviet weather-yield modeling is constrained by lack of information or, indeed, of expertise. For a detailed discussion of the weather variables in Soviet models for estimating or forecasting crop yields in a variety of regions, see Kogan, *Grain Production in the U.S.S.R.*

APPENDIX 3—DERIVATION OF THE EXPLAINED VARIANCE

To derive the explained variance, let

$$y_t = a + bx_t + cz_t + u_t, \qquad (42)$$

where $t = 1, 2, \ldots, T$. Then it can then be shown that

$$R^2 \text{ variance } (y) = \hat{b} \text{covariance } (x,y) + \hat{c} \text{ covariance } (z,y), \qquad (43)$$

where R^2 is the square of the sample multiple correlation coefficient, and $\hat{b}$ and $\hat{c}$ are the estimators of b and c. The following notations are used:

$\bar{x}$, $\bar{y}$, and $\bar{z}$ are the means of x_t, y_t, and z_t;
V_{yy} is the variance of y_t and S_{yy} is $V_{yy}T$;
V_{xy} is the covariance of (x_t, y_t) and S_{xy} is $V_{xy}T$;
V_{zy} is the covariance (z_t, y_t) and S_{zy} is $V_{zy}T$; and
S_{xx} and S_{zz} are the sum of the squares of the deviations of x_t and z_t from their means $\bar{x}$ and $\bar{z}$.

Then the sum of squares of residuals (SSR) is

$$SSR = \sum_{t=1}^{T} [(y_t - \bar{y}) - \hat{b}(x_t - \bar{x}) - \hat{c}(z_t - \bar{z})]^2 \qquad (44)$$

$$= S_{yy} + (\hat{b})^2 S_{xx} + (\hat{c})^2 S_{zz} - 2\hat{b} S_{xy} - 2\hat{c} S_{zy}. \qquad (45)$$

By definition,

$$\hat{b} = S_{xy} / S_{xx} \qquad (46)$$

and

$$\hat{c} = S_{zy} / S_{zz} \qquad (47)$$

When equations (46) and (47) are substituted into equation (45), the resulting equation is

$$SSR = S_{yy} + \left(\frac{S_{xy}}{S_{xx}}\right)^2 S_{xx} + \left(\frac{S_{zy}}{S_{zz}}\right)^2 S_{zz} - 2 \frac{S_{xy}}{S_{xx}} S_{xy} - 2 \frac{S_{zy}}{S_{zz}} S_{zy} \qquad (48)$$

$$= S_{yy} - \hat{b} S_{xy} - \hat{c} S_{zy} \qquad (49)$$

Again, by definition,

$$R^2 = 1 - \frac{SSR}{S_{yy}}. \qquad (50)$$

By substituting equation (49) in equation (50), R^2 is derived as

$$R^2 = \frac{1}{S_{yy}} (\hat{b} S_{xy} + \hat{c} S_{zy}). \qquad (51)$$

Multiplying each side of equation (51) by V_{yy}, the following equation is derived:

$$R^2 V_{yy} = \frac{1}{S_{yy}} (\hat{b} S_{xy} + \hat{c} S_{zy}) \frac{S_{yy}}{T} \qquad (52)$$

$$= \hat{b} V_{xy} + \hat{c} V_{zy}. \qquad (53)$$

In other words,

R^2 variance (y) = $\hat{b}$ covariance (x,y) + $\hat{c}$ covariance (z,y), which is equation (43) above.

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