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Soviet Climate Change: Implications for Grain Production

A Research Paper

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Soviet Climate Change: Implications for Grain Production

Summary

Information available as of 23 April 1985 was used in this report.

During the past several decades, grain production in the USSR has benefited from a general improvement in climate—increased precipitation and slightly higher temperature—and massive investments in agrotechnology. Of these two factors, climate and agrotechnology, the former has been the most important. Aside from its direct impact on crop growth, climate indirectly determines in large measure the effectiveness of technology such as fertilizer applications. Other determinants of grain output such as political decisions, the quality of management, and worker incentives, while important, have had much less impact

While the long-term climate trend has been favorable, there has been a slight drop in precipitation in the 1980s. However, it is too early to assume a permanent change in the long-term pattern. Our analysis indicates that precipitation probably will remain near its present level during the rest of the decade. At the same time, we expect temperatures to continue their rise in the grain area because of worldwide increases in atmospheric carbon dioxide. Temperature increases will lengthen the growing season in the north—providing opportunities for increased production of hardier crops such as rye. Increased temperatures, however, will exacerbate the dry conditions in the southern Urals, lower Volga, and Kazakhstan—areas that account for 20 percent of Soviet grain production

Long-term weather patterns and trends in fertilizer deliveries to agriculture suggest that Soviet grain production during the 1986-90 period most likely will average 195 million metric tons annually—about 60 million tons below target. Thus, at this level of production, Moscow will remain dependent on foreign sources for grains if the leadership intends to achieve projected levels of livestock production and fulfill promises to improve the diet of Soviet citizens. Given the uncertainties of climate prediction, the grain-growing environment in the USSR could be somewhat better or worse than this most likely estimate:

- If a more favorable climate prevails, one with precipitation equal to the 1976-80 period—the best five-year average of the last 65 years—and if fertilizer deliveries reach planned levels, the Soviets could produce an average of 221 million tons per year.
- With bad weather similar to the 1961-65 period—the lowest five-year average precipitation of the last 25 years—and fertilizer deliveries increasing at only the average rate of the last 10 years, production could average as low as 165 million tons annually

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Given the scenarios, Moscow will not be able to make rapid progress on two key goals of the Food Program—improving food supplies while reducing dependence on Western farm products. Indeed, the Soviets would need to import an average of 15 to 65 million tons of grain annually during the 1986-90 period to meet domestic requirements. Although imports at the upper end of this range are logistically and financially feasible, they would strain the transportation system and could force reduction in other hard currency imports

At least two options could enable the Soviets to boost grain output substantially above our most likely estimate. For example, grain yields could be raised significantly by importing more and better agrochemicals and improving application techniques. We believe the Soviets could also increase grain production by changing the crop mix. Specifically, we estimate that a substitution of corn for wheat and other grains on irrigated land could result in a net increase of as much as 12 to 14 million tons by 1990. Despite the benefits associated with such options the Soviets have always been slow to change agricultural policy

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Soviet Climate Change: Implications for Grain Production

A Research Paper

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Soviet Climate Change: Implications for Grain Production

Introduction

Soviet efforts to put more and better meat on the table—a principal measure by which Soviet citizens judge their standard of living—have resulted in massive investments in agriculture and in grain production in particular. Over the past two decades, Moscow has committed billions of rubles to land reclamation and irrigation, the production of agrochemicals, farm machinery and equipment, and to a wide variety of construction. These measures, coupled with generally favorable weather, have caused grain production to increase impressively. Nonetheless, the demands of the steadily increasing livestock herds for grain still far exceed the amount farms have been reliably able to produce. As a result, the Soviets have been forced to expend sizable amounts of hard currency for grain imports.

Numerous factors have prevented the Soviets from achieving their grain production goals, including poor management and lack of incentives for farm workers. We believe that the most important factor in the year-to-year variation in Soviet grain production has been weather. Indeed, the climate,[1] although gradually getting warmer and wetter, is generally unfavorable for grain cultivation. Because climate changes slowly over many years, while weather varies widely from year to year, a long weather record is necessary to analyze climate trends properly. We developed a climate data base, covering 1920-84, to analyze historical weather records and project weather for the next five years. Our research also indicated that fertilizer deliveries to agriculture, an important factor in Soviet attempts to increase grain yields, can serve as a surrogate for other kinds of technological improvements in regression analysis. This study shows that past changes in Soviet climate and technology—particularly the precipitation component of climate and the fertilizer component of technology—correspond well with historical variations in grain production and should provide a key to future Soviet performance.[2]

The Role of Climate

Grain is grown primarily in a zone extending from the borders of Eastern Europe to western Siberia—nearly 4,500 kilometers (km) west to east—and from the dry steppes of Central Asia to the tundra regions—some 1,800 km south to north. For the most part, soils in the zone are comparable or somewhat inferior to those of the northern plains of the United States. Soil deficiencies aside, our analysis indicates that the low precipitation in the relatively more important southern regions (Ukraine, Volga Valley, and the Caucasus) has been the key limitation to grain production in the USSR. Primarily because of yearly variation in precipitation, total grain production during the 1971-80 period ranged from a low of 140 million metric tons in 1975 to an alltime high of about 237 million tons in 1978. Only about 2 percent of the grain area in the USSR is irrigated, and it accounts for only about 6 percent of production

The timing of rainfall can be as important as the annual volume. In the Soviet Union, most grain crops are grown with less reliable precipitation than in the United States. Moreover, in most grain areas a smaller percentage of annual precipitation is concentrated during the growing season than in the United States. This is the case, for example, throughout most

[1] Climate is weather over a longer period. For example, daily mean temperature is used to describe weather, while mean temperature for 10 years or longer is used to characterize climate. Both are averages, and both change

[2] For previous studies on climate change in the USSR, see [redacted] and Joint Economic Committee, Congress of the United States, *Soviet Economy in the 1980s: Problems and Prospects, Part II, Selected Papers*, December 1982, pp. 10-12, "Climate and Grain Production in the Soviet Union."

of the Ukraine and northern Caucasus—the most important Soviet grain-growing region—which is generally comparable in climate to eastern Nebraska and southern Minnesota. The Nebraska/Minnesota areas generally receive over 610 millimeters (mm) of precipitation per year, of which 75 percent occurs during April to September (when the grain is growing) and thus can be used most effectively by the plants. In contrast, the Ukraine/Caucasus region receives about 510 mm, with only 55 percent falling during the growing season.

Although precipitation is the principal determinant of grain yields in the most important grain regions of the USSR, agricultural decisions by the Soviet leadership can have a lesser but still important impact on production. For example, the record-high five-year average production of 205 million tons during 1976-80 resulted not only from three consecutive years of good weather (1976-78)—highly unusual—but also from a decision to substantially increase planted area. Total harvested area during the three-year period averaged almost 129 million hectares (ha). In contrast, during the 1981-84 period, the weather was relatively poorer and the average harvested area dropped to an estimated 122 million ha, mainly because of a decision to increase fallow, a technique used in the USSR primarily to build up soil moisture and dampen year-to-year fluctuations in production. Largely because of these factors, production during 1981-84 declined to an estimated average of 180 million tons.

Climate Change

Our analysis of the two most common measures of climate, average annual precipitation and temperature, shows a slow change in the climate throughout the Soviet grain-growing region. Both temperature and precipitation are increasing. While precipitation and temperature are related, our analysis indicates that precipitation is normally the more important factor in determining Soviet grain yields.

Long-Term Trend. Since the 1930s there has been a general trend of increasing precipitation in the Soviet grain-growing region (figure 2). Although precipitation has varied greatly from year to year, on average it has increased about 20 mm per decade since the 1940s. Precipitation averaged about 476 mm in the 1970s—25 mm more than the 1960s and 71 mm (almost 3 inches) more than the dry 1930s. The latest five-year average (1980-84) shows a slight decrease to 470 mm—still considerably above the long-term (1920-84) average of 435 mm

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Climate Data Base

The precipitation and temperature regimes of the major grain-growing regions of the Soviet Union were compiled from data recorded at 66 Soviet climatological stations.[a] The stations are distributed nearly evenly across the grain-growing regions of the USSR (figure 1). Of the 66 stations, 21 provided data from 1920 to 1949, all provided data from 1950 to 1974, and 36 provided data from 1975 to 1984.

Because of the good correspondence between annual averages obtained from the sets of 21, 36, and 66 stations for the period 1950 to 1974, we were able to use the data from only the 21 stations for 1920-49 and the 36 stations for 1975-84 with confidence. The grain region's annual temperature and precipitation averages were obtained by weighting each station's average by the fraction of total grain area within a surrounding polygon.[b] The annual precipitation averages of the 21 and 36 station sets were in most cases within 2 to 3 percent of the annual averages of the 66 stations, and the five-year averages of the 21 and 36 station sets were within 1 to 1.5 percent of the five-year averages of the 66 stations (table 1). Even better correspondence was obtained in the temperature comparison.

[a] Sources of information for this data base are "World Weather Records," published by the old US Weather Bureau, and "Monthly Climatic Data for the World," published by the National Oceanographic and Atmospheric Administration (NOAA).

[b] A standard technique called the Thiessen polygon method was used. The technique assumes that the precipitation at any station can be applied halfway to the next station in any direction. The polygons are formed by the perpendicular bisectors of the line joining nearby stations. The grain area in each polygon is used to weight the precipitation amount (or temperature) of the station in the center of the polygon.

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Figure 1
Selected Climatic Stations

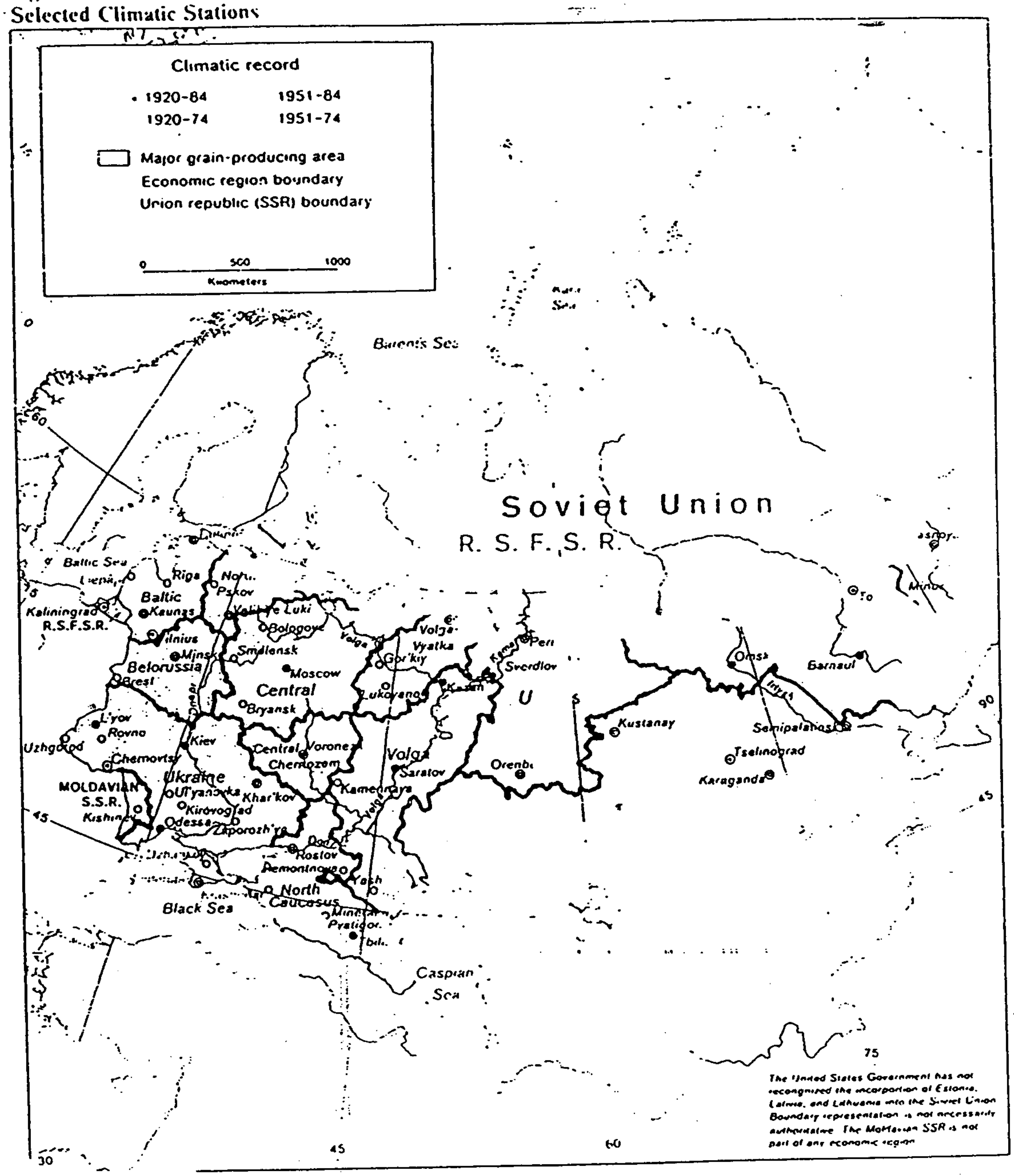

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Table 1
USSR: Precipitation and Temperature Averages for the Grain Area

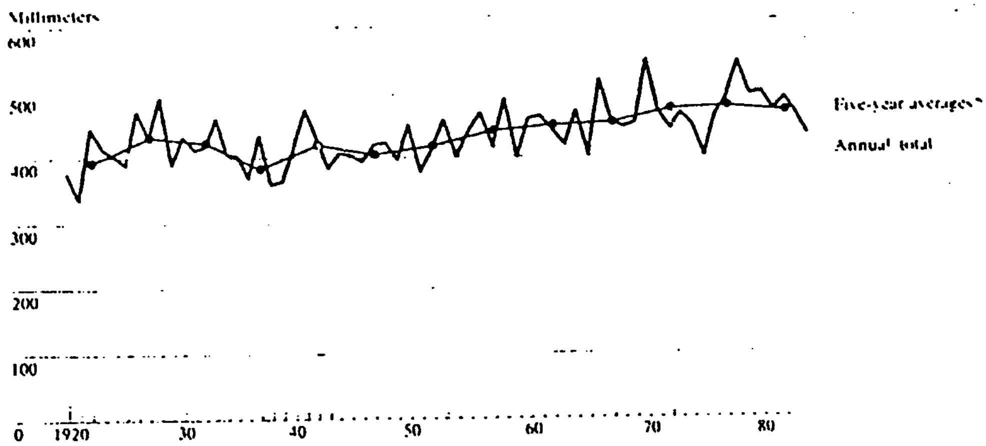
Year	Precipitation (*millimeters*)			Temperature (°C)		
	21-Station Average	36-Station Average	66-Station Average	21-Station Average	36-Station Average	66-Station Average
1920	375			5.3		
1921	335			4.6		
1922	443			4.5		
1923	413			4.9		
1924	402			5.4		
1920-24	394 •			4.9 •		
1925	388			6.0		
1926	470			4.6		
1927	429			5.0		
1928	491			3.5		
1929	389			3.8		
1925-29	433 •			4.6 •		
1930	431			5.1		
1931	412			4.1		
1932	417			5.2		
1933	459			4.2		
1934	405			4.1		
1930-34	425 •			4.5 •		
1935	403			5.0		
1936	369			4.8		
1937	433			5.4		
1938	359			5.7		
1939	363			5.1		
1935-39	385 •			5.2 •		
1940	415			4.3		
1941	472			4.0		
1942	429			2.7		
1943	383			4.7		
1944	405			5.8		
1940-44	421 •			4.3 •		
1945	404			3.5		
1946	393			5.0		
1947	419			3.8		
1948	422			5.7		
1949	396			5.2		
1945-49	407 •			4.6 •		
1950	442	449	448	4.3	4.7	4.7
1951	351	376	377	4.9	4.9	4.9
1952	385	400	412	4.9	4.8	4.8
1953	446	452	455	4.8	4.8	4.8
1954	405	390	400	3.2	3.6	3.5

Table 1 (continued)

Year	Precipitation (*millimeters*)			Temperature (°C)		
	21-Station Average	36-Station Average	66-Station Average	21-Station Average	36-Station Average	66-Station Average
1950-54	406 [a]	413 [a]	419 [a]	4.5 [a]	4.6 [a]	4.5 [a]
1955	442	443	438	5.2	5.1	5.1
1956	478	471	466	3.3	3.7	3.7
1957	426	420	414	5.2	5.1	5.1
1958	480	481	487	4.8	4.7	4.7
1959	397	393	399	5.3	5.2	5.2
1955-59	445 [a]	442 [a]	441 [a]	4.8 [a]	4.8 [a]	4.8 [a]
1960	437	456	457	3.6	3.9	3.9
1961	479	462	461	5.4	5.4	5.4
1962	459	430	439	5.8	5.6	5.7
1963	418	407	417	4.8	4.8	4.8
1964	429	459	469	4.7	4.3	4.4
1960-64	444 [a]	443 [a]	449 [a]	4.9 [a]	4.8 [a]	4.8 [a]
1965	402	395	402	5.3	4.9	5.1
1966	505	540	516	5.6	5.4	5.5
1967	454	459	451	4.7	4.5	4.8
1968	453	458	444	5.3	5.2	5.3
1969	454	463	450	2.7	2.9	2.7
1965-69	454 [a]	463 [a]	453 [a]	4.7 [a]	4.6 [a]	4.7 [a]
1970	606	585	547	4.9	4.8	5.0
1971	478	462	468	4.7	4.6	4.6
1972	438	425	441	5.1	4.9	4.7
1973	453	474	465	5.4	5.2	5.0
1974	459	448	447	5.1	5.0	5.1
1970-74	487 [a]	478 [a]	474 [a]	5.0 [a]	4.9 [a]	4.9 [a]
1975		401			6.4	
1976		462			3.6	
1977		490			4.2	
1978		545			4.7	
1979		494			4.6	
1975-79		478 [a]			4.7 [a]	
1980		498			4.1	
1981		470			5.8	
1982		489			5.2	
1983		464			6.5	
1984		432			5.3	
1980-84		470 [a]			5.4 [a]	

[a] Five-year average.

Figure 2
Annual Precipitation in Major Grain Area,[a] 1920-84



[a] Total is for October through September.
[b] Averages for 21 stations, 66 stations, and 36 stations, respectively, were used for the periods 1920-49, 1950-74, and 1975-84.

Although precipitation in the grain-producing zone has increased overall, analysis of the weather data shows a significant change in the geographical distribution of precipitation during the last 10 years (1975-84) compared with the 1950-74 period (figure 3). Most of the grain area experienced an increase in precipitation—as much as 75 mm in parts of European RSFSR and eastern Ukraine. Significant decreases occurred, however, in some important grain-producing areas of the southern Urals and western and eastern Kazakhstan—in some cases a decline of about 25 mm or more occurred in these regions.

As for temperature, our analysis also shows a gradual increase overall in the grain-growing region, from a 10-year average of about 4.5°C in the 1940s to about 5.0°C for the 1975-84 period (table 1 and figure 4). Part of this long-term temperature increase may reflect urbanization (increased pollution and city heat-island effects). The rest may represent an increase in air temperature worldwide that US scientists generally attribute to a rise in atmospheric carbon dioxide.

* *Changing Climate*, National Academy of Science, National Academy Press, 1983

An analysis of changes in temperatures by geographic area shows regional changes in annual temperature during the last 10 years (1975-84) compared with the 1950-74 period (figure 5). Temperature increases of about 0.5° to 1.0°C are evident over most of the north, central, and eastern regions of the grain area. A climatic increase in temperature usually causes a lengthening of the growing period, which in the future may permit additional areas in Siberia and northern European RSFSR to come under cultivation, especially with the hardier rye varieties that are already showing success. On the other hand, we believe future temperature increases in the southern Urals, lower Volga, and Kazakhstan would further exacerbate the already dry climate there.

Future Trends. Our analysis of climate indicates that temperature will continue to increase and precipitation is likely to remain above the long-term average. Although average annual precipitation during the 1980-84 period was slightly less than during the 1970s—470 mm compared with 476 mm—it is still too early to conclude that a downward trend—or leveling off—has set in. Indeed, recent precipitation levels are still well above the pre-1970 averages.

Figure 3
Change in Mean Annual Precipitation for 1975-84 Compared With 1950-74

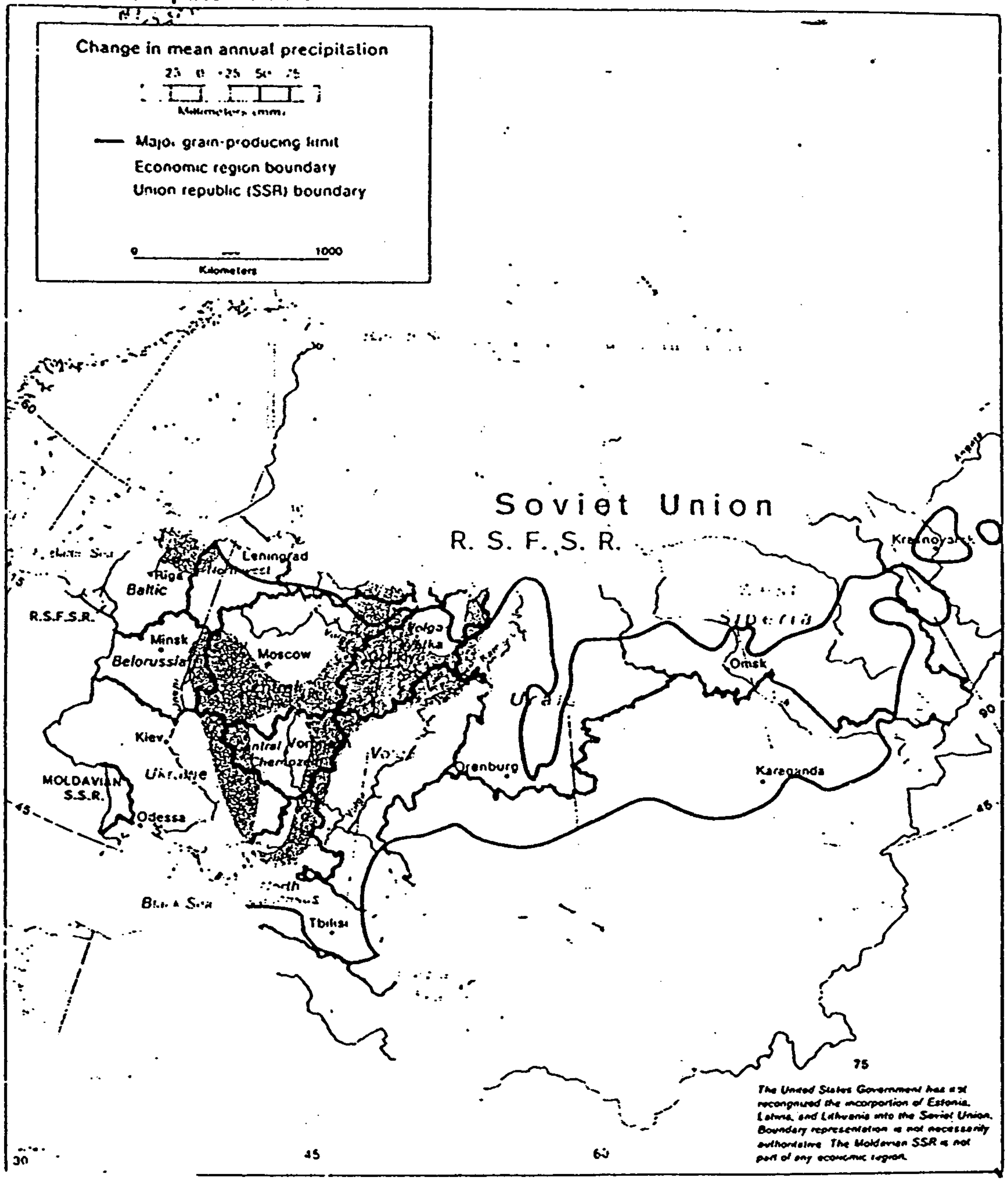
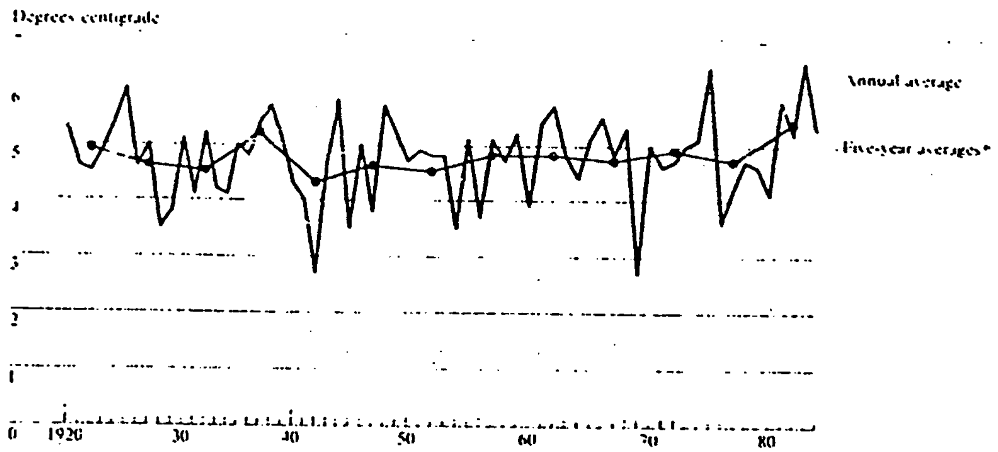


Figure 4
Average Annual Temperature for the Soviet Grain Area,[a] 1920-84



[a] Average is for October through September.
[b] Averages for 21 stations, 66 stations, and 36 stations, respectively, were used for the periods 1920-49, 1950-74, and 1975-84.

We postulate that, for the 1986-90 period, average rainfall should not depart greatly from the 1980-84 average of 470 mm even though year-to-year precipitation amounts will continue to vary widely. Statistical analysis of the change in precipitation between sequential five-year intervals during the 1920-84 period showed about a 50-percent probability that precipitation in the 1986-90 period will average 476 mm or above, and about a 15-percent probability that it will be above 500 mm or below 440 mm.

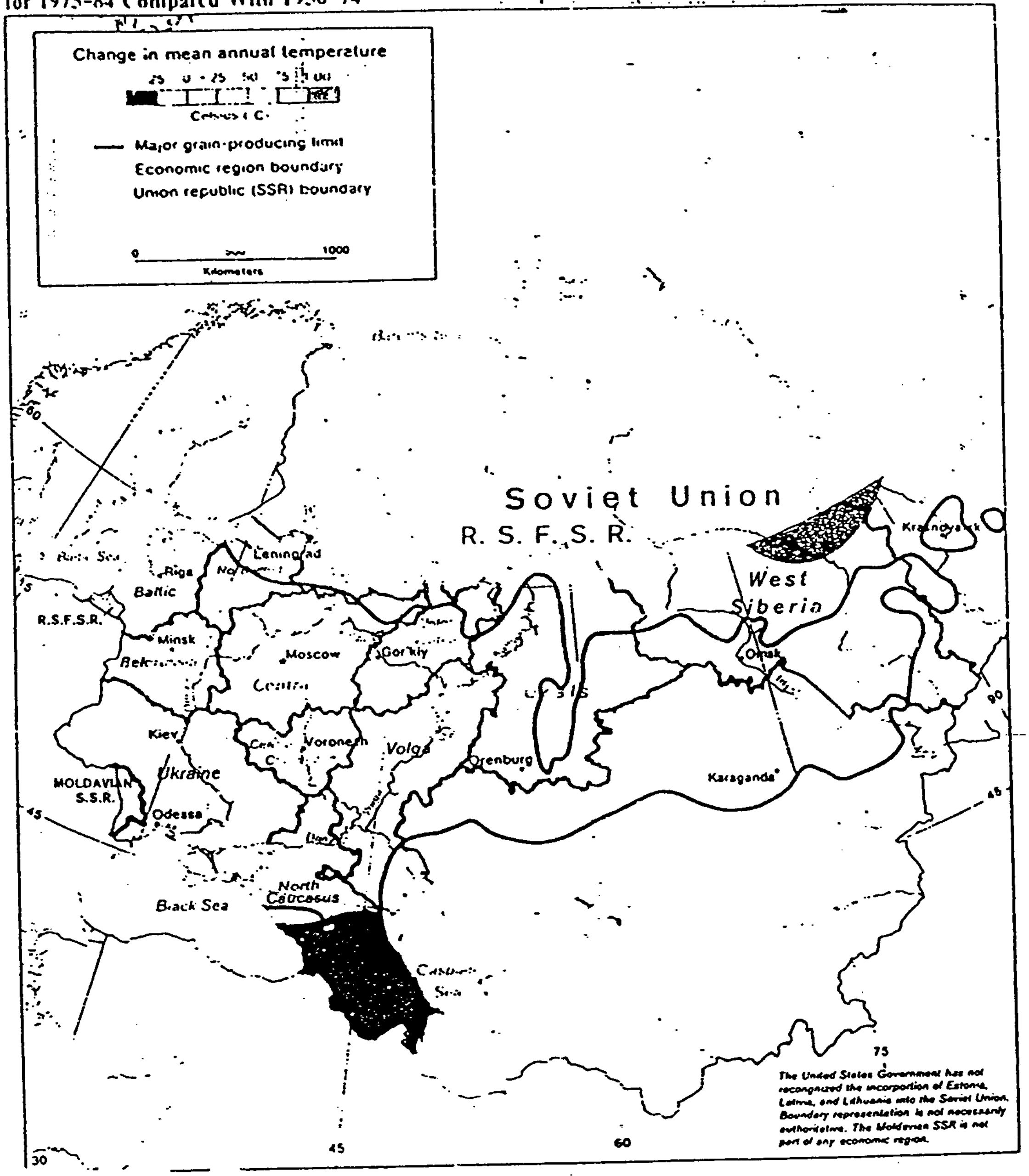
As for temperature, we expect an increase that will generally follow the long-term trend, as a result of a continued increase in atmospheric carbon dioxide. The temperature increase, however, may not be as great as that experienced from 1975-79 to 1980-84 (4.7° to 5.4°C), since the latter period was considerably above trend. Continuation of the trend of five-year averages from the 1940s to 1990 would place the average 1985-90 temperature at about 5.0° to 5.2°C.

Climate and Technology

Climate directly affects crop growth and technology inputs, namely fertilizer. Together climate and technology are key determinants of grain yields. Furthermore, other technological improvements—such as new seed varieties and the application of improved herbicides and pesticides—are not totally effective without good weather. For example, should precipitation in the USSR return to the low levels of the 1930s and 1940s, the benefits of most of the new technology would be greatly reduced.[a] If the climate continues to improve for grain production or remains about the same, more likely in our view, Soviet success in raising production will increasingly rely on technology. Our analysis indicates that chemical fertilizer has been an

[a] Under such circumstances, lack of moisture would be the key yield-limiting factor. For example, fertilizer needs moisture to be used effectively by crops. Furthermore, additional technological investments such as new seed varieties, herbicides, or farm tillage and irrigation equipme[illegible] have little value without timely and adequate precipitation.

Figure 5
Change in Mean Annual Temperature for 1975-84 Compared With 1950-74



important input in enhancing grain yields. We also found that, in regression analysis, fertilizer can serve as a surrogate for the other kinds of technological improvements gradually introduced during the last 25 years.

Looking Ahead

To evaluate the impact of climate change on future grain output in the Soviet Union, we selected three alternative weather scenarios—favorable, most likely, and unfavorable. Because of the important impact of technology on grain production, we also developed three corollary scenarios for fertilizer deliveries to agriculture. The combinations of weather and fertilizer scenarios were used in a newly developed regression model to estimate future grain yields. We believe that the nominal—or most likely—combination of weather and fertilizer scenarios provides the best indication of Soviet grain production for the rest of the 1980s.

Weather Scenarios. We estimate with confidence from weather trends (figures 2 and 4 and table 1) that during 1986-90 the average precipitation in the grain area will most likely range between 450 and 490 mm and that temperature will average between 5.0° to 5.2°C. The general upward trend in temperature and precipitation is consistent with the findings of the National Academy of Science,[*] which projects that mean global temperature and precipitation will increase because of increases in atmospheric carbon dioxide. Nevertheless, the Academy cannot predict the magnitude or location of such increases. The climate probably would not suddenly revert to the lower precipitation levels of the 1940s and 1950s, although sudden shifts in precipitation—as in the 1930s—are still possible

The three weather scenarios we selected to estimate the range of Soviet production in the 1986-90 period are:

- The *most likely*, derived from the precipitation and temperature regimes of the 1970-84 period with annual averages of 474 mm and 5.0°C.
- The *favorable*, based on the 1976-80 period, which shows the highest five-year precipitation average (498 mm) of our 65-year record.
- The *unfavorable* and least likely, based on the five-year period 1961-65, which averaged 438 mm, the lowest of the last 25 years.[*]

Fertilizer Delivery Scenarios. Following a four-year lull that began in the mid-1970s, fertilizer deliveries to agriculture regained their upward momentum after 1979, growing at an average rate of 1.1 million tons per year to a record 23.1 million tons in 1984. Such a continued rate of growth (almost 6 percent per year) in fertilizer deliveries during the next six years would fulfill Soviet plans to deliver 30-32 million tons of fertilizer for crops in 1990.[*]

We developed three fertilizer delivery scenarios:

- The *high* or best case, which projects an annual 6-percent increase in fertilizer delivery, or an average of about 1.5 million tons per year. Although the 6-percent rate of growth approximates the 1979-84 average, we doubt that the Soviets will be able to maintain this rate because of expected lags in the commissioning of new facilities for the production of fertilizers, poor management, and the underuse of existing facilities. The 1984 rate of growth was in fact less than 1 percent.

- The *medium*, or most likely case, which projects that deliveries will increase by about 1.0 million tons per year, or a 4-percent growth, yielding a total delivery to agriculture of 29 million tons by 1990. We judge this scenario the most likely because we expect the Soviets to fall 1-2 million tons short of plan in 1985 and be unable to produce enough fertilizer in 1986-90 to make up the 1981-85 shortfalls and meet 1986-90 goals as well.

[*] Average grain yields for the 1986-90 period were estimated using a simple regression model (see the appendix). To derive these estimates, we examined various factors which influence grain production. Statistical analysis showed that precipitation, temperature, and the level of fertilizer deliveries to agriculture adequately capture the variability in Soviet grain yields.

[*] *Changing Climate*, National Academy Press, 1983

[*] A statistical analysis of the change in precipitation between five-year intervals during 1920-84 results in the following approximate probabilities of occurrence for the three precipitation scenarios chosen for the 1986-90 period:
15-20 percent probability that precipitation will be 498 mm or above.
45-50 percent probability that precipitation will be 474 mm or above.
5-10 percent probability that precipitation will be 438 mm or below. (C)

[*] From Brezhnev's statement at the CPSU Central Committee Plenum on the Food Program, May 1982.

- The *low* case, which projects a 2-percent-per-annum growth rate. This rate was derived from a model[9] using the last 10 years' deliveries of fertilizer to agriculture. The model results project a total delivery of 26 million tons by 1990, for an increase of only about 0.5 million tons per year

The projected fertilizer deliveries to agriculture for the entire USSR for the three scenarios described above were translated into fertilizer delivery rates in kilograms per hectare (kg/ha) for each republic by dividing by agricultural area. In all cases, we assume total harvested area will approximate 124 million ha, roughly equal to the annual average hectarage for 1979-83. This relatively low hectarage figure assumes that the Soviets will maintain current levels of fallow.

Projected Yields and Production

Grain yields and production to 1990 were calculated with the regression model using the three fertilizer scenarios and the actual weather variables for 1961-65, 1976-80, and 1970-84, periods typical of unfavorable, favorable, and most likely weather conditions (table 2).

The model forecasts that, given what we consider the *most likely* weather and fertilizer scenario, the USSR's average grain yield during 1986-90 will be 15.7 centners per hectare (ce/ha). Using a harvested area of about 124 million ha, this equates to an average annual production of 195 million tons. Given this scenario, the model projects that there is a 95-percent probability[10] that Soviet grain production during 1986-90 will average between 180 million tons and 210 million tons

With a *favorable* weather scenario similar to 1976-80 and the high fertilizer delivery levels that the Soviets are striving to achieve, Moscow could average 17.8 ce/ha or 221 million tons, with a 95-percent probability that the average will be more than 206 million tons but less than 236 million tons.

An *unfavorable* weather scenario typical of 1961-65 (the least likely of the three scenarios) and low fertilizer delivery growth rates could plunge average grain production to 165 million tons, with less than a 5-percent probability that it would be above 180 million tons

Analysis of the regression model results, using the three weather and three fertilizer scenarios and assuming a harvested area of 124 million ha, shows that, at a constant fertilizer level, every 10-mm increase in average annual precipitation will result in a 7.5-million-ton increase in average grain production. Correspondingly, at a constant precipitation level, every million-ton increase in fertilizer deliveries to agriculture will produce about an additional 2.5 million tons of grain.[11]

Implications

The three grain production scenarios for the 1986-90 period suggest that the USSR will not progress rapidly on two key goals of the Food Program—improving food supplies while reducing dependence on Western farm products. Indeed, even if grain production averages 221 million tons, Moscow would still need to import at least 15 million tons of grain annually to maintain current levels of seed, food, and industrial use, as well as to achieve planned output levels for meat, milk, and eggs.[12] Given the most likely scenario of 195 million tons, grain imports would have to exceed 35 million tons annually

In the unlikely event that production falls to 165 million tons, the Soviets would require an average of roughly 65 million tons of grain imports annually. This would be an enormous amount, but probably not one beyond the USSR's improved logistic capability. It would be financially difficult, but possible, so long as grain prices remain relatively low. If Moscow

[9] A best fit re[illegible]ion technique was used to make these calculations.

[10] The 95-percent probability range is approximately defined by the model's estimate ± two standard errors of estimate, or within 15 million tons of the projected average of 195 million tons. One standard error of estimate was calculated to be 7.5 million ton[illegible]

[11] Roughly 60 percent of the 75-million-ton Soviet grain production increase from the 1961-65 period to the 1976-80 period (130 million tons versus 205 million tons) was caused by an increase in average precipitation (438 mm versus 498 mm). The remaining 40 percent was caused by improvements in agrotechnology

[12] This assumes that neither [illegible] of feed nor current levels of animal productivity change.

Table 2
USSR: Projections of All-Grain Average Yields and Production, 1986-90

Weather Scenario	Increase in Fertilizer Deliveries to Agriculture [a]	Yield (centners per hectare)	Average Production [b] (million metric tons)	95-Percent Probability Range of Production [c] (million metric tons)
Unfavorable weather	Low	13.3	165	150-180
	Medium	13.6	169	154-184
	High	14.2	177	162-192
Favorable weather	Low	15.8	209	194-224
	Medium	17.2	214	199-229
	High	17.8	221	206-236
Most likely weather	Low	15.3	190	175-205
	Medium	15.7	195	180-210
	High	16.2	202	187-217

[a] Low, medium, and high increases in fertilizer deliveries to agriculture correspond to approximately 2-, 4-, and 6-percent increases per year.
[b] Production is estimated by assuming an average grain area of 124 million hectares, similar to that of the 1979-83 period.
[c] The 95-percent probability range is approximately defined by the average ± 2 standard errors of estimate.

chooses not to test the transportation system and/or not to reduce other hard currency imports, however, the need for grain could be reduced in several ways. Planners could save a few million tons by reducing the quantity of grain used for food, industrial purposes, and export, as they have done in the past. They could cut grain demand by reducing livestock inventories—a tactic strenuously avoided since 1975. This would increase meat supplies temporarily but would probably slow subsequent growth in meat production. A third alternative is to curtail quantities of grain fed per animal. But the reduction would have to be offset by other feeds or animal productivity, and thus meat, milk, and egg production would suffer. Consumers would be faced with diets of somewhat lesser variety and quality, but the extensive special food distribution systems put in place during 1979-81 to cope with the widespread food shortages probably would help offset the effects.

Soviet Policy Options

In our view, the Soviets have at least two policy options that may enable them to boost output substantially above the levels indicated in our *most likely* weather and fertilizer scenario by 1990:

- Grain yields could be raised significantly if a decision were made to purchase more and better agrochemicals, that is, pesticides, herbicides, fungicides, plant-disease protective agents, etc., from foreign suppliers, and if steps were taken to improve application at the farm level.

- We also believe the Soviets could increase overall grain production by changing the crop mix.[a] For example, by substituting corn for wheat and other grains on irrigated lands, Moscow could boost output by as much as 12-14 million tons by 1990.

[a] The potential to increase grain production in the USSR by changing c-- mixes is the topic of a forthcoming CIA research paper

Other options, such as the purchase of turnkey agrochemical plants, are possible but would not significantly affect production by 1990.

Despite the potential benefits associated with these options, history has shown that the Soviets are slow to change their agricultural policy, particularly for wheat production. We judge the possibility of the Soviets deciding to import larger amounts of agrochemicals and agrochemical technology to be somewhat greater than the likelihood of the crop mix being changed. Recent information, [ ] indicates that the Soviets will test several million hectares in 1985 with imported agrochemicals. Purchases of large quantities of agrochemicals from the United States and other Western nations could help boost grain production above trend in the near term, but the time required to install turnkey production facilities would preclude domestic chemical output from reaching a high enough level to significantly affect grain production before 1990

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Appendix

A Simple Regression Model for Estimating Grain Yields of the USSR

A grain-yield regression model enables us to estimate grain yields during the 1986-90 period under different weather and technology growth scenarios. The model, therefore, has to be a function of variables that measure the contribution of weather and technology to grain yields

Figure 6 illustrates the historical all-grain yields, total precipitation in the grain area during the growing period (October-July), and the average amount of fertilizer (kg/ha) delivered to agriculture in the USSR. The graph shows a considerable increase in yields from the mid-1960s to the late 1970s, with simultaneous increases in fertilizer delivery and levels of precipitation. With a few exceptions, there is a general correspondence between high and low points of precipitation and yield. Thus, precipitation and fertilizer delivery rates are likely candidates for describing grain yields by means of a regression equation.

Because of the paucity of published Soviet grain data since 1975, our grain-yield equations were derived for large areas covering one or more republics and having sufficient climatic stations to adequately describe weather parameters. For example, from 1975 through 1980, only republic grain yields were published by the Soviets; after 1980 practically no grain-yield information was published

We used the RSQUARE procedure of the Statistical Analysis System (SAS) computer software package to narrow down the selection of variables for the predictive model. The RSQUARE procedure performs all possible regressions for a dependent variable (grain yield, in this instance) and a collection of independent variables, and gives the r-square value for each model. With the selected parameters, we then derived the yield equations using the General Linear Model (GLM) procedure of SAS

Table 3 lists the variables tested by the RSQUARE routine and the equations finally adopted.[14] An interesting result of the selection process was that fertilizer application variable (FERTH) produced higher r-squares than the variable YEAR, a term traditionally used as a surrogate for technology.[15] Fertilizer application rates to grain area would be an even better parameter to use in the regression, but these data are not generally available at the republic level. We found no improvement in estimating Soviet all-grain yields by using separate winter and spring grain yield equations. We therefore elected to use the all-grain yield equations for the combinations of republics shown in table 3, which also gave better results than a single equation derived for the entire Soviet Union.

The major assumptions inherent in the use of the regression model for forecasting grain production in the 1986-90 period are:

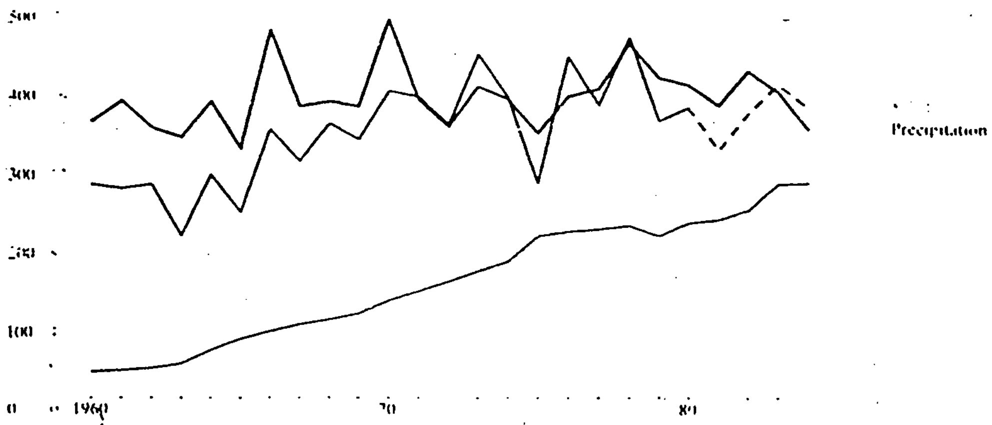
- That projected increases in fertilizer deliveries to agriculture represent the major contribution of technology to grain-yield increases.

[14] We tested three variables for describing the technology contribution to yield: YEAR, total fertilizer deliveries to agriculture (FERTD), and average fertilizer deliveries per hectare of agricultural land (FERTH) from Soviet published data. We also tested cross terms such as FERTH*PREC to detect any interaction between fertilizer response and precipitation amounts, and nonlinear terms such as log(FERTH) to describe diminishing yield returns at high fertilizer delivery levels. In all instances, except one, we found no significant increase in r-square when crossterms or other nonlinear terms were added to the candidate models. We believe that this occurred because the geographic areas covered by the model's equations were too large to adequately capture the interaction between FERTH and PREC. Only in Belorussia and in the Baltic, where fertilizer delivery levels are among the highest in the country, did we find that the use of a log(FERTH) term produced significantly higher r-squares

[15] Fertilizer delivered per hectare of agricultural land (FERTH) has increased nearly linearly with time (FERTH and YEAR show a correlation coefficient of 0.98). Therefore, FERTH, in addition to being directly related to grain-yield increases, is also a surrogate for other technological improvements that have gradually been introduced during the last 25 years and have also been responsible for grain-yield increases

Figure 6
Growing Period Precipitation, All-Grain Yields, and Average Fertilizer Per Hectare,[a] 1960-84

Note scale changes
Millimeters



[a] October-July precipitation for the Soviet grain area. Average fertilizer delivered is per hectare of agricultural land.
[b] All-grain yields after 1980 are CIA estimates.

- That any changes in the mix of grains planted or in other agricultural practices, such as the amount of cropland under irrigation, will take place gradually and therefore will be included in the model variable representing the delivery of fertilizer per hectare (FERTH).

- That the mean square error of our regression model adequately describes the errors of the model. (U)

Figure 7 and table 4 show how the model's estimated yields compare with the actual yields for 1960-80, the period used to derive the model. Also plotted on figure 7 are the model estimates for 1981-84 compared with CIA estimates. The model fits the observations with an average error of 1.1 ce/ha and a mean square error of 1.4 ce/ha for individual years and 0.6 ce/ha for a five-year period.[16] The model is able to explain 80 percent of the variation in the all-grain yield.

The model's errors may be caused by a combination of factors. The first is the gross nature of the model itself. Because of a paucity of data, the model must use meteorological variables averaged for relatively long periods (four to 10 months) and for very large areas (as large as the RSFSR). Second, although the years used in the model (1960-80) are the most relevant in terms of describing recent Soviet agricultural and climate changes, they may not be sufficient to capture the range of errors inherent in the model. Third, the variables in the model may be related to yield in a more complex, nonlinear, and interactive way than can be represented by our simple linear model. Finally, there are certainly other variables such as short-term weather events, the quality of management, work incentives, and political decisions, that influence yield but could not be included in the model

[16] The mean square error for a five-year period is $1.4/\sqrt{5} = 0.6$. Three years (1971, 1973, and 1976) show particularly large model errors of the order of 2 to 3 ce/ha. We will investigate the causes of these large errors in the coming month

Table 3

USSR: An All-Grain Yield Regression Model

Variables Tested by the RSQUARE Procedure [a]

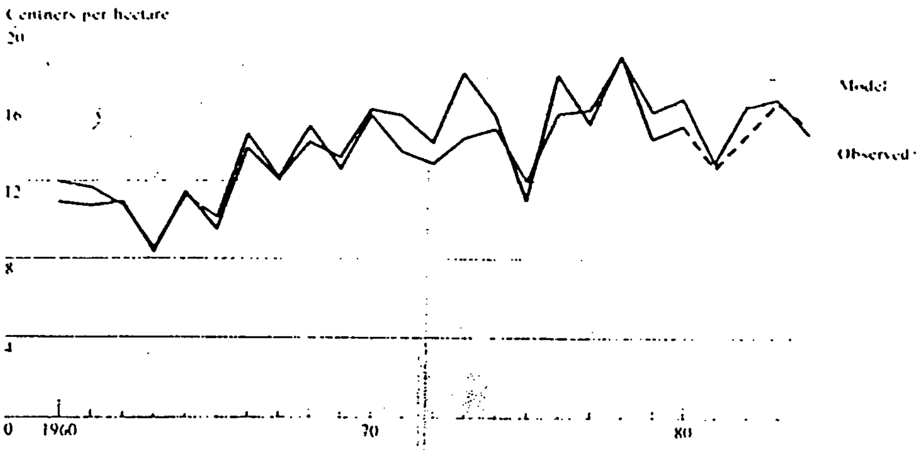
$PREC_{(4-9)}$	$PREC_{(10-3)}$	$PREC_{(10-9)}$	$PREC_{(10-8)}$	$PREC_{(4-7)}$
$TEMP_{(4-9)}$	$TEMP_{(10-3)}$	$TEMP_{(10-9)}$	$TEMP_{(10-8)}$	$TEMP_{(4-7)}$
FERTD	LOG(FERTD)	SQRT(FERTD)		
FERTH	LOG(FERTH)	SQRT(FERTH)		
YEAR	$YEAR^2$			
(FERTH) × (PREC)				

Equations Selected for Estimating All-Grain Yields [b]	R^2
For the RSFSR: $YIELD_r = -3.97 + 0.0875\ PREC_{(4-7)} + 0.0141\ FERTH$	0.80
For Kazakhstan: $YIELD_k = 3.52 + 0.0472\ PREC_{(10-8)} - 0.5367\ TEMP_{(4-7)} + 0.1277\ FERTH$	0.73
For Ukraine + Moldavia: $YIELD_u = 25.44 + 0.0313\ PREC_{(4-9)} + 1.334\ TEMP_{(10-3)} - 1.156\ TEMP_{(4-7)} + 0.0544\ FERTH$	0.81
For Belorussia + Baltic: $YIELD_b = -15.069 - 1.1584\ TEMP_{(4-7)} + 9.519\ LOG(FERTH)$	0.83
For all areas combined: $YIELD_p = (A_r\ YIELD_r + A_k\ YIELD_k + A_u\ YIELD_u + A_b\ YIELD_b)/A_p$, where A_r, A_k, A_u, A_b are the grain areas, and $A_p = A_r + A_k + A_u + A_b$	
For the USSR: $YIELD = -1.472 + 1.104\ YIELD_p$	0.80

[a] PREC—average region precipitation in millimeters weighted by grain area.
TEMP—average region temperature in °C weighted by grain area.
FERTD—total fertilizer delivered to agriculture in million metric tons.
FERTH—average fertilizer delivered per hectare of agricultural land in kilograms.
$YIELD_r$—average region grain yield of major grain area in centners per hectare.
Number subscripts refer to first and last months of period averaged for temperature (TEMP), or totaled for precipitation (PREC). For example, $PREC_{(10-3)}$ refers to total precipitation during October-March.

[b] Letter subscripts r, k, u, and b refer respectively to RSFSR, Kazakhstan, Ukraine plus Moldavia, Belorussia plus Baltic; p refers to all these areas combined, representing about 96 percent of total Soviet grain area.

Figure 7
Comparison of Observed All-Grain Yields and Model's Yields, 1960-84



[a] All-grain yields after 1980 are CIA estimates.

Table 4
USSR: All-Grain Yields and Production, 1960-84

Year	Actual Yield (centners per hectare)	Actual Production (million metric tons)	Model Yield (centners per hectare)	Model Production (million metric tons)
1960	10.9	125.5	11.9	137.5
1961	10.7	130.8	11.6	141.8
1962	10.9	140.2	10.7	137.7
1963	8.3	107.5	8.5	110.4
1964	11.4	152.1	11.2	149.3
1965	9.5	121.1	10.1	129.3
1961-65		130.3 [a]		133.7 [a]
1966	13.7	171.2	14.4	179.7
1967	12.1	147.9	12.2	149.0
1968	14.0	169.5	14.8	179.8
1969	13.2	162.4	12.6	154.6
1970	15.7	186.8	15.4	183.7
1966-70		167.5 [a]		169.4 [a]
1971	15.4	181.2	13.5	159.2
1972	14.0	168.2	12.9	155.1
1973	17.6	222.5	14.2	180.0
1974	15.4	195.7	14.7	187.0
1975	11.0	140.1	12.0	153.5
1971-75		181.6 [a]		167.0 [a]
1976	17.5	223.8	15.5	198.1
1977	15.0	195.7	15.7	204.6
1978	18.5	237.4	18.5	237.7
1979	14.2	179.2	15.6	197.1
1980	14.9	189.1	16.3	206.3
1976-80		205.5 [a]		208.8 [a]
1981	NA	NA	13.0	163.3
1982	NA	NA	15.9	195.5
1983	NA	NA	16.3	196.9
1984	NA	NA	14.5	173.3

[a] Five-year average.