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Grain Production in the USSR

Present Situation, Perspectives for Development and Methods for Prediction

In cooperation with the Atmospheric Science Department of the University of Missouri

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ABSTRACT

Over the past 30-35 years, the USSR grain production generally has been less than Soviet requirements for grain. Climate and weather have been primarily responsible for this shortfall. Many statistical models based on weather and technology, their utilization for large-scale predictions of grain crop production, and related topics are described in this report. The current level of grain production in the USSR is estimated and prospective grain production for the next year, the next several years, and in the near future is projected. The compatibility of probable future grain supplies and requirements in the USSR is discussed.

Key words: Soviet grain production, statistical models, climate and weather variability, yield prediction.

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GRAIN PRODUCTION IN THE USSR: PRESENT SITUATION, PERSPECTIVES FOR DEVELOPMENT AND METHODS FOR PREDICTION

by

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AgRISTARS
Yield Model Development
Project

YMD-2-1(81-08.1)

FOREWORD

The Soviet Union is the second largest grain producing country of the world. But over the past 6-8 years, increased variability in weather patterns in the USSR caused a substantial shortfall in grain production. This shortfall had a very great effect on agricultural production, especially on livestock and on consumption of food by the Soviet people. To overcome the shortage of grain, the Soviet Union has increased purchases of grain in the international market. Over the past two years, the USSR became the leading grain importing country of the world. Accordingly, having a reliable and early forecast of USSR grain production is very important for assessment of total world grain production and trade.

The problem of assessment corresponds to the task of "Early Warning/Crop Condition Assessment and Commodity Production Forecasting." This work is considered by the Yield Model Development Project; one of the eight projects of the AgRISTARS[1/] Program. The project specifies mathematical model development, based on environmental and plant measurement characteristics that represent the yield potential of a crop.

Many models for forecasting grain production of the USSR as a whole and grain production of different regions of the USSR have been developed and utilized in the USSR since the 1960's. But unfortunately, very little was know about these models and little information has been available in American literature.

The author of this Report had been working in the field of model development and operational utilization of them in the USSR during the past 17 years. This Report is the result of his scientific and operational experience.

The Report presents classification of models developed in the USSR, different background for model development and detailed description of models. There is an assessment of the capability of the models, and possibility of their utilization by the AgRISTARS is considered. Organizational principle of utilization of models and verification of them are also described.

A large portion of this Report is devoted to the problem of assessment of the future possibilities of Soviet agriculture in producing of grain. Based on scientific works made by the author some near term and distant perspectives of Soviet grain production in response to climate and weather limitations are estimated.

Some of the author's views on the need for future development of mathematical models, middle-term and long-term predictions of agricultural productivity, assessment of possible climate change impacts and other aspects of problems in agricultural meteorology are also discussed in the Report.

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1/ Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) is a multi-agency program to meet some current and new information needs of USDA.

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GRAIN PRODUCTION IN THE USSR: PRESENT SITUATION, PERSPECTIVES FOR DEVELOPMENT AND METHODS FOR PREDICION

F. N. Kogan

INTRODUCTION

The goals of the report are:

- ---to show the present situation with grain production and analyze basis for elaboration of methods for forecasting grain production in the USSR;
- ---to describe the operational and research methods developed in the USSR for forecasting grain production;
- ---to use some of the methods for estimating perspectives of grain production in the USSR in the future;
- ---to discuss some possibilities for improving the existing methods and further developing new methods for prediction of grain production in the USSR.

During the last 35 years, the average level of grain production in the USSR has almost tripled, from 65 million tons in 1946-1950 to 205 million tons in 1976-1980. This growth was connected with the process of technological improvement in agriculture--a process which can be observed in the majority of countries of the world. Utilization of fertilizers, which are the main factor of technological improvement, increased more than ten times during the last 35 years in the USSR. At the same time mechanization of the whole process of grain production was substantially improved. The number of tractors and grain combines, the most important source of mechanization, increased more than four times. Significant increases in grain productivity was obtained through plant breeding. New varieties of grain crops dramatically increased their productivity, especially such varieties of winter wheat as "Mironovskaya-808," "Bezostaya-1," "Avrova," "Caucasus." Important results for increasing grain production were obtained by improving weed, insect and plant disease control, and soil management. Progress in increased grain production in the USSR during the post Second World War period was very great. But, the level of grain production obtained by the end of 1980 did not correspond to Soviet demands for grain. According to non-official assessments of Soviet economists, the USSR has to produce 1.0-1.2 tons of all types of grain per capita a year for normal development of industry and agriculture, for supplying the main nutritional needs of the population and for international, political and economic purposes. Taking into consideration only the lower limit of demands in grain production, 1.0 ton per capita a year, and the recent (1978) figure for Soviet population, 261.3 million persons [16], one can easily calculate the total Soviet needs in grain. Around 260 million tons per year are needed. This figure must be increased by 2.5-2.8 million tons each year in accordance with the rate of Soviet population growth (approximately 0.9 percent per year). Thus, by 1981 Soviet needs in grain can be estimated at 265-270 million tons.

Average yearly grain production in the USSR during the past five years, as mentioned above, was approximately 205 million tons. Thus, considering only recent years, the USSR has had an average shortage of grain of about 60 million tons per year. But the gap between the production of grain and the demand for it widens in years with unfavorable weather conditions. In the past five years such conditions occurred three times. The shortages of grain in these three years in the USSR totaled around 230 million tons or 76 million tons per year. That was 50% higher than average for 1976-1980. And even in years with favorable weather conditions (1976, 1978) grain production in the USSR was 25-40 million tons lower than Soviet needs for grain.

Because of such a great shortage of grain, the Soviet Government has had to induce Soviet agriculturists to increase productivity. That is why the Government has used a very simple way of setting much higher goals for grain production than they have potential to produce. Accordingly, such planning does not give good results because agriculturists cannot cope with non-realistic goals for increasing grain production. Figure 1 shows discrepancies between planned and obtained production of grain for five-year periods (the basic period of planning in the USSR) from 1946 through 1980. With the exception of 1966-1970, the differences between the figures are more than 10 million tons. For individual years, especially those with unfavorable weather conditions, these differences are much greater. For example, in 1979 and 1980, grain production in the USSR totaled 179 and 189 million tons instead of the planned 227 and 235 million tons.

To close the gap to some extent, the USSR purchases certain amounts of grain on the international market. But this amount is much less than Soviet needs. There are two main reasons for limited Soviet purchases of grain: internal and external. From the internal standpoint, the USSR does not have enough hard currency to pay for grain purchases, as they spend hard currency first of all for the development of their military strength, then for industry and natural resources development, and last of all for agriculture. From the external standpoint there are some economic and political limitations placed by grain trading countries on selling grain to the USSR. The most striking instance is the "U. S. Grain Embargo."

Among other factors, weather is of great importance in regulating grain purchases for a specific year. During the last six years alone, weather variation has caused the USSR grain production to vary by some 69% from 140 to 237 million tons which in turn have led to variation of imported grain by some 67% from 26.1 to 15.1 million tons. More detailed analysis of variations of grain production and grain imports in the USSR (Figure 2, 3) showed asynchronous variability of them during the past ten years. Thus the more production of grain in the USSR the less imports of it and vice versa. Even exports of Soviet grain which is in general considerably less (sometimes ten times and more) than imports depend on production of grain in specific year as well, but with a positive relationship.

To carry out profitable international grain policy, and to plan the work of industry and agriculture, the Soviet Government has to know possible production of grain in the USSR well in advance of the harvest. Because of these demands, the development of methods for forecasting grain production was widely stimulated. Since the late 1960's, these methods have been used

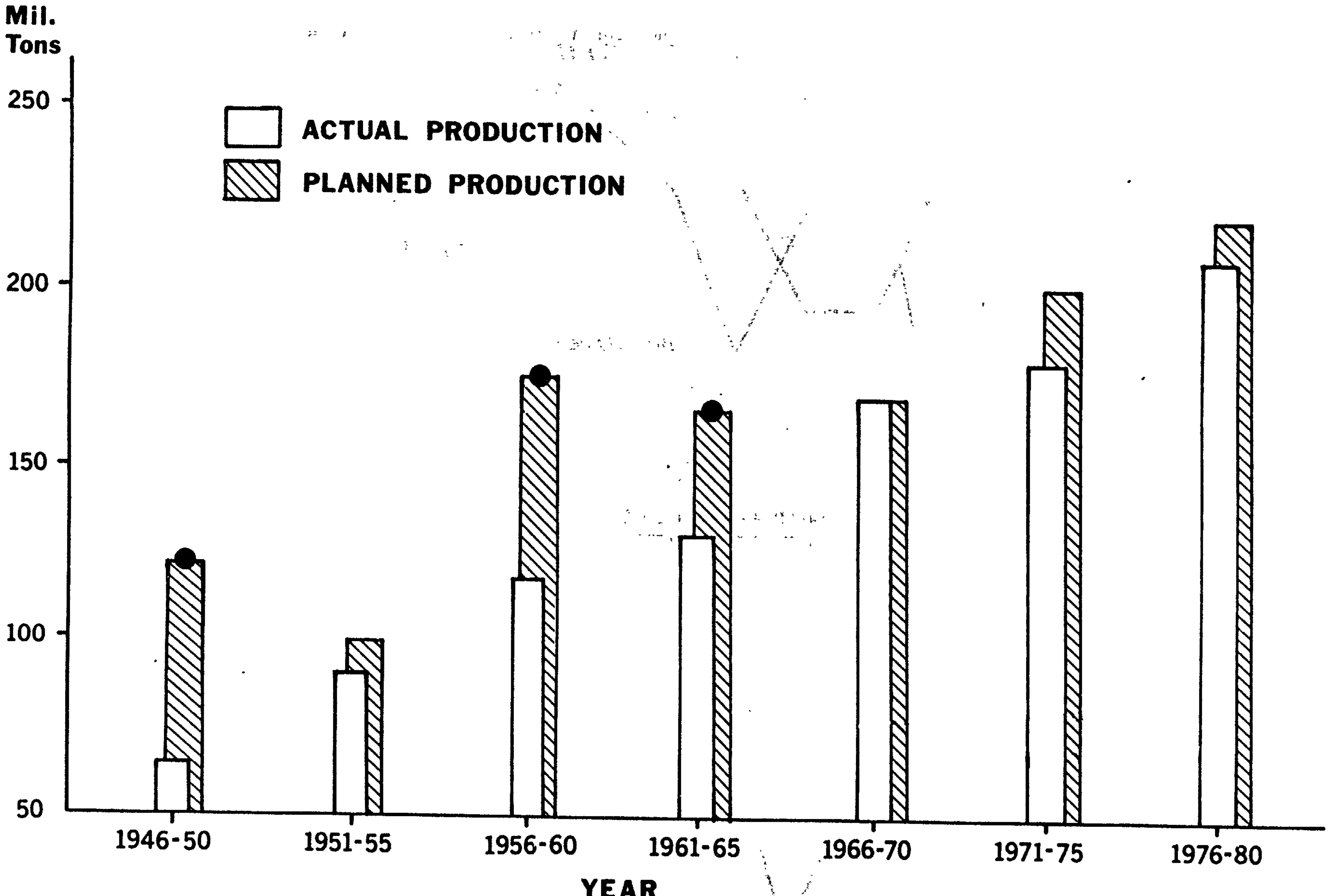


Figure 1. Actual and planned five-year average grain production in the USSR.

● Planned production includes unripened maize cobs.

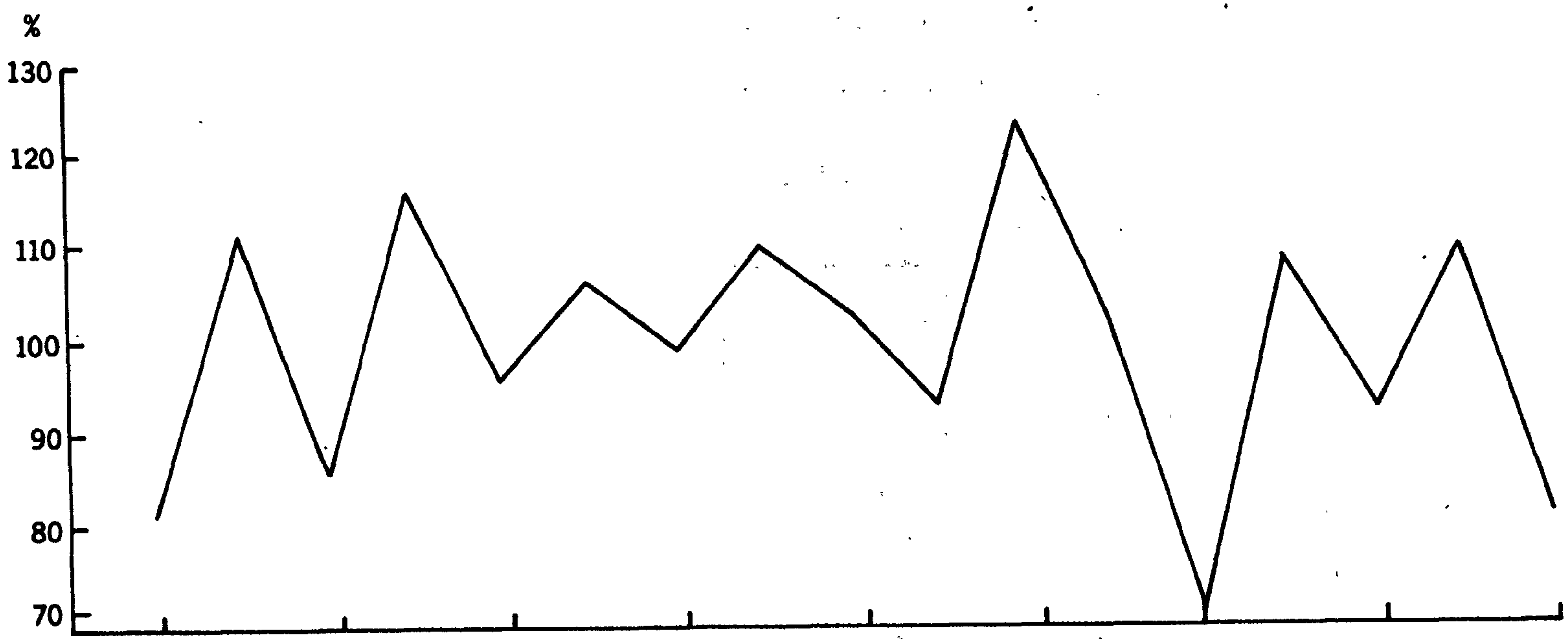


Figure 2. The USSR variation of grain production (in % of trend production).

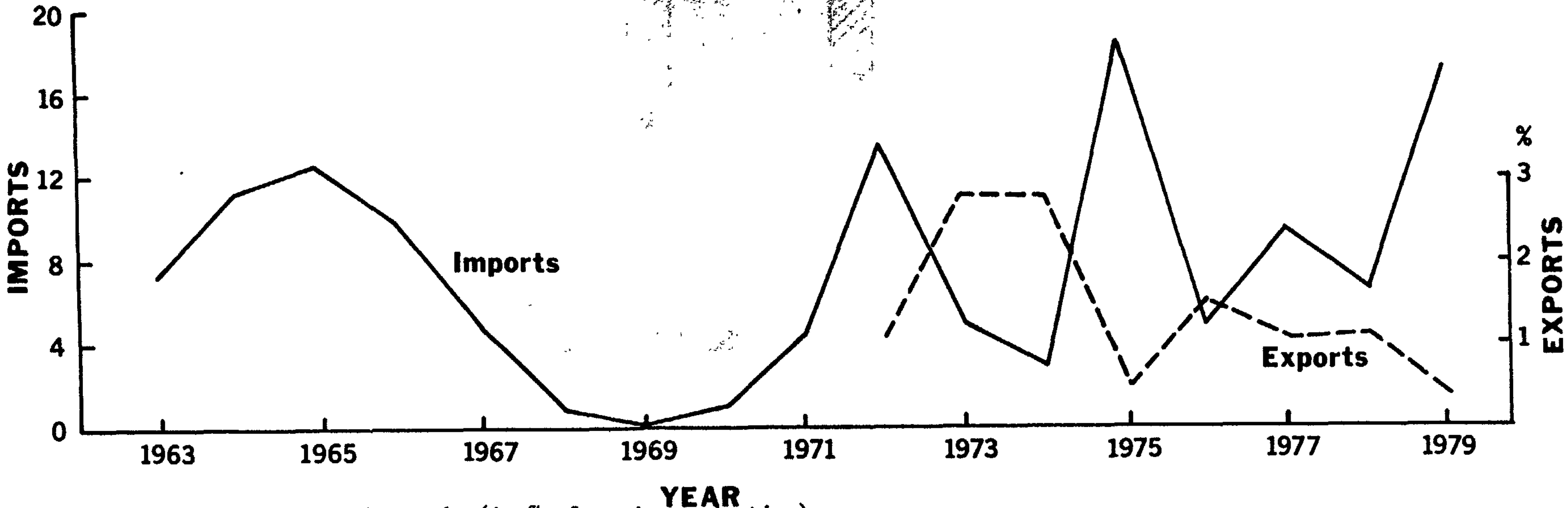


Figure 3. The USSR grain trade (in % of grain production).

in operational practice of grain production prediction. Work on developing methods has continued. In 1978 the National Institute of Agricultural Meteorology (Obninsk, Kalugskaya oblast) was set up for further development of theoretical base for crop-weather modeling and agricultural meteorology as a science.

Up to now, many weather-crop models have been developed and applied for forecasting production in the USSR [29]. Among these are large scale weather-crop models initiated by the author of this report in the early 1970's. These models turned out to have a very successful application in forecasting production [19, 20, 23, 32].

This report is based on the author's

---scientific experience in the field of developing methods for forecasting grain production for the USSR as a whole, for the republic and economic regions of the USSR;

---operational experience in applying these and some other methods and presenting Forecast Reports to the Central Party Committee, the Soviet Government and their organizations;

---analysis of literature devoted to description of scientific and operational methods for forecasting grain production;

---personal scientific and operational contact with other forecasters and agriculturists involved in forecasting grain production.

The report consists of five sections. The first section introduces the idea of the report, underlying a great need for accurate grain production forecasts because of substantial shortages of grain in the USSR. The second section describes specific features of natural and economic conditions which define the basic assumptions applied for the development of methods. Description of scientific and operational methods for forecasting grain production in the USSR with assessments of the application in practice, organizations involved in the procession of operational forecasting and some other problems are discussed in Section III. Section IV is devoted to some long and short-term future assessments of grain production in the USSR which are based on models developed by the author and the results of his scientific works. And in Section V, the author presents his views on the problem of further development of methods for forecasting agricultural production based on weather and climate assessments and their application.

II. IMPORTANT FEATURES OF NATURAL, ECONOMIC AND POLITICAL CONDITIONS AS A BASIS FOR GRAIN PRODUCTION MODELING

Natural, economic and political factors control grain production in the USSR. The first two objectively reflect conformity to the natural laws. The last factor is subjective but its effect on agriculture of the USSR can be dramatic.

Importance of Grain Crops for the USSR

Normally, natural and economic factors control the amount and distribution of crops. The USSR is the largest country in the world with 2227.5 million hectares of territory. In accordance with natural and economic conditions only a quarter of this territory is now used for agricultural purposes. Arable lands cover only 30% of this agricultural part (230 million ha.), with grain crops occupying more than half of arable land (130 million ha.). This fact indicates the importance of grain crops for the USSR. Of all grain crops the most important one is wheat. According to recent figures, wheat covers 48% of the grain crop area and its production accounts for 47% of grain production in the USSR (Table 1). Winter wheat production equals spring wheat production, but spring wheat occupies twice as much area. So, yield levels of winter wheat are much higher than that of spring wheat. But taking into consideration the economic factors, winter wheat does not have such a great advantage. This is so because, first, winter wheat is very susceptible to unfavorable winter conditions in the main zone [30]. Here every 3-4 years the winterkill or other winter damage destroys the crops. Sometimes this damage destroys 30% of the winter wheat area in the USSR, as occurred in 1969. In winters with unfavorable weather conditions, such as 1955-56, 1959-60, 1962-63, 1968-69, 1971-72, Soviet farmers have to resow some 8-14 million hectares of damaged winter wheat crops in the spring [30, 48]. For this purpose alone, they use an additional 2-3 million tons of grain seed. In some regions of the USSR farmers have to resow up to 90% of the winter wheat area. Secondly, the quality of spring wheat is generally better than that of winter wheat. Although geneticists have made great strides in increasing the amount of most important ingredients in winter wheat grain by increasing its productivity, they have failed to make substantial improvements in the quality of the grain.

The second type of grain crops in the USSR, as seen in Table 1, is feed grains. They yield 37% of all grain production from 36% of area. Of the feed grains barley dominates--28% of grain production. And its total production is even higher than those of either winter or spring wheat. Oats usually make up one tenth of all grain production.

Corn is the most productive of all grain crops. Even so, the contribution of corn to the grain balance of the USSR is not large (5%) since corn covers only 2.5% of the grain area. Natural and economic conditions in the USSR do not allow expansion of the area of corn for the effective growth of it. The well known attempt of the Soviet Government in the late 1950's and early 1960's to increase total grain and silage production in the country by increasing corn area, while reducing the area of other crops did not give good results. On the contrary, this practice, when corn was sown even in such unusual areas as the northern part of the European territory of the USSR or Siberia, brought adverse effects. Corn acreage was almost doubled, but production of all grain crops during this period increased only 10% which can be accounted by the technology improvement alone. Five years after abolishing this practice, grain production in the USSR increased by 17%. Of course, these figures reflect

Table 1

AREA AND PRODUCTION OF GRAIN IN THE USSR
(percentage of all grain)

CROPS	AREA	PRODUCTION
All Grain	56*	--
Wheat	48	47
Including Spring Wheat	32	23
Winter Wheat	16	24
Main Feed Grains	36	37
Including Barley	26	28
Oats	10	9
Rye	6	6
Corn	2.4	5
Others	8	5

* Percent of all arable land.

the influence of weather conditions as well as technological factors, but they also give an idea of the importance of the political factor in regulation of agriculture.

The last among the main grain crops is rye, partly winter, partly spring. It contributes an average of 6% of Soviet grain production. But one should note that the rye grain, especially spring rye, is very high in quality and the Soviet Union produces around 40% of the world's rye--more than any other country in the world. But the area covered with rye has been constantly decreasing. Between 1970 and 1978 it decreased by 2 million hectares (from 9-10 to 7-8 million hectares), but without essential changes in level of production (around 11 million tons with variation 8.5-15.2 million tons) as rye yields tended to increase during this period.

The rest of the grain crops (pulses, rice, buckwheat, millet and others), mentioned in the Table 1, normally makes up only 5% of grain production. But some of the crops such as buckwheat are very important in the USSR as a good food for the population. The USSR is the world's main producer of buckwheat (85% of the world production). But even in the USSR the area sown with buckwheat has constantly been decreasing in the past 28 years. Beginning in the early 1950's area of buckwheat dropped by 75%, from 2.5-2.7 to 1.3-1.5 million hectares in the late 1970's, with production decreasing by 10-20%. In 1977 the Soviet Government undertook some measures to expand the area and increase production of buckwheat, with positive results.

Regulation of Grain Crops Distribution

Natural, economic and political conditions in the USSR regulate distribution and productivity of grain crops throughout its territory. The typical distribution of main grain crops is shown in Figure 4. The size of the circle represents the proportion of cereal area within each economic region (the number shows the relative importance of the area as a percentage of the total cereal area in the USSR). The size of sectors in the circles show the percentage of cereal area devoted to each main crop in the region. The figure shows the following features:

1. Main area of grain crops is concentrated in the southern part of the European Territory (ET) of the USSR (Ukraine, North Caucasus, Volga) and in the southwestern part of the Asiatic Territory (AT) (Ural, Kazakh, West Siberia.) This main area produces, on the average, 80% of grain in the USSR.

2. The major winter wheat area is ET, particularly the southern part (Ukraine, North Caucasus.) About 70% of winter wheat area of the USSR is located within this part. This distribution is natural since winter conditions and soil here fit the demands of winter crops much better than anywhere else.

3. The spring wheat area falls in the eastern part of the USSR. Kazakh, Siberia, Ural account for 88% of total spring wheat area.

4. Barley is almost equally spread throughout the grain area of the USSR. This is because barley is very tolerant of soil and climaticl conditions and economically useful as livestock feed and as a replacement crop for winter killed winter wheat.

5. The northern part of the ET is suitable for growing winter rye and oats. Winter rye, more resistant to frost than wheat, usually survives here during the cold winter. Oats are quite tolerant of the colder summers and poorer soils of this area.

6. The southeastern part of the ET is good for spring rye. Here the combination of natural conditions satisfies the requirements of this crop.

7. The extreme southern part of the ET has the most favorable natural conditions for corn. Almost all corn crops are concentrated here.

Now, these are main characteristics in the distribution of the main grain crops. It is important to recognize the vast availability of different grain crops in the USSR and, at the same time, the substantial concentration of them in some parts of Soviet territory which corresponds to favorable natural, mainly climatic, conditions. This fact leads us to a need for an understanding of the peculiar features of climatic conditions in the USSR and their role in each crop's productivity.

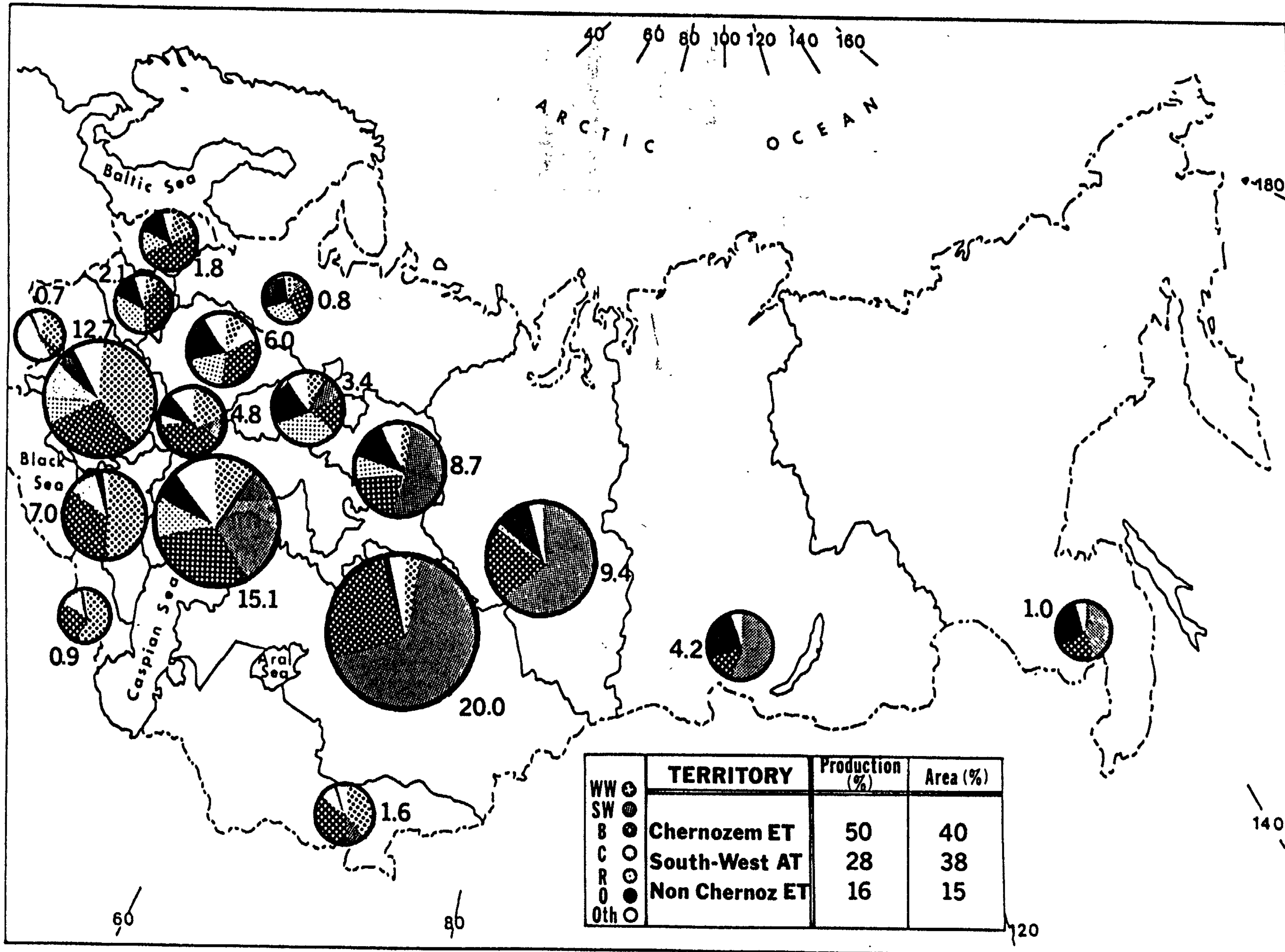


Figure 4. Distribution of grain crops in the USSR in 1975 and 1976; WW-winter wheat; SW-spring wheat; B-barley; C-corn; R-rye; O-oats; Oth-others.

Peculiar Features of Climatic Conditions

Figure 5 shows the distribution of the most important climatic factors which control to a certain degree the productivity of grain crops. Here the available potential water resources are expressed in the form of differences between precipitation representing the incoming part of water balance, and potential evapotranspiration representing the potential discharge of water from soil and vegetation [3] (See table of P-E). Thermal conditions are expressed in the form of air temperature totals for the period with a temperature above 10°C (see degree day isolines.)

As seen in the figure, water resources are a factor of primary importance for the USSR. The main grain zone (the southern) which accounts for more than three-fourths of total grain production in the USSR has an average deficit of water of about 200-400 mm a year. The greatest deficit occurs during the growing season as the distribution of water balance during the year shows. Unfortunately snow can not make up for this deficit as this zone has very little snow during the cold period of the year. And moreover, snow cover, typical for the eastern part of the grain belt (Kazakh, West Siberia), could hardly protect more productive winter crops from winterkill (even such resistant crops as winter rye) in winter period with air temperature below -22, -25°C.

In the northern zone, water balance is positive because the income of water in the form of precipitation exceeds water discharge, and depth of snow is great enough for protection of winter crops from winterkill. But here crops suffer from lack of heat during the growing season, and excessive moisture (for north) or excessive snow cover (for northeast).

Taking into consideration climatic and soil conditions as well as economic and political factors, it is possible to distinguish in general three different grain belts in the USSR. These three grain belts with the description of peculiar features of the natural and economic conditions are presented in Table 2.

<u>The Chernozem zone of the European Territory of the USSR</u> is the most productive grain area. Occupying only 40% of the USSR grain area, this zone produces on the average 50% of the total USSR grain. Such a high productivity is connected with highly productive crops such as winter wheat, corn and barley distributed here and very good natural resources expressed in high fertility of chernozem and chestnut soils, abundant sunshine and heat. But the lack of water, which in some years can be characterized as drought, desiccative wind and also very cold winters with very little snow cover creates limitations on the agricultural productivity of this zone. In years with any or all of these limitations grain production in this zone decreases and amounts to only 40% of the total USSR grain. In favorable years the amount of grain produced by this zone moves up to 60% of the total USSR grain.

<u>The West-Central part of the Asiatic Territory of the USSR</u> has almost the same area of grain crops as the previous one, but only one half of the production, and experiences a very great variation over the time. This low production is a result of more limited natural resources of the zone

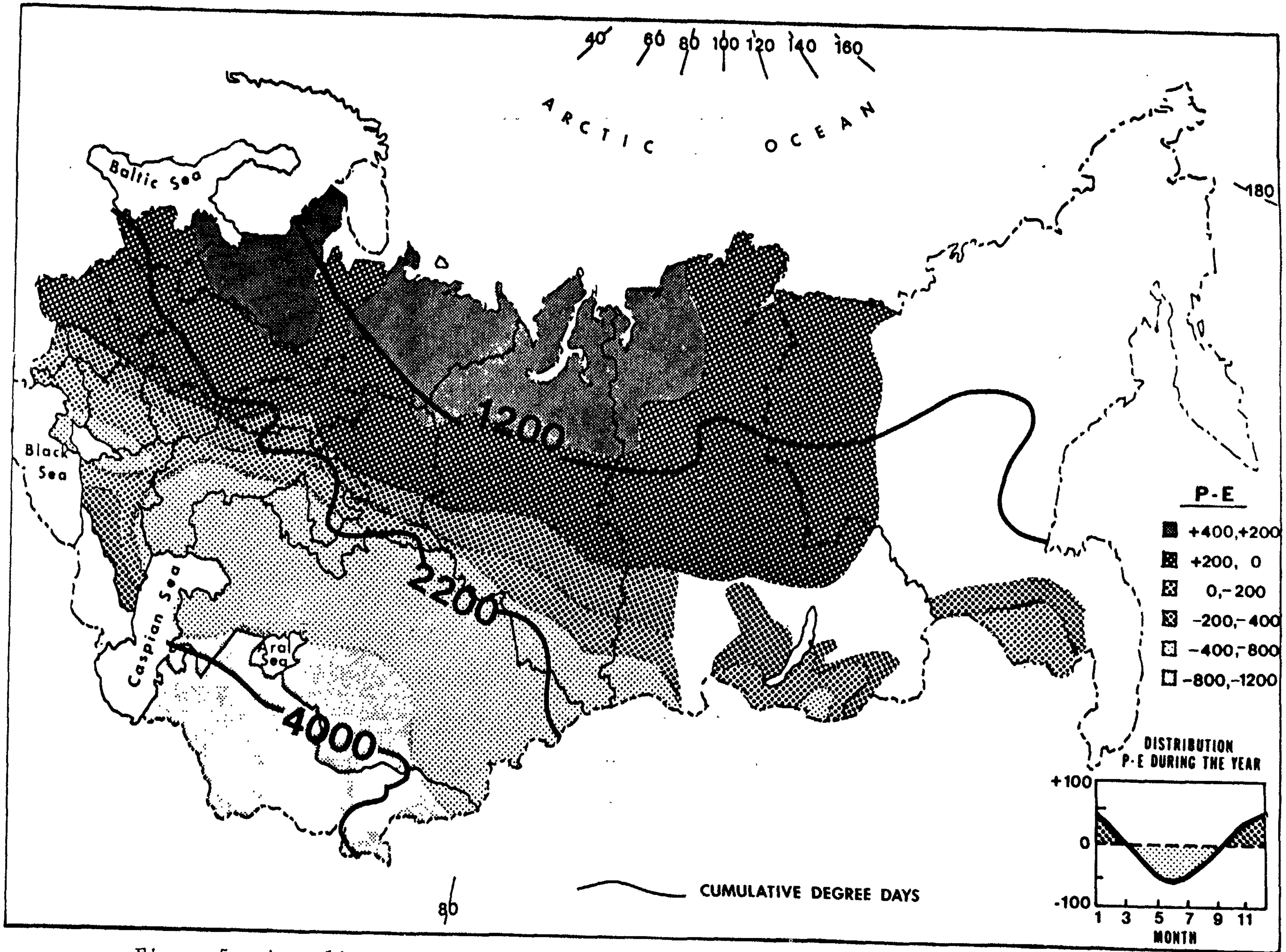


Figure 5. Agroclimatic resources in the USSR; P-E is difference between precipitation (P) and potential evapotranspiration (E).

Table 2

CHARACTERISTICS OF THE MAIN ZONES OF GRAIN AREA IN THE USSR

CHARACTERISTICS	CHEZHOZEM ZONE ET	NON-CHEZHOZEM ZONE ET	WEST-CENTRAL PART AT
Soils	Chernozem, Chestnut	Gray and Brown Forest	Chernozem, Chestnut Less Fertile
Sunlight	Abundant	Deficient	Abundant
Heat	Abundant	Deficient	Abundant
Moisture	Deficient	Sufficient and Abundant	Deficient
Weather Hazards	Drought, Desiccative Wind Winter Frost	Early Winter Thaw	Drought, Desiccative Wind, Winter Frost
Main Crops	Winter Wheat, Barley, Corn	Barley, Oats, Winter Rye	Spring Wheat, Barley, Oats
Average Production (% of the USSR)	50	16	28
Variation (% of the USSR)	40-60	14-19	20-37
Average Area (% of the USSR)	40	15	38

and much lower productivity of spring wheat, the main crop here. The greatest problem here is water deficit and hazardous phenomena (drought, desiccative wind) more severe in intensity than anywhere else.

The Non-Chernozem zone of the USSR has quite limited solar and soil resources, but very good natural water consumption--the most important factor of crop life. That is why the productivity of the zone is moderate enough with a very small variation in grain production.

III. METHODS AND APPROACHES FOR FORECASTING GRAIN YIELD AND PRODUCTION

Before describing methods and approaches for forecasting grain production, it seems useful to present some organizational principles of forecasting, in the Soviet Union. The principles, as they apply to Soviet Agriculture, have never been officially introduced and written. They were worked out based on practice of demand-utilization of forecasting information.

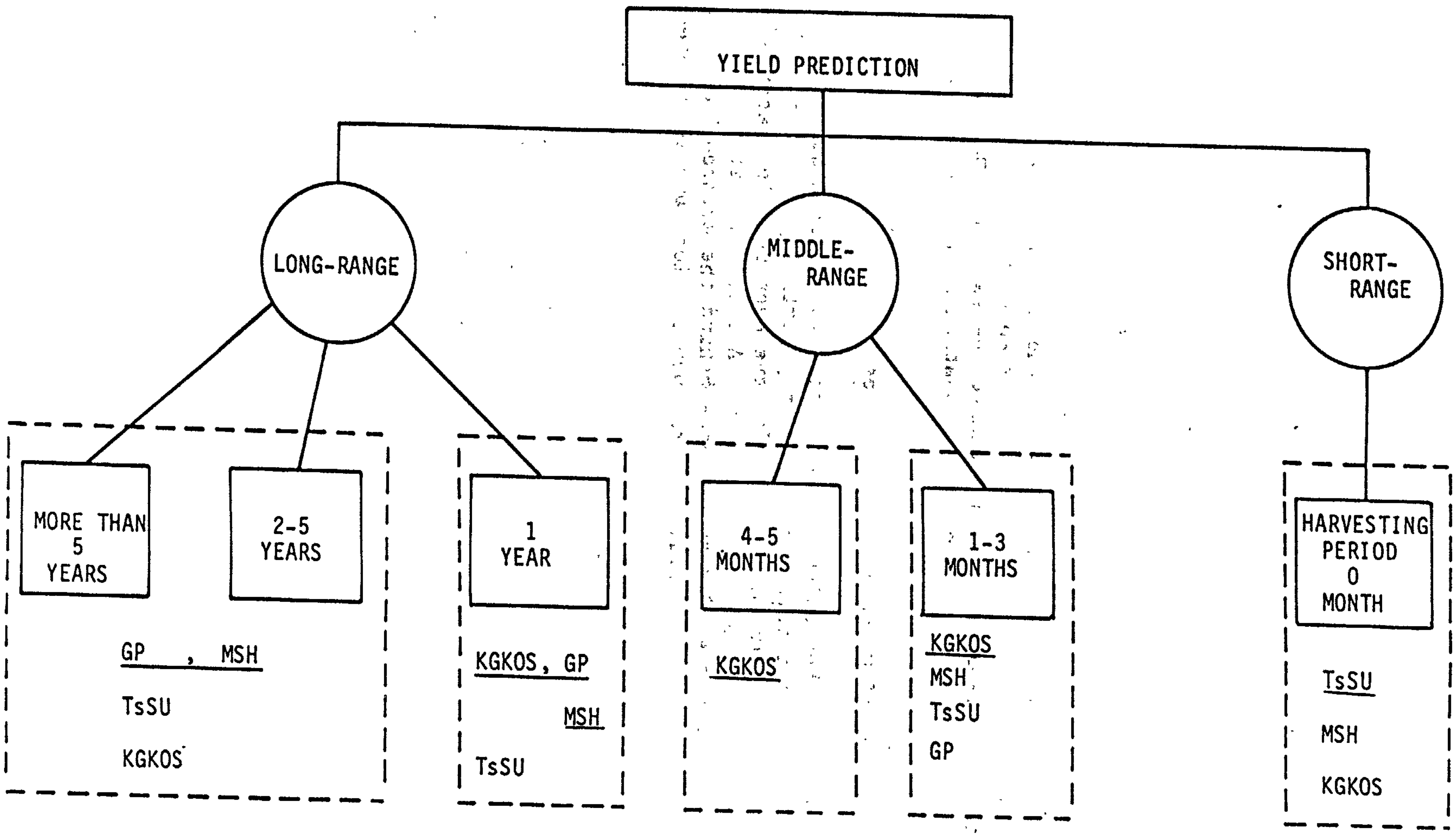
Organizational Principles in Forecasting

The scheme of different forecasts, used in practice, and the responsible organizations releasing these forecasts, are shown in Figure 6. The scheme was worked out based on routine needs of the Central Party Committee, the Soviet Government and some of the organization in grain forecasts for making internal and external decisions. The scheme defines three types of forecasts corresponding to the lead time or duration between time of prediction and crop harvest; long-range, middle-range and short range. Normally four Governmental Departments, (names in the Figure 6) work out grain production forecasts and present the reports with these forecasts to the higher level organizations. Reports are usually reproduced in limited quantities for specific individuals. The Hydrometeorological Service usually submits its reports to 40-50 officials. But in years with unfavorable weather and bad grain production perspectives, the number of copies of the report is often decreased. For instance, in 1975 the Yield Forecast Report issued by the Hydrometeorological Service was submitted only to the highest eight officials of the USSR.

The responsibility among the organizations depends on the type of forecast. The most responsible organizations are underlined in the Figure 6. The long-range type of forecast includes forecasts for periods of one, two to five and more than five years. All these terms are standard for planning in the Soviet society. Forecasts for a period of more than five years are usually used for assessment of long-range perspectives in the development of industry and agriculture.

As it is seen in Figure 6, the State Planning Organization of the USSR (GP) and the Department of Agriculture (MSH) take major responsibility for long-range forecasts. Recently the Hydrometeorological Service (KDKOS) has begun to submit its report with assessment of next year's grain production based on the method developed by the author of this report.

Middle-range forecasts cover two basic periods with lead time of 1-3 and 4-5 months. These forecasts, especially the first group, are usually used



GP - GOSPLAN (STATE PLANNING ORGANIZATION)

MSH - MINISTERSTVO SELSCOGO HOZAISTVA (DEPARTMENT OF AGRICULTURE)

TsSU - TSENTRAL'NOYE STATISTICHESKOYE UPRAVLENIYE (CENTRAL STATISTICAL ADMINISTRATION)

KGKOS - COMMITET PO GIDROMETEOROLOGY I CONTROLU OKRUGAUSHEY SREDI (STATE COMMITTEE ON HYDROMETEOROLOGY AND ENVIRONMENTAL CONTROL)

Figure 6. Types of forecasts and responsible organizations.

by the Soviet Government for making some decisions particularly with respect to the purchase of grain. The year 1972 is a very good example of use of information for guiding very timely purchases of grain in the USA. The decision was based on a very correct and timely estimation of Soviet grain production worked out by the team of the Hydrometeorological Center (in which the author participated). These forecasts are also used for making decisions of grain storage, organization of grain harvesting, processing and some other operations. The Hydrometeorological Service has many methods based on weather and technology assessment for timely forecasting of all grain and particular grain crop production. The forecasts of the other organizations are in general based on the personal estimates of a large army of agronomists and some other people involved in the process of growing grain and controlling work of agriculture throughout the USSR.

Short-range forecasts do not have such great importance as the previous two types. They are mainly used for checking and updating of the previously issued forecasts. The Central Statistical Administration (TsSU) is the organization of main responsibility for these forecasts. It receives current weekly information about harvested and swathed area, and also threshing and yield. Based on this information TsSU makes decisions about current levels of production. The rest of the organizations receive the same information from TsSU and are also involved in the process of updating previously issued forecasts.

Description of Methods and Approaches

Some of the methods and approaches which were developed in the USSR have been published in the scientific literature (sometimes only partially), but most of them have not been published. Some of the methods have been used in practice since the early 1960's, some of them--only recently. Accordingly, it seems to be useful to describe not only the idea and essence behind the methods but also ways of using them in practice, their authors, publications and advantages and disadvantages.

Approaches and Methods for Long-Range Forecasting

The current level of world scientific knowledge has not allowed the development of good methods for long-range forecasting of grain production. Nevertheless, historical data and some experience have made it possible to develop empirical and in some cases regressional models for approximate assessments of future possibilities in grain production.

Empirical approaches

These approaches are based on present experimental knowledge concerning the influence of technological factors on yields, and the assumption that this type and rate of influence will continue in the future and also that the climate and weather variables will be at their average level.

Simple empirica. One of the approaches which is often used by GP for assessment of increases in grain production in the USSR over five or more years is described below. It has been known from scientific literature that every additional unit of technological factors increases yield in some proportion. The total yield increase over some planning period (5 or 10 years) can be easily calculated based on this proportionality and given the planned amount of increase in technological factors for the same period. Unfortunately, I can not give an example with real figures of this type of planning. But to make the explanation of the idea clearer, some invented figures are shown in Table 3.

Residual Assessment. One more empirical approach based on extrapolation is usually used by GP for assessment of grain production while developing a future five-year plan. Here the highest increase in grain production between adjacent five-year periods in the past (approximately 28-37 million tons) extrapolated on to the planned five-year period. Thus grain production for 1966-1970 was planned 37 million tons higher than average production for 1961-1965 (130 million tons), for 1971-1975 it was planned 28 million tons higher than production for 1966-1970 (167 million tons); for 1976-1980 it was planned 35 million tons higher than production for 1971-1975 (182 million tons). And at last the recent figures for 1981-1985 place the expected USSR grain production 36 million tons higher than the average grain production for 1976-1980 (205 million tons). Unfortunately, this approach is less reliable than the previous one, because the so called "constant of increase production" contains some amount of production which results from the differences of weather conditions between two five-year periods. In the long-range yield predictions (more than one year), the shorter the period of forecast, the more uncertainty there usually is about the weather and less known about the part of production connected with

Table 3

ASSESSMENT OF YIELD INCREASE FROM INCREASING TECHNOLOGICAL FACTORS (INVENTED FIGURES)

Technological Factors	Planned Increase of Technology Over		Present Yield Increase (Q/HA) From 1% of Factor Increase	Planned Increase of Yield Over (Q/HA)	
	5 Years	10 Years		5 Years	10 Years
Fertilizers	14	25	0.05	0.70	1.25
Machinery	8	15	0.01	0.08	0.15
Varities Improvement	10	20	0.04	0.40	0.80
....	...	...	...	...	...
Productivity Per Man	5	10	0.01	0.05	0.10
			TOTAL	1.23	2.30

weather. That is why the actual average figures of the USSR grain production for the past two five-year periods, 181.6 million tons for 1971-1975 and 205.2 million tons for 1976-1980, differed from planned figures.

There have also been many attempts to develop different types of regression, autoregression, economic models for long-range forecasting grain production in the USSR. But, to my knowledge, none of them have received practical utilization.

Regression models

This type of modeling involves several methods for estimation of grain production in the USSR.

Trend Assessment. It is based on assessment of technological level in the form of the trend (most often linear form) in yield-series. The extrapolation of the trend is used for forecasting the level of yield in the future. Grain production in the USSR in 1945-1980, trend and extrapolation of trend is shown in Figure 7. The extrapolation shows that grain production in the USSR is expected to be around 300 million tons by the end of the century.

It is well known that the accuracy of trend estimation and extrapolation based on it depends on the initial information used. As it is seen in Figure 7, the trend estimate changes for different historic periods. Thus, for 1963-1980 the trend would have a greater rate of increase than for 1971-1980. And, as it will be shown in part 4 of this report, these differences can be explained not only by the differences in weather, but also by the changes in economic and political factors. At any rate, it is very difficult to find numerical assessment of future changes for both types of factors, especially for the weather.

Accordingly, this method for long-range forecasting should be used cautiously.

Method Based on Cyclicity (author Kogan, F. N.). Forecasting grain production for a year ahead is a more complicated task than forecasting for a longer period because of the weather in a particular year can substantially differ from average weather, which is usually postulated for the longer period of yield assessment. The weather forecast for a year in advance is not a realistic task at present and it seems to be a non-realistic task in the near future at least for the next 10-20 years. Taking into consideration all these things, the author of the report has developed an indirect method of forecasting the USSR grain production for one year in advance. The method was developed in 1972. It is based on two principals: eliminating the technological component and separating the cyclic component in yield-series. Based on scientific knowledge, it was possible to apply the same approach to both tasks taking a residual (Δ) between yields of two consecutive years in yield-series and considering this residual as a parameter for assessment. A two-year cycle was chosen as a basic component for consideration. This choice is founded upon two phenomena. The first one is quasi two-year cycle of the atmospheric process found in the upper atmosphere of the equatorial zone and affecting spring and summer weather of the

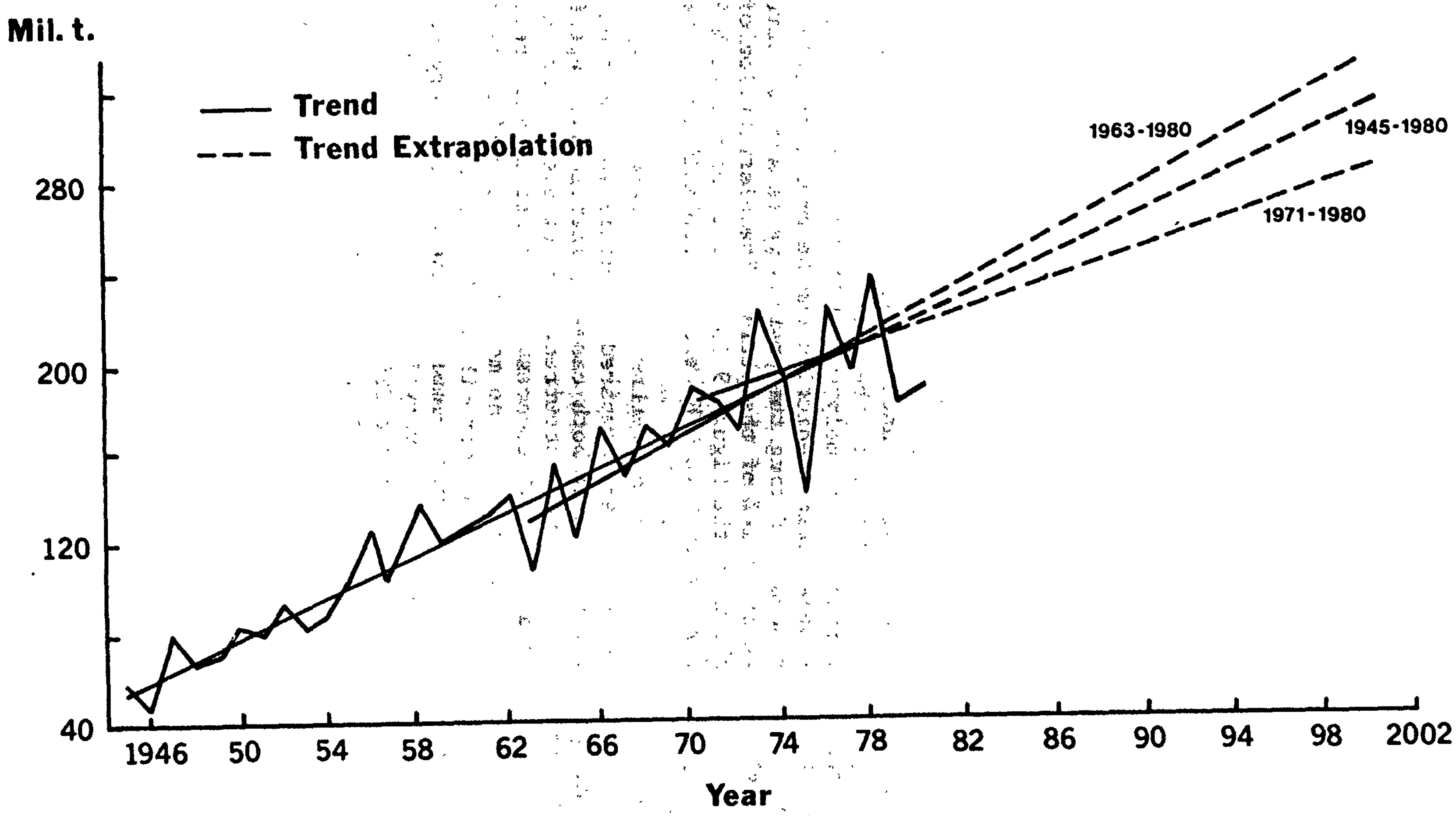


Figure 7. Cereal production in the USSR in 1945–1980.

USSR [17, 40]. The second one is the biological two-year cycle of crop-soil interaction intensifying in the years with extremely adverse weather conditions. Up to now nobody has mentioned the reasons for this cycle, although some authors showed two-year yield variations. But analyzing variations in yield-series for relatively small regions. they received different results for some regions [25, 33]. The correlation which reflects the main principle of the cycle is shown in Figure 8. The equation for this regression is:

$$\Delta_1 = 5.265 - 3.179 \log (\Delta_2 - A). \quad (1)$$

The equation for estimating yield is:

$$Y_{n+1} = Y + 5.265 - 3.179 \log [(Y - Y_{n-1}) - A]. \quad (2)$$

Here Y represents yield (Q/HA); n is year; A is constant. The analysis shows that the correlation is broken for some years. This happens when the two-year cycle is disturbed or when against a background of the cycle some specific conditions change the rate of yield variation. Only of recent years the disturbance of the cycle occurred in 1974-75 and the rate of change occurred in extremely wet 1980. In cases like these the error of the long-range yield prediction can be great, especially when cycle disturbances occur. During the past 35 years such disturbances have occurred five times or in 14% of the years. The distribution of ΔY error definition shown in the Figure 9 is close to normal with 90% probability of error within ± 2.0 Q/HA and 73% probability of error within ± 1.0 Q/HA variation of ΔY.

Actual and predicted yields are compared in Figure 10. As seen in the figure, the yearly variation in both cases is identical except for 1975 when a disturbance of the cycle occurred. Out of eight years of operational use of the model the differences between actual and predicted yield for one year in advance were no more than 1.0 Q/HA in five years, within 1-2 Q/HA in one year and more than 2.0 Q/HA in two years (1975 and 1980). Thus, this method is very simple to use and has very good lead time of prediction. And, what is very important in the past eight years, is that it showed good results for the USSR yield prediction in independent tests which produced 75% of correct predictions.

Methods for Middle-Range Forecasting

As has been mentioned, the Hydrometeorological Service of the USSR (KGKOS) is the main organization responsible for this type of forecast. The Hydrometeorological Center of the USSR in Moscow is the leading scientific and operational institute of the Hydrometeorological Service, developing methods and producing forecasts based on these methods. The whole procedure of method development and utilization is very well organized. Every new method must be tested by the author over a period of one or two years using independent data. Then it must be tested in operational practice for one or two years. The results of the testing must be compared with the results obtained from other methods officially used in practice. And after that a special Commission at KGKOS discusses the idea of the method, the results of testing and comparisons with other methods. Based on this discussion, a decision is made on the possibility of utilizating the method in operational practice. Thus, the procedure is very long and complicated, but it is justified because it reduces the

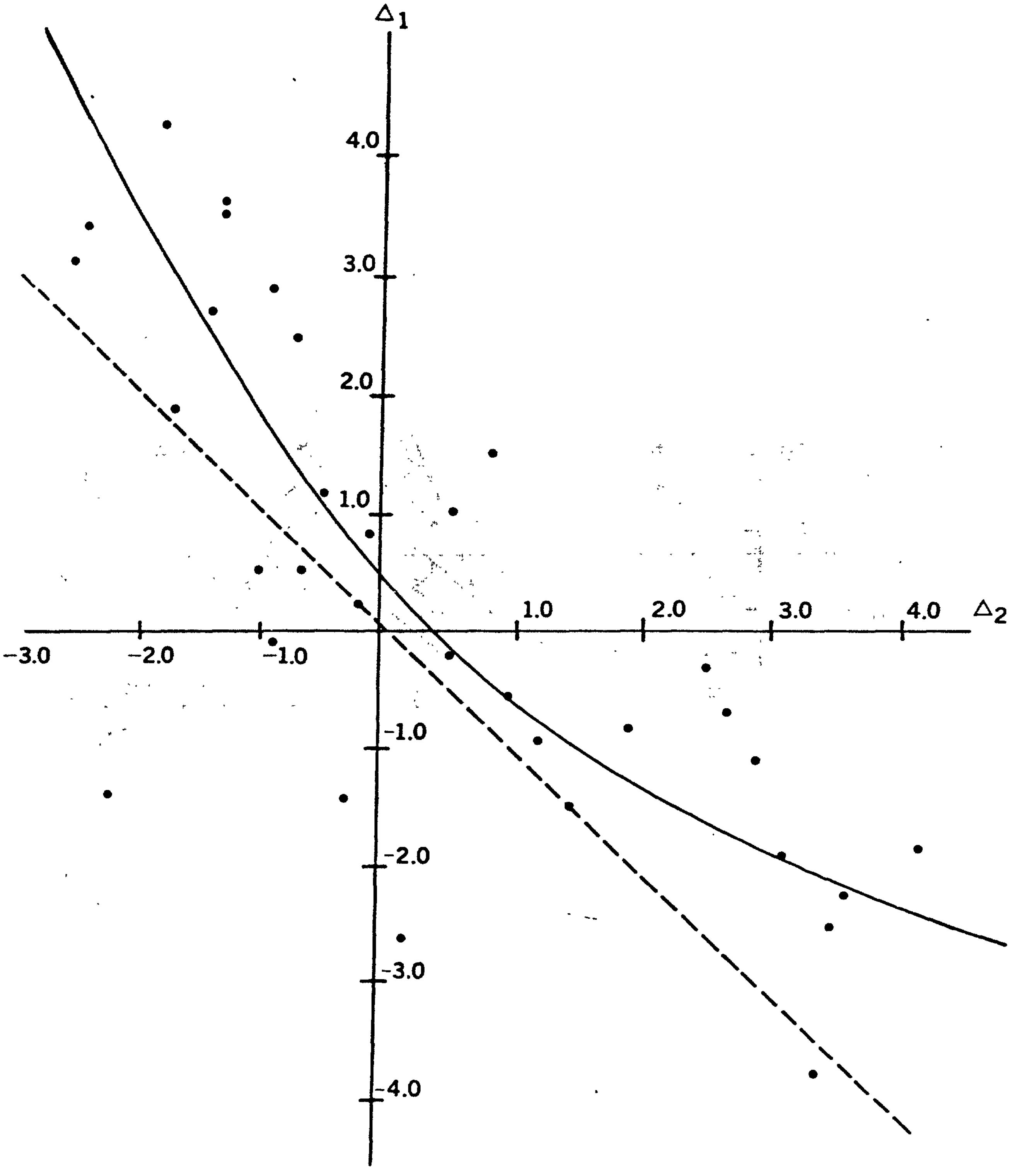


Figure 8. Correlation between cereal yields in the USSR, based on the two-year cyclicity.

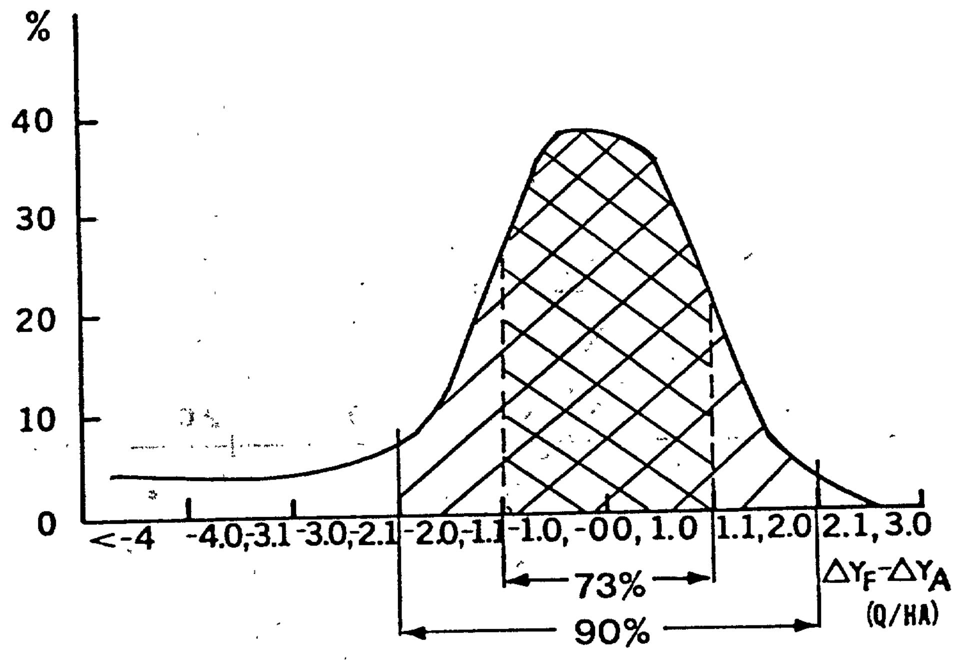


Figure 9. Distribution of errors for prediction based on two-year cyclicity.

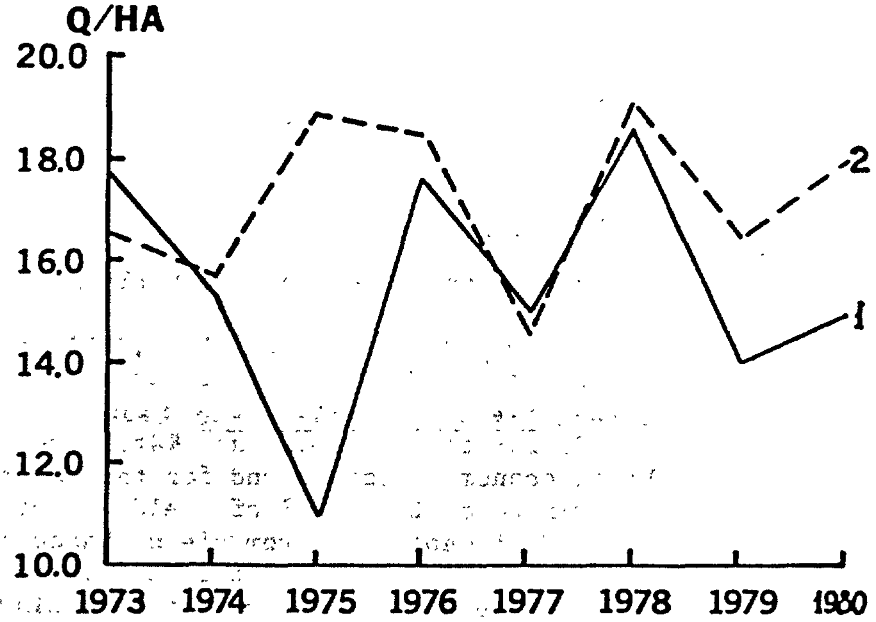


Figure 10. Cereal yield in the USSR (1-actual, 2-predicted independently).

possibility of introducing unreliable methods. Therefore, the majority of the methods developed in the Hydrometeorological Service are well documented and the procedure of releasing forecasts is very well scheduled. According to the timetable, all middle-range forecasts are issued four times a year. The first one is released at the end of March (early spring forecast) and contains an assessment of grain production for the USSR and main economic grain producing regions (Ukraine, Kazakh, Volga and North Caucasus). The second one is released at the end of May. This time the forecast gives an estimation of winter wheat yield and production for each oblast and kray,1/ and after summarizing oblast and kray production, for republics2/ and the entire USSR. The third forecast is released at the end of June. It estimates yield and production of all grain for the entire USSR, by republics and economic regions and also the production of specific crops, particularly spring wheat, barley, oats, buckwheat and millet for each oblast and kray. This forecast also corrects previously issued winter wheat forecasts. The fourth forecast is released at the end of July. It estimates corn grain yield and production and corrects previous predictions. The second, the third and the fourth forecasts are assigned to the late spring and summer forecasts.

Forecast Released in Early Spring

The method used in preparing forecast to be released in Early Spring is decribed below.

Scaling Assessment of Cereal Yield for Large Areas (author, Kogan, F. N.) This method was developed in 1975 for the Ukrainian and Kazakh republics, the North Caucasus and the Volga economic regions and for the entire USSR. It is founded on a numerical estimate of the level of yield, based on a trend in yield-series and scale estimate of departure from yield, based on actual and forecasted seasonal precipitations. The forecast is carried out for the largest grain regions. Then these data are used in forecasting for the entire USSR. Figure 11 shows yield-series, trend and the range with different scaling assessments of yield (from 2 to 5) for the main regions. Table 4 shows combinations of January-March and April-June precipitation for definition of different scaling assessments of cereal yield. In the forecast the actual precipitation is used for the first period, the forecasted precipitation is used for the second period. Forecast of seasonal precipitation is based on the synoptical method of matching seasonal analogue. It has shown satisfactory results in practice. In some years when low winter temperatures cause winterkill and large areas of damaged winter crops occurred, the scaling assessment of yield falls by one. The results of operational utilization of the method are presented

1/ Oblasts and krays are two types of elementary units of political-administrative divisions within the USSR.
2/ Republics are units of political-administrative division of the USSR sometimes containing several oblasts and krays.

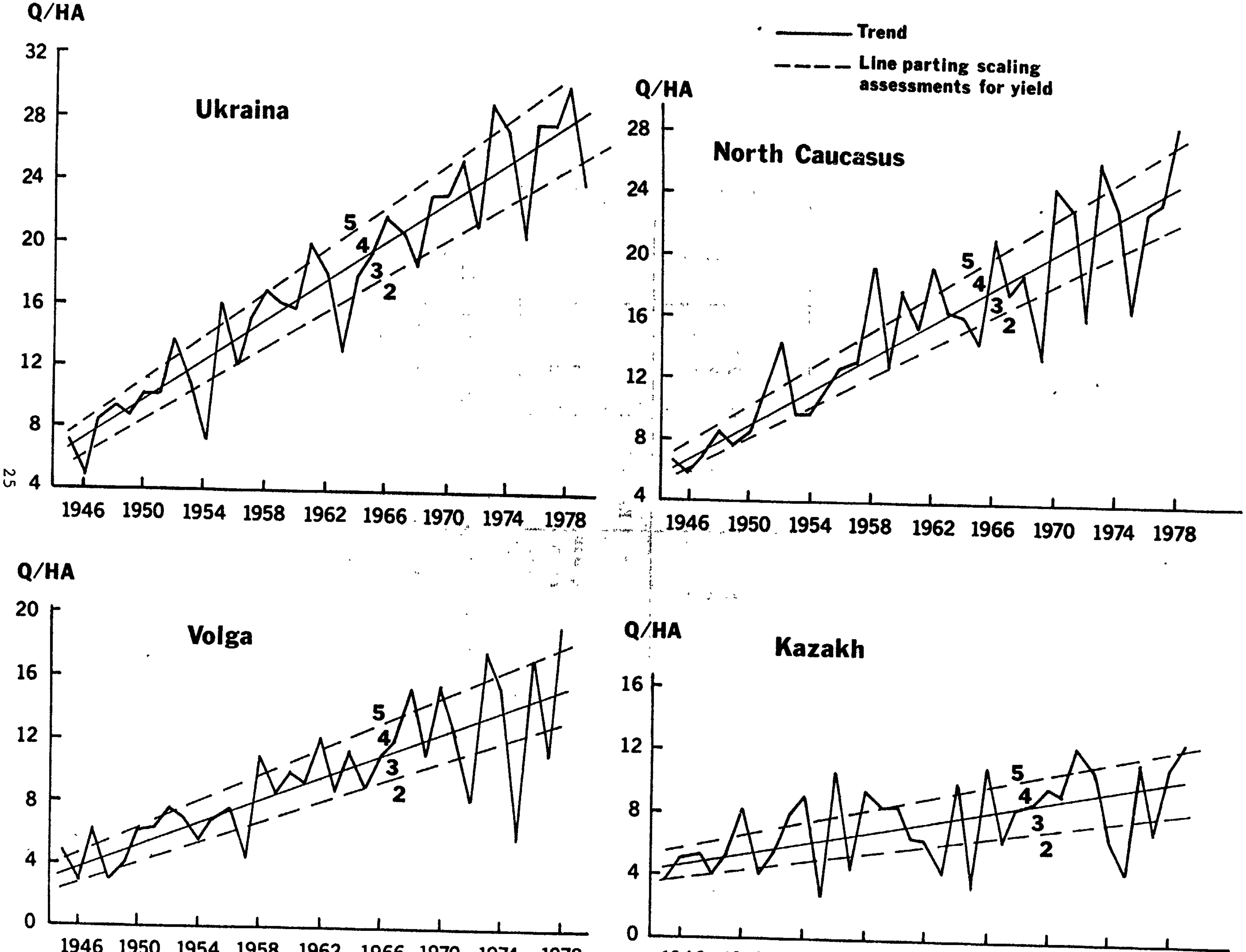


Figure 11. Cereal yield in 1945-1979 (5, 4, 3, 2 are areas with scaling assessments corresponding to excellent, good, satisfactory and bad yields, respectively).

Table 4

SCALING ASSESSMENT OF CEREAL YIELD
BASED ON PRECIPITATION

Precipitation (% from Normal) for January - March	PRECIPITATION (% from normal) FOR APRIL - JUNE					
	≥110	109-100	99-90	89-80	79-70	<70
		UKRAINA, NORTH CAUCASUS				
>110	5	5	5	4	3	2
110-100	5	4	4	3	2	2
99-95	5	4	3	3	2	2
<95	5	3	3	2	2	2
			VOLGA			
>130	5	5	4	2	2	2
130-100	5	4	3	2	2	2
<100	5	3	2	2	2	2
			KAZAKH			
>100	5	4	4	3	2	2
<100	5	4	3	2	2	2

in Table 5. The best coincidence of actual and forecasted figures was obtained for the Ukraine republic. Sixty percent of the entire coincidence was obtained for the Volga economic region. Three of the regions (Volga, N. Caucasus and Kazakh) showed entirely incorrect forecasts in one out of five years. This seems to be connected with specific distribution of precipitation which has a very important role in dry areas. Regional figures of actual yield for 1980 were not known at the time of the preparation of this report. But, preliminary assessment shows an incorrect forecast for the Ukraine and Volga which seems to be a result of excess precipitation causing crop lodging. Even with these limitations, taking into consideration the lead time of prediction (5 months in advance of harvesting) this type of forecast can be quite useful.

The Soviet Union has recently developed the method of early spring forecast for predicting spring wheat yield in Kazakh. This method is based on an anlysis of peculiarities in atmospheric circulation, particularly the circumpolar vortex, and its influence on weather formation of Kazakh area and on yield. The essence of the method is not known, but the general idea has been described in two papers [4, 5]. Using the same approach, the authors have developed a method for forecasting corn yield in the USA with lead time of prediction of 4-5 months in advance of harvest.

Table 5

SCALING FORECAST OF CEREAL YIELD
BASED ON PRECIPITATIONS
(INDEPENDENT TESTS)

REGION	YEAR	Precipitation (% from normal) for period		Yield Assessment Scaling Mark	
		JANUARY - MARCH	APRIL - JUNE	FORECAST	ACTUAL
UKRAINE	1980	167	146	5	3*
	1979	162	69	2	2
	1978	130	103	5	5
	1977	126	149	5	4
	1976	115	86	4	4
VOLGA	1980	92	147	5	3*
	1979	148	86	2	2
	1978	87		5	5
	1977	107	128	5	2
	1976	106	127	5	5
N. CAUCASUS	1980	84	124	5	4*
	1979	102	41	2	3
	1978	81	132	5	5
	1977	107	139	5	4
	1976	90	78	2	3
KAZAKH	1980	132	109	4	3*
	1979	74	92	3	5
	1978	62	107	4	4
	1977	94	52	2	3
	1976	84	77	2	5

*approximate figures

Forecasts released in Late Spring and Summer

Methods used in preparing forecasts to be released in late spring and summer are described below. This group of methods is the most numerous. For better understanding the ideas of approaches used in these types of forecasts, three groups of methods can be separated in accordance with environmental parameters used to estimate yield (Figure 12). These parameters are soil moisture, meteorological factors or combination of the two. From the agricultural standpoint, these methods use crop calendar, yield structure parameters, technological factors or a combination of the above.

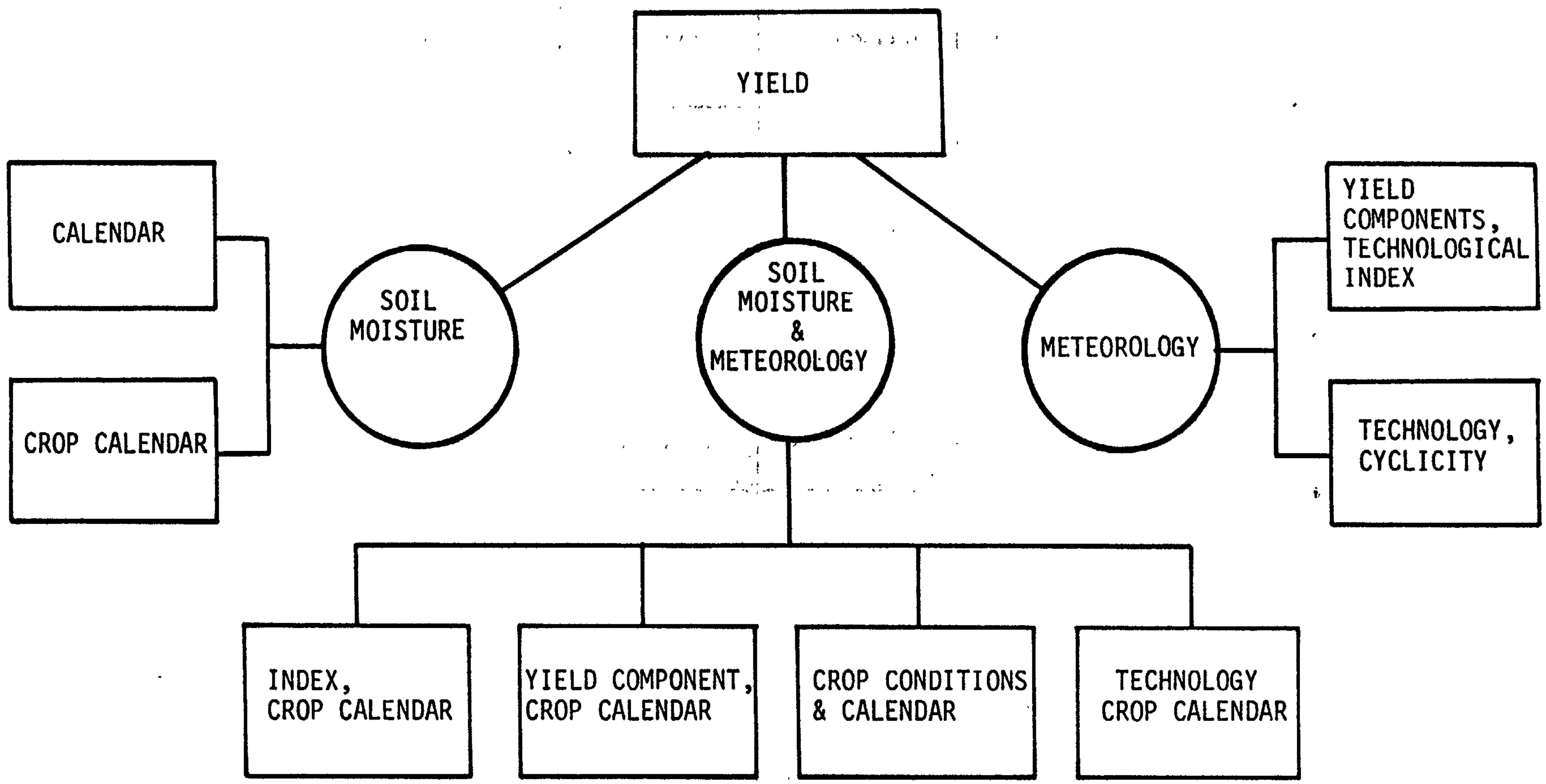


Figure 12. Classification of statistical methods for yield prediction.

The first group of methods based on soil moisture assessment are discussed below.

Method Using Crop-Calendar (author Verigo, S. A. [43]). This method was developed based on statistical analysis of data for small grain crops. It consists of three types of forecasts: available soil moisture forecast; assessment of appropriateness of available soil moisutre to crop requirements; yield forecast.

Available soil moisture forecasts were developed for two types of soil: chernozem and podzolic, and for three calendar periods: planting-shooting, shooting-flowering and flowering-dough ripeness. As it is seen in Figures 13 and 14 and in Tables 6 and 7, the change in available soil moisture is defined from initial soil moisture, total precipitation for a ten-day period and a ten-day average temperature. This change is defined by those of the diagonal lines on the graph that meet the intersection point of the vertical line for the corresponding figure of available soil moisture and the horizontal line for the corresponding figure of total ten-day period precipitation. For example, 100 cm layer of podzolic soil contains 160 mm of available soil moisture, precipitation and temperature are 55 mm and 15°C, respectively. Figure 13 Bb shows that the point from intersection of the vertical line corresponding to 160 mm of soil moisture and the horizontal line corresponding to 55 mm of ten-day period precipitation lays on the diagonal line of +10mm. This value means that soil moisture will increase by 10 mm because of precipitation (given the initial soil moisture). But this figure has to be corrected by -6mm (based on information of Table 6Ab) because of relatively high temperature. Thus, the final change of soil moisture is 10 - 6 = 4 mm and the calculated soil moisture for this particular period is 160 + 4 = 164 mm.

Based on soil moisture data the method allows us to estimate conditions of crops, using the empirical relationship shown in Tables 8-10. Yield assessment can be done based on final (scaled) estimation of crop conditions and data of Table 11. This Table contains a ratio of yield corresponding to different scaling assessments of crop conditions to maximum yield when crop conditions were excellent.

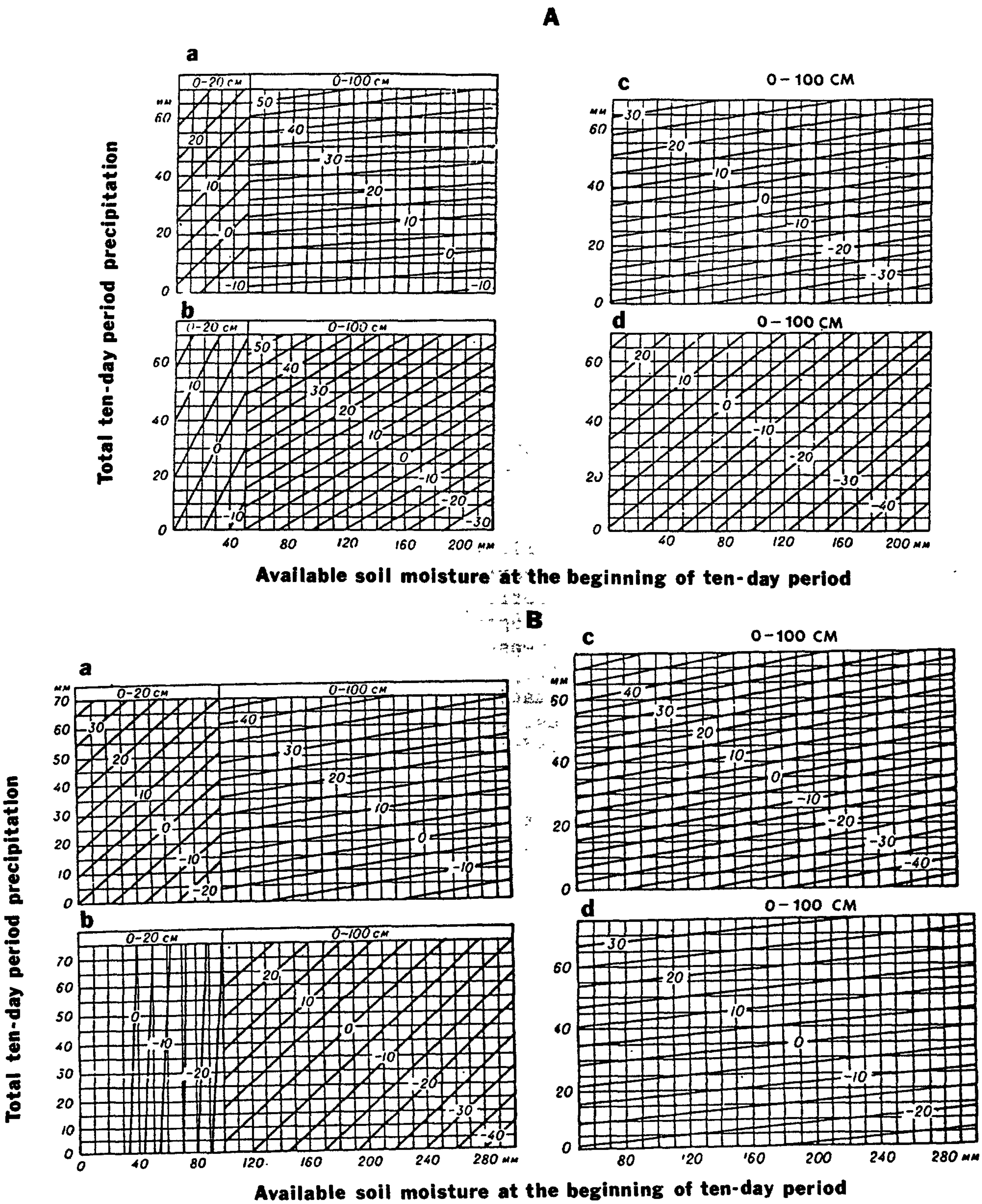


Figure 13. Change of available soil moisture (mm) over ten-day period for winter wheat in zones with chernozem (A) and podzolic (B) soils; a) fall growing season; b) spring growing season (before shooting); c) shooting-flowering; d) flowering-dough ripeness.

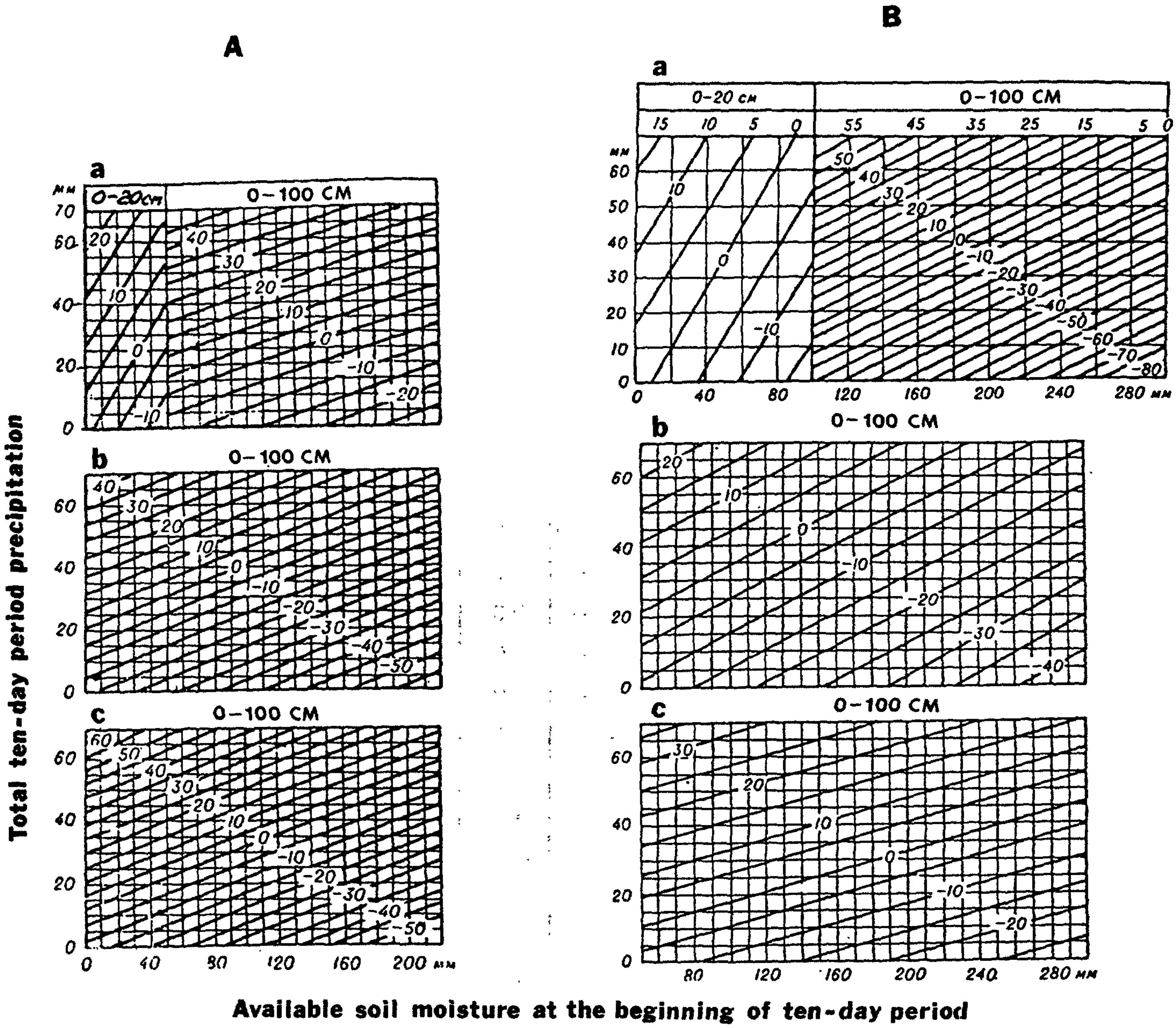


Figure 14: Change of available soil moisture (mm) over ten-day period for spring small grain crops in zones with chernozem (A) and podzolic (B) soils; a) planting-shooting; b) shooting-flowering; c) flowering-dough ripeness.

Table 6

CORRECTIONS FOR TEMPERATURE TO FIGURE 13 (MM)

Ten-Day Average Temperature of Air	A				B					
	a	b		d	a		b		c	d
	0-20 CM	0-20 CM	0-100 CM	0-100 CM	0-20 CM	0-100 CM	0-20 CM	0-100 CM	0-100 CM	0-100 CM
5	1	4	6	---	1	6	2	11	---	---
6	1	3	4	---	1	5	1	9	---	---
7	1	2	3	---	1	4	1	7	---	---
8	0	1	2	---	0	2	1	4	---	---
9	0	1	1	---	0	1	0	2	4	---
10	0	0	0	---	0	0	0	0	4	2
11	0	-1	-1	---	0	-1	0	-2	3	1
12	0	-1	-2	---	0	-2	-1	-4	2	1
13	-1	-2	-3	---	-1	-4	-1	-7	1	1
14	-1	-3	-4	---	-1	-5	-1	-9	1	0
15	-1	-4	-6	3	-1	-6	-2	-11	0	0
16	-1	---	---	3	---	---	---	---	-1	0
17	-1	---	---	2	---	---	---	---	-1	-1
18	---	---	---	1	---	---	---	---	-2	-1
19	---	---	---	1	---	---	---	---	-3	-1
20	---	---	---	0	---	---	---	---	-4	-2
21	---	---	---	1	---	---	---	---	-4	-2
22	---	---	---	1	---	---	---	---	---	-2
23	---	---	---	2	---	---	---	---	---	-2
24-25	---	---	---	3	---	---	---	---	---	-2
26-27	---	---	---	4	---	---	---	---	---	-2
28	---	---	---	5	---	---	---	---	---	-2
29-30	---	---	---	6	---	---	---	---	---	-2

Table 7

CORRECTIONS FOR TEMPERATURE TO FIGURE 14 (MM)

Ten-Day Average Temperature of Air	A			B			
	a		c	a		b	c
	0-20 CM	0-100 CM	0-100 CM	0-20 CM	0-100 CM	0-100 CM	0-100 CM
5	0	1	---	3	2	---	---
6	0	1	---	2	2	---	---
7	0	1	---	2	1	---	---
8	0	0	---	1	1	---	---
9	0	0	---	1	0	---	---
10	0	0	---	0	0	8	5
11	0	0	---	-1	0	6	4
12	0	0	---	-1	-1	5	3
13	0	-1	---	-2	-1	3	2
14	0	-1	---	-2	-2	2	1
15	0	-1	9	-3	-2	0	0
16	-1	-2	7	-3	-2	-2	-1
17	-1	-2	5	---	---	-3	-2
18	-1	-2	3	---	---	-5	-3
19	-1	-2	2	---	---	-6	-4
20	---	---	0	---	---	-8	-5
21	---	---	-2	---	---	---	---
22	---	---	-3	---	---	---	---
23	---	---	-5	---	---	---	---
24	---	---	-7	---	---	---	---
25	---	---	-9	---	---	---	---
26-27	---	---	---	---	---	---	---

Table 8

AVERAGE SCALING ASSESSMENT OF EMERGENCE STAGE
BASED ON AMOUNT OF AVAILABLE SOIL MOISTURE IN TOP 0-20 CM

Soil	Available Soil Moisture (MM)												
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-50	51-60	61-70	71-80	>80
Chernozem	---	2.0	2.8	3.1	3.4	3.6	3.8	4.0	4.0	---	---	---	---
Podzolic	1.4	1.4	3.0	3.6	3.9	3.6	3.5	3.4	3.3	3.2	3.1	3.0	3.0

Table 9

CHANGES IN SCALING ASSESSMENT BASED ON TABLE 8 CONNECTED
WITH SOIL MOISTURE (TOP 0-20 CM) CONDITIONS IN TILLERING PERIOD

Available Soil Moisture (MM)								
1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-50
-1.0	-0.5	-0.3	-0.2	0	0	+0.2	+0.5	+0.5

Table 10

CORRECTIONS FOR FINAL SCALING ASSESSMENT OF CROP CONDITIONS
BASED ON SOIL MOISTURE (0-100 CM) IN FLOWERING PERIOD

Available Soil Moisture (MM)										
1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161-180	181-200	>200
0.87	0.92	0.95	0.96	1.03	1.05	1.06	1.15	1.02	1.06	1.00

Table 11

RATIO OF YIELD TO MAXIMUM YIELD AND FINAL CROP CONDITION ASSESSMENT (FCCA)

FCCA	1	2	3	4	5
Ratio	0.0	0.15	0.50	0.75	1.00

The method also makes it possible to assess yield based on available soil moisture in the period of heading and flowering (Table 12).

Table 12

RELATIONSHIP BETWEEN RATIO OF YIELD TO MAXIMUM YIELD AND AVAILABLE SOIL MOISTURE IN THE PERIOD OF HEADING AND FLOWERING

Available Soil Moisture (MM)	1-25	26-50	51-75	76-100	101-125	126-150	≥150
Ratio	0.18	0.46	0.70	0.86	1.00	0.74	0.68

<u>Method Using Ten-Day Calendar</u> (author Kulik, M. S. [27]). This method can be applied to assessment of spring small grain crops productivity. Based on statistical analysis of data the author found the percentage of yield decrease depended on soil moisture conditions. He distinguished two types of soil moisture conditions: dry, when available moisture in the top 20 cm of soil is no more than 10 mm, and semidry, when moisture is no more than 20 mm. Every ten-day period with conditions like those causes some percentage of yield losses. The figures of these losses are in Table 13.

Final estimating of yield can be done by using the following equation:

$$Y = Y_{max} - \sum_{i=1}^{n} Y_{max} \Pi_i \qquad (3)$$

where Y, Y_{max} are actual yield and maximum yield (Q/HA) respectively; Π is adjustment for decrease of yield; i is number of ten day period.

The second group of methods based on assessment of both soil moisture and meteorological factors are discussed next.

Table 13

PERCENTAGE OF LOSSES IN YIELD IN DRY AND SEMIDRY PERIODS

No.	Vegetative period, Divided Into Ten-Day Intervals	Dry Intervals (<10 mm in the Plowed Layer)	Semidry Intervals (<20 mm in the Plowed Layer)
1	10th-20th day...	5	---
2	20th-30th day...	10	5
3	30th-40th day...	30	20
4	40th-50th day...	20	15
5	50th-60th day...	10	5
6	60th-70th day...	5	5
7	70th-80th day...	5	---
8	80th-90th day...	5	---

There are several theoretical approaches on which these type of methods are based: approaches using weather indexes and approaches using crop condition assessment. There are many indexes which are used in agricultural meteorology and agricultural climatology for crop assessment conditions and productivity. Two of them were used for development of method of grain forecasting. They are the index of water availability for crops and the transpiration coefficient index. The background for development of the index of water availability for crops were set up by Alpat'ev [7, 8] and later on developed by Protserov, A. V. [35]. They introduced the index of water availability in the form:

$$V = \frac{I}{D} \qquad (4)$$

where I, D are water income and discharge (mm) respectively. Water income is defined in the form of the simplified water budget equation:

$$I = W_1 - W_2 + P \qquad (5)$$

where W_1, W_2 are available soil moisture (mm) at the beginning and at the end of some period, respectively; P is total precipitation (mm) during this period. Water discharge is defined as following:

$$D = K * d \qquad (6)$$

where d is the total saturation deficit of air (mm) in the period between two consecutive stages of crop development and K is a coefficient which determines the potential possibility of crop to transpirate water during a specific stage of crop development.

The methods described below are based on the water availability index.

Spring Wheat Yield Assessment for Kazakh Republic (author Protserov, A. V. [35]). This method specifies the following general form of equation.

$$y = a_0 + \sum_{i=1}^{n} b_i V_k$$

The specific form of the equation is:

$$y = 0 + 0.39V_. + 0.29V_2 + 0.52V_3 + 0.30V_4 + 0.25V_5 +$$

$$0.07V_6 + 0.06V_7 + 0.06V_8 \qquad (7)$$

where y is spring wheat yield (Q/HA); $V_1 - V_8$ are indexes of water availability (%) for eight ten-day vegetative periods, beginning from planting.

Spring Wheat Yield Assessment for Western Siberia and North Kazakh (author Kirilicheva, K. V. [18]). This method specifies estimation of yield based on the index in general form, like those which follow.

$$y = a_0 + b \sum_{i=1}^{n} V_i$$

and

$$V_i = \frac{W_1 - W_2 + P}{K_. \Sigma d_i + K_2 \Sigma d_i} .100,$$

where $K_1 = 0.45$ is used over period of planting-heading; $K_2 = 0.30$ is used over period of heading-dough ripeness. Specific forms for estimating yield as the season progresses are:

$$y_1 - 0.24V_1 - 2.0 \qquad (8)$$

$$y_2 = 0.25V_2 - 4.8 \qquad (9)$$

Equation (8) is used at the end of the planting-shooting period while (9) is used after the shooting-heading period.

Spring Wheat Yield Assessment for Northern Kazakh (authors Razumova, L. A., Meschaninova, N. B. [36]). Based on index of water availability for crops, the authors obtained the equation for calculating spring wheat yield. The equation is:

$$Y = -7.4 + 0.017V_1 + 0.127V_2 + 0.147V_3 \quad (10)$$

where V_1, V_2, V_3 are indexes of water availability during periods of (1) planting-shooting, (2) Shooting-heading and (3) heading-dough ripeness; y is yield (Q/HA).

Spring Wheat Yield Assessment (author Kontorschikov, A. S. [26]). This method uses the transpiration coefficient index that was developed in the late 1950's. An estimation of yield is based on assessment of ratio of water actually used by crop to optimal or average requirements of the crop for water. The equation is:

$$RAY = \frac{TR}{K_{TR}} \quad (11)$$

where RAY is relative assessment of yield; TR is actual transpiration of crop (mm); K_{TR} is usually estimated from experiments or from statistical data. Transpiration of crop can be estimated by the equation

$$TR = ET - E \quad (12)$$

where ET is evapotranspiration; E is evaporation from the soil surface. ET is a function of W, P and T; E is in turn a function of ET and K; W is soil moisture (mm); P is precipitation (mm); T is temperature (^{o}C); and K is a coefficient, depending on the crop stage.

Evapotranspiration is usually estimated based on Figure 15 for each ten-day period. The figure shows the correlation between evapotranspiration and three parameters: available soil moisture, precipitation and temperature for three periods of crop development. Based on Figure 15 and the equation

$$E = K_i * ET \quad (13)$$

it is possible to estimate the evaporation from soil. The coefficient K_i in the equation (13) was determined in the experiments when crop had optimal water supply. For the period of emergence-shooting the coefficient (K_1) is equal 0.72; for the shooting-flowering $K_2 = 0.17$ and after the flowering $K_3 = 0.32$. The difference between evapotranspiration and evaporation (ET-E) estimates transpiration from the crop itself. Comparison of estimated transpiration with transpiration of crop when water supply is optimal determines the numerical assessment of crop conditions and as a results the assessment of its productivity.

Method Using Yield Component Assessment and Crop Calendar (author Ponamareow, B.P). [41]). This method has been developed for spring wheat grown in the European Territory of the USSR (mainly central and eastern part). It is based on well known expression for yield assessment as a function of number of stems per unit area (S), number of grains in the ear (G) and weight of 1000 grains (A). The equation is

$$y = S * G * A \quad (14)$$

Using regression analysis, the author of the method found equations for calculating the number of grain in the ear and weight of 1000 grains for

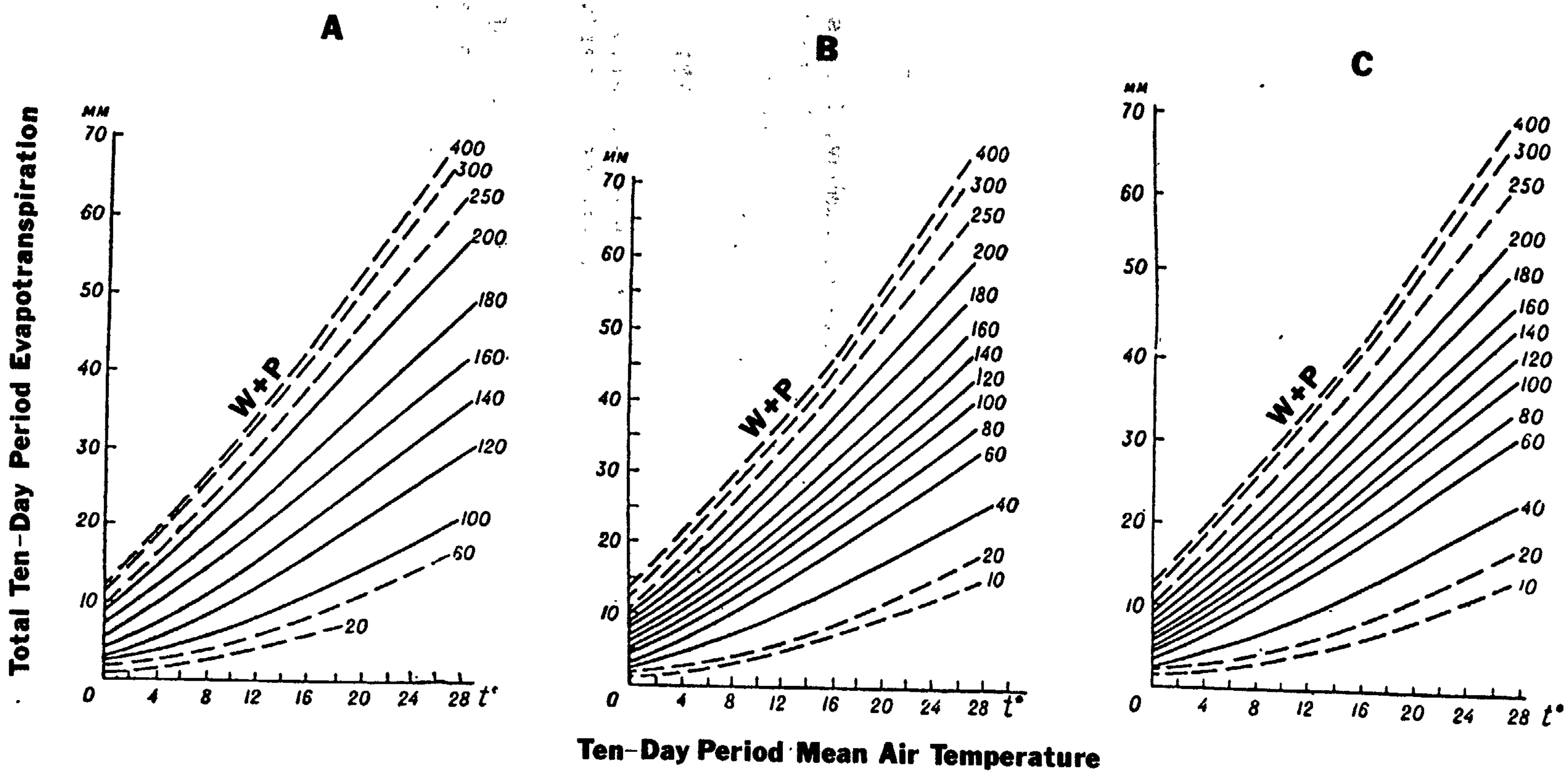


Figure 15. Graph for computation of evapotranspiration from spring wheat in the periods of emergence-shooting (A), shooting-flowering (B), after flowering (C); W is available soil moisture (mm); P is precipitation (mm).

spring wheat. The equations allow assessments to be made based on conditions of crop growth.

$$G = 2.46K + 0.05W - 14.9 \quad (15)$$

$$A = 0.04V - 1.04T + 2.46G + 42.7 \quad (16)$$

where K is quantity of spikelets in the ear; W is available soil moisture (mm) in 1 meter depth layer; V is the index of water availability over the period of filling grain; T is mean air temperature over the same period.

Winter Wheat Yield Assessment for the Chernozem Zone (author Ulanova, E. S. [41]). The methods can be applied to varities of winter wheat "Bezostaya 1" and "Mironovskaya 808." The author of the method represented two equations for different areas. For Krasnodar and Stavropol Kray, Severo-Osetin autonomous republic, Moldavian republic, Ukranian republic (excluding Zgitomir and Chernigov oblast) and Kursk oblast the equation is:

$$y = -21.14 + 0.31W - 7 \cdot 10^{-4} W^2 + 0.023S - 8 \cdot 10^{-6} S^2 \quad (17)$$

For Volgograd, Saratov, Kuybyshev, Voronezh, Belgorod, Tambov, Lipetsk, Penza oblast the equation is:

$$y = -21.12 + 0.33W - 8 \cdot 10^{-4} W^2 + 0.023S - 8 \cdot 10^{-6} S^2 \quad (18)$$

where W is available soil moisture (mm) in 1 m. depth layer in early spring period; S is the numberof stems of winter wheat per square meter early in spring; y is yield (Q/HA).

Another method developed by the same author is based on assessment of soil moisture and conditions of winter wheat crop [41]. These conditions are estimated visually from aircraft in early spring period. These equations are

$$y = 2.8 + 0.13W + 0.12C_1 + 0.03C_2 \quad (19)$$

for the Moldavian and the Ukrainian republics and the North Caucasus region and

$$y = -4.39 + 0.07W + 0.18C_1 + 0.12C_2 \quad (20)$$

for Lower and Middle Volga, and Southern and Eastern parts of the Central Chernozem Zone (the second group of regions). In these equations C is the percentage of examined fields which have excellent and good (C_1) and satisfactory (C_2) crop conditions. Equations (17)-(20) predict winter wheat yield with lead time of three months in advance of harvest.

Equations similar to those in (17) and (18) were developed by the same author for winter wheat yield prediction in the period after winter wheat shooting (21, (22), (23), and after heading (24), (25).

$$y = -35.75 + 0.55W_1 - 17.0W_1^2 + 0.03S - 9\cdot 10^{-6}S^2 \quad (21)$$

$$y = -11.32 + 0.3W_1 - 8\cdot 10^{-4}W_1^2 + 0.014S - 4.10^{-6}S^2 \quad (22)$$

$$y = -13.0 + 0.2W_1 - 4\cdot 10^{-4}W_1^2 + 0.02S - 7\cdot 10^{-6}S^2 \quad (23)$$

$$y = -19.92 + 29\cdot 10^{-2}W_2 - 13\cdot 10^{-4}W_2^2 + 45\cdot 10^{-3}S - 3\cdot 10^{-5}S^2 + 23\cdot 10^{-2}H - 14\cdot 10^{-5}H^2 - 805\cdot 10^{-3}K + 57\cdot 10^{-3}K^2 \quad (24)$$

$$y = 14.237 + 245\cdot 10^{-3}W - 39\cdot 10^{-5}W^2 + 96\cdot 10^{-4}S + 1\cdot 10^{-6}S^2 + 29\cdot 10^{-3}P_5 + 3\cdot 10^{-4}P_5^2 - 59\cdot 10^{-3}P_6 + 5\cdot 10^{-4}P_6^2 \quad (25)$$

where W, W_1, W_2 are available soil moisture (mm) within 1 m. depth layer at the beginning of growing season, at shooting and at heading, respectively; S is quantity of stems per square meter; H is height of crop; K is quantity of spikelets in the ear; P_5, P_6 is total amount of precipitation in May and June, respectively.

Equation (21) can be applied to the first group of regions, (22)--to the second and (23)--to the following oblasts: Belgorod, Voronezh, Tamboz, Lipetsk, Penza, Ul'yanovsk, Kuybyshev, Saratov, Volgograd. The lead time for these equations is two months before harvest. The lead time for equation (24) and (25) which can be applied to any chernozem zone oblast, is one month before harvest.

Corn Yield Assessment (author Chirkov, Y. I. [11]). The method is based on assessment of the most important factors which influence corn productivity. These factors are soil moisture, temperature, number of cloudy days and total leaf area. First, the the yield is calculated based on Figure 16, which represents the correlation between yield and two parameters: soil moisture and leaf area during the period of tasseling. Then, the resulting figure is corrected in accordance with temperature and soil moisture conditions, conditions of cloudiness and existing leaf area after tasseling, based on data in Tables 14 and 15.

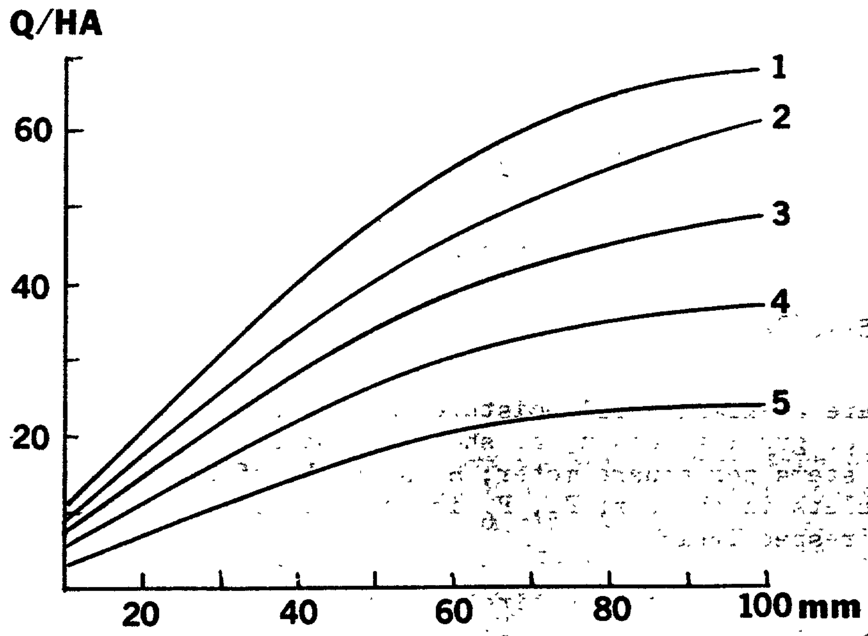


Figure 16. Correlation between corn yield, available soil moisture (mm) and leaf area (thousand sq. m. per ha) in the period of tasseling; line 1 corresponds to leaf area 30 thousand sq. m/ha; 2-25; 3-20; 4-15; 5-10.

Table 14

COEFFICIENTS FOR CORN YIELD CORRECTION BASED ON TEMPERATURE AND SOIL MOISTURE CONDITIONS IN THE PERIOD AFTER TASSELING

Available Soil Moisture (mm)	Monthly Mean Temperature of Air (°C)				
	16-17	18-19	20-21	22-23	23-24
100	0.68	0.86	0.97	1.00	0.98
80	0.72	0.88	0.99	1.00	0.97
60	0.78	0.90	1.00	1.00	0.95
40	0.84	0.93	1.00	0.96	0.90
20	0.94	1.00	0.96	0.90	0.80

Table 15

COEFFICIENT FOR CORN YIELD CORRECTION BASED ON NUMBER OF CLOUDY DAYS AND LEAF AREA

Number of Cloudy Days	Leaf Area (Thousand Sq. M Per Hectare)				
	10	15	20	25	30
0-3	1.09	1.06	1.04	1.02	1.00
4-6	1.02	1.00	0.99	0.98	0.97
7-9	0.97	0.96	0.96	0.95	0.94
10-12	0.94	0.93	0.92	0.91	0.90

For calculating leaf area the author of the method defined the following equation:

$$LA = \frac{(39.9H - 1632.8)D}{10^5} \tag{26}$$

where LA is leaf area (thousand sq. m); D is number of plants per one hectare; H is height of crop (cm).

There are two methods belonging to the type which uses technological factors and crop calendar as predictors.

Winter Wheat Yield Assessment (author Kulik, M. S.[23]). The author presents two equations for predicting winter wheat yield in the Non-Chernozem zone of the USSR. The first equation can be applied in the fall, after dormancy has set in.

$$y_1 = y_a + 0.115\ (F_n * N_n - F_a * N_{1_a}) - 3.607\ (F_n - N_{1_n}) \tag{27}$$

where y_1 is forecasted yield in fall (Q/HA); y is yield of analogous year (Q/HA); F is amount of fertilizer (Q/HA); N_1 is duration of a period with the air temperature below 15°C but above 5°C; n denotes the forecasted year; a denotes an analogous year.

The second equation can be applied from the beginning of the growing season in spring.

$$y_2 = y_1[1 - 0.01(0.47D + 6.5)] + 0.15(N_{2_n} - N_{2_a}) - (YD_n - YD_a) \tag{28}$$

In the equation y_2 is forecasted yield in spring (Q/HA); D is density of crop in spring or number of stems per hectare; N_2 is duration of a period with air temperature above 5°C but below 10°C; YD is decreasing of yield because of runoff in spring. Unfortunately, literature was not available which would describe the way such parameters as analogous year or decreasing of yield were defined.

Barley Yield Assessment (authors Polevoy, A. N., Mizina, T. I. [34]). This method was developed for evaluating barley yield in the Non-Chernozem zone. The actual yield is estimated from the relationship

$$y/y_{max} = -42\cdot10^{-4}T_1 - 77\cdot10^{-4}T_2 + 8\cdot10^{-4}W_1 + 31\cdot10^{-4}W_2 + 15\cdot10^{-4}H + 0.5878 \tag{29}$$

where y, y_{max} are barley yield (Q/HA) predicted and maximum, respectively; T_1, T_2 are mean temperature (°C) of air over periods emergence-shooting (1) and shooting-heading (2); W_1, W_2 are mean available soil moisture (mm) in the top 20 cm of soil over periods 1 and 2; H is mean height of barley crop. Maximum yield represents some theoretical maximum level for particular climatic and technological conditions of a region. It can be defined by using the Goombol's [12] method. The lead time of yield prediction using this method is about one month.

The third group of methods based on assessment of only meteorological factors are summarized below.

Method Using Yield Components and Technological Index (author Dmitrenko, V. P. [12, 13]). This method is based on assessment of indexes of weather productivity and crop conditions, and also on assessment of the maximum geographical yield as a potential index of technology. The equation presenting the general idea follows below:

$$y = y' \cdot C \cdot \frac{m(T)}{M(T_0)} \cdot \frac{m(P)}{M(P_0)} \qquad (30)$$

where y, y' present yield and the maximum geographical yield (Q/HA), respectively; C is expressed in form:

$$C = (1 - p)\ [1 - (\frac{K-K_0}{K_0})^2] \qquad (31)$$

where p is the density of plant population in spring; it can be calculated as a ratio $\frac{A_w}{A}$, where A_w is the area with winterkill or other damage to crops after winter and A is the whole area of crop; K, K_0 are actual and optimal amount of stems per one plant, respectively; m(T,P) is a parameter for assessment of the weather productivity for crop. In the author's terminology, the weather productivity is a ratio of actual to optimal weather parameter. Thus, the temperature productivity index is expressed in form:

$$\frac{m(T)}{M(T_0)} = e^{-a(\frac{T-T_0}{10})^2} \qquad (32)$$

where T is the actual temperature (°C); T_0 is the optimal temperature (°C) for the highest crop productivity; and a is an empirical parameter.

The precipitation productivity index is expressed in form:

$$\frac{m(P)}{M(P_0)} = (1 + \frac{P-P_0}{P_0-P_{min}})^{a_1} \cdot (1 - \frac{P-P_0}{P_{max}-P_0})^{a_2} \qquad (33)$$

where P, P_0, P_{min}, P_{max} are actual optimal, minimal and maximal precipitations, respectively (mm); a_1, a_2 are empirical parameters.

Thus, as it is seen from equations (30)-(33), the idea of the method is to define the proportionate reduction in the maximum geographical yield when actual parameters of weather and conditions of crop differ from optimal ones. The greater the difference between these parameters the greater is the difference between the maximum geographical yield and actual yield. In the ideal case of optimal weather and crop conditions, when $A_w = 0$, $K = K_0$, $T = T_0$ and $P = P_0$ then in accordance with equations (31)-(33)

$$C = \frac{m(T)}{M(T_0)} = \frac{m(P)}{M(P_0)} = 1$$

and the actual yield will be equal to the maximum geographical yield. If weather and crop conditions are not optimal and $A_w > 0$, $K < K_0$, $T \gtrless T_0$ and $P \gtrless P_0$ then

$$C < 1, \frac{m(T)}{M(T_0)} < 1 \text{ and } \frac{m(P)}{M(P_0)} < 1$$

In a case like this the actual yield will be less than the maximum geographical yield $(y < y^1)$. Based on historical weather and yield data the author of the method carried out evaluation of optimal weather variables for every month of the year (Table 16) and for interphase periods of winter wheat, spring barley and corn (Table 17) [13].

Method Using Technology and Cyclicity Assessment (author Kogan, F. N. [23]). The idea of the method consists of the well known procedure of expanding a yield-series into two components: deterministic and random

$$y = \hat{y}(\tau) + \varepsilon_\tau \qquad (34)$$

where y is actual yield; $\hat{y}(\tau)$ is the evaluated yield (trend) when time (τ) is accepted as a variable; ε_τ is the error or random component and can be expressed in different forms: $y - \hat{y}$ or $y/\hat{y}$. The trend can be expressed in linear or non-linear form. And in every particular case the decision should be made based on a thorough examination of climatic and economic conditions of the area. In the case of the cereal yield-series of the USSR, the trend is expressed in linear form. The random component or yield (variation) is expressed as the ratio $y/\hat{y}$. This component, as it has been proved, depends on weather variation [22, 23]. Precipitation and temperature were chosen as principle weather parameters for assessment of the variation of yield around the trend.

$$\varepsilon_\tau = F(t, p) \qquad (35)$$

where t and p are temperature and precipitation, respectively. To take into account the time of influence of weather without a substantial decrease in the degrees of freedom in regression models, weather variables of separate months were combined into so called index-variables. The calculation of index-variables was carried out in accordance with proportionality and direction of influence of weather of separate months on yield. Thus, using the index-variables, the equation (35) can be written in the form:

$$\varepsilon_\tau = a_o + \sum_{k=1}^{M} a_k T_k + \sum_{p=1}^{N} a_p P_p \qquad (36)$$

where a are the regression coefficients and T, P are index-temperature and index-precipitation , respectively. Equations (37), (38) express the correlation between index-variables and variables of separate months.

Table 16

OPTIMAL MEAN MONTHLY AIR TEMPERATURE (T_0, ^oC) AND OPTIMAL MONTHLY SUM OF PRECIPITATION (R_0, mm)

Month	Winter Wheat		Spring Barley		CORN					
					pre-forest		forest-steppe		steppe	
	T_0	P_0	T_0	P_0	T_0	P_0	T_0	P_0	T_0	P_0
I	-4,5	50								
II	-2,6	60								
III	2,2	70	2,4	40						
IV	8,6	60	5,4	60	8,0	30	8,0	36	10,5	50
V	13,4	40	10,0	120	13,0	60	13,0	64	15,0	80
VI	17,0	17	18,0	90	17,0	80	17,0	80	18,8	90
VII	22,0	4(65)*	22,0	>15	18,5	100	18,5	100	19,5	90
VIII	--	65			17,0	110	16,0	70	18,0	60
IX	14,8	70			11,5	<10	12,5	<10	13,5	40
X	10,7	100								
XI	5,0	120								
XII	2,0	50								

$$T_k = \sum_{i=1}^{m} \left[\frac{R_i^2}{\sum_{i=1}^{m} R_i^2} t_{ki} \right] \quad (37)$$

$$P_s = \sum_{j=1}^{n} \left[\frac{R_j^2}{\sum_{j=1}^{n} R_j^2} p_{sj} \right] \quad (38)$$

Here t, p are mean monthly temperature (^oC) and total monthly precipitation (mm), respectively; R is the correlation coefficient between temperature or precipitation and ε_τ; i, j define the number of calendar months; k, s define the number of index-periods.

The first group of methods based on soil moisture assessment are discussed below.

Method Using Crop-Calendar (author Verigo, S. A. [43]). This method was developed based on statistical analysis of data for small grain crops. It consists of three types of forecasts: available soil moisture forecast; assessment of appropriateness of available soil moisutre to crop requirements; yield forecast.

Available soil moisture forecasts were developed for two types of soil: chernozem and podzolic, and for three calendar periods: planting-shooting, shooting-flowering and flowering-dough ripeness. As it is seen in Figures 13 and 14 and in Tables 6 and 7, the change in available soil moisture is defined from initial soil moisture, total precipitation for a ten-day period and a ten-day average temperature. This change is defined by those of the diagonal lines on the graph that meet the intersection point of the vertical line for the corresponding figure of available soil moisture and the horizontal line for the corresponding figure of total ten-day period precipitation. For example, 100 cm layer of podzolic soil contains 160 mm of available soil moisture, precipitation and temperature are 55 mm and 15°C, respectively. Figure 13 Bb shows that the point from intersection of the vertical line corresponding to 160 mm of soil moisture and the horizontal line corresponding to 55 mm of ten-day period precipitation lays on the diagonal line of +10mm. This value means that soil moisture will increase by 10 mm because of precipitation (given the initial soil moisture). But this figure has to be corrected by -6mm (based on information of Table 6Ab) because of relatively high temperature. Thus, the final change of soil moisture is 10 - 6 = 4 mm and the calculated soil moisture for this particular period is 160 + 4 = 164 mm.

Based on soil moisture data the method allows us to estimate conditions of crops, using the empirical relationship shown in Tables 8-10. Yield assessment can be done based on final (scaled) estimation of crop conditions and data of Table 11. This Table contains a ratio of yield corresponding to different scaling assessments of crop conditions to maximum yield when crop conditions were excellent.

This method allows us to estimate the influence of technology on yield in the form of trend, the influence of weather in growing and pre-growing seasons and also weather in previous year, which reflects the two year cyclicity in atmospheric and biological processes mentioned above.

To calculate average yield of cereals for the USSR the following equations can be applied:

$$y = \frac{y_{TR} \quad \varepsilon_{TR}}{100} \tag{39}$$

$$y_{TR} = 4.31 + 0.368\tau \tag{40}$$

$$\varepsilon_{TR} = 6.87P_1 - 0.084P_1^2 + 9.76P_2 - 0.127P_2^2 - 1.80T_1 + 143.62T_2 - 4.57T_2^2 + 149.47T_3 \; 4.842T_3^2 + K \tag{41}$$

$$P_1 = 0.55p_5 + 0.098p_6 + 0.353p_7$$

$$P_2 = 0.138p_{13} + 0.116p_{14} + 0.113p_{15} + 0.194p_{16} + 0.187p_{17} + 0.252p_{18} \tag{42}$$

$$T_1 = 0.313t_3 + 0.687t_{10}$$

$$T_2 = 0.391t_6 + 0.356t_8 + 0.254t_{16}$$

$$T_3 = 0.461t_{17} + 0.539t_{18} \tag{43}$$

Here y is yield (Q/HA); y_{TR} is yield from trend (Q/HA); τ is time expressed in the form τ = YR - 1945, where YR is the year of yield definition; ε_{TR} is the departure of yield from trend (%); P, T are the index-precipitation (mm) and the index-temperature (°C), respectively; p, t are total monthly precipitations (mm) and mean monthly temperatures (°C), respectively, K is constant. All months are enumerated in order from January of the last year, which has the number 1, up to August of the present year, which has the number 20.

The correlation coefficient for equation (41) is 0.83 and the error of definition of ε_{τ} is 9%. The lead time of cereal yield prediction for equations (40) - (43) is three months in advance of harvest. To make a prediction with a lead time of two or one month in advance of harvest, the next groups of equations can be used:

For a lead time of two months (prediction at the end of July)

$$\varepsilon_\tau = 7.76P_1 - 0.092P_1^2 + 6.90P_2 - 0.080P_2^2 - 1.37T_1 + 138.21T_2 - 4.38T_2^2 + 340.81T_3 - 10.26T_3^2 + K \quad (44)$$

$$P_1 = 0.55p_5 + 0.098p_6 + 0.353p_7$$

$$P_2 = 0.127p_{13} + 0.107p_{14} + 0.104p_{15} = 0.179p_{16} + 0.173p_{17} + 0.233p_{18} + 0.075p_{19} \quad (45)$$

$$T_1 = 0.313t_3 + 0.687t_{10}$$

$$T_2 = 0.391t_6 = 0.356t_8 + 0.254t_{16}$$

$$T_3 = 0.333t_{17} + 0.389t_{18} + 0.278t_{19} \quad (46)$$

For a lead time of one month (prediction at the end of August)

$$\varepsilon_\tau = 8.25P_1 - 0.098P_1^2 + 11.93P_2 - 0.140P_2^2 - 1.023T_1 + 164.91T_2 - 5.266T_2^2 + 359.53T_3 - 10.767T_3^2 + K \quad (47)$$

$$P_1 = 0.55p_5 + 0.098p_6 + 0.353p_7$$

$$P_2 = 0.112p_{13} + 0.094p_{14} + 0.092p_{15} = 0.158p_{16} + 0.152p_{17} + 0.205p_{18} + 0.066p_{19} + 0.122p_{20} \quad (48)$$

$$T_1 = 0.313t_3 + 0.687t_{10}$$

$$T_2 = 0.391t_6 + 0.356t_8 + 0.254t_{16}$$

$$T_3 = 0.333t_{17} + 0.389t_{18} + 0.278t_{19} \quad (49)$$

Correlation coefficient and errors for equations (44) are 0.90 and 8%, and for equation (47) are 0.92 and 7%.

Figure 17 shows the variation of actual and independently predicted production based on equations (40) - (43) with a lead time of 3 months before harvest. Results of the independent tests are in fairly good agreement with actual grain production in the USSR in the period of 1972-1980. Only in 1974 and 1975 the error of ε_τ definition was higher than the estimated error for the equation (41).

Consideration for Using Models

All of the models presented above are statistically well-founded. And all of them were or are used in practice for prediction of grain production in the USSR. Our task is to single out models which could be used in the future for estimation of the USSR grain production. To do this it is necessary to itemize some characteristics for the assessment of the suitability of methods. These characteristics are:

- Availability of information for prediction
- Reliability of a model.
- Accuracy of a model.
- Lead time of prediction
- Simplicity in use of a model
- Consistency of a model with scientific knowledge.

From the point of view of the availability of information for prediction it is impossible to use models in which prediction is based on the actual soil moisture, or indexes including soil moisture or on crop calendar, or yield components as this type of information is not available. Only models which use precipitation and temperature as predictors (equation 36) can be utilized effectively because the World Meteorological Organization provides regular and timely flow of this information. Among other factors the broad spectrum of weather situations is a very important requirement for obtaining reliable and accurate regression models. The longer the series of observations with different weather situations for the same location, the higher the reliability and accuracy of models. Unfortunately, the development of almost all models has been founded on the opposite principle of the collecting historical data that is a series of only 5-10 years of weather observations aggregated from different locations were combined and each sample was treated as an independent sample. These models can not be very reliable or accurate as the estimated regression coefficients have inflated values. The three models based on cyclicity, scaling assessment of yield and on equation (36) are exceptions in that since a series of approximately 30 years of actually independent observations were used for their development.

Lead time of prediction is a very important characteristic. To forecast production of crops well in advance of harvest is very useful for making timely decisions relative to prospective supply of the crop. Most of the methods presented have a lead time of prediction of only one month,

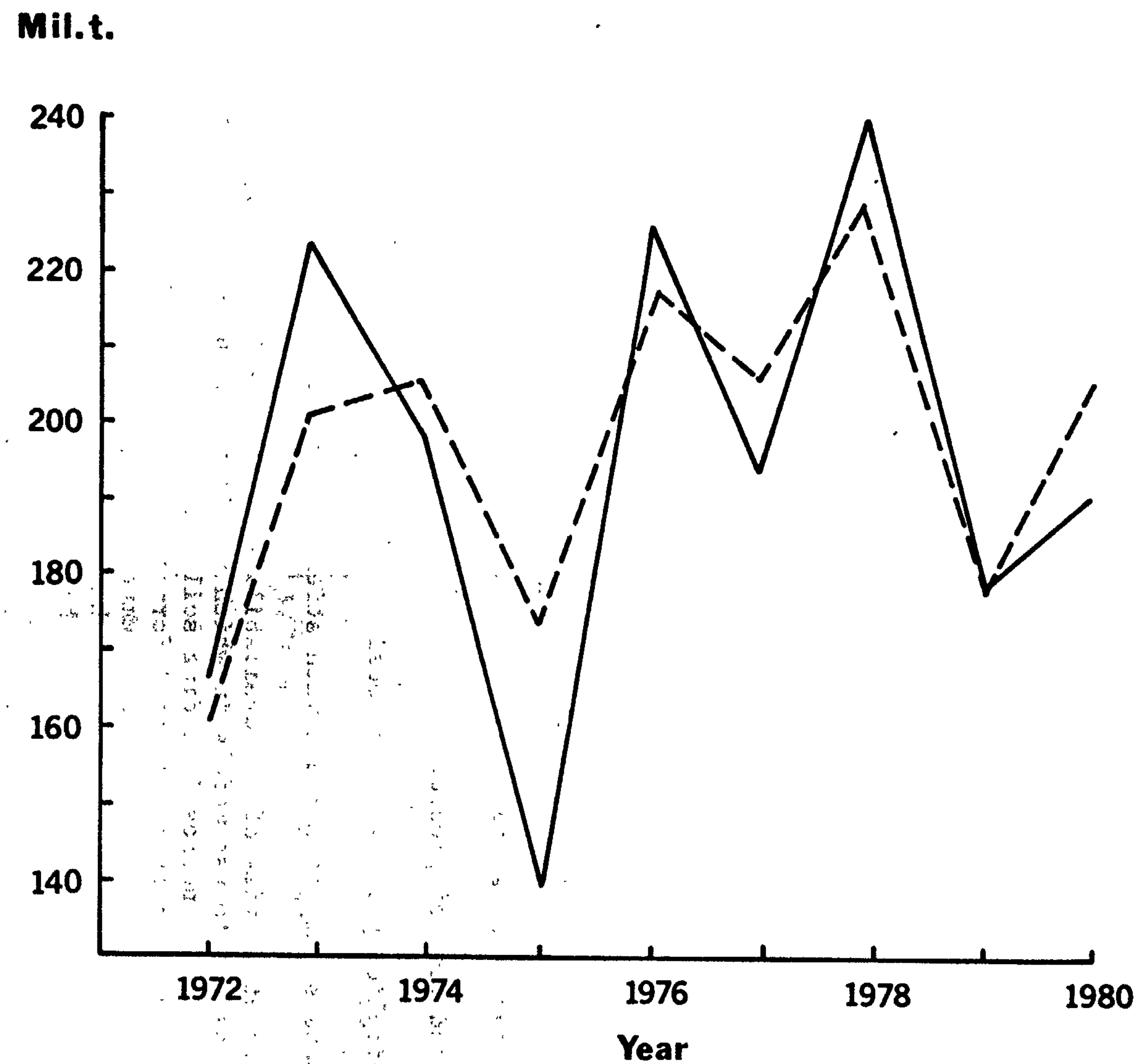


Figure 17. Production of grain in the USSR actual (1) and predicted (2), based on the equations 40-43 (independent test).

in as far as they require use of weather information up to heading. The lead time of prediction for equations (8), (19) - (23), (44) - (46) is approximately two months. And equations (17), (18) and (41) - (43) have the longest lead time of prediction, three months in advance of harvest among models used for middle-range forecasts.

Almost all regression methods presented here are very simple to use. The exceptions can be related to methods expressed by equations (27), (28), and (30). At the same time, some of the methods are very difficult to use, in so far as they specify use of such parameters as maximal or optimal geographical yield or optimal (minimal, maximal) precipitation and temperature which are variable and then it is necessary to have a long-series of observations.

Concerning the consistency of methods with scientific knowledge, it is possible to state that in general all methods presented meet this requirement when weather influences productivity estimates. But at the same time we should emphasize a very important disadvantage of the majority of these models. They ignore technological factors. Only some of them take into consideration individual characteristics of technology. Thus, models presented by equations (17) - (25) were developed for two new varieties of winter wheat and presented by equations (27) - (28) take into consideration amount of fertilizer used.

Models (14), (29), and (30)estimate technology using invented indexes of crop productivity provided that growing conditions were optimal. Only models presented by equations (40) - (49) take into account technological factors expressed in a general form (trend).

Thus, all things considered, we can state that only the method presented by models (40) - (49) meets all requirements and this method can be used directly for prediction of the USSR grain production without any significant changes in the equations.

Physical-Mathematical Models (Physiological)

Over the past 10-15 years improvement of the knowledge of the "plant-soil-atmosphere" system has made it possible to create physical-mathematical models. The models are based on biological modeling of the most important vital processes of plants such as photosynthesis, respiration, mineral nutrition, water demand, and also modeling the processes of energy-and momentum-exchange in the plant-soil-atmosphere medium. These models have some advantages over regression models in allowing one to better understand the mechanism of processes in the plant-soil-atmosphere system, and governing the environment to obtain higher productivity of crops at the field scale. But they also have disadvantages because of their complexity and parameterization problems makes it difficult to use them especially for large-scale predictions.

The authors have simplified [39] the huge and very complicated model, like that shown in Figure 18 [38], for practical use and to bring the results obtained by the model to some reality.

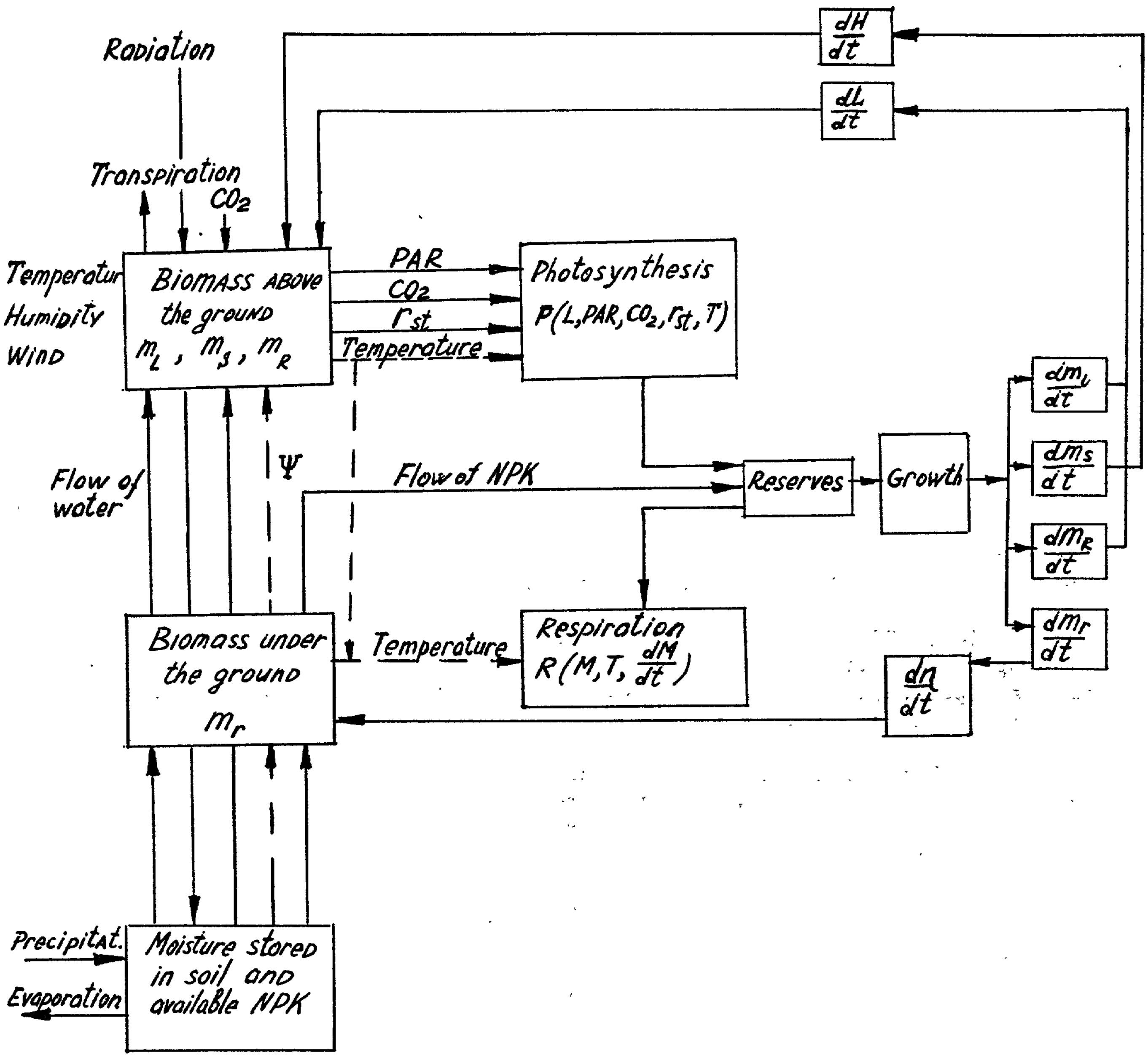


Figure 18. Scheme of the dynamic model of the agro system; t is water potential; r_{st} is stomatal resistance; H is height of agro system; L is leaf area index; n is density of roots length (cm/cm^3); M_L, M_S, M_r, M_R are weight of dry matter of leaves, stalks, roots and fruits, respectively; $M = M_L + M_S + M_r + M_R$; T is temperature; t is time.

The model is based on a system of difference equations, which are following.

$$m_p^{j+1} = m_p^j + \frac{a_p^j \varepsilon}{1+R_R} \Phi j - \frac{1}{1+R_R} \qquad ({}_\tau^i R_0 + \beta_p^i) m_p \text{ for } 1,\ s,\ r$$

$$W_j^{j+1} = W_i^j - TR_i^j - \sigma_i E^j + q_{i-1}^i - q_i^i \quad {}_\tau^i R_0 m_c^i - \sum_{p\varepsilon 1,s,r} \beta_p^i m_p^j \text{ for } c$$

$$h^{j+1} = h^j + \frac{0.1E^j}{\Theta_{mfc} - \Theta_{mh}} \tag{50}$$

where $p\varepsilon 1$, s, r, c; and $i \varepsilon 1$, 2, 3, 4.

$$\Phi^j = \frac{\tau^j \psi_T^j L^j}{2(r^j - r_c)} [CO_2 + a\bar{I}^j r^j - \sqrt{(a\bar{I}^j r^j - CO_2)^2 + 4r_c \bar{I}^j CO_2})]$$

Here j is the number of the time step (of the day); i is the number of the soil layer; 1, s, r, and c are the leaf, stalk, root, and ear subscripts, respectively; w_1^j are the amounts of stored moisture; TR_1^j are the amounts of moisture transpired; σ is a logic variable ($\sigma_i = 1$ if i = 1 and σ = 0 otherwise); q_{i-1}^j, q_i^j are the moisture fluxes across the upper and lower boundaries of the i-th soil layer, respectively; h^j is the depth of the absorbing layer; E^j is the evaporation from the surface of the soil; τ is the length of the day; L^j is the area of the photosynthesizing phytomass; $\bar{I}^j$ is the daily average total radiation; ψ_T^j is the temperature coefficient of the total photosynthesis Φ^j; r is the diffusion resistance on the path of the carbon dioxide, which depends on the soil moisture pressure; Θ_{mfc} and Θ_{mh} are the minimum field moisture capacity and the maximum hygrocapacity of a unit volume of soil, α_p^j; and β_p^j are biological functions; R_0, R_R, α, and r_c are constants; and CO_2 is the carbon dioxide concentration. In addition to equations (50) it is necessary to use many other equations enumerated in [1] for calculating such parameters as evaporation from the surface of the soil, evapotranspiration of crop, total area of green part of crop, parameters connected with the sun elevation and many other parameters. And sometimes it is necessary to use special approaches and experimental information for the identification of many parameters of the model that does not improve the accuracy of the model. Unfortunately, this simplified model, like many other models of this type can not predict yield of crop directly. The model computes biomass of crop and based on this computation estimates conditions of year in comparison with normal conditions [39].

The simplified physical-mathematical model, presented here, has many weaknesses for use. For example, values necessary to start the model, such as the actual initial information about the beginning weight of dry matter, the moisture stored in soil by layers, and the agrohydrological constants of soil, are not available. Also, it is difficult to accurately estimate the values of the 15-20 parameters which are required as input to the model.

Even if this large number of parameters has been identified accurately, the performance of the model is not improved because of the difficulties in estimating the parameters. The model does not reflect technological influence on crop productivity. It is not simple to identify technology parameters and use them in a model for prediction. The performance of the model for large-scale assessment and prediction of crop productivity is not known.

IV. SOME PERSPECTIVES IN PRODUCTION OF GRAIN

As it was seen from previous discussion, the amount of grain produced in the USSR does not meet Soviet requirements for grain. Now, the question naturally arises about the perspectives in these discrepancies. Will the gap between production of grain and requirements become wider or closer with the time? The question itself is very complicated and goes into the field of long-range predictions.

It is clear that future requirements for grain in the USSR will continue to increase. This is connected with further development of Soviet economy, growth of population, international Soviet policy and others. It is also clear (from the tendency of grain production increase) that the USSR grain production will gradually increase in the near future. To predict the rate of this increase is a very difficult task. Even so, some direct or indirect projections can be done based on historical agricultural and meteorological data.

Analyses of Resources for Increasing Production

From 1945 through the mid-1960's, grain production in the USSR increased in two different ways. One way improves the effectiveness of agriculture by using advanced technology. The other one, which is economically less effective, involves increasing production by means of increasing planted area.

Figure 19 shows the dynamics in area under cereal in the USSR. As ~~it is~~ seen, from 1945 to 1964 the area of grain crops in the USSR increased by 1.5 times from 85 million hectares to 130 million hectares. The most dramatic increase in the area happened in the well known period of plowing the virgin lands (1954-1959). During this period the rate of increase of grain production in the USSR was higher than the rate of yield increase. And it happened only due to increase of the area under grain crops. In the late 1950's and the early 1960's the rate of increase of the area slowed down. After 1964 there was a tendency in the USSR to improve effectiveness of used land in agriculture. That is why the area under grain crops during that period decreased a little. But after the drought of 1972 the Soviet Government made a decision to increase the area with grain crops to its maximum for increasing grain production in the country; and agriculturalists increased the area in production by using all reserved lands. During the latest seven years, the grain crop area did not increase. This was because nearly all the reserve of wasted lands suitable for effective growth of grain was exhausted. The only additional source of land would come from the improvements of lands in the Non-Chernozem Zone of the RSFSR. But this source will have only a limited impact on the total grain production of the USSR.

Thus, there is only one effective way to increase grain production in the USSR, namely improving the technology for producing grain. Analysis of the yield-series for different regions of the USSR showed that the improvements of technology doubled, tripled and in some regions increased yields of cereal crops by four or five times over a thirty year period. The greatest increases in yields occurred in the Chernozem Zone. This is natural since

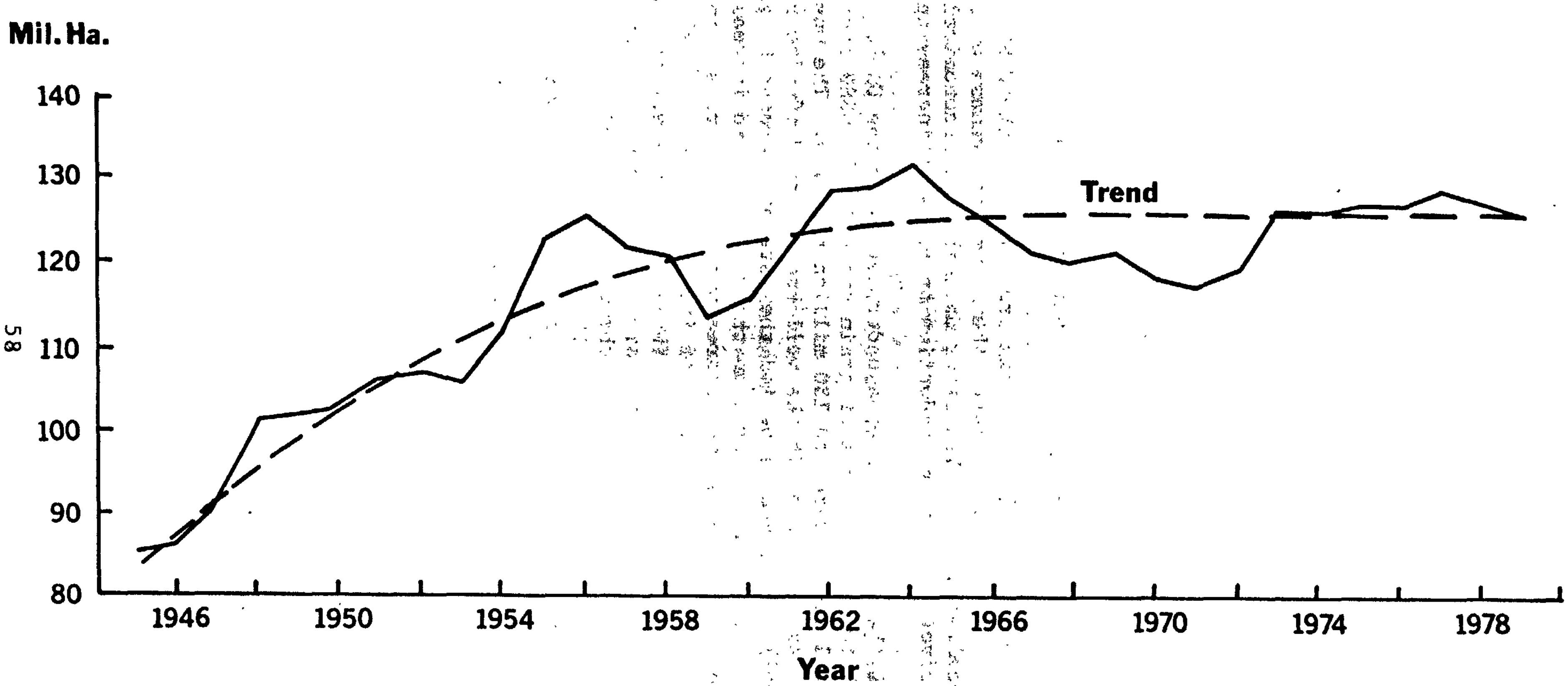


Figure 19. Total area of grain crops in the USSR.

the Chernozem Zone, as shown in part two of this report, is the area with the best natural and economic resources in the USSR. The lowest increases in yields occurred in most regions of Asiatic territory of the USSR, although even these increases doubled the beginning level of yield in the regions. Now, the reasonable question to ask is, what future yield increases due to technological improvements should be expected?

Some judgments can be made out of the calculated growth of the rate in yield increase or the acceleration of yield increase, expressed by the quadratic coefficient in the polynomial equation of the trend in yield-series. Analysis of this acceleration in the period of 1945-1975 (Table 18) show that 37% of regions which produced approximately 47% of the total USSR grain production have the negative acceleration in yield increase. This means that natural conditions of these regions have begun to be not fully compatible with the type of existing technology. The most important fact is that such a deceleration in the rate of yield growth has taken place in regions located in the most productive geographical area of the USSR, the Chernozem Zone. Other regions of this Zone, having better natural water supply, especially South-West still have an accelerated rate of yield growth, but the magnitude of these accelerations is very small. The only area which has an appreciable magnitude in the acceleration of the rate of yield growth is the Non-Chernozem Zone.

Over the past 20 years improvements of technology in the Non-Chernozem Zone of the USSR have dramatically changed the productivity of grain crops there. During this period, farmers applied advanced technology for growing grain crops. And this technology, in cooperation with existing natural resources, had a very large effect on grain production (Figure 20). The rate of cereal yield grown there in this period was even higher than for the Ukraine republic, well known as the best area for agriculture in the USSR.

And it should be recognized that natural resources of the Non-Chernozem Zone have not been exhausted yet for obtaining higher productivity of grain crops. Figures 21 and 22 confirm this statement. Cereal yields in Moscow oblast (Figure 21) and Leningrad oblast (Figure 22) are much higher than in Tula and Vologda oblasts, respectively. The last two have natural conditions for grain growth which are not worse, and in some very important characteristics even better, than do the Moscow and Leningrad oblasts, respectively. These great differences in yield are connected with the differences in technology applied for producing grain in these oblasts. Agriculturalists of Moscow and Leningrad oblasts applied higher technology to grow grain crops than their co-workers from other oblasts of the same economic regions. Maybe against a background of the Soviet society with planned industry and agriculture it looks strange that the distribution of technology is not fair for regions with equal opportunities. But it is true that the communist party leader of Moscow oblast and the communist party leader of Leningrad oblast, belonging to the group of the highest rank of communist party leaders of the USSR, provide better technological supply to their regions to show the great achievements of these regions in agriculture. This is a striking instance of influence of the political factor on agriculture of the USSR, as mentioned previously.

Table 18

RELATIVE CEREAL YIELD GROWTH (PERCENTAGE TO THE BEGINNING LEVEL, Y) AND ACCELERATION OF THE RATE OF YIELD GROWTH DUE TO IMPROVEMENT OF TECHNOLOGY IN 1945-1975

Geographic Area	Name of Region	Y	A	Percentage of Cereal Production From the USSR Production in 1978
Chernozem Zone	Moldavia	502	-0.0003	1.5
	South	467	-0.001	4.4
	North Caucasus	293	-0.004	10.6
	Lower Volga	322	-0.003	7.4
	Donets-Dnepr	281	0.001	9.1
	South-West	290	0.011	7.8
	Central Chernozem	448	0.002	5.4
	Middle Volga	291	0.003	8.1
Non-Chernozem Zone	Central	215	0.018	4.7
	Belorussia	199	0.044	3.1
	Baltic	198	0.048	2.2
	North-West	124	0.020	0.4
	Volga-Vyatka	161	0.012	2.6
Asiatic Part of the USSR	Ural	162	0.002	6.8
	Kazakh	90	-0.003	11.8
	West Siberia	145	-0.002	8.2
	East Siberia	111	-0.010	2.3
	Middle Azia	187	0.011	1.9
	Far East	112	0.004	0.7

Thus, the Non-Chernozem Zone has good potential natural resources to increase grain production in response to additional technological investments.

That is why seven years ago the Central Committee of the CPSU and the USSR Council of Ministers had the resolution "On Measures for the Continued Agricultural Development of the Non-Chernozem Zone of the RSFSR." The main reason for this is the substantial increase of agriculture production and particularly grain production based on improvement of the lands and the whole agricultural system of this area. It was an entirely reasonable decision. The only question which can appear is why this Resolution concerns only the Non-Chernozem Zone of the RSFSR but not the whole Non-Chernozem Zone of the USSR. At any rate, six years have passed since the Resolution has been adopted. And now some results received from the improvements can be analyzed and discussed from the point of view of the utilization of natural resources of the Zone to increase its grain production and to satisfy requirements of the USSR for grain. During the period that has passed since the Resolution

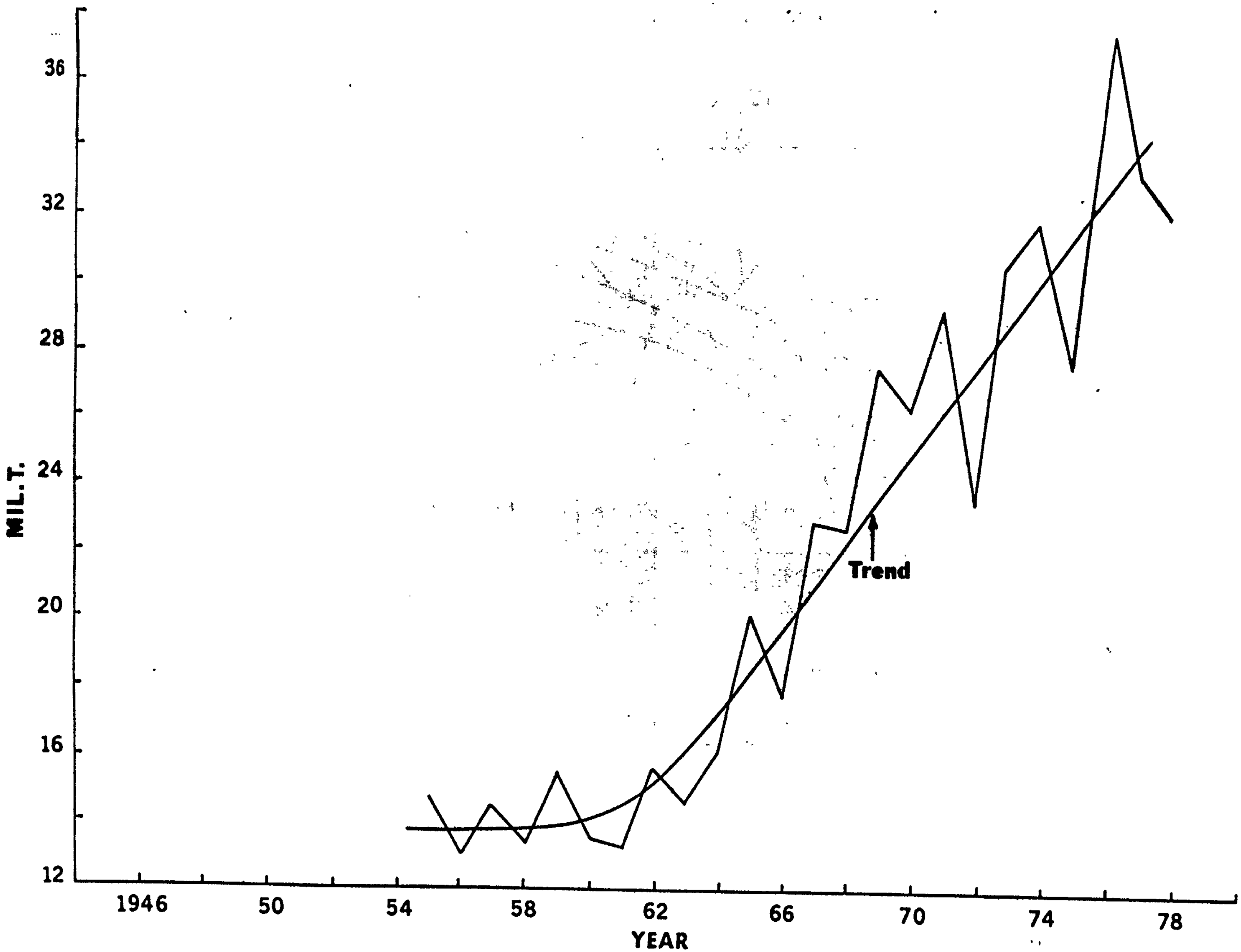


Figure 20. Total grain production in the Non-Chernozem Zone of the USSR.

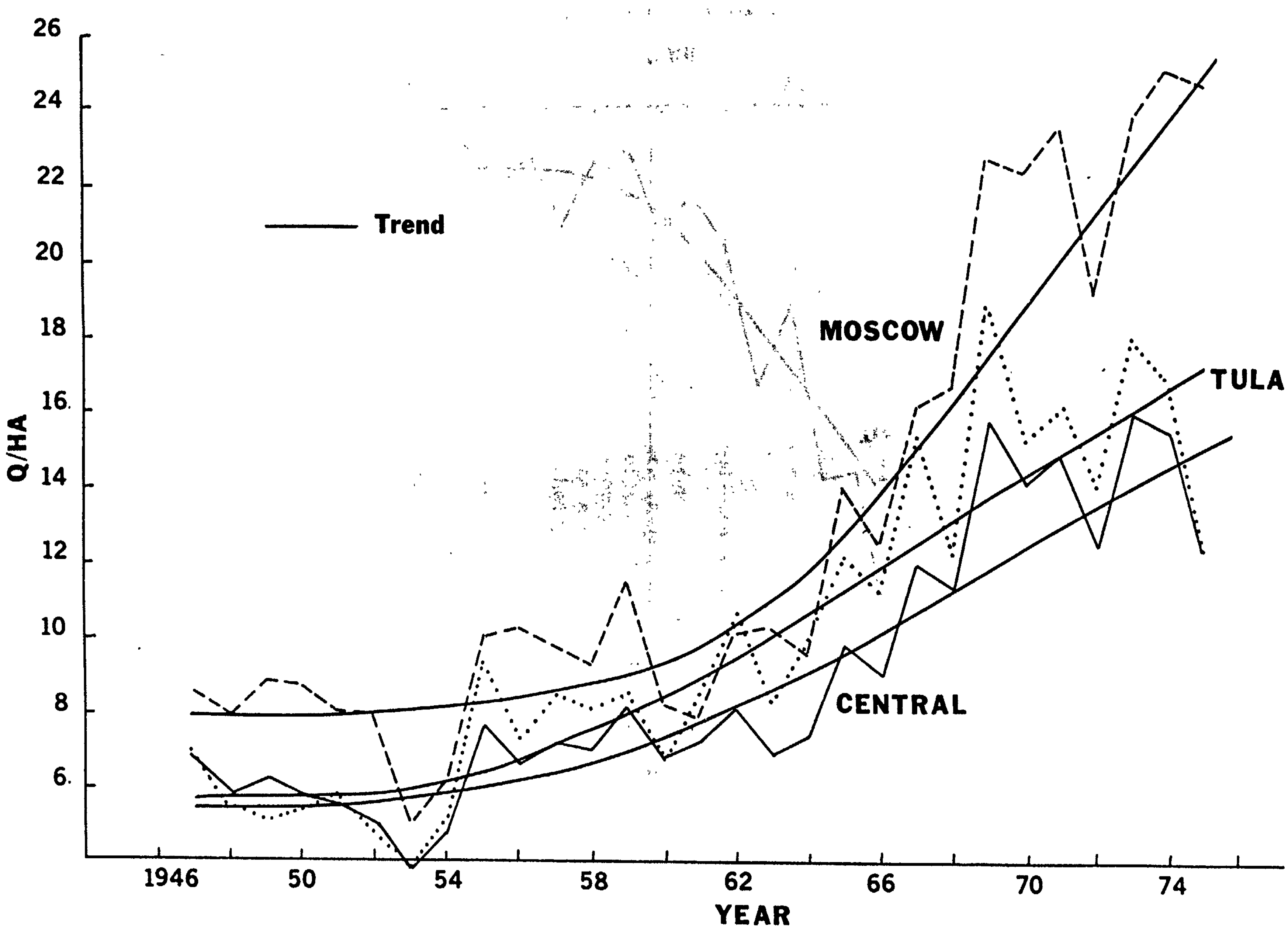


Figure 21. Cereal yield in central region, Moscow and Tula oblasts.

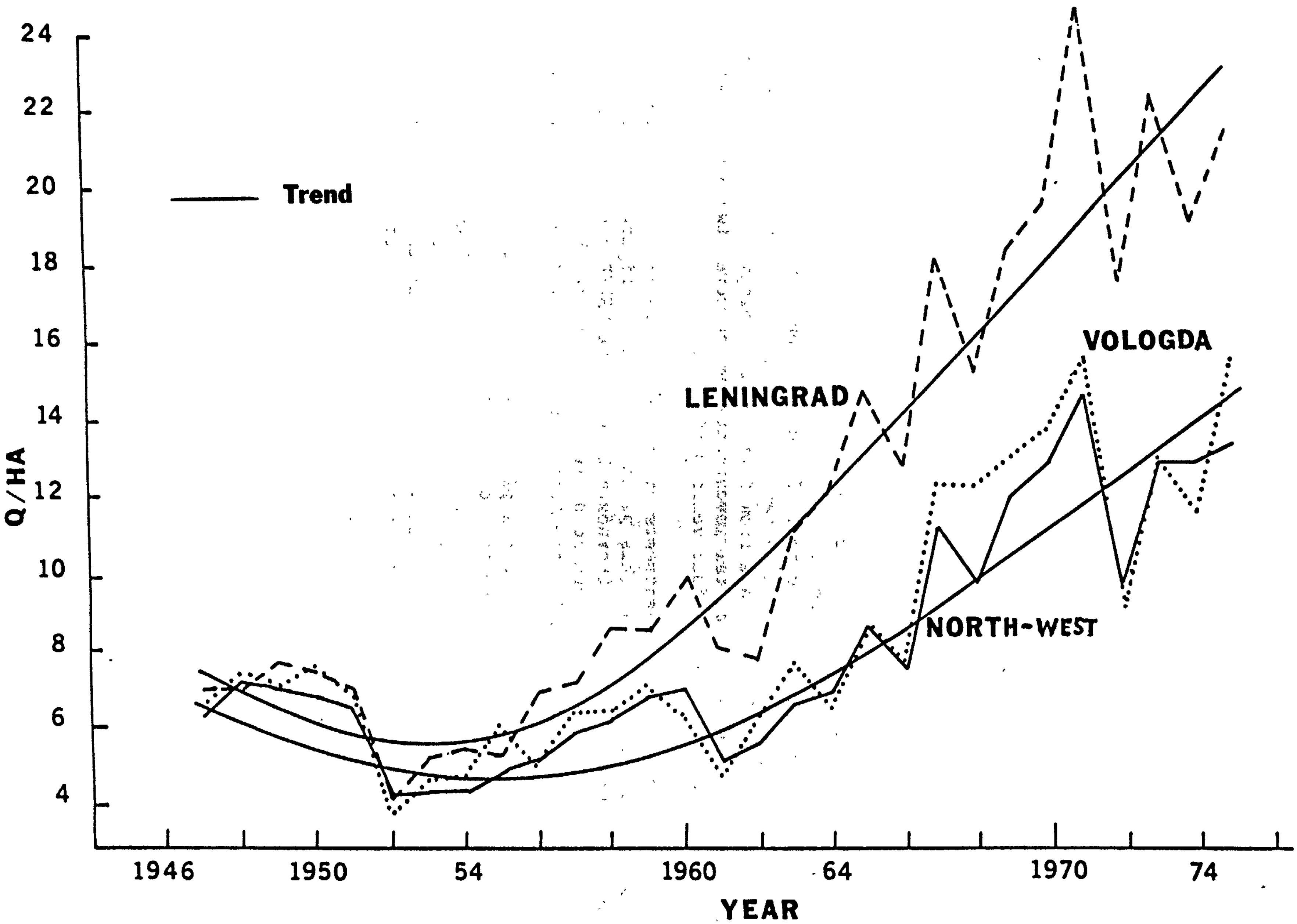


Figure 22. Cereal yield in North-West region, Leningrad and Vologda oblasts.

(from 1975 to 1978) great investments have been made for the accelerated development of the Non-Chernozem Zone. According to the Soviet literature [6], the enterprises of the Zone have been supplied with 265,600 tractors, 60,000 grain-harvesting combines, 160,300 trucks and 64.3 million tons of mineral fertilizers. At the same time drainage and irrigation systems were put into operation on an area of 1,148,000 hectares which is 20 percent more than in 1971-1974. In addition, cultivation operations were performed on 1,709,000 hectares that did not require drainage. And as a result of these things, as stated in the Soviet literature [6], the average annual grain production in the Non-Chernozem Zone of the RSFSR increased by 25 percent. A thorough investigation shows that approximately 11 percent of grain production increase (out of 25 percent) was connected with better weather conditions during this period. The previous period (1971-1975) had two years (1972, 1975) with very unfavorable dry conditions which is a very rare pheonmenon for this area. If those two years had been excluded from the estimation of the average annual grain production of this period, then the annual grain production in 1976-1978 would have exceeded the grain production of the previous period with equivalent weather conditions by only 14 percent, not the 25 percent as claimed in the Soviet literature. A part of this 14 percent increase in grain production occurred as a result of 5 percent increase in the area with grain crops. Therefore, approximately only 9 percent of grain production increase can be explained by the application of improved technology. The increase from improved technology is seen to be not as great as the increase in capital investments, which were "twofold higher as compared with the preceding four years period" [6].

This sharp increase of the investments did not significantly increase the trend of cereal yield growth in this period. As seen in Figure 23, the rate of trend growth in the Non-Chernozem Zone of the RSFSR beginning from the early 1970's was very slow and no differences exist in this rate between the two periods: before bringing the Resolution into action and afterward.

The highest rate of increase of cereal yield was in the 1960's when there was a wide gap between the application of technology and the existing natural resources in the Zone. Later on, after the advanced technology was introduced into practice for growing grain crops in the Zone, the gap narrowed. And now for the substantial increase of cereal yield tendency only the two fold increase of the capital investments is not enough. The investments must be several times higher. Going away from the economical side of the problem of producing grain in the Non-Chernozem Zone of the RSFSR, and taking into account only the total additional amount of grain produced by this area for the purpose of closing the gap between requirements of the USSR for grain and its production the following should be noted. Twenty-five percent of annual increase of grain production obtained recently [6] is only 4-5 million tons of additional grain. This amount totals only 2 percent from the average USSR grain production. And, of course, this amount can <u>not</u> cover 50 million tons of the annual shortage of grain in the country. And finally, it should not be overlooked that the quality of grain produced in the Non-Chernozem Zone is significantly worse than the quality of grain produced in the Chernozem Zone. On the whole it is impossible to consider the Non-Chernozem Zone of the RSFSR as an effective source for solving the problem of grain shortage in the USSR.

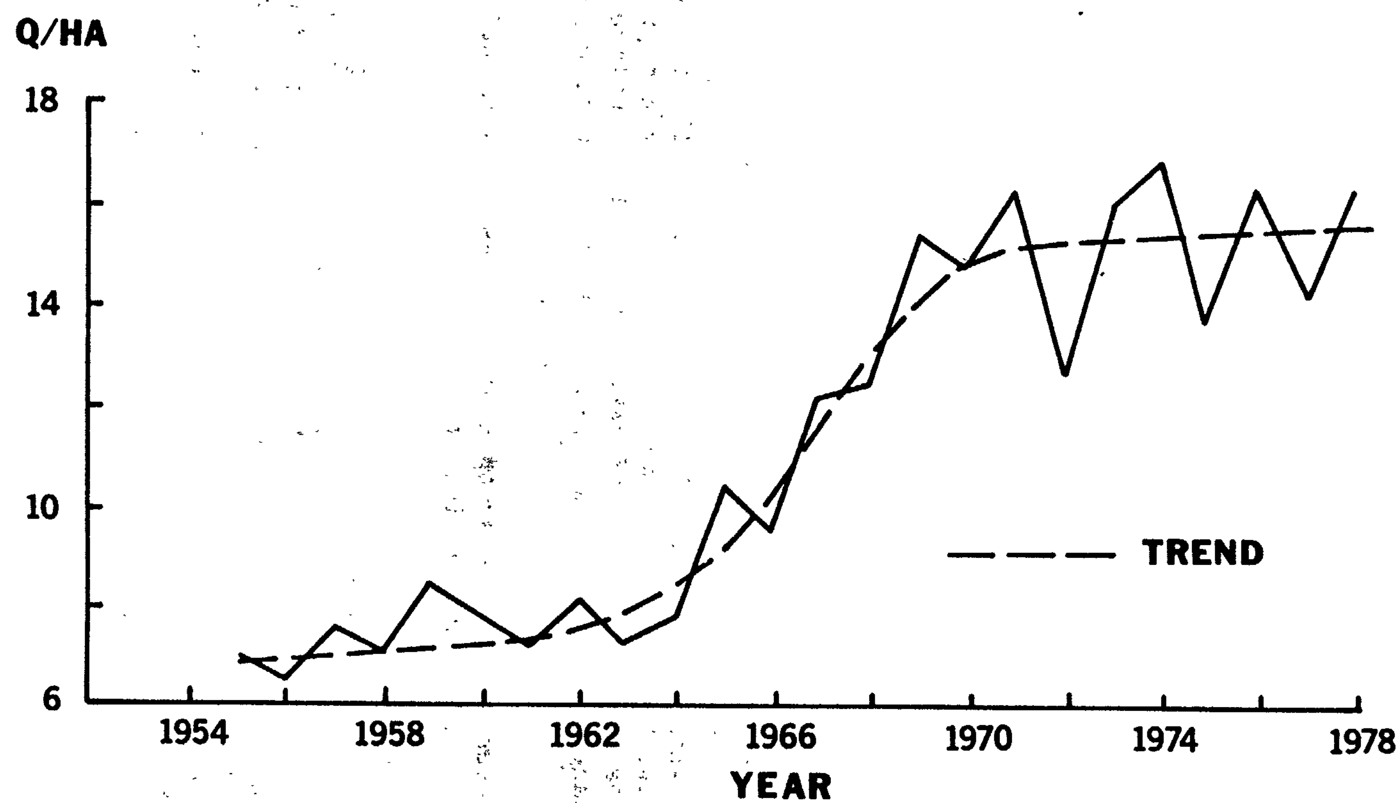


Figure 23. Cereal yield in the Non-Chernozem Zone of the RSFSR.

Assessment of Future Grain Production

The deceleration of the rate of yield growth mentioned above does not mean there will be a decrease of grain production in the USSR in the near future. At this time the trend is going up, and with continued technological improvements, it will continue to go up. But accompanying the trend increase is a gradual increase in the variability of cereal yields around the trend. Changes in the variability of yield for two of the main regions of the USSR are mentioned in Figure 24 [23]. This variability has a tendency to increase with the time and basically involves the pattern of yield decrease rather than increase. Precipitation during the period of April-June, which accounts for the significant part of the cereal yield variability, does not have a trend similar to the yield trend. As seen in the figure, at the beginning of the period, precipitation and yield had almost the same variability (about 15 percent) for West Siberia. For North Caucasus, the variability of yield was 3 times less than the variability of precipitation. By the end of the period the variability of yield was two-threefold higher than the variability of precipitation for both regions. Thus, the improvement of technology does not lead to the reduction of yield variability. Over the period of 1945-1978 the variability of yield had a stable upward trend and the magnitude of the variability almost doubled. From these considerations this trend is expected to continue in the future and by the end of the century the magnitude of the cereal yield variability is expected to be on the average around 20-30 percent for the USSR and 40-50 percent for the main grain producing regions. The increasing variability of cereal yield will continue to maintain the shortage of grain in the USSR in the near future, especially in years with unfavorable weather as 1975, 1979, or 1980.

And the important questions concerns the perspectives of eliminating the grain shortage in the USSR in the distant future.

Some figures on recent rates of growth in grain production and Soviet population allow us to make some projections. Changes in the grain production level in the USSR in 1945-1980 and in Soviet population in 1950-1979 are shown in Figure 25. For recent years, the rate of the grain production growth has been around 3 percent and the population growth has been 0.9 percent. Assuming the same rates in the future ($R_G = 3.0$ and $R_p = 0.9$) and accepting the lowest figure for the yearly Soviet requirement in grain per capita, D = 1.0 ton, it is possible to calculate when the gap between production of grain and requirement for it in the USSR will be closed. For this purpose the following two equations should be solved.

$$\begin{cases} A + AR_p y = x \\ B + BR_G y = Dx \end{cases}$$

where A, B are the present levels of Soviet population and grain production, respectively; x is the number of years between today and the time when the gap will be closed; y is the Soviet population by the time of the closing of the gap. Thus, under the given assumptions, and considering the present level of grain production at around 205 million tons and the present level of Soviet population at approximately 262 million persons, the gap will be closed in 16 years. At this time the Soviet population will be around 296 million persons (Table 19). But as it was mentioned above, the Soviet requirements for grain right now are greater than 1.0 ton per person a year.

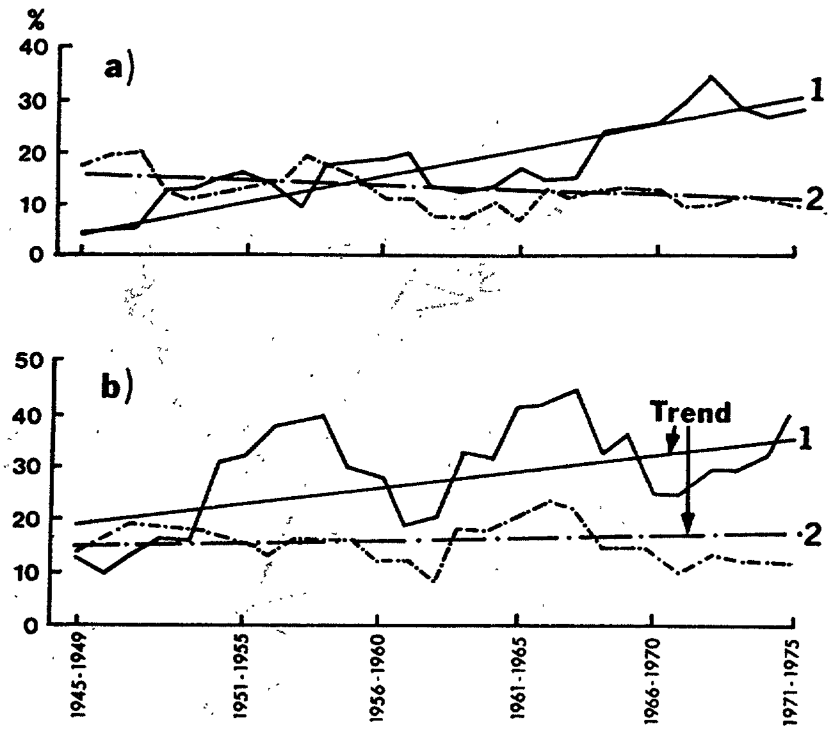


Figure 24. Average five-year-running cereal yield (percentage to trend, 1) and Precipitation (percentage to normal, 2) in North Caucasus (a) and West Siberia (b).

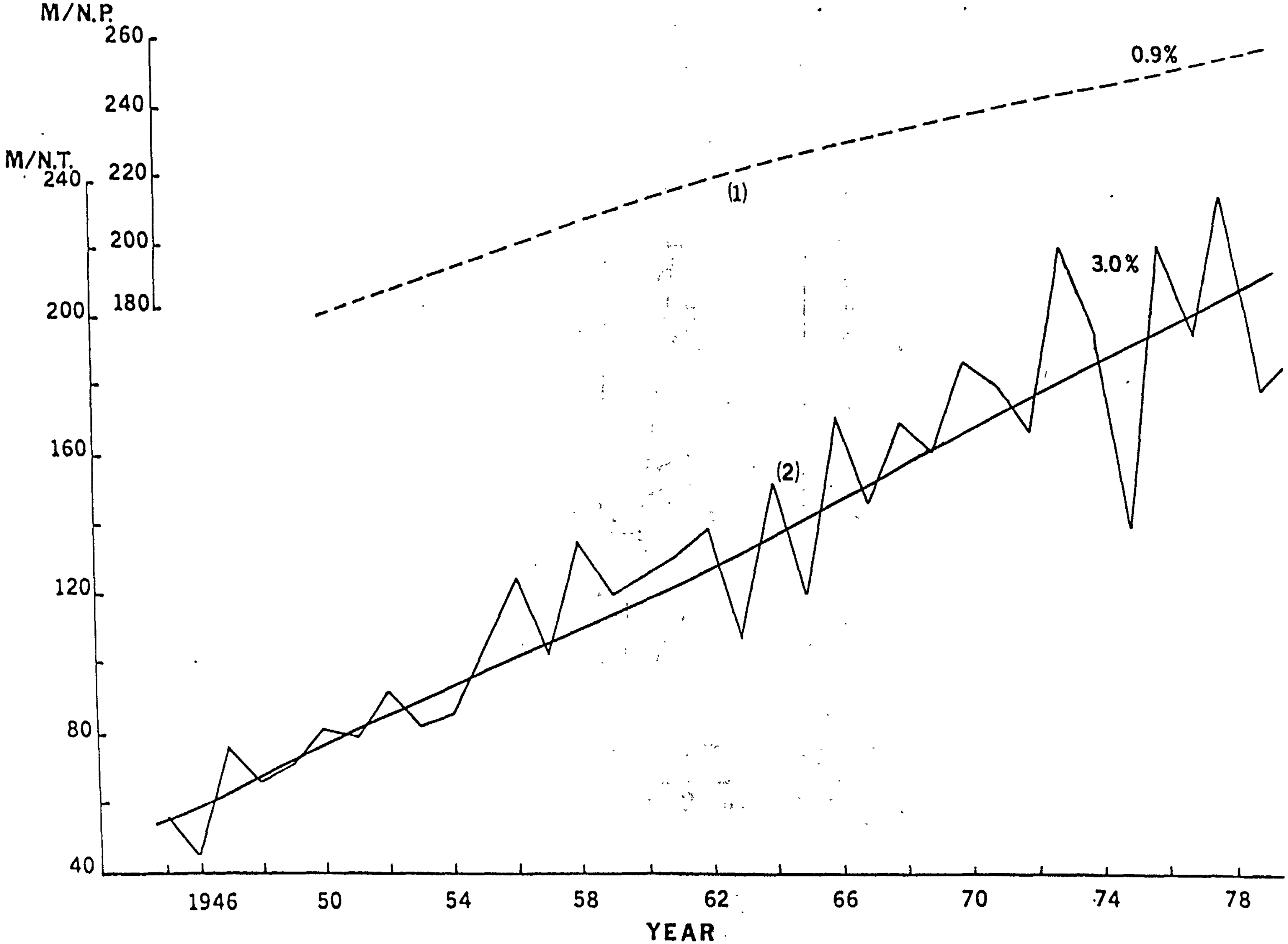


Figure 25. Growth of population (1) and grain production (2) in the USSR.

Taking into account the upper limit of this requirement (1.2 tons per person) the term of closing the gap will be delayed by 17 additional years. Judging by previous discussion of the problem, the rate of grain production growth in the USSR seems to be decreasing, but requirements for grain seems to be increasing. It is difficult to evaluate these figures. But trying some figures, which seem to be fairly probable, the estimation of closing the gap will give us the years 2025 and 2063, respectively. At any rate, the calculations showed that because of a very low rate of the Soviet population growth closing the gap between the grain production and the requirement for grain in the USSR may occur in 30-50 years.

By the end of this century, grain production in the USSR might be 300 million tons (Figure 26, line 1) if the evaluation is made by extrapolating the present linear tendency in grain production growth and assuming unchanged area cultivated in grain crops. But the present tendency shows a stable deceleration in the rate of growth of grain production which can be estimated. Taking into account this deceleration, which will probably continue in the future, the USSR grain production might be estimated at 290 (line 2) or 285 million tons (line 3). But the extrapolation in itself is not very reliable for grain production predictions. It is well known that the weather makes substantial "corrections" in predictions like these and it should be taken into consideration. But unfortunately even short range weather forecasts are unreliable, not to mention long range weather forecasts. In such a case some indirect assessments of hazardous phenomenon, like drought which usually cause great losses in production, can give us the impression of possible changes in forecasts of grain production in the USSR.

Observation of the past 34 years of cereal yields show that every three to four years (probability 27 percent) negative deviation from the USSR trend totals more than 1.0 quintal per hectare (Table 20). This means approximately 12 million tons less grain is produced. In some very important grain producing regions (Kazakh) the probability of decreasing yield by one quintal per hectare can be as high as 36 percent. Every 9-10 years a very significant decrease of cereal yield (3 Q/HA) can occur on a nationwide scale. Such decreases are usually connected with severe and widespread droughts (1963, 1979). And three times within one hundred years a drought like that in 1975 has caused a decrease of cereal yield of 5 Q/HA and more, bringing losses to about 60 million tons grain in the country. The probability of very severe droughts in the main grain producing regions of the USSR as seen in Table 20 is 6-7 percent. Quantitative descriptions of droughts, which have occurred in Russia during the past one thousand years show that very severe and widespread droughts have occurred 7-15 times each one hundred years. Occurrence of local drought is 15-20 times per century.

From the beginning of this century Russia has been affected by eight very severe and large-scale drought and 15 moderate droughts. Severe droughts occurred in 1911, 1921, 1931, 1946, 1963, 1965, 1975, 1979. Following these statistics of the droughts' occurrence Russians can expect, by the end of this century, 3-4 more droughts when yield would decrease 15-30 percent and 6-7 moderate droughts.

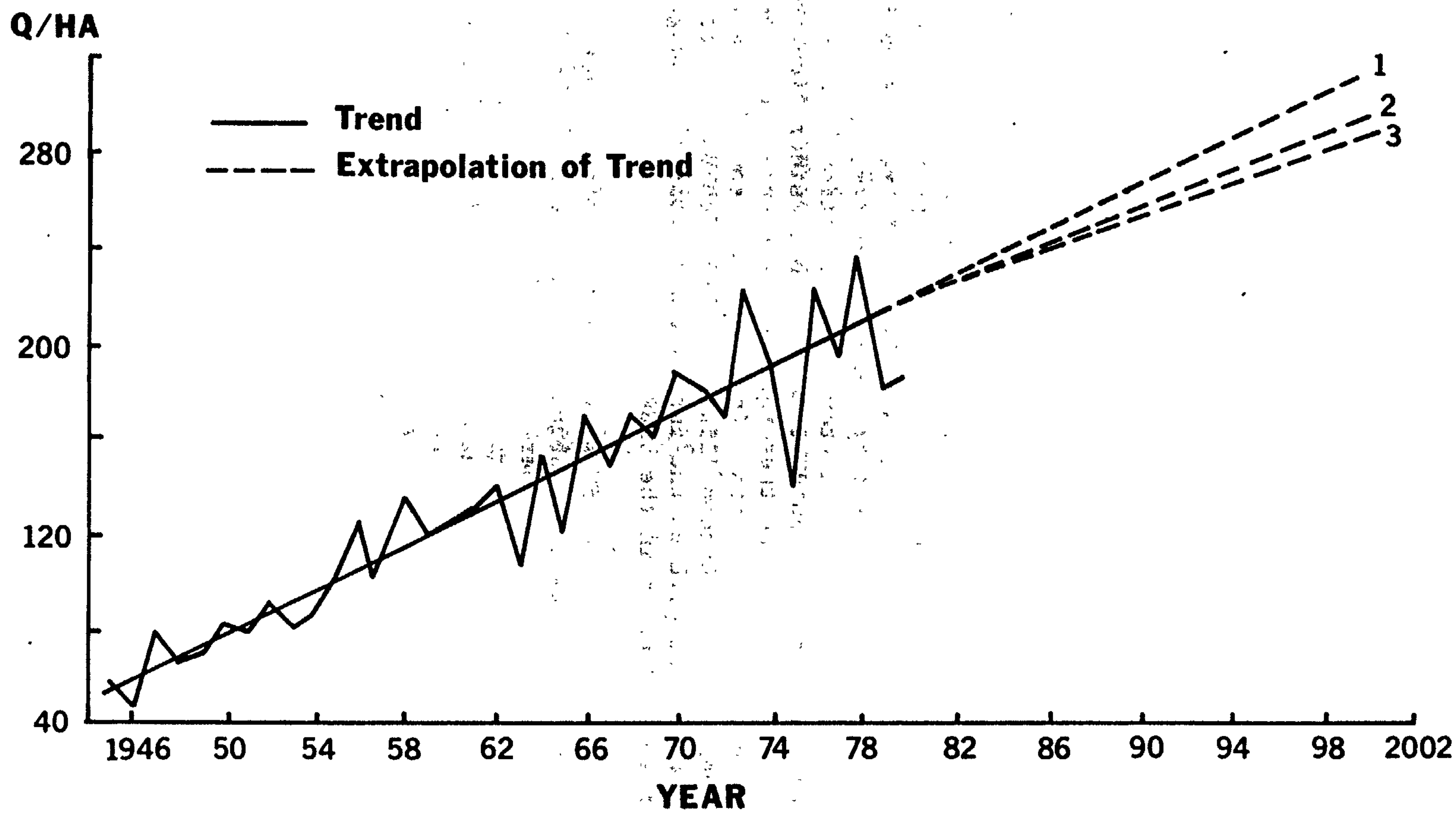


Figure 26. Total grain production in the USSR.

Table 19

ESTIMATION FOR THE TIME WHEN GRAIN PRODUCTION IN THE USSR WILL MEET SOVIET REQUIREMENTS FOR GRAIN

Assumptions			Closing the Gap	
Rate of Population Growth R_p	Rate of Grain Production Growth R_G	Requirements in Grain (Tons/Person*Year)	By Year	With Population (mil. Person)
0.9	3.0	1.0	1955	296
0.9	3.0	1.2	2012	336
0.9	2.5	1.2	2025	368
0.9	2.5	1.4	2063	458

Table 20

FREQUENCY (%) OF CEREAL YIELD DECREASE

Region	Decreasing of Yield More than (q/ha)		
	5	3	1
USSR	3	9	27
CENTRAL	0	3	25
UKRAINE	6	16	26
KAZAKH	7	17	36

Table 21

FIVE-YEAR AVERAGE SCALING ASSESSMENT OF METEOROLOGICAL CONDITIONS FOR CEREAL'S PRODUCTIVITY IN 1951-1980 AND QUALITATIVE FORECAST OF THE PRODUCTIVITY IN 1981-2000

REGION	1951-1955	1956-1960	1961-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000
USSR	3.6	3.8	3.4	4.0	3.3	3.9	-	+	-	+
UKRAINA	4.0	4.0	3.6	4.0	5.4	4.0	-	+	-	+
VOLGA	3.6	3.8	4.0	4.0	3.2	3.8	-	+	-	+
NORTH CAUCASUS	3.4	3.6	3.2	4.0	3.4	3.9	-	+	-	+
KAZAKH	3.6	4.0	3.0	4.0	3.4	3.8	-	+	-	+

Meteorological observations of the past 35 years and assessment of the productivity of grain crops based on these observations show that the type of conditions in the USSR as a whole and particularly in the main grain producing regions has changed in accordance with a five-year cycle (Table 21). In general, a five-year period with favorable weather for growing grain crops follows a five-year period with unfavorable weather. Thus the productivity of weather average in a five-year period was changing each five years during the past 30 years. That is why the growth of the USSR grain production in 1956-1960, 1966-1970 and 1976-1980 with more favorable weather was higher than in 1951-1955, 1961-1965 and 1971-1975, respectively with less favorable weather. For the first group of five-year periods grain production of the USSR was above trend, for the second group it was below trend (Figure 27).

Following this type of cyclicity, we could expect by the end of this century two five-year periods with favorable weather conditions for growing grain crops in 1986-1990 and 1996-2000 and two periods with unfavorable weather conditions in 1981-1985 and 1991-1995. As a result of these conditions, Soviet grain production will be above the trend in the first two periods and below the trend in the second two. Thus, for the 1981-1985 five-years period with unfavorable weather conditions average grain production in the USSR will seem to be 2-7 percent below the trend or 218-230 million tons (Figure 27, lines 1 and 3: the average decrease is 3.5 percent, line 2). These figures again are lower than the figures of grain production, planned by the USSR for the eleventh piatiletka (five year period, 1981-1985) and recently announced by the 26th Congress of CPSU.

Using the average cereal yield obtained by the USSR in 1980 and equation 1 the USSR cereal yield in 1981 can be estimated at 14.5-16.0 Q/HA and grain

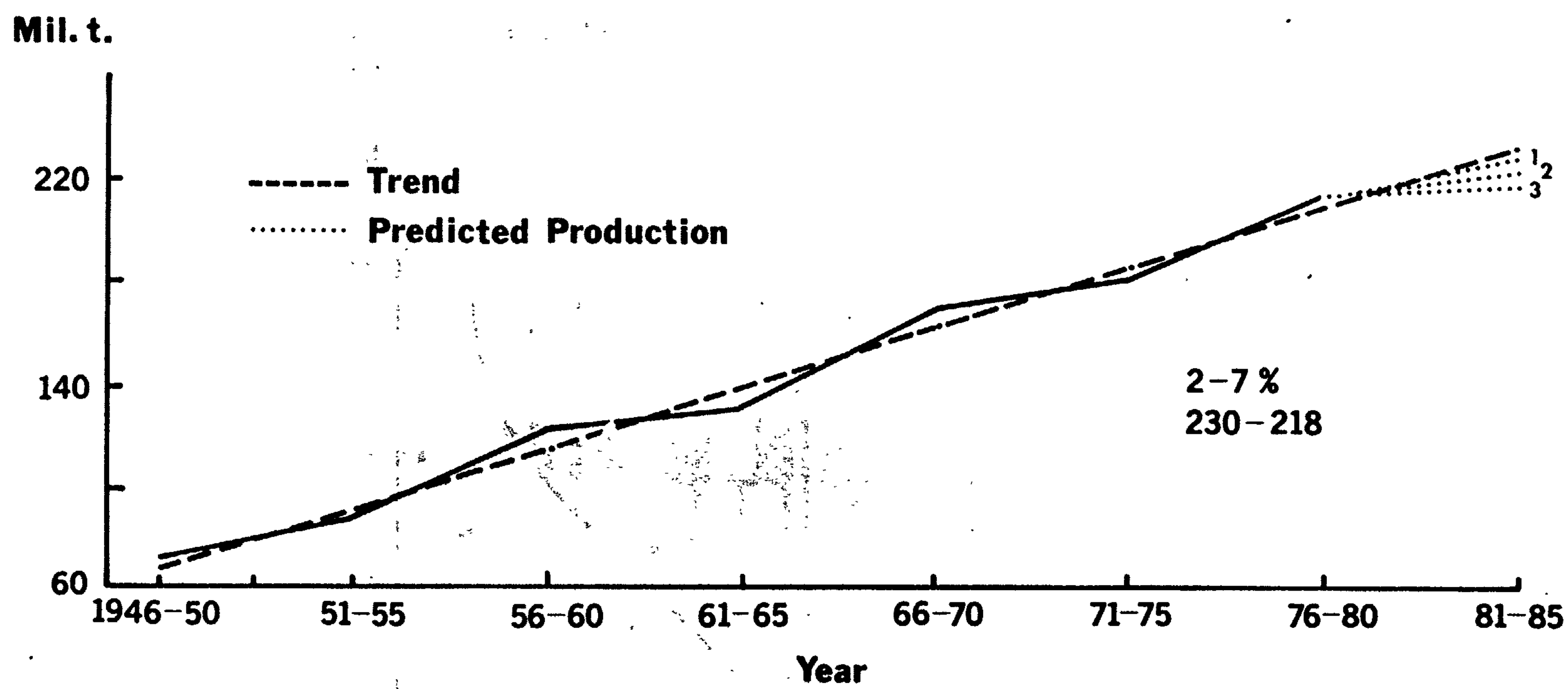


Figure 27. Five-year average grain production in the USSR.

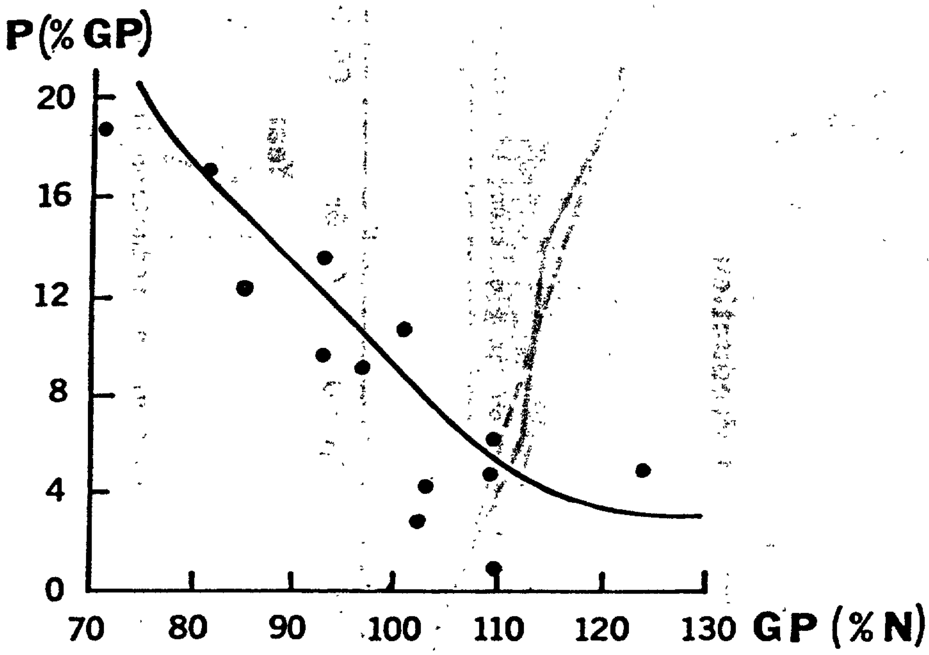


Figure 28. Correlation between imports of grain (P, percentage to grain production in mil. tons) and grain production (GP, percentage to the trend, -N) in the USSR in 1970-1979.

production at 185-205 million tons from 128 million hectares of planted grain crops area. Unfortunately, the reliability of these figures is lower than usual as the weather conditions in the USSR in 1980 were very abnormal. Extremely excessive and frequent precipitation throughout the USSR territory during the growing season of 1980 caused excess of water in the fields and lodging small grain crops. These phenomena combined with the low temperature sharply reduced grain production in the USSR in 1980.

At the same time even less reliable long-range estimation of the USSR grain production might be fairly useful for making many important decisions. One of the decisions is about the amount of Soviet purchases of grain from the international market. The prediction of Soviet purchases is based on estimated figures of the Soviet grain production in 1981 and on correlation between grain production and purchase of grain by the USSR during the past 10 years (Figure 28). Thus, the Soviet purchases of grain in 1981 can be estimated at 12-16 percent of the USSR grain production in 1981 or around 22-31 million tons of grain.

V. CONCLUSIONS

According to data of the past five years, the USSR is the second grain producing country after the United States. The average USSR grain production was around 13 percent of the world grain production (Table 22). In addition to this it should be mentioned that the USSR produces around a quarter of the worldproduction of such crops as wheat, barley, and oats, one third of the world rye, and 85 percent of the world buckwheat production. At the same time, as seen in the table, the USSR imported approximately 13 percent of the total grain involved in world trade. This average amount of purchased grain is around 35 percent greater than for the seven socialist countries of Eastern Europe. And in 1979 the Soviet imports of grain exceeded the imports of not only the East European countries but also exceeded those of Japan and was equal to the total grain imports of the sixteen West European countries (with 350 million population, 35 percent greater than in the USSR). These figures are very impressive and there is no evidence that, at least in the near future, the USSR imports will decrease. Taking all of these facts into consideration we should emphasize the importance of the problem of prediction of the USSR grain production for:

- the assessment of the total world grain resources and the grain resources of separate crops;

- the assessment of prospective Soviet imports of grain.

The successful implementation of schemes for the prediction of Soviet grain production will allow us to solve many very important internal and external economical and political problems.

To solve these problems, we need to have fairly reliable methods for estimating total USSR grain production and grain production of separate crops well in advance of harvest and also for longer perspectives. As it was shown in Section II among the many methods, it is possible to utilize only three of them without additional work or modification. The rest of the methods would be possible to utilize only if the special methods of the distant definition of available soil moisture, crop conditions, crop calendar and identification of crops in the large scale could be developed. But in addition to this it would be necessary to adjust these new methods of the definition of the mentioned parameters to the existing methods of the estimation of crops' productivity, described in Section III. This development is a very complicated and indirect way of utilizing the presented methods. It seems to us that a more reasonable, cheaper and effective way is to develop new statistical methods for predicting crop production based on the simplest methodology such as that presented by equations (34) - (38). Presently available historical data will allow us to develop fairly good methods for large-scale prediction of productivity of very important USSR grain crops like barley, oats, corn, buckwheat and to improve existing methods for winter and spring wheat.

It was shown in Section III that very little has been done in the most important and complicated field of the long-range predictions of crop

Table 22

GRAIN PRODUCTION, IMPORTS AND EXPORTS
(PERCENTAGE TO THE WORLD GRAIN PRODUCTION, IMPORTS AND EXPORTS)

Country	Item	Year					Average
		1975	1976	1977	1978	1979	
U. S. S. R	Production	10.0	15.0	13.0	15.0	12.0	13.1
	Imports	18.0	7.0	12.0	9.0	17.0	12.6
	Exports	0.3	2.0	1.3	1.6	0.3	1.1
Japan	Imports	14.0	15.0	14.0	15.0	14.0	14.3
Eastern Europe	Imports	9.0	10.0	9.0	9.0	10.0	9.4
Western Europe	Imports	22.0	28.0	21.0	19.0	17.0	21.4

productivity. At the same time scientific information presented in Section IV shows that there are some possibilities for development of models for long-range prediction of grain production in the USSR. Unfortunately, it is difficult to expect quite successful achievement in this area. But the developments will not allow us to make some predictions, but also will help to gain insight on many important aspects of the problem of grain production improvement.

The problem of the development of models for the long-range predictions interacts with the problem of the possible climatic changes and their effect on agriculture. Our research showed that not all climatic changes cause important changes in productivity of agriculture. Long-term series of meteorological observations and observations of crop productivity as well will help us to understand the possible effect of climate change and improve our long-range predictions in agriculture.

One of the very important problems in asssessment of crop productivity is connected with the evaluation of influence of technology on crop and the numerical estimation of this influence. The complication of the problem appears because of the additional effects of weather which are linked to technological changes. Technological factors as they interact with weather, produce some additional effects which can significantly change crop production. Such effects of the weather-technology interaction increased grain production of the USSR in 1973 by 10 million tons. During the past 10 years this effect was observed in the USSR several times. Accordingly for the improvement of model performance we should develop methods for the assessment of the weather-technology interaction effect.

For further development and improvement of methods for the assessment of grain productivity it is necessary to improve and extend the theoretical basis of agricultural meteorology for better understanding very complicated processesof the weather-technology-soil-crop interaction. In these aspects the development of bio-physical models, based on the principles of the energy and mass exchange in the soil-crop-atmosphere system would be beneficial. In this development the principles of the interactions between the main biological processes such as photosynthesis, respiration, translocation and others will be very useful. At the same time it is necessary to improve utilization of the traditional statistical methods and to introduce the new ones to increase the effectiveness of the models for assessment of productivity of agriculture. Up to now only the regression and correlation analysis have obtained widespread use for the development of the weather-technology-crop models. There are many other possibilities of using statistical methods such as the Monte-Carlo method, discriminant analysis and others.

All presented problems of analytical methods for estimating production concern not only the agriculture of an individual country, but the agriculture of the world. The solution of these problems of estimation is a very important task right now because the differences betwen produced agricultural products and requirements for them is small. The earlier we increase our efforts in the directions of improved estimates of agricultural production, the sooner we will be able to foresee the many problems connected with the productivity of agriculture and especially the most important problem of supply-demand.

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