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Adjustment of Regional Agriculture to Expected Climatic Changes

INTRODUCTION

There are many direct observations, indirect facts and theoretical estimates showing that through intensification of industrial production, global climatic changes will occur in future decades. In (Sov-Amer 1982) the following estimates of the observable and probable increase in atmospheric CO_2 concentration up to 2050 are given 280–297 $mill^{-1}$ (pre-industrial period), 336–338 $mill^{-1}$ (1980), 360 ± 6 $mill^{-1}$ (1990), 394 ± 9 $mill^{-1}$ (2000), $700 \pm (50 - 100)$ $mill^{-1}$ (2050). A global warming is expected to be induced by this process. Changes in the mean annual temperature (for example, in several degrees in high latitudes) and precipitation are likely to have a significant impact on agriculture and the environment. Therefore, the assessment of the impact of the adjustment of agriculture in different regions to expected climatic changes is of great importance.

The successful adjustment to such changes will require detailed information on how regional agricultural systems and the environment will react to them. Because experimenting with real agricultural systems is time and cost consuming and is in some sense unrealistic, the development of corresponding models to study possible ways of adjustment and assessment of their economic and ecological consequences is considered as an appropriate approach.

This paper contains the description of such methodology and demonstrates how it operates on the data for the Leningrad region in the USSR.

METHODOLOGY

The proposed methodology included three main interacting tools for:

(1) generating scenarios of changes in regional weather conditions induced by global climatic changes;

(2) simulating the behaviour of regional agriculture and environment under different generated scenarios;

(3) assessing economic and ecological consequences of adjustment of regional agriculture to changing climate based on results of simulation.

Generating scenarios of changes of regional climatic conditions is implemented with using two alternative approaches: General Circulation Models of the atmosphere, for example GISS model developed by J. Hansen et al. (1983) and modified by W. Bach (forthcoming), simulating anthropogenic effects on climate, particularly CO_2 induced climatic changes; and a second approach which employs empirical climatic data to construct regression models for describing changes in temperature and precipitation for different regions (Vinnikov and Groisman 1979).

For investigating the behaviour of regional agriculture and environment under different scenarios of climatic changes and agrotechnological transformations the VNIISI model is used (Pegov et al. 1983; S. Pegov et al. forthcoming). It is the so-called 'index' simulation model allowing one to study dynamic behaviour of soil, vegetation, water and air indexes based on empirical data and the major trends in regional crop production in response to climatic changes and agrotechnological transformations given exogenously as time series of the scenario's control parameters. This model consists of four parts: a submodel for adjustment to a specific region's conditions (lithology, geographical belt, etc.) a hydrological submodel, an environmental pollution submodel and a submodel of biogeosystem dynamics. For the descriptions of the dynamic processes in these parts of the model, ordinary difference equations are used. As results of simulation, such time-dependent variables as soil productivity, crop yield, soil moisture and salinity, surface, ground and deep ground water pollution with chemicals etc. are generated as outputs. Besides climatic scenarios describing changes in mean annual temperature and precipitation, this model allows one to use scenarios for agrotechnology transformations as the following input time dependent variables: rate of fertilizers and other chemicals application, intensity of irrigation and drainage activity, changes in acreage, changes in acreage for shelter belts, etc.

Based on results of simulation assessing economic consequences for adjustment of regional agriculture to changing climate is implemented on the basis of application of multi-objective decision making methods. For this purpose results of simulation of different variants of adjustment obtained from the VNIISII model are transformed into a number of economic and ecological indicators which are used then for multi-criteria comparison of those alternatives and selection of the most preferable one.

RESULTS OF THE DEMONSTRATIVE APPLICATION OF THE METHODOLOGY

The methodology was applied to conditions of the Leningrad region of the USSR to demonstrate how models are operative. This work was done by IIASA (Laxenburg, Austria) in collaboration with the All Union Research Institute for Systems Studies (Moscow). The complete description of results will be available in a forthcoming publication (Iakimets, Pitovranov 1985). The results of these models fit very well the observed data of the period 1947–80. Some results related to future dynamic changes of winter rye yield (one of the major crops in the region) and several environmental characteristics of the region under 1 reference and 4 selected scenarios of climatic changes and simple agrotechnological transformations are given in Figures 1–3. The scenario of climatic changes used for the region is given in Figure 4 (approximately the same as used in other studies on climatic impacts). The description of 5 considered scenarios is given in Table 1. Table 2 contains comparisons of results of the reference scenario (variant 1) and the scenario of only climatic changes (variant 2). One can see from this table that changes considered for regional weather conditions are unfavourable as a whole for agriculture: the soil index is dropping, surface water pollution with nitrogen and the depth of an already detrimentally high of the first ground water table are increased. These changes lead also, in the second half of the period under consideration, to a decline in winter rye yields. Therefore we tried to find ways of agrotechnological transformations in order to support the level of winter rye yield at the same time as minimising negative ecological consequences. In this paper we do not report about possible changes in cropping patterns. Here only 3 ways for adjustment (variants 3–5) from many other studied are given. Table 3 contains the results of a comparison of those with variant 2 (with climatic changes but without agrotechnological adjustment). A simple analysis of these data shows that variant 5 is the candidate to be the most preferable one because it provides for support of the level of yield more than in 1980 with the least level of surface water pollution with chemicals and an admissible level of first ground water table.

To implement more rigorous integrative assessment of different variants of the adjustment of agriculture to possible climatic changes, three criteria were constructed:

1. Index of the economic efficiency of variants ($E_1(t)$).

$$E_1(t) = \sum_i p_i(t) \cdot y_i(t) - \sum_j c_j(t) \cdot x_j(t),$$

where

- $y_i(t)$ is the yield of crop ($i = 1$) and by-products in the year t (for example, the straw ($i = 2$));
- $p_i(t)$ is the price of the crop and by-products produced in the year t;
- $x_j(t)$ is the value of the j-th agrotechnological input applied in the year t (for example, nitrogen fertilizer ($j = 1$), phosphorous fertilizer ($j = 2$), etc.);
- $c_j(t)$ is the cost of the preparation and application of the j-th input.

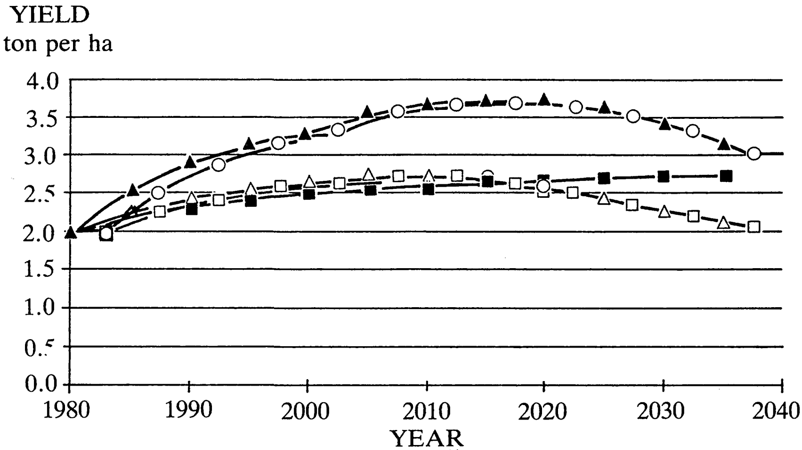

Figure 1. Winter Rye Yield

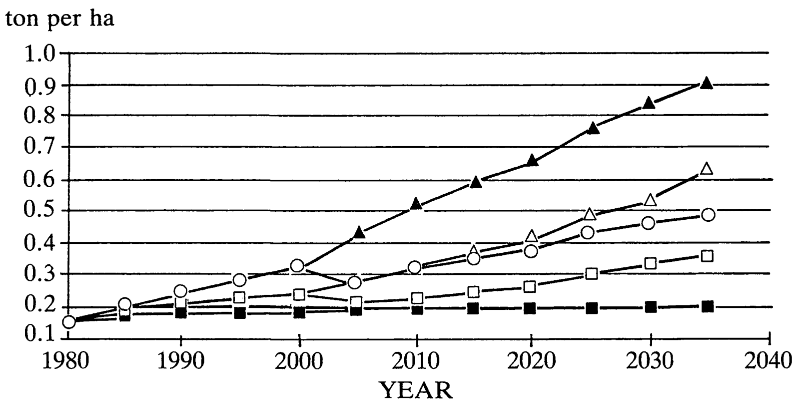

Figure 2. Surface Water Pollution with Nitrogen

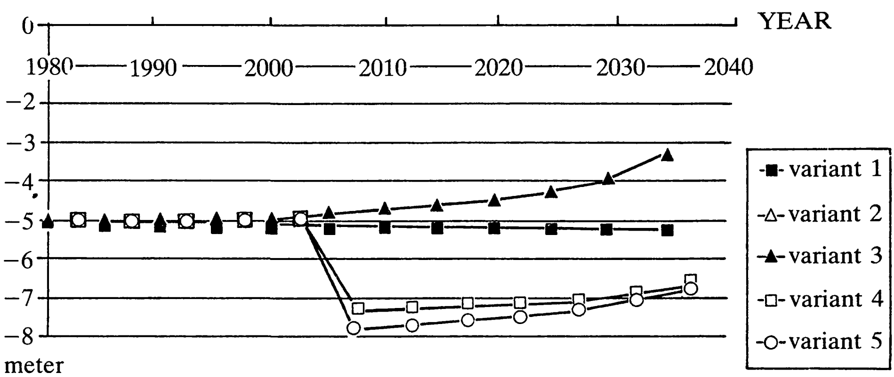

Figure 3. Depth of the 1 Ground Water Table

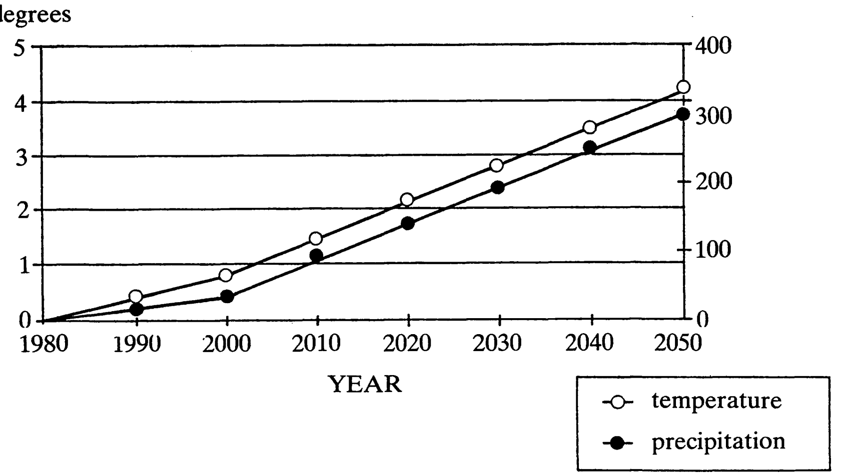

Figure 4. Scenarios of Temperature and Precipitation Increase (relative to 1980)

Table 1. *Selected Scenarios*

	Reference Scenarios (variant 1)	of climatic and agrotechnological (variant 2)	changes[1] (variant 3)	scenario (variant 4)	(variant 5)
Climatic changes (Annual T° and precipitation)	average as for 1980–3 for the whole period	←see Figure 4→			
Annual fertilizer applications (in kg per ha. of nutritional units)	2035	2035	1980–2000 2000–2035	2035	as in variant 3
nitrogen	55	55	80 120	55	
phosphorous	45	45	70 100	45	
potassium	45	45	70 100	45	
organic	150	150	250 375	150	
Drainage[2] activity increases				0.5km/km² (2001–2002) 1km/km² (2003)	as in variant 4

[1]Liming effects will be considered in future applications
[2]Expressed as length of surface drains of 5 m depth per km²

Table 2. *Comparison of results for variant 2 relative to variant 1 (in percentage)*

	1980	1990	2000	2010	2020	2035
winter rye yield	0	+4.3	+5.2	+4.7	−4.1	−23
soil index	0	−1	−4	−11	−22	−42
depth of the 1st ground water table	0	+2	+4	+9	+14	+38
surface water pollution with nitrogen	0	+17.5	+30.2	+75.4	+213.7	+325

Table 3. *Comparison of variants 3, 4 and 5 relative to variant 2 (in percentage)*

variants	1980	1990	2000	2010	2020	2035
			winter rye yield			
3	0	+19	+25	+35	+45.8	+50.2
4	0	0	0	−2	−3	−3.4
5	0	+19	+25	+34.8	+43.5	+43.4
			soil index			
3	0	+20.5	+24.6	+36.4	+47.2	+49.4
4	0	0	0	−2.5	−1	−4.8
5	0	+20.5	+24.6	+36.4	+44.4	+42.2
			surface water pollution with nitrogen			
3	0	+20.8	+34.6	+56.4	+60.8	+44.7
4	0	0	0	−33	−36	−43
5	0	+20.8	+34.6	−4	−7	−23
			depth of the first ground water table			
3	0	0	0	0	0	0
4	0	0	0	+53.9	+60	+204
5	0	0	0	+64.3	+68	+208

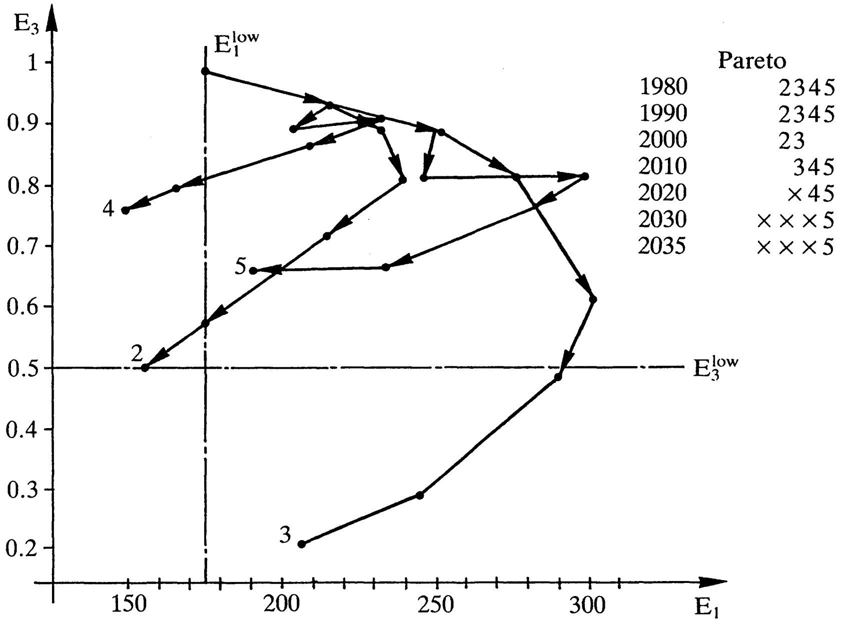

Figure 5. Projections of trajectories in two-dimensional space

It should be noted that for the sake of simplicity the values of $p_i(t)$ and $c_j(t)$ were taken as constant for the whole period under consideration.

2. Index of the energy utilization efficiency ($E_2(t)$).

$$E_2(t) = \frac{\sum_i q_i \cdot y_i(t)}{\sum_j q_j \cdot x_j(t)}, \tag{2}$$

where $y_i(t)$ and $x_j(t)$ have the same meaning as in formula (1) and q_i and q_j are values of energy equivalents of yields and inputs.

3. Index of the ecological sustainability ($E_3(t)$)

$$E_3(t) = v^\circ - v(t), \tag{3}$$

where v° is the admissible level of the nitrogen concentration in the surface water (the WHO recommended value of it is 1.13 gN per litre) and $v(t)$ the calculated value of this concentration.

Values of these indices were calculated for all considered variants for each year based on values of simulated variables. Thus the trajectories of variants in three-dimensional space of the above mentioned indices were found. In order to select the most preferable variant of the adjustment the corresponding multi-objective decision making procedure was developed. This procedure has the following main steps:

1. The low constraints on values of each index are fixed for the whole period $E^1 = \{E^1_k, k = 1,2,3\}, \forall t \in \overline{O,T}$.
2. Vector values of trajectories of each variant (t) are calculated for each year under simulation, according to (1–3):

$$E_\tau(t) = (E_{1\tau}(t),E_{2\tau}(t),E_{3\tau}(t)), \forall t \in \overline{O,T}.$$

Hence the set V of vector values of variants was determined.

3. Pareto-optimal set (P_t) of variants is determined for each year following the definition

$$\forall t,\tau E^{\cdot}_\tau(t) \in P_t \Longleftrightarrow E^{\cdot}_{k\tau}(t) \geqslant E_{k\tau}(t), \forall k \in \{1,2,3\} \text{ and}$$
$$\exists\, k \in \{1,2,3\} : E^{\cdot}_{k\tau}(t) > E_{k\tau}(t).$$

4. The most preferable trajectory (and hence the preferable variant) is determined as that which for the whole period under consideration was selected more times as the Pareto-optimal one and which did not violate the low constraints or violated these less times than other trajectories.

Based on this procedure the variant 5 was found as the most preferable one. Figure 5 contains projections of all considered trajectories in a space of indexes E_1 and E_2. One can see that only trajectory 5 does not violate both low constraints.

SUMMARY

Illustrative application of the methodology described in this paper shows that possible climatic changes induced by the increase of atmospheric CO_2 concentration can have negative impact on regional agriculture (see Table 2). The analysis of results of different scenarios for adjustment of agriculture to those changes based on simulation runs allows one to select the ecologically and economically appropriate alternative.

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DISCUSSION OPENING – SHOHSAKU SENDA

The two papers presented were instructive and interesting. However, due to constraints on both my knowledge and time I wish to refer only to the first paper which described river basin development projects in Nigeria.

I have two questions. The first question concerns the motivation and initiatives for the irrigation project. What are the farmers' desires for the irrigation programme in Nigeria? Who established the project originally? Was it government or farmers by themselves?

The second question concerns the organization of the farmers' irrigation association. What is the actual situation of the farmers' activities regarding, for example, allocation and adjustment, maintenance and management of water facilities? To what extent do farmers have to pay for water charges?

GENERAL DISCUSSION – RAPPORTEUR: GLENN T. MAGAGULA

In answer to questions from the discussion opener, the presenter of the first paper, F. J. Idachaba replied that it should be noted that Government involvement began early in the 1970s and the intention was to augment farmers' efforts and to assure an adequate water supply for farmers. Farmers were not involved in policy formulation, articulation of needs and priorities nor in determining the scale of operation. The RBDAs provide and maintain the water systems and the financial contribution by farmers is minimal. The issue of cost recovery had not been adequately addressed in programme formulation.

One questioner noted that river basins are normally characterised by heavy soils and this might lead to high labour costs which might, in turn, reduce the profitability of the programme. He further pointed out that small-scale irrigation projects might be more profitable than the large-scale projects. Finally, he took issue with the concern of the authors regarding non-involvement of State Governments – this might accentuate bureaucratic control.

In reply, while conceding the point that heavy soils might increase labour costs, Idachaba pointed out that the profitability of the schemes could be related to the extent to which high value crops are produced. He agreed that small-scale irrigation schemes e.g. those using small pumps, might be more economical; in fact, there was a high demand for such pumps. He further agreed that bureacratic control should be reduced and this was one of the authors' recommendations.

Another participant asked if these programmes had been examined in relation to other rural development strategies in Nigeria to assess their appropriateness. Idachaba replied that the authors' intention was to evaluate the RBDP's effectiveness in meeting its objectives and to suggest policy changes for improving its performance. He was then asked if the founders of the programme determined the optimal farm size in these programmes and whether the RBD projects were developed simultaneously or sequentially. Idachaba replied that nobody could estimate questions of optimal farm size for Nigeria as a whole. It was true that the farm sizes of the RBDP were small but this was not fundamental, as Japanese, Chinese and Korean experiences indicate. A large number of the river basin schemes were developed almost simultaneously and this was creating a lot of problems.

Another questioner asked what kind of crops were grown in these schemes – cash or subsistence crops? Did men and women jointly participate in producing the crops or was there a division of labour? Idachaba replied that in Nigeria they had abandoned the distinction between cash and subsistence crops. The schemes were created for farm families and it was in this context that the farms were run. He was further asked if the lands on which the RBDPs were established were already occupied or were they Government lands, and were farmers resettled there? Since the construction of large dams was obligatory, according to the Statute, how could the Authorities be expected to construct small-scale dams?

In reply the presenter said that the lands on which the RBDPs were established were originally occupied by farmers. However, the construction of the dams entailed widespread resettlement of farm homesteads and reallocation of fields in such a way that each farm family had about 4 hectares of land. The Act establishing the RBDPs did not specify that dams had to be large. Nevertheless, because the programmes were initiated during the 'oil boom' and money was not wanting, the Authorities took it upon themselves to construct large dams. Now that the 'oil boom' was no longer with us, there was a pressing need for the construction of small dams.

Participants in the discussion included S. Senda, Kiragani, A. C. Nwosu, U. Malik, I. Tinker and S. Bellete.