THE RATIONAL USE OF MINERAL FERTILIZERS IN RUSSIA

Vladimir ROMANENKOV

Russia Research Institute on Agrochemistry, Russia

International Fertilizer Industry Association

Russian Research Institute on Agrochemistry
Pryanishnikova st., 31a, 127550 Moscow
Russia
Tel: 7 495 9764957 - Fax: 7 495 9763739
E-mail: viua@online.ru

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VA Romanenkov, MV Belichenko, OV Rukhovich, MP Listova
Russia Research Institute on Agrochemistry of DN Pryanishnikov

OD Sirotenko, VN Pavlova
All-Russia Scientific Research Institute of Agricultural Meteorology
249039 Kaluga region, Obninsk, Lenin Avenue, 82, E-mail: vnp2003@bk.ru
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The main component of the scientific-methodical and the organizational activity of the Scientific Research Institute of Agrochemistry is a study of the geographic patterns of fertilizers use efficiency. The necessary tool to perform this task is the Geographical Network used for research into fertilizers. The creation of such Geographical Network was initiated by DN Pryanishnikov. Experimental agro chemical network started its official existence in 1941. In the period until 1970, collected data set has pointed out a number of zonal patterns of fertilizer use effects, which depend on different types and forms of fertilizers applied. Also, the coefficient of efficacy of average fertilizers doses was established. Consolidation of the data from the field research of the Geographic Network, which was conducted using the same program and the same methodology, helped to create the All-Union Card Index of field research.

The analysis of this information has resulted into preparation of practical recommendations on:

- Identification of the needs for agricultural fertilizers in the country;
- Regional distribution of fertilizers;
- Advisable fertilizer assortment.

Also, with regard to an effect on the yield of major crops, the coefficient of efficiency of fertilizers' use was determined.

Despite the fact that the extensive experience was acquired and despite the existence of the variety of methods to calculate the right doses and combinations of fertilizers, the multi-factorial system "soil-plant-fertilizer-agricultural technology-weather-crop" in many ways remains to be an insufficiently studied issue. Thus, the tasks to optimize the doses and combinations of mineral fertilizers remain relevant in spite of the sound experience and the abundance of calculation methods. Rising prices for the materials and the equipment and a consequent increase in agricultural production costs makes the above problem even more acute. The method of dynamic modeling, which is used to optimize the doses of fertilizers is problematic due to the lack of input data. It is also impaired by absence of the models that would take into account not only the separate factors of productivity, but also the full range of indicators that might limit development of plants (Poluektov, 2002). With regard to non-optimal plant nutrition, research models of multiple regression were most widely used to solve practical problems of assessing the effectiveness of fertilizers (Peregoudov, 1978). The development of modeling has made it possible to study patterns of fertilizers effect with the help of numerical experiments. This solved the problem of representativeness of small samples, while studying a large number of factors. Based on such modeling, a detailed analysis is conducted to assess the role of soil, weather and agro technical factors. The analysis would also take into account the species specificity of crops and tiller crops.

Current computational methods for optimizing the efficiency of fertilizers are limited due to difficulties encountered while transforming the growing body of knowledge into a relatively simple calculation schemes available to practitioners. The need to address the stochastic nature of weather conditions - one of the main difficulties in solving the above problem. In recent decades, the meteorological aspect of this problem has become even more complicated. Previously, the hypothesis of "constancy" of climate was not debated. Whereas in the 21 st century, any environmental and economic forecasts are unlikely to be recognized as valid without consideration of climate changes caused by global warming. In order to conduct such calculations, the systemization of experimental data of the Geographic Network has to take into account the following patterns of the effectiveness of mineral fertilizers: the dependence of their action on various parameters of soil fertility, variety of weather conditions, features of the predecessor and modern agricultural techniques.

The calculation of equity of fertilizers effect on harvest is practically important – in the Non-chernozem belt it is 30-35%, in the forest-steppe areas - over 20% and 10-12% in the Chernozem zones and in the Chestnut soils. Within the European part of Russia, the effectiveness of fertilizers decreases 3-5 times in the direction from northwest to southeast. Almost the same decline is observed when comparing responsiveness of crops to fertilizers use in the Derno-podzolic soils compared to that of the Chernozems and the Chestnut soils (Fedoseev, 1979) Partial influence of soil cultivation degree is estimated to be 20-23% for Non-chernozem belt and 30-45% for the steppes and the forest-steppe areas. With regard to ratio of precipitation and evaporability, the impact of weather conditions is felt at maximum in the dry steppe zones and is less significant in the areas of steppe and forest-steppe (Table 1).

The experience of leading foreign countries has shown that current widely used approach is to evaluate the level of realization of the bioclimatic potential (BCP). This approach is used to analyze separate elements of agricultural production technologies as well as different levels of farming in general. Evaluating the effectiveness of the use of mineral fertilizers, depending on the BCP, has shown that it is determined by a complex of factors, foremost among which are soil fertility, biological characteristics of crops and their varieties, agricultural-technical practices, methods, timing and amount of fertilizers introduced, as well as to the large extent - the weather conditions. The latter factor determines 20-60% of the variation of fertilizer efficiency in the Non-chernozem belt and 35-70% - for the Chernozem soils (Bioclimatic Potential of Russia ..., 2006) (Биоклиматический потенциал России..., 2006).

Table 1. Partial impact of different factors on the yield of cultivated crops (according to Sychiov, 2003).

Zone	Fertilizers	Degree of soil cultivation	Impact of weather conditions
North taiga	34.4	21.3	44.3
Middle taiga	36.7	23.5	39.8
South taiga	30.5	20.1	49.4
Forest-steppe	23.3	35.8	40.9
Steppe	12.6	44.3	43.1
Dry steppe	10.4	30.5	59.1

To assess the BCP, the present study has used a method based on the imitational system CLIMATE-SOIL-CROP, originally developed to predict the yield by the State Committee for Hydrometeorology.

The basis of the imitational system is formed by the dynamic models WEATHER-CROP. On the basis of standard meteorological data, such models allow to calculate (predict) the dynamics of biomass agrocenosis with a daily step from germination to ripening of crops. With that, soil moisture and daily values of the elements of water and heat balances of sowing are identified. The imitational system includes the data base that allows to assess the effect of the climatic conditions on the yearly dynamics of harvest. Such assessment is based on the retrospective observations for 20th century and on the prognostic forecasts for the 21st century. Table 2 presents the values of a bioclimatic potential as well as their augmentation for a number of areas of Russia. The table also includes the Krasnodar region, soil and climatic conditions of which are often taken as reference for the whole territory of Russia. In comparison, we are going to present the BCP values in the conditions of optimal mineral nutrition of plants in several European countries, namely France - 16.5 Germany - 14.5, Sweden - 9.7 tons / ha. To our estimates, in Russia, the ratio of average yield to bioclimatic potential of the country would be about 15%. For the developed countries of Europe this ratio equals to: for Germany - 44%, Sweden - 57% and Finland - 36%. Table 2 presents an analog forecast for average yield for the regions of Russia, in case if the standards of technological level of the Swedish agriculture at the end of the last century would be reached. When conditions of the optimized mineral nutrition and sufficient soil moisture are met, the average yield of wheat should reach 7.1-7.2 t / ha in Moscow, Vladimir and Nizhny Novgorod regions; 8.5 t / ha in the Voronezh region and 10.4 t / ha in the Krasnodar region.

The realistic increases that were seen owing to long-term observations during field research of the Geographical Network in the non-chernozem zone were on average 38-42% of the possible potential. Such increases have happened thanks to the optimizing nitrogen nutritional diet of the plants. The results were 2.2 t / ha in the Moscow region; they decreased to 1.6 t / ha in the southwest of the Nizhny Novgorod region and were up to 1.4 tones / ha in the Vladimir region.

Table 2. The estimates of components and possible augmentation of bio-climatic potential by optimizing the water regime and mineral nutrition

Region	BCP value, ton/ha·year				Augmentation of BCP, ton/ha		
	BCP_0	BCP_W	BCP_N	BCP_{WN}	Δ_W	Δ_N	Δ_{WN}
Moscow Region	5,2	5,6	12,6	12,6	0,4	7,4	7,4
Vladimir Region	6,0	6,9	12,3	12,5	0,9	6,3	6,5
Nizhny Novgorod Region	5,0	5,8	12,3	12,7	0,8	7,3	7,7
Voronezh Region	7,0	10,9	11,7	14,9	3,9	4,7	7,9
Krasnodar Territory	10,1	15,9	11,9	18,3	5,8	1,8	8,2

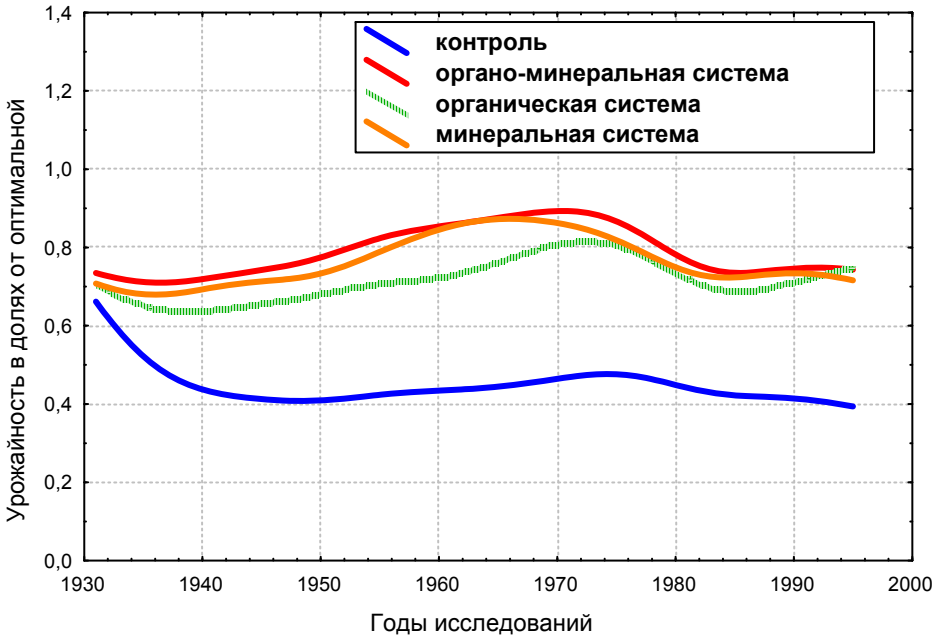
BCP_0 corresponds to low cost system of agriculture, BCP_W - low cost with irrigation, BCP_N - intensive based on application of chemicals, BCP_{WN} - intensive based on application of chemicals and irrigation. $\Delta_W = BCP_W - BCP_0$ – augmentation owing to the optimization of water regime, $\Delta_N = BCP_N - BCP_0$ – augmentation owing to optimization of mineral nutrition, $\Delta_{WN} = BCP_{WN} - BCP_0$ – augmentation owing to the complex optimization of water regime and mineral nutrition.

According to our data based on our observations from mid-1970's, majority of indicators has shown that for agricultural regions of Russia, ensuring the production of about 85% of commodity grain, the changes of climatic conditions have been favorable. However, the positive potential of such climatic changes was not fully used. Positive trends for the harvests from 1975 to 2005 years were reported for 70% of the RF subjects (despite the failures associated with the restructuring of the countries economy) confirm, or at least do not contradict the above conclusion.

Summing up the collected for many years agro climatic data and regression equations, which describe the efficiency of fertilizers application, enabled to conduct a retrospective analysis of changes in the average efficiency of nitrogen fertilizers use for grain crops for the period from 1975 to 2004. The analysis has taken into account the observed changes in climate and was based on the account of hydro-meteorological and soil parameters. The calculations were performed using the information from the database of 455 hydro-meteorological stations on the territory of the CIS. The efficiency of fertilizers used for most agriculturally important regions of our country over the past 30 years has increased or remained the same. The potential yield increase has ranged from 0.5 to 3 tons per hectare. This conclusion applies primarily to the North Caucasus, Volga and Ural economic regions. However, as a result of increasing aridity in some regions of Siberia (Altai Region, Zabajkalje Region), as well as in the Far East and in parts of the Nonchernozem areas (Smolensk, Tver, Yaroslavl, Vologda and Novgorod regions), the potential effectiveness of fertilizers decreased by 0.5 -2 M ha.

For the several long-term research programs of the Geographical Network, the comparative analysis was used to analyze the data obtained by using the imitational system CLIMATE-SOIL-CROP. The yield values achieved using the optimal nitrogen nutrition were compared to those when fertilizers were not used at all. Also, the comparative analysis was conducted to discover the influence of: average doses of fertilizers, the equivalent introduction of organic fertilizers and that of mix of fertilizers with means of chemical protection. As a result, it was established that in the absence the optimal nitrogen nutrition, the natural fertility of the soil (when fertilizers are not used) has the potential productivity of 40-50%. When the organic fertilizers were applied, the potential was higher by 10-15%. Organic-mineral and mineral (equivalent to doses of NPK) nutrition cases were closer to realizing the potential productivity of spring grain crops reaching on average 80-85% from possible optimal values. (Figure 1). Thus, organic-mineral fertilizers use system is efficient in maintaining a long-term productivity potential, which is equal to an equivalent amount of introduced mineral fertilizers. The introduction of herbicides (on this background and in the same period) has allowed to reach the optimal values of productivity. When competition for mineral nutrition with weeds was eliminated, the achievement of sustainable increases in productivity has taken place. The use of the additional means of defense, on this background, has given only unsustainable effects. For the Nonchernozem zone, it will require at least 10-20 years to reach a new level of soil fertility when mineral nutrition of plants is optimized.

Figure 1. Dynamics of the realization of the potential productivity of spring grain crop when organic and mineral fertilizers are used. Moscow region, research DAOS (ДАОС) using pure steam, oats.



With the rise of farming culture and with the increase in soil cultivation levels, relative contribution of weather conditions on the variability of crop yield in the Nonchernozem zone in practice does not cause any decrease. We have analyzed whether there was a possibility for profitable farming for the cultivation of winter wheat in the conditions of the Moscow region. The analysis was based on the management of doses of fertilizers, taking into account possible return on investments in case if weather conditions and soil fertility would change. The sort related specifics as well as the prices of fertilizers were also taken into account. In order to evaluate the different scenarios, the following factors were considered: the functions of productivity, the investment return on fertilizers use and the profits from the sales of the grain. The calculations were made on the base of models of productivity, which take into account the soil parameters, the doses of fertilizers used, the temperature and the precipitation during the period of vegetation, as well as the interaction of the above indicators.

A standard indicator was used as a profitability criterion, which was calculated by deducting the nitrogen fertilizers costs (the gross return over fertilizer cost, GRF) from the gross profit from the grain sales. The costs of the introduction of fertilizers and of the management of additionally acquired production were not included into the profitability criterion calculation. Therefore, the real profits will be lower than the presented results of the calculations. Nevertheless, this profitability criterion is an important comparative indicator, which allows to measure the efficacy of the agro technical measures taken.

The results of the calculations are presented in the Table 3. As it is seen from the table, according to the calculation of the optimal doses of fertilizers, based on the mean weather conditions of many years , the dose of N, providing maximum profit, would be 100-140 kg / ha. In terms of process prevalent in 2007, such dose provided production of 2.8 t / ha of grain on a well cultivated soils and of 2.1 t / ha on soils with low fertility. In such conditions, the return did not exceed 10 kg grain / kg fertilizers. Due to the increase in soil fertility, the doses of N can be reduced by 10 kg / ha. Use of new varieties of wheat with a high agro technical background gives a possibility to generate greater return on fertilizers measuring up to 15 kg / kg. However, that would require to increase the doses of N to 100 kg / ha. In such case, the yield would increase to 3.2 t / ha (or 57% of maximum capacity).

With an increase of soil cultivation, gross profits were increasing by $ 80 per hectare, and moreover, with the use of new crop varieties – by additional $ 30 per hectare.

Pricing prevalent in 2009, is much more favorable for farmers with regard to price ratio of grain / fertilizer price. This gives possibility to increase the optimal doses up to 140 kg / ha. Consequently, there is a noticeable gain in return when using cultivated soils, which increases from 8 to 13 kg / kg. At the optimum doses of fertilizers, the harvest increased to 3.1 t / ha, therefore approaching the maximum capacity. Introduction of new crop varieties can reduce an optimum dose of N to 110 kg / ha with a simultaneous increase in a return to 14 kg / kg. In this case, the yield reaches 3.2 t / ha. Economic efficiency of measures for improvement of plant fertility, in prices of 2009, can measure to $ 110 per hectare, while the use of the new crop varieties is causing an augmentation to $ 40 per hectare.

Taking into account the actual weather conditions can greatly adjust the optimal dose of applied fertilizers. For example, at 2009 prices, the optimum dose of N could have been increased to 210 kg per hectare, ensuring the production of 4.9 t / ha of grain with return of 10 kg / kg. In such case, the gross revenues would measure to more than $ 250 per hectare in comparison to mean conditions calculated for many years. With regard to 2007 prices, the optimal dose N would be 150 kg / ha, with the payback 13 kg / kg, providing a yield of 4.6 t / ha (or 90% of optimal capacity). In an unfavorable year, the optimal dose is reduced to 100 kg / ha at 2009 prices and 40 kg / ha at 2009 prices for both well cultivated and poorly cultivated soils. In such case, the possible yield would be 1.2 to 2.3 t / ha (80-85% of the optimal capacity at prices of 2007) with a return of 6 and 9 kg / kg respectively. The losses in profits, compared with a hypothetical mean year calculated on the base of many years, would amount to $ 65-110 per hectare. As it can be seen from this example, the price situation has a significant influence on the optimum dose of N fertilizers. Therefore it is necessary to make adjustments depending on the prevailing weather conditions, thus avoiding the use of excess fertilizers. How can such adjustments be made?

The applied research has shown that the there is a possibility of sustainable management of yield augmentation and possibilities for a return on fertilizers used. Above results are reached for grain crops in the Nonchernozem zone when the range of doses of nitrogen fertilizers used were 60-90 kg / ha, with variations related to changes in levels of soil cultivation, comparable to that due to influence of weather conditions. The optimum dose of fertilizers increased to 120-180 kg / ha in years with favorable climatic conditions. The annual adjustment of the doses requires to take into account the level of soil cultivation. With doses of less than 60 kg / ha, the weather conditions can increase the uncertainty about the effectiveness of fertilizers, more than doubling therefore the increased risk of correct assessment of return.

The optimum dose of nitrogen fertilizers can be calculated on the basis of a set of factors that determine the interaction of doses introduced with the amount of rainfall during the resumption of vegetation of winter wheat and during the initial faze of vegetation of spring barley. Maximum increase of yield per unit of active ingredient of nitrogen fertilizer for winter wheat is proportional to the amount of April precipitation. The later defines the conditions of humidity after the resumption of growth and enhances the return on fertilizers use by yield augmentation of winter crops by 0,6-1,5 kg grain / kg of nitrogen per 10 mm of rain (Figure 2). For spring barley, the gain is 0,5-0,9 kg grain / kg of nitrogen for every 10 mm of rain in May, i.e. during the beginning of intensive growth of the culture. Thus, knowing the conditions of moisture during the spring period, it is possible to adjust the doses of N fertilizers in the early stages of vegetation.

Conclusions:

So far, the efficiency of fertilizer application, the criteria of harvests dependence on the level of soil cultivation, as well as the best indicators of soil fertility were calculated on the basis of sample research. The samples collected contained identical or very similar doses of fertilizers. In such calculations, the interaction of climate, soil conditions and mineral fertilizers was not taken into account. The proposed approach refines the patterns of the formation of grain yield on the level of individual agricultural enterprises. It also gives a possibility to forecast the effectiveness of the use of mineral fertilizers, while including into the normative calculations a paramount factor of weather conditions. The above approach has proposed the means of formalizing of the task of calculation of potential yields for different levels of productivity and that of the management of amounts of mineral fertilizers introduced. The doses of fertilizers are assessed on the basis of their efficiency and payback of fertilizers in the conditions of simultaneous changes in climate and in soil fertility. The study has built a fundament for a possibility of rapid optimization of the doses of fertilizers in the early stages of the initial growth period of spring crops and in the periods of continuation of the growth of winter crops. Commercial output consists of the implementation of the strategy of use of separate fields to obtain the maximum possible profit depending on a climate prevalent during a particular year, on the level of soil fertility and on the agricultural techniques applied as well as on the choice of most suitable cultures.

Figure 2. Change of the return on nitrogen fertilizes used for winter wheat, depending on the amount of April precipitation and doses of nitrogen fertilizers.
a) The Nizhny Novgorod region, gray forest soils, 16 years of observation,
b) The Moscow Region, sod-podzolic soils, 32 years of observations.