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Diagnostics and optimization of crops' nitrogen nutrition in rainfed conditions of the Northern Kazakhstan

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Abstract—Northern Kazakhstan is the basic region producing grain in the Republic of Kazakhstan. National economy depends on its state. A brief description of the characteristics of soil and the climatic conditions is given in the article. The results of years' research (n=600) in diagnostics and optimization of crops' nitrogen nutrition in the conditions of insufficient and unstable moistening of Northern Kazakhstan are considered in this article. The methodological approach to the evaluation of soil nitrogen state and crops with nitrogen is explicated. New method of determining the needs and dose calculation in nitrogen fertilizers with individual requirements of crop and the main factors defining their effectiveness is represented. The method is based on identification of major factors of soil fertility defining the efficiency of crops and nitric fertilizers. On the basis of the correlation analysis, the quantitative interrelation of factors with efficiency of crops is defined. Optimum parameters for measuring the content of nitrogen in the soil required for the maximum efficiency of crops and ways for achieving it are determined. The method considers individual requirements of crops and the main factors defining effectiveness. The developed technique allows purposefully managing soil nitrogen regime supplying optimization of nutrition and implementation of crops' potential possibilities.

I. INTRODUCTION

Kazakhstan is an agrarian country. It is among the largest countries in the world by the occupied area. Land Fund of the Republic makes up 272.5 million hectares among which the agricultural land makes up 222.5 million including the arable lands making up 22.3 million hectares. From all of these, about 60 % of arable lands are in the North zone of the Republic where agriculture is a vital sector [1]. Arable land in the Northern Kazakhstan is represented mainly by the chernozem (black soil) (ordinary and southern) and dark chestnut types of soil [2], [3]. They are characterized by relatively favorable physical and physico-chemical properties but differ considerably in the humus content and gross forms of nutrition elements. Black soil is characterized by a high humus content: ordinary - 6-8%, south - 4.5-6.0 %, dark brown from 3.0 % to 4.5%. Soil of the Northern Kazakhstan is characterized by a very high content of exchange-absorbed potassium (K2O to 80 mg per 100 g of

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soil). Limiting factors of harvest are moisture deficit, mobile phosphorus and nitrogen.

Extensive farming led to a serious drop of potential and effective soil fertility. Humus loss, for the last half century according to agrochemical service of Kazakhstan reached 25-30%. Annually about 2.5 million tons of nutrients irrevocably get alienated which leads to degradation deepening and fertility reduction. Approximately 70% of soil is characterized by high soil phosphorus deficiency and requires about 50% of nitrogen. Reason for the decline in the effective and potential fertility of soils is the low level of fertilizer application [4]. About 4 kg of acting matter is applied per hectare of an arable land. But the formulaic application of fertilizers can lead to negative consequences - contamination of soil and environment [5], [6].

For efficient and environmentally safe production of the crops, it is very important to determine the most accurate method of diagnosing their needs, taking into account all factors determining the efficiency. This fact has been neglected till date. In practice, fertilizers are the most commonly used stereotype whose average dose is determined empirically based on the field experience and are applied to any given crop considering them universal. Interpolation of this dose to the vast territory does not guarantee their effectiveness. Balanced methods are applied without proper approbation to the zone conditions [7], [8] with the help of a formula and this can have negative consequences as well.

P–productivity, c/hectare; C –an indicator of carrying out an element by crop unit; N – the content of the easily hydrolyzed nitrogen in the soil, mg/kg; n– nitrogen efficiency from the soil; Cf – coefficient of nitrogen efficiency from fertilizers.

Approbation of used and the development of improved diagnostic methods and crop nutrition as well as fertilizer application are the goals of long-term studies.

II. OBJECTS AND METHODS

Objects: the main types of arable soils of the Northern Kazakhstan (dark brown and black soil), cereals and legumes (wheat, chickpeas, peas). 200-330 mm of precipitation for the crop year falls on dark chestnut soils located in the dry steppe zone and 350 mm and above falls on the black soils in the forest-steppe zone. The vegetation period makes up 140-150 days. The sum of temperatures during the growing season in average makes up 2300-2400^{o} [9].

Methodological approach to the development of diagnostic methods and ways of soil fertility management were based on the results of long years' research in the long stationary multivariate experiments with fertilizers by which different levels (not less than 4) of nitrogen and nitrogen-phosphorus nutrition were determined. Availability of potassium is high (600-800 mg / kg soil). For this purpose, in spring before seeding soil tests were conducted from each option of experience from 5 points on a plot in which the main agrochemical indicators of fertility and soil properties were defined. Potential and effective soil fertility, their changes under the influence of climatic, agronomic factors and fertilizers were studied during the experiments [10].

Basic indexes of soil fertility were determined by conventional methods in agro chemistry and the methods for neutral and calcareous soils [11].

The content of humus was determined by I.V.Tyurin's method which is based on oxidation of soil humus with chromic acid, with the subsequent titration by Mohr's salt in the presence of phenylanthranilic acid. Easily hydrolyzed nitrogen was determined by Tyurina-Kononova's method. The method is based on soil processing on cold 0,5 n. by H2SO4 solution with the subsequent infusing within 16-18 hours. Restoration of NO3 to NH4 was made possible by adding mix of the restored iron and a zinc dust to the solution (1:9).

Absorbed ammoniac was determined in a salt soil extract (1% KCL solution) by a colorimetric method with Nessler's reagent.

Definition of nitrogen of nitrates was carried out by two methods:

In a water extract according to Grandval-Lyazhu's method with phenoldisulfonic acid by a colorimetric method on the KFK-3-01 ZOMZ and ion selective method on pX-150MI device (Russia, "Measuring equipment", 2013).

III. THE RESULTS OF STUDIES

By using the most advanced diagnostic methods of mineral nutrition, the results of the field experience and balance method of defining the doses of fertilizers were obtained. By the method of correlation analysis the major factors for productivity and their quantitative communication with efficiency of crops and efficiency of fertilizers were identified. By correlation curve the optimum parameters leading to maximum efficiency were determined.

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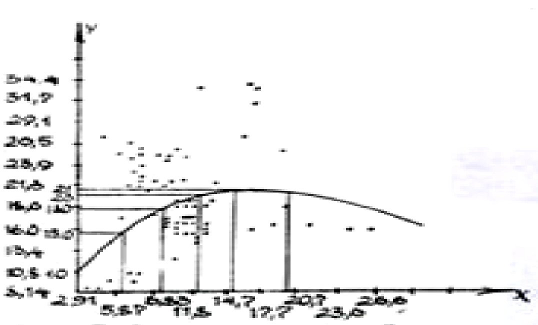
Studies have shown that the results of field experience, not based on fundamental theoretical studies are purely private, local, and objectively reflect only that situation in which it is held. Any change in the experimental conditions (soil, moisture, etc.) entails a change in the results of the experiment, table 1.

From table1 it can be seen that on the same soil in different years, the same dose of fertilizer worked with different effect.

TABLE I
EFFECT OF FERTILIZER ON PEAS AND CHICKPEAS PRODUCTIVITY, DT/HA*

Applied (kg a.s. /ha)	Harvest on control and increment to it (dt/ha)								
	2006	2007	2008	Average	2005	2006	2007	2008	average
	Peas				Nut				
0	15.4	13.4	15.2	14.7	9.6	8.3	20.3	11.1	13.2
P_{60}	1.8	0.7	1.8	1.3	1.3	1.7	3.8	2.1	2.2
P_{90}	3.1	1.1	2.2	2.1	2.6	3.3	4.8	4.5	3.8
P_{120}	3.6	2.0	3.6	3.1	3.6	3.9	6.1	4.7	4.6
P_{150}	5.0	2.2	-2.6	0.6	4.8	4.1	4.0	4.2	4.3
P_{210}	6.0	2.7	-3.2	1.8	3.8	5.3	2.5	3.9	3.9
N_{30}	2.3	1.0	-0.6	0.9	3.7	1.6	4.8	1.2	2.8
N_{60}	-1.1	2.8	-1.2	0.5	5.3	2.6	5.9	1.1	3.7
$P_{90}N_{30}$	8.5	4.0	1.0	4.5	0.7	3.8	1.9	2.8	2.3
$P_{90}N_{60}$	3.6	1.9	0.4	2.0	1.8	3.7	2.7	5.4	3.4
HCP_{05}	1.5	1.0	1.0	1.2	1.21	1.06	1.68	1.14	1.27

a.s- active substance; dt/ha**-0, 1t LSD - the least significant difference on options



N-NO_3 mg/кg, layer 0-40

Fig. 1. Relation of wheat yield (У) with N-NO_3 mg/kg in the layer 0-40 см (Y), on dark chestnut soils, n 90, r=0.46 Y=5.34*0.76x^2*EXP (-0.049x).

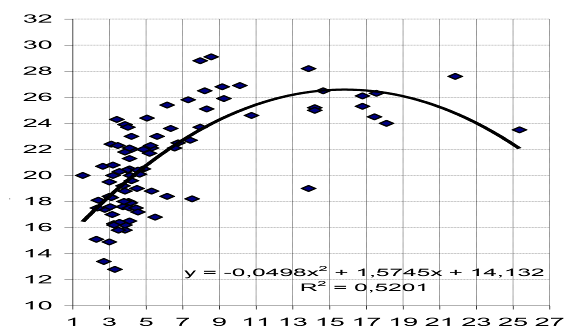
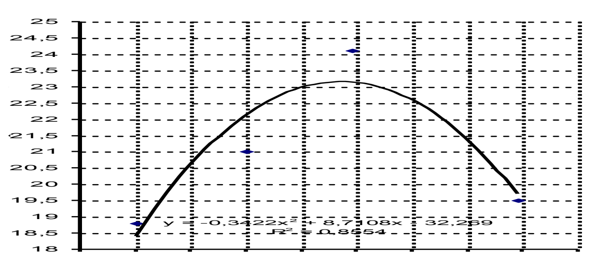
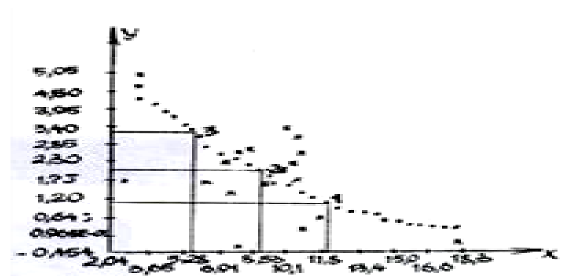


Fig. 2. Interrelation of wheat yield with N-NO_3 (by crop rotation) on general black soils, 2003.



N-NO_3 mg/kg, layer 0-40

Fig. 3. Relation of nut yield with N-NO_3 ,2003 г., R =0,94.



N-NO_3 mg/kg, layer0-40

Fig. 4. Relation of peas yield with N-NO_3, 2009, R. =0,94.

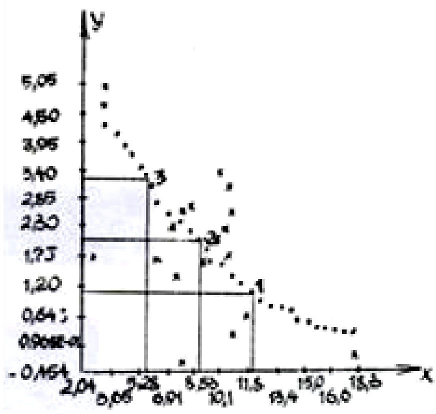


Figure 5. Wheat gain relation (y) with N-NO_3mg/kg at P_2O_5>25 mg/kg, n 0, r=0.64;У =-1.86 + 40.9/x 70.1/x^2.

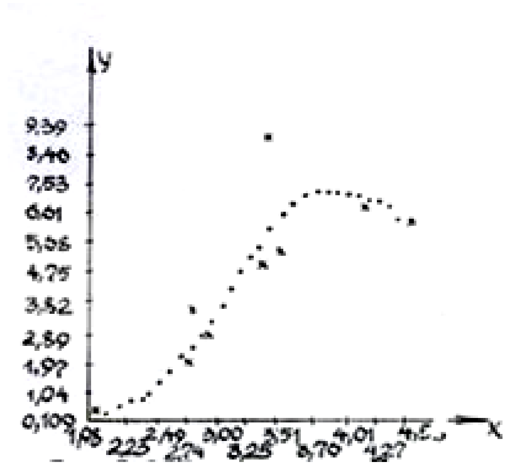


Figure 6. Effectiveness N_{30} (y) according to the content of P_2O_5 in soil (x),r=0.98; У=0.0562*19.3x*УХР (-4.9).

The average yield on the variants of the experiment reflects only the arithmetic mean value, but does not rule. Fertilizer efficiency depends not only on the initial content of elements in the soil, but also on their relations, which should be considered when determining element deficiency in the soil and calculating doses.

This is one of the major reasons that restricts broad interpretation of the findings and the reproducibility of the results of field experience in other conditions and obstructs the choice of the best solution. Studies have shown that a single "universal" medium dose of fertilizer that would always provide the best result cannot be considered as aprinciple. And it is impossible to deliver the same field experience on every field.

Studies have shown that the balance method is totally unacceptable for the area of Northern Kazakhstan having unstable moistening due to the high degree of variation of all parameters used in this method which are dependent on many factors like very dynamic - hydrothermal conditions, soil properties and fertilizer, nutrient state in soil, agricultural methods, precursor doses, types and forms of fertilizer [12].

In search of new solutions for a long time, we have studied the full range of issues related to both soil fertility and efficiency of nitrogen fertilizers in order to establish patterns of fertilizer action and establish a quantitative relationship between the indicators of soil fertility, efficiency of fertilizers and crop productivity.

There is a wide variety of nitrogen forms in the soil.Determination of the diagnostic indicator of crops provision with nitrogen and requirements for nitrogen fertilizers without which it is impossible to solve the problem of effective targeted soil fertility management are complicated issues..

In the literature a large number of diagnostic methods for soils with nitrogen are available: the sum of mineral and soluble organic compounds) [13], [14] by the sum of ammonia and nitrate nitrogen [15], nitrifying capacity [16], [17], the method of alkaline hydrolysis [18] content in the soil N-NO3 in the layer 0-40 cm in autumn or pre-period [19], [20], [21].

Studies have shown that by applying all of these methods in the conditions of the Northern Kazakhstan only with the content of N-NO3 in soil, correlation yield can be established [10]. Figures 1-4.

From figures 1-3 it is seen that the yield increases with increasing content of nitrate nitrogen in the soil and goes to a certain limit beyond which efficiency decreases, which allows determining the optimum level of nitrogen content for the crop. For spring wheat, the upper limit of saturation is at a level of 15 mg N-NO3 per kg of soil layer from 0-40 cm inall soil types, figure 1.2. The lower limit is 12 mg. Increasing N-NO3 from 12 to 15 mg (1 centner increase) does not guarantee economic efficiency, Figure 1. Different crops require different levels of saturation of soil nitrogen. So, chickpeas and peas (Figure 3,4)deliver the maximum productivity in all the years when the content of nitrate nitrogen in the 0-40 cm layer is at the level of 10-12 mg per kg of soil.

Correlation curve, Fig. 1, reflecting connection between the results of 42 field experiments allowed us to determine the zonal scale security and regulatory

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allowances. Elevated levels of N-NO3 in the soil for up to 6 mg / kg soil (very low supply) increased yield by 5 centner; from 6 to 9 mg (low) gain 3 kg / ha, from 9 to 12 per 2 centner and from 12 to 15 mg per 1 centner, which is confirmed by figure 6. Excess nitrogen saturation of soils, as well as a lack leads to reduced productivity of spring wheat.

Determination of optimal level of nitrate nitrogen in the soil is highly essential to evaluate and justify the economic and environmental viability of fertilizer application.

Studies have shown a high dependence of the efficiency of nitrogen fertilizer not only on the content of mineral nitrogen in soil, but also on cultural phosphorus, figure 5, where the maximum effect is obtained from N30 on the optimal phosphorus background-35 mg/kg of soil, figure 6.

TABLE II
SCALESECURITY OF CROPS WITH NITROGEN,NEEDS ANDEFFICIENCY OF NITROGENFERTILIZERSCONTENT BY N-NO3 ANDP2O5IN SOIL,MG /KG (CHERNENOK)

Class security	$N\text{-}NO_3$ mg/kg at security with P_2O_5		Needs in N fertilizers	Recommended dose of N, kg d. v/ha	regulatorygrowth, c/ ha	Growth, %
	Very low- average	Average				
Very low	till4	till 6	Very	60	5-3	30 и.>
Low	4-8	6-9	High	45	3-2	20-30
Average	8-12	9-12	Average	30	2-1	10-20
Increased	12-15	2-13	Low	0	Less 1 dt	<10

*$N\text{-}NO_3$ in layer 0- 40 см and P_2O_5 in layer 0-20 см, mg/kg

* Scale is seton the basis ofcorrelation analysison the respectivebackgroundsof phosphorus.

Excess and deficiency of phosphorus reduce the efficiency of nitrogen fertilizer, which is important to consider when determining the deficit and doses of nitrogen fertilizer and it is accounted for in the zonal scale security indices, Table 2.

The given scale is significantly different from the one previously identified [19]-[20]-[21] by depth study and validity of the results of mathematical analysis. Previously proposed gradation does not consider a number of important confounding factors that affect the efficiency of nitrogen fertilizer in the soil. The content of phosphorus in soil and the moisture content also need to be considered.

It is known that the most important factor determining the efficiency of fertilizers is moisture content of crops. At the conditions of higher moisture, allowances within the class will be much higher and lower in dry. To clarify the dose and regulatory adjustments the gain correction factor for moisture conditions (CF (Correction Factor) for humidity)is used based on the ratio of projected rainfall for crop year to regulatory (275) adopted by probation for one, formula 1. This gives the ratio > or <1 multiplying by which gives the adjusted regulatory increase and dose of fertilizer.

$$CF = \frac{\text{Pr}\,ecipitatio\,n\ \ forecast}{\text{Pr}\,ecipitatio\,n\,regulatory\,(275)} \qquad (1)$$

275 value is constant. This average annual precipitation for the period is established by research facilities where studies were conducted. This approach stems from the fact that it was the rainfall for crop year that set the highest relationship (r = 0.60), with spring moisture reserves totaling to 0.37 and precipitation of the vegetation period of 0.46 [10].

Projected for the current year, precipitation is suggested to be calculated not by long term average but in fact by the established planting period for the previous crop year. For the Northern Kazakhstan rainfed conditions continue from September till May. Precipitation for June-August (months of the vegetation period) is added on the basis of the forecast. If the forecast rainfall is below normal in June it is added with 0.5 standards-term averages. If higher, then it is done with 1.5 norms. fin the normal range, then the average annual rate is added. This reduces to a minimum error calculation of CF (Correction Factor) for humidity. In the worst outcome, the error does not exceed 10% if the monthly deviations from the calculated values for all three months will be familiar only with the "+" or just "-",

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but usually it is within 3%.

Introducing the correction factor for moisture at times, the accuracy of dose determination and prediction of fertilizer efficiency are by reducing the dose step from 15-30 to 3-6 kg / ha, Table 3.

TABLE III
DOSESOF NITROGEN FERTILIZERS ANDCROP INCREMENT(T/HA), DEPENDING ON THE CONTENT OFN-NO3IN SOIL ANDCF(CORRECTION FACTOR)FOR HUMIDITY

Rainfall for agricultural year, mm	PK wet	Provision with nitrogen					
		Very low		Low		Average	
		dose, kg a. s.	Gain of yield	Dose N, kg	Addition to the yield	Dose of N, кg	Addition to the yield
200	0.7	42	2.1-3.5	32	1.4-2.1	21	0.7-1.4
225	0.8	48	2.4-4.0	36	1.6-2.4	24	0.8-1.6
250	0.9	54	2.7-4.5	40	1.8-2.7	27	0.9-1.8
275	1.0	60	3.0-5.0	45	2.0-3.0	30	1.0-2.0
300	1.1	66	3.3-5.5	50	2.2-3.3	33	1.1-2.2
325	1.2	72	3.6-6.0	54	2.4-3.6	36	1.2-2.4
350	1.3	78	3.9-6.5	58	2.6-3.9	40	1.3-2.8
375	1.36	82	4.2-6.8	61	2.7-4.1	41	1.4-2.7

*$N\text{-}NO_3$ in 0-40 cm layer, and P_2O_2 in 0-20 cm layer, mg/kg
*scale is established on the basis of the correlation analysis on the corresponding phosphorus backgrounds.

This gives great cost savings and fertilizers. The range of variation is due to increase of dose and class performance security in accordance with graduation.

This table is convenient to use for specialists. By focusing on rainfall, class of security (for example low), and knowing the price of fertilizer and grain, you can calculate how profitable it is in a given year to apply nitrogen fertilizer.

More precisely, with respect to each element in the soil mg, the need for nitrogen fertilizers can be calculated by formula optimization (Chernenok)

DN kg a m=(Nopt-Nact)*7.5* CF (2)

where DN-dose of nitrogen fertilizers, kg/ha acting matter;

Nopt-the optimum nitrogen content of nitrates (N-NO3) in soil, mg / kg in a layer of 0-40 cm;

N act.-actual content of N-NO3 in the soil, mg/kg;

7.5 - equivalent nitrogen fertilizers of 1 mg of N-NO3 of soil established experimentally.

CF (Correction Factor) for humidity

Formula allows with high accuracy to bring the nitrogen content of nitrates in the soil to the optimum level. The calculation of dose should be based on expediency to bring nitrate nitrogen content to the lower limit of the optimum, i.e to 12 mg/kg of soil for wheat and to 10 mg/kg of pea and chickpea. It is not advisable to bring it to15 mg, as it is not accompanied by a significant increase in productivity.

In determining the doses of nitrogen fertilizer it is necessary to consider the security of soil phosphorus. According to formula 2, it is advisable to calculate whether the dose of fertilizer in the soil phosphorus content is lower than middle class.

If a significant deficiency of phosphorus is based on the need to preserve the optimal ratio of phosphorus and nitrogen in the soil, which is 2.5-3 P2O5-in the 0-20 cm layer to the N-NO3 content in the layer of 0-40 cm, the dose of nitrogen fertilizer should be calculated by formula 3 (Chernenok):

DN kg ai=(1/3Ropt-Nact)*7.5*CF (3)

where: 1/3 means the amount of nitrogen which is necessary to have for the actual content of phosphorus.

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Identified quantitative relationships between agrochemical parameters of soil fertility and fertilizer efficiency allow to predict the increase of nitrogen fertilizer, using the formula 4 (Chernenok):

Pn = 1,24 - 0,14 N-NO3 + 1,62 CF+0,06 P/N, (4)

where: Pn - an increase of nitrogen fertilizer, c/ha; N-NO3 -content in the soil, mg / kg in a layer 0-40 cm; P/N - ratio of the actual content of P2O5 mg / kg soil in a layer of 0-20 cm to N-NO3, mg / kg in a layer of 0-40 cm.

The equation includes all the factors that determine the efficiency of nitrogen fertilizer and allows to predict the increase in yield with high accuracy, (R = 0,93), Figure 7.

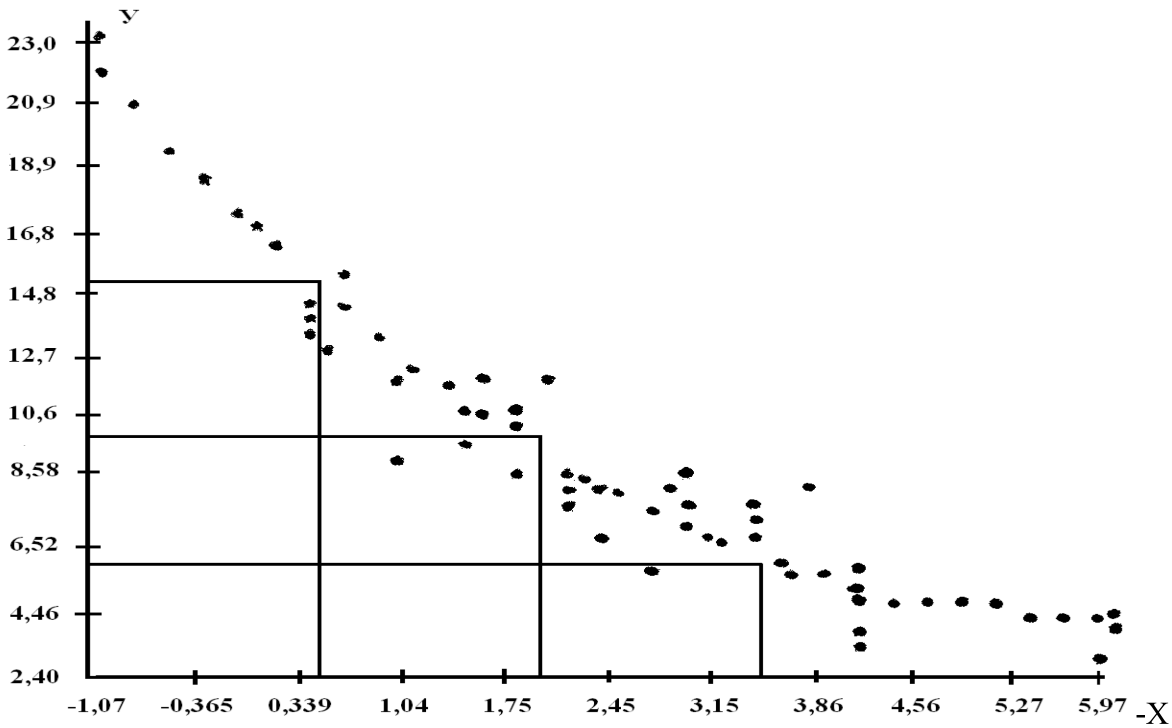

Fig. 7. Relation of projected growth (x) with CF(Correction Factor) for humidity from $N\text{-}NO_3$ (y). r = 0.93, X = A+B×У+C×$У^2$, where A = 16.6; B =4.67, C=0.427

X - Increase from nitric fertilizers; У- level of $N\text{-}NO_3$ in soil layer 0-40 cm, mg/kg.

After developing a range of issues related to establishing the main factors determining the productivity, diagnostic indicators of security crops, nitrogen quantitative relationships with productivity, to determine the optimal parameters of nitrogen in the soil for different crops and the ratio of nutrients, developing methods to achieve these goals will allow to control regime of soil nitrogen.

IV. CONCLUSION

Proposed method for the diagnosis and optimization of nitrogen nutrition of crops and calculation of the demand for nitrogen fertilizers takes into account: the biological requirements of crop, the source of nitrate nitrogen content in the field in the late autumn or pre-period in the layer of 0-40 cm, the content of mobile phosphorus, their relations with and conditions of humidity. This method is principally new, scientifically sound, the most accurate and appropriate for the targeted control regime of soil nitrogen and productivity of crops. Method is appropriate for precisionfarming. It eliminates not only the effective and environmentally dangerous patterns in fertilizer application, but also provides the most accurate way of determining nitrogen deficiency in the soil and fertilizer requirements, based on a certain culture for each optimum level, thus providing targeted management of soil fertility and crop productivity. The proposed method of purposeful management with nitrogen regime and fertilizer dose calculation provides an implementation of the potential in the emerging crop in moisture conditions, while ensuring a high payback and environmental safety of fertilizer application. Optimum level of nitrogen content in the soil for a particular crop is outside the threshold and environmental safety.

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— This article does not have any appendix. —

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