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Regulation of fertility of soils and efficiency of fertilizers in conditions of climate fluctuations

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The purpose. To determine regularities of effect of warming of a climate upon fertility of soils and utilization of nutrients by plants. **Methods.** Systems analysis, field and laboratory probes. **Results.** The possibility is substantiated of adaptation of fertilizer system and sorbtion of microelements by plants for heightening their resistance in conditions of aridity of a climate. **Conclusions.** At warming of a climate the directedness of processes of interaction of nutrients with soil varies. Speed of phosphates' saturation increases. In drought years productivity of sugar beet is positively influenced with the high content of mobile potassium in soil.

Key words: *soils, nutrients, fertilizers, climate, soil fertility.*

Formulation of the problem. Now observed in Ukraine global climate changes exert a significant unfavorable impact on productive efficiency of national agricultural and agro-farming industry. The climate is a crucial factor for soil- genesis and formation, because air temperature and atmospheric precipitation directly govern character of crops' vegetation and soil-formation processes' evolution. Majority of agrochemical transformations that form up an effective status of soil fertility(*) are closely associated with soil-moisture content and soil-temperature indications.

Climatic indications across agricultural lands of Ukraine reflect a wide amplitude of average/mean annual values. Thus, from May to September, values of SHC-index vary from 0.45 on Sivash-bay chestnut soils, toward 1.8 - 2.0 in Carpathian region burozem-podzolic surface-gleyed soils; whereby precipitation rates during cold period (November to March) amount to 120 - 200 mm.

Almost 50% of Ukraine's arable land is located on terrains of agronomically- risky farming areas. Accumulation of moisture in soil, losses of water via evaporation and ability to provide a required degree of moisture-assimilation by plants during the entire vegetation season are guided mainly by aqua-physical soil-properties. Soil-hydrological constants depend mainly on spatial features of soils' granulometric composition that specify conditions for accumulation and conservation of firmly- & weakly- bound, as well as free forms of moisture [1].

One of the most important indicators of positive soil-water properties is the moisture-content rate. As a rule for the most arable soils, amount of potentially available to plants water is only below 1/2 of the overall moisture supply. About 80% of Ukrainian arable land area (over 24 mio ha) possess the types of soil-water-regime that totally or periodically dominate in shaping up the water-deficient moisture-content.

The purpose of the study is to determine the climate- warming impact on soil fertility and assimilation of nutrition elements by crop-plants.

Research methodology. Methodological basis of this study is generalized on results from research on influence of climatic indicators on properties and fertility of agro-soils.

A set of laws that describe impact by arid conditions on (i) mobility of nutrients and their assimilation by plants, (ii) soil moisture consumption per unit production on various agrochemical backgrounds, (iii) dependence of sugar-beet yielding capability on dosage of fertilizer inputs and (iv) potassium background of typical chernozem, in a series of field test-trials and laboratory experiments, have been established.

Research results. Due to numerous hydrometeorological criteria and indicators during the recent 25 years, a phenologically new type of climate has settled up in Ukraine. According to the Ukrainian R&D Institute for Hydro-Meteorology, the most notable climatic changes occur usually in winter and springtime. Compared with data from early 1900-ies, now air temperature in winter and spring has increased by 1.0 to 1.7°C, simultaneously with occurrence of abrupt fluctuations (between low and abnormally high); whereas in summer through autumn, temperature rates remain more or less stable. Rates of atmospheric precipitation in winter have increased by 20 to 50 mm, while in summer-time, precipitation rates either remained the same as usual, or decreased in the following manner: Western Ukraine - by 40 to 50 mm; Eastern and South-

Eastern Ukraine - by 10 to 30 mm; Crimean peninsula - by 20 to 35 mm [2].

Such climatic changes influence the transition of phenological phases in regard of winter-wheat crops, which fact obliquely affects (i) the timing of pre-sowing soil- tillage and (ii) optimal tierms of winter-wheat sowing.

The warming-up of the autumn-winter period by 0.9 to 4.5°C promotes (i) a somewhat longer vegetative period for winter crops in autumn and (ii) an earlier wakening-up for new vegetation in springtime. Due to elevation of average daily temperature rates, vegetation-process of winter wheat in autumn is subsequently extended (from November 7, 2006 to November 27, 2007); which fact opens a possibility to seed up this crop at later terms. Thus, according to the research results gained in 2005 to 2008, the richest yield is typically harvested after sowing the winter wheat inbetween the 2nd and beginning of 3rd decades in September [3]; on the contrary to previous years, when the optimum sowing time across the Eastern Forest-Steppe zone was most optimal inbetween August 25 to September 10.

Changes of weather conditions compel one to undertake adaptive activities in agro-farming business to comply with factual climatic realities.

Among these activities, main attention should be paid to:

- introduction of moisture-saving soil cultivation technologies,
- adjusting the terms of sowing (especially for winter crops);
- determining an impact by climate change on availability of soil nutrients;
- the role of balanced fertilization for crops in increased resistance of plants to stressful conditions;
- forms and optimal terms of fertilizers' application;
- methods of fertilizing procedures in dependence on soil layer differentiation per content of nutrients.

Guaranteed restoration of soil fertility and well-balanced fertilizer inputs are an indispensable condition for enhancing the agroecosystems' stability to climate changes. Turnover, balance and transformation of macro- and micro-elements in soil depend on hydrothermal conditions and therefore, management of soil- nutrient regime can become one of the most important factors of adaptive practice of minimizing potential impact by the climate change on agro-production output [4].

According to numerous studies, the unstable meteorological conditions result from year to year in up to 40 - 50% cases of of crop-yield fluctuations on the average; whereas on well-cultivated land, such abnormalities are not frequent, mostly thanks to soil-management per principles of expanded reproduction of efficient soil-fertility. Due to generalized data, grain crop yields on well-cultivated soils suffer from dry conditions almost twice as less frequently (depending on soil type, of course) vs those on poorly-cultivated lands (Table 1).

Climate changes affect nutrients' mobility in soil and nutrients' availability to plants. Temperature rise multiplied by moisture decrease lead to reduced mobility of nutrients and simultaneously, to slowing down the growth of plants' root-system.

The most part of plants- needed nitrogen arrives into soil with mass-transfer flows, while soluble forms of N are water-driven to plant- roots being absorbed thereby. Accession of phosphorus and potassium to crop-roots runs due to diffusion- effect. Through decrease in transpiration rates under drought conditions, the nutrients' distribution in soil is significantly inhibited [6].

TABLE 1 - INFLUENCE OF ADVANCED SOIL-CULTURIZATION ON YIELDING CAPACITY OF GRAIN CROPS [**Ошибка! Источник ссылки не найден.**]

Soils	Average yielding capacity, Centner/ ha		Decrease in yield in unfavorable years, %	
	1	2	1	2
Podzolic & sod-podzolic	10-15	25-35	30	16
Gray forest	15-20	30-35	30	18
Dark gray loose	19-23	35-40	26	12
Chernozem of Forest-Steppe	20-26	35-40	26	12
Chernozem of Steppe	18-22	30-32	40	18
Solonetz complexes	5-15	18-25	60	20
*Keynotes	1* - little or poorly-cultivated soils			
	2* - well-cultivated soils			

Increased amount of precipitation in autumn-winter period leads to eluvium (washing-out) of nitrate forms of nitrogen beyond the soil profile. According to [7], value of mineral 160 cm-deep nitrogen supply in typical heavy-grained chernozem (fed up with nitrogen fertilizers) has exeded the corresponding indicator in control tests by 5 times! However, it should be noted that with soil-temperature and soil-moisture optimization, the nitrification ability is normally increasing and hence, the nitrogen regime should be regulated by aid of winter-wheat fertilization in springtime. But before doing so, values of mineral nitrogen reserves in 0 - 60 cm-deep soil-layer must be taken an account.

A long-term drought during the crops' growing season in non-irrigated systems is often accompanied with incomplete soil nutrients' assimilation, which fact indicates the need for scientifically proven methods of governining the fertilization systems in order to avoid excessive (thus ineffective) fertilizer inputs and losses of nutrient materials [8].

An influence of certain nutrient elements on drought- tesistance of cultivated plants is characterized by various processes in soil. Thus, active genesis and intensive branching of crop- root system are influenced by (i) plants' assimilable forms of nitrogen (preferably nitrates) in soil at early spring vegetative period in favorable temperature and moisture conditions, and (ii) increased dosage of nitrogen fertilizer inputs for winter wheat after such precursors as black fallow or perennial grasses.

Under such conditions, crop-plants prevailably do not germinate their ear, yet spend a significant amount of soil moisture to create fresh vegetative mass. In springtime under dry conditions, the upper soil (0-10 cm-deep) layer is rapidly drying up, thus decreasing the nitrification processes' activity. General temperature elevation in autumn-winter period (together with simultaneous increase in amount of precipitation) contribute to leaching the nitrate nitrogen beyond the boundaries of soil profile; thus causing the young winter wheat sprouts to suffer from lack of nitrogen in springtime. In this connection, the task to optimize normatives of additional nitrogen fertilizer inputs is very complicated, - taking into account values of mineral nitrogen content within 0 to 60 cm- deep layer, especially if winter- wheat is seeded on a black-fallow or evergreen grasses' background.

Effective nitrogen assimilation at synthesis of proteinous substances is facilitated by an optimal correlation between mineral nitrogen and mobile forms of phosphorus in soil; therefore, in soils with high and elevated phosphorus contents, degree of nitrogen fertilization's influence on drought- resistance is ever increasing.

Phosphorus is an important factor for growth and development of cultivated plants, especially at initial stages of their genesis / vegetation. Conditions for active growth of well-branched root system, able to readily assimilate existing nutrients and moisture from soil, can only be possible via sufficient soil provision with mobile forms of phosphorus. Unlike nitrogen, phosphorus is characterized by very low rate of mobility in soil, and also by ability to be rapidly absorbed by solid phase of soil, in dependence on its granulometric composition and moisture content. According to authors' data, absorption of phosphorus in a lab experiment (at constant 24 C temperature and 60% field moisture content) runs intensively within first 30- 60 days (with its peak value on 120th–130th day of composting), under conditions of elevated to natural phosphate backgrounds of typical and ordinary chernozems.

In natural conditions during growing season, soils reside in alternating wetting- and- drying ambience. In order to find out how much do these conditions affect the content of mobile phosphates and their degree of mobility, a special laboratory test was carried out. Samples of typical and ordinary chernozem were (i) fertilized with 30 mg P2O5 per 100 g soil, (ii) evaporated within 30 days at 24 C and 60% field moisture content, (iii) thermostatted at 24 C to air dry state, (iv) wetted up again; (v) exposed to another evaporation session within follow-on 30 days; (vi) dried up to the air- dry state finally. After each procedural session, consecutively wetted and dried samples were tested for (i) content of P2O5 in 0.5 n CH3COOH- solution and (ii) P- mobility / concentration in extract of 0.03 n K2SO4. In ordinary chernozem after secondary drying on the natural background, content of mobile P- forms in dry samples decreased from 27.6 mg P2O5 /100 g soil to 20.8 mg; while in typical chernozem, this was from 20.5 mg to 12.2 mg, respectively. In other words, evaporating and double-drying procedures have significantly activized phosphates' absorption by solid soil phase. Upon agrochemical phosphate-fertilized backgrounds, increased fixation of phosphorus from dried samples (by solid soil phase) was registered as well.

Yet on agrochemical backgrounds with high content of residual phosphates, phosphate- ions' concentration in soil- solutions exceeded the relevant data from natural background by several times. Thus, stimulated elevation of phosphate- content in soil provides better conditions for plants' nutrition with phosphorus, even at arid periods. This process is largely contributed to by a uniform saturation of arable soil layer with residual phosphates.

Potassium:

- maintains the osmotic pressure inside plants' cells;
- enhances the hydration of colloids (which results in better moisturization of
- tissues, whereby plants become more
- resistant to (i) extreme situations, (ii) excess or lack of moisture, (iii) temperature
- changes);
- reduces a risk of excessive accumulation of nitrates in consumer/ food sector of crop output;
- enhances photosynthetic activity in plants;
- accelerates the rate of nitrogen assimilation and protein formation;
- amplifies the synthesis of cellulose.

Analysis of results from studies [9] indicates the positive effect of trace elements on plants' resistance against unfavorable weather conditions. Mechanism of plants' resistance is considered as a consequence of such processes running in plants' organism under impact by trace elements as (a) re-grouping of aqueous forms in plants and (b) increasing: (i) hydration of protoplasm-colloids; (ii) water/ moisture-retaining ability of leaves; (iii) efficiency of carbohydrate- nitrogen exchanges.

Under drought-hot temperature conditions, foliar nutrition with micro-elements helps to: (i) increase the content of colloid-bound water; (ii) maintain the protein synthesis; (iii) lower hydrolysis- intensity; (iv) inhibit accumulation in plant-tissues of ammonia and other toxic substances. The research revealed a positive effect by microfertilizers on processes of water re-grouping in plants, whereby amounts of bound water(*) rose by 12 to 50%.

Optimization of plant root nutrition regime by introducing mineral fertilizers can significantly expand the range of soil moisture distribution for plants. Due to this merit, water consumption by crop seedlings under insufficient moisture conditions is enhanced, thus ensuring a rich crop-yield output. In particular, optimal fertilization of winter- wheat with nutrition, phosphorus and potassium promises (i) a 21- 42% increment to assimilation of hard-to-access forms of moisture from soil-roots layer; and (ii) reduce the share of physical evaporation from the total transpiration sum by factor of 1.5 [10].

Mineral fertilizers result somewhat in increase of overall water-loss due to moisture transpiration at formation of rich yields; however, in per unit output category, amount of such moisture losses is not critical. In particular, crops that are well-supplied with mineral nutrients, consume for grain formation by 1.5 - 2.7 times less moisture than crops with poor nutrients' supply. The cost of water consumption is returned back especially well if soil is fed with mineral fertilizers under moisture- deficit conditions in the following manner: at optimal moisture regime - by 1.4 – 1.6 times, at water deficiency by 2.0 – 2.4 times.

Moisture deficit inhibits accession to plants more to phosphorus and potassium than to nitrogen; hence at a drought time, crop seedlings eagerly respond to phosphorus inputs. Potassium fertilizers' application has proven a trend of significant rise in efficiency of moisture- assimilation, judging by accelerated growth and development of plants' leaves and roots. The optimized way of plants' nutrition with potassium increases: (i) cellular juice osmotic pressure; (ii) degree of colloids' hydration; (iii) content of colloidal-bound water in leaves and (iv) intensity of plastic substances' assimilation. An effect of increasing the agri-crops' resistance against unfavorable water-supply situations is specified also by (i) structural changes in cellular organoids; (ii) disordered function of water-absorption under phosphate- starvation conditions; and vice versa,- (iii) elevated activity of plants after their adequate provision with phosphorus. The soil-accumulated residual fertilizer phosphates differ in their properties from natural forms inherent to a given type of soil; i.e., they are (i) active, (ii) conserved in plants' accessible compounds, and thus, (iii) display characteristic features of well-cultivated soil [11].

Results of studies [12] show that on chernozem soils with high content of residual phosphates, conditions for soil-moisture assimilation to create agro-products are rather favorable (Table- 2). Water consumption per 1 ton of dry matter at cultivation of silage maize and sugar beet is less intensive on soils with high phosphorus content of (by 20 - 25% compared to soil with its poor content). Once the phosphorus - poor soil receives fertilizer inputs, such a difference decreases, yet still remaining rather significant.

During droughty periods, resultant from absence of systematic precipitation during the plant-vegetative season, role of potassium among all other nutrition elements in formation of crops is clearly evident. Due to potassium deficit, synthesis of proteins is inhibited, thus leading to disorder in nitrogen exchange process. The ability of potassium to enhance plant-cells' water supply (and thus to support plants' turgor) explains its great importance for increasing plants' resistance against summer droughts and/ or springtime night-frosts.

Results of authors' own studies on agrochemical backgrounds with various contents of mobile potassium-forms indicate that sugar beet yielding ability depends on (i) potassium background in typical chernozem, (ii) fertilizers activity and (iii) year-round weather conditions [13]. In droughty years (when amount of precipitation during the vegetative season did not exceed 215 mm), the sugar beet harvest increased significantly at the expence of soil-accumulated potassium residues (left over from K-fertilizers) in the following manner. At control test is from 22.3 t / ha with low K- content to 26.9 t / ha with high K-content. In the $N_{180}P_{180}$ variant is from 33.3 t / ha to 35.7 t / ha (Table-3).

Potassium fertilizers in K_{90} and K_{180} dosage (if applied additionally upon the $N_{180}P_{180}$ background) provide (on a natural background with low soil-potassium content) a maximum yield- increment in amount of 34 and 26 t/ha, correspondingly. Application of potassium fertilizers on agrochemical backgrounds with elevated to high potassium contents in soil still does not ensure any crop-yield increment.

In years with elevated to high amounts of precipitation (at an average amount of 350 mm from April to August), sugar beet does not actively respond to changes in potassium background of typical chernozem. Thus, in control variant only a slight increase in yield was noted and only on elevated to high potassium background in soil; because increments in yield occur more substantially and regularly in $N_{180}P_{180}$ variant, - due to accumulation of residual potassium in agrochemical background in a range from natural to high.

TABLE 2 - IMPACT OF FERTILIZERS ON YIELD AND USE OF MOISTURE ON TYPICAL CHERNOZEM WITH VARIOUS DEGREES OF PHOSPHORUS AVAILABILITY

Mobile P-content, mg / kg	Test-trial variant	Yield, t / ha	Reserves of productive moisture in 160 cm-deep soil layer, m^3 / ha		Water/ moisture consumption, m^3		
			Early vegetation	Crop harvesting	Evapo-Trans piration	Per 1 ton of basic product	Per 1 ton of dry matter
Silage maize							
40-50	Control	34,0	1050	550	2280	0,67	2,87
	NPK	34,4	1000	460	2330	0,52	2,24
140-160	Control	36,9	1140	510	2410	0,65	2,32
	NPK	41,2	890	460	2200	0,53	2,29
Sugar beet							
40-50	Control	21,4	1040	210	3160	1,48	3,88
	NPK	38,9	1250	130	3750	0,96	3,07
140-160	Control	33,4	980	180	3130	0,94	2,91
	NPK	40,9	1380	130	3510	0,89	2,66
(*) Notes	Amount of precipitation at period of silage maize vegetation - 1780 m^3 / ha						
	Amount of precipitation at period of sugar beet vegetation - 2340 m^3 / ha						

TABLE 3 - INFLUENCE OF FERTILIZERS ON YIELD OF SUGAR BEET ON TYPICAL CHERNOZEM, IN DEPENDENCE OF MOBILE POTASSIUM ON SOIL MOISTURE CONDITIONS

Amount of precipitations, mm *		Test-trial variant	Yield of Sugar Beet (ton/ ha) by Contents of Potassium in Soil, mg/kg							
In April-August	For one year		85-87 mg/kg		92-96 mg/kg		96-117 mg/kg		107-139 mg/kg	
			1	2	1	2	1	2	1	2
215 (167-243)	517 (340-727)	Control test	22,3	-	21,4	-	24,6	-	26,9	-
		N180+P180	33,3	-	23,0	-	34,8	-	35,7	-
		$N_{180}P_{180}+K_{90}$	36,7	3,4	33,9	0,9	37,5	2,5	36,0	0,3
		$N_{180}P_{180}+K_{180}$	35,9	2,6	35,4	2,4	34,9	0,1	36,1	0,4
350 (313-389)	657 (564-711)	Control test	33,4	-	31,6	-	34,5	-	34,2	-
		$N_{180}P_{180}$	40,1	-	42,4	-	43,5	-	44,1	-
		$N_{180}P_{180}+K_{90}$	38,9	-	39,5	1,9	44,0	0,5	44,8	0,7
		$N_{180}P_{180}+K_{180}$	42,2	2,1	44,0	1,6	43,7	0,2	43,5	0,6

(*) Notes 1 - Yield of sugar beet, ton/ ha

2 - Increment to yield due to potassium fertilizing upon $N_{180}P_{180}$ background

In plants' nutrition processes optimization, a significant role is played (together with nitrogen, phosphorus and potassium) by silicon as one of the most important factors in increasing plants' drought-resistance. It has been found that owing to effects of lowering plant-leaf temperature, and/ or adjustment of transpiration regimes, optimization of silicon nutrition enhances the plants' resistance to stresses of diverse origin. In processes of maintaining internal soil-water reserve can participate up to 20 - 30 per cent of plant's available silicon. Increased drought-tolerance of soils (owing to application of silicon-containing compounds) is specified by improvement of water-retaining properties of soil, plus intensified development of plants' root system as well.

During unfavorable soil-moisture years across arid areas of Ukrainian Steppe zone, a very effective agro-method was invented that helped plants withstand drought stresses; and namely, this is in-row application of superphosphate / complex fertilizers in dosage of 10 - 15 kg P2O5 / ha. The long-term research data show that owing to the above-mensioned agro-methodological activity, the total demand for soil moisture (needed per grain-yield unit) was economized by 15% for winter wheat; by 30% for barley; by 24% for wheat- grain; whereas yield rate rose up by 4 - 5 centner/ ha. In this connection, employment of the scientifically-substantiated plant-fertilizer system (i) re-arranges moisture- consumption in favor of crop-yield formation needs, and (ii) moderates unexpected water-usage fluctuations at unfavorable seasons.

Conclusions.

In most part of Ukraine in recent decades, the climate is changing up to a warmer and more aridous form of, whereby much-wanted precipitation fallouts occur mainly as rain-sleet-snow in autumn-winter period, and as heavy showers or rainstorms in mid-summer. An increase in the average daily temperature by [0.7 to 1.5°C] contributes to extension of plants' vegetation season in autumn, and predetermines the later growing season for winter- wheat, which enables agrarians to put off the terms of winter- wheat sowing by 2 or 3 decades ahead (i.e., nearer to the late September).

About 80% of the arable land in Ukraine (over 24 mio ha) are characterized with such types of water regime which form up a prevailable or periodic soil-moisture deficit, thus being a crucial agrochemical factor that mainly constrains the soil-fertility or limits the crop yields' productivity / output. Decrease in moisture supply to soil inhibits the mobility of nutrient substances in soil and slows down the growth of plants' root system. Increase in content of mobile forms of phosphorus and potassium in soil contributes to efficient use of existing stocks of effective moisture and formation of future agro- products. In optimization of plants' nutrition processes, a significant role is played by application of micro-fertilizers and silicon-based compounds. Implementation of the whole complex measures of rational conservation and use of moisture-saving and soil- reclamation activities will help (i) minimize negative effects of global warming and periodic droughts, (ii) gain stability of agriculture and (iii) keep on collecting rich yields of agro-crops.

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