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THE EFFECT OF WATER DEFICIENCY ON THE PRODUCTION PROCESS OF MISCANTHUS (*MISCANTHUS* SPP.)

Anisimov A.A. – Candidate of Biological Sciences, Senior Lecturer of the Department of plant physiology, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Russian Federation.*

Skorokhodova A.N. – Candidate of Biological Sciences, Senior Lecturer of the Department of plant physiology, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Russian Federation.

Skorokhodov D.M. – Candidate of Technical Sciences, Associate Professor of the Department of materials resistance and machine parts, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Russian Federation.

The article discusses the main physiological features of the formation of productivity elements of three species of miscanthus (Giganteus, Sinensis and Sacchariflorus) in drought conditions. The aim of the study is the comprehensive characterization of the responses of three miscanthus species under conditions of water deficit in order to identify potential mechanisms of drought resistance of this crop and assess the possibility of its cultivation in a more arid climate. The objectives of the study included assessing the level of biomass accumulation by miscanthus plants under normal and drought conditions, determining growth indicators and functional activity indicators, as well as evaluating indicators of the aquatic regime of miscanthus plants.

The results obtained indicate the presence of a wide species-specificity of the responses of miscanthus plants to water deficiency. In the case of prolonged drought, the relative growth rate of all miscanthus species decreases. The drought leads to the decrease in Miscanthus sacchariflorus photosynthetic yield, but the water consumption efficiency in these plants remained at the level of plants growing under normal water supply conditions. Miscanthus giganteus and especially miscanthus sinansis have demonstrated a wider range of reactions to drought, which includes not only maintaining photosynthetic yield, but also optimizing it, as well as increasing the efficiency of water consumption. In studied miscanthus species two strategies for adaptation to draught were confirmed – the preservation and maintenance of vital processes under conditions of water deficit, along with the mechanisms that optimize the efficiency of water consumption.

Key words: *miscanthus, energy crops, biomass, drought, water consumption efficiency, water-retaining capacity, photosynthetic gas exchange.*

ВЛИЯНИЕ ВОДНОГО ДЕФИЦИТА НА ПРОДУКЦИОННЫЙ ПРОЦЕСС РАСТЕНИЙ МИСКАНТУСА (*MISCANTHUS* SPP.)

Анисимов А.А. – кандидат биологических наук, старший преподаватель кафедры физиологии растений, Российский государственный аграрный университет – Московская сельскохозяйственная академия имени К.А. Тимирязева, г. Москва, Российская Федерация.*

Скороходова А.Н. – кандидат биологических наук, старший преподаватель кафедры физиологии растений, Российский государственный аграрный университет – Московская сельскохозяйственная академия имени К.А. Тимирязева, г. Москва, Российская Федерация.

Скороходов Д.М. – кандидат технических наук, доцент кафедры сопротивление материалов и детали машин, Российский государственный аграрный университет – Московская сельскохозяйственная академия имени К.А. Тимирязева, г. Москва, Российская Федерация.

В статье рассматриваются основные физиологические особенности формирвания элементов продуктивности трёх видов мискантуса (гигантского, китайского и сахароцветкового) в условиях засухи. Цель исследования заключается в проведении комплексной характеристики ответных реакций трёх видов мискантуса на условиях водного дефицита для выявления потенциальных механизмов засухоустойчивости данной культуры и оценки возможности её выращивания в более засушливом климате. В задачи исследования входила оценка уровня накопления биомассы растениями мискантуса в нормальных условиях и в условиях засухи, определение ростовых показателей и показателей функциональной активности, а также оценка показателей водного режима растений мискантуса.

Полученные результаты свидетельствуют о наличии широкой видоспецифичности ответных реакций растений мискантуса на водный дефицит. В случае наличия продолжительной засухи у всех видов мискантуса снижается относительная скорость роста. У мискантуса сахароцветкового засуха приводит к снижению продуктивности фотосинтеза, однако эффективность *водопотребления у данных растений оставалась на уровне растений в условиях нормальной водообеспеченности. Растения мискантуса гигантского и особенно мискантуса китайского обнаружили более широкий спектр реакций на засуху, который включает в себя не только сохранение продуктивности фотосинтеза, но и её оптимизацию, а также увеличение эффективности утилизации воды. У мискантуса исследованных видов были подтверждены две стратегии адаптации к условиям недостатка влаги – сохранение и поддержание процессов жизнедеятельности в условиях водного дефицита наряду с наличием механизмов, которые позволяют оптимизировать эффективность водопотребления.*

Ключевые слова: *мискантус, энергетические культуры, биомасса, засуха, эффективность водопотребления, водоудерживающая способность, фотосинтетический газообмен.*

СУ ТАПШЫЛЫҒЫНЫҢ МИСКАНТУС ӨСІМДІКТЕРІНІҢ ӨНДІРІС ПРОЦЕСІНЕ ӘСЕРІ (*MISCANTHUS* SPP.)

Анисимов А.А. – биология ғылымдарының кандидаты, Өсімдіктер физиологиясы кафедрасының аға оқытушысы, Ресей мемлекеттік аграрлық университеті-К.А. Тимирязев атындағы Мәскеу ауылшаруашылық академиясы, Мәскеу қ., Ресей Федерациясы.*

Скороходова А.Н. – биология ғылымдарының кандидаты, Өсімдіктер физиологиясы кафедрасының аға оқытушысы, Ресей мемлекеттік аграрлық университеті-К.А. Тимирязев атындағы Мәскеу ауылшаруашылық академиясы, Мәскеу қ., Ресей Федерациясы.

Скороходов Д.М. – техника ғылымдарының кандидаты, материалдар мен машина бөлшектеріне төзімділік кафедрасының доценті, Ресей мемлекеттік аграрлық университеті-К.А. Тимирязев атындағы Мәскеу ауылшаруашылық академиясы, Мәскеу қ., Ресей Федерациясы.

Мақалада құрғақшылық жағдайында мискантустың үш түрінің (алып, қытай және қант гүлдері) өнімділік элементтерінің қалыптасуының негізгі физиологиялық ерекшеліктері қарастырылады. Зерттеудің мақсаты-осы дақылдың құрғақшылыққа төзімділігінің әлеуетті механизмдерін анықтау және оны құрғақ климатта өсіру мүмкіндігін бағалау үшін су тапшылығы жағдайында мискантустың үш түрінің реакцияларының кешенді сипаттамасын жүргізу. Зерттеудің міндеттеріне қалыпты және құрғақшылық жағдайында мискантус өсімдіктерінің биомасса жинақталу деңгейін бағалау, өсу және функционалдық белсенділік көрсеткіштерін анықтау және мискантус өсімдіктерінің су режимінің көрсеткіштерін бағалау кірді.

Нәтижелер мискантус өсімдіктерінің су тапшылығына реакцияларының кең түрге тән екендігін көрсетеді. Ұзақ құрғақшылық болған жағдайда, мискантустың барлық түрлерінде салыстырмалы өсу қарқыны төмендейді. Мискантус сахарофлорасында құрғақшылық фотосинтез өнімділігінің төмендеуіне әкеледі, бірақ бұл өсімдіктердегі суды тұтынудың тиімділігі қалыпты сумен қамтамасыз ету жағдайында өсімдіктер деңгейінде қалды. Алып мискантус өсімдіктері және әсіресе Қытай мискантусы құрғақшылыққа реакциялардың кең спектрін тапты, бұл Фотосинтездің өнімділігін сақтауды ғана емес, оны оңтайландыруды, сондай-ақ суды кәдеге жарату тиімділігін арттыруды қамтиды. Зерттелген түрлердің мискантусында ылғалдың жетіспеушілігі жағдайларына бейімделудің екі стратегиясы расталды-су тапшылығы жағдайында тіршілік процестерін сақтау және сақтау, сонымен қатар суды тұтынудың тиімділігін оңтайландыруға мүмкіндік беретін механизмдер бар.

Түйінді сөздер: *мискантус, энергетикалық дақылдар, биомасса, құрғақшылық, суды тұтыну тиімділігі, суды сақтау қабілеті, фотосинтетикалық газ алмасу.*

Introduction. In modern agriculture, cultivation of various crops is beginning to play an increasingly important role every year in order to obtain biomass, which can be used for a number of needs, for example, for the production of biofuels, composite and building materials. Interest in energy crops increased in the second half of the 20th century in Europe and the United States of America. As a result of studying the available resources of the Earth's flora, various groups of crops that can be used to produce biomass have been described. The studied plants were classified by life forms: annual and perennial herbaceous, as well as woody plants [1, p.275].

Among the representatives of the group of perennial herbaceous plants, today one of the most promising from the point of view of obtaining biomass are species of the Miscanthus genus (*Miscanthus* spp.). These are perennial rhizomatous grasses belonging to the Poacea familia. The homeland of miscanthus is the Southeast Asia – China, the Korean Peninsula, the islands of the Japanese archipelago, as well as the southern part of the Russian Far East. Among more than twenty representatives, two species of plants were introduced into the culture – *miscanthus sinensis* Anderss., and *miscanthus sacchariflorus* Maxim. *Miscanthus giganteus* Greef at Deut. is a hybrid that appeared naturally by crossing a diploid species – *M. sacchariflorus* and tetraploid – *M. sinensis*. The resulting triploid plants are unable to form seeds and reproduce only vegetatively [2, p.88].

A characteristic feature of representatives of this genus is the presence of a special photosynthesis pathway – C4-type, which is the reason for high potential productivity – up to 40 tons of dry matter per hectare. The possibility of long-term cultivation in one place (up to 20 years), as well as high potential yields, along with the quality of the resulting biomass, led to the inclusion of miscanthus in a number of the most promising crops for bioenergy purposes [3, p. 116].

The modern genotypes of Miscanthus were obtained as a result of breeding work and have a fairly wide potential area of cultivation in Europe (including in the European part of the Russian Federation) [4, p.3]. However, on the territory of the central part of Russia and, in particular, at the latitude of Moscow, the maximum potential yield cannot be achieved. This is due to a number of reasons. Firstly, the amount of photosynthetically active radiation (FAR) at the latitude of Moscow is insufficient to achieve maximum photosynthesis efficiency. Secondly, the duration of the growing season in Moscow is significantly lower than in the regions most suitable for the cultivation of miscanthus (which include, for example, the countries of the Northern and Eastern Mediterranean). And, finally, thirdly, even at the latitude of Moscow, in some years miscanthus may experience a lack of moisture in the soil, as, for example, in a rather dry 2014 [5, p.148]. During summer soil droughts, both the death of individual shoots on the plant and the entire plant as a whole can be observed [6, p.12].

The responses of various C4 plants include the following mechanisms [7, p.907]:

1. The ability to avoid the damaging effects of water scarcity by adapting life rhythms;
2. Adaptation to stress factors, which allows the plant to preserve and maintain vital processes in conditions of drought;
3. The presence of mechanisms that allow plants to optimize the process of using water for the formation of dry matter (efficiency of water consumption).

Mechanisms of osmotic regulation of the water regime have been found in miscanthus plants, which correlates with the second strategy of responses to water stress conditions [7, p.165]. Osmotic regulation allows the plant organism to support the processes of vital activity even under conditions of low values of water potential. In addition, a number of researchers have noted the presence of a third strategy for avoiding drought damage in miscanthus. It is also worth noting that the maximum productivity of the plant can be achieved only under the condition of high efficiency of water consumption, which is especially relevant in conditions of drought [9, p.300].

Since irrigation of energy crops is economically unprofitable, the search and study of such genotypes that will be able to ensure optimal productivity even in conditions of insufficient moisture supply, as well as the identification and verification of those physiological mechanisms that cause these reactions, is of particular relevance. The available literature data show a higher plasticity of *M. sinensis* in relation to drought, therefore, varieties based on it are of particular interest for cultivation without irrigation in areas where short-term and medium-term droughts are observed [10. p.468].

Aim, objectives. The aim of the study is the comprehensive characterization of the responses of three miscanthus species under conditions of water deficit in order to identify potential mechanisms of drought resistance of this crop and assess the possibility of its cultivation in a more arid climate. The objectives of the study included assessing the level of biomass accumulation by miscanthus plants under normal and drought conditions, determining growth indicators and indicators of functional activity, as well as evaluating indicators of the aquatic regime of miscanthus plants.

Materials and methods. Miscanthus plants from on the territory of the field experimental station of the Russian State Agricultural Timiryazev Academy were used as objects of research. Various plants were taken: *miscanthus sinensis*, *miscanthus sacchariflorus* and *miscanthus giganteus*. The rhizomes of plants from the third year of life were used.

The vegetation experiment was carried out in the greenhouse of the Laboratory of Artificial Climate of the Russian State Agricultural Timiryazev Academy. The plants were grown in natural light with additional illumination by high–pressure sodium lamps (the PPFD of the light source was 180 mmol/m^2* sec), the photoperiod was 18 hours. The plants were grown in soil in vegetative vessels with a volume of 2 liters. The planting material was obtained by dividing the rhizomes of uterine plants of the third year of life, extracted from the field site before the start of the experiment. A ready-made soil mixture of Agrobalt-C, filled with fertilizers, was used as a substrate. All vessels contained an equal weight of substrate – 1500 g of air-dry soil.

Within 30 days from the beginning of vegetation, miscanthus plants were watered to the level of 70% full soil water capacity. Further, watering of some plants was reduced to 30% of the full soil water capacity.

Sampling to determine biometric indicators was carried out in dynamics from the moment of termination of watering of plants of the experimental group with a frequency of once every two weeks. The biomass of plants (by organs), the area of leaves were determined, the relative growth rate (RGR, g/g* dry weight*day) and the net productivity of photosynthesis (NPF, g/m^2*day) were calculated.

The parameters of photosynthetic gas exchange were determined (photosynthesis intensity, mmol CO^2/m2*sec, transpiration intensity, mmol H2O/m^2*sec, stomatal conductivity, mmol/m^2*sec) plants using the LI-6400 RX automatic gas exchange registration system (Li-Cor, Lincoln, Nebraska, USA). Gas exchange was recorded on the upper leaf plastics that had completed it's development at a fixed evening time for all measurement points (18-00). Based on the photosynthetic gas exchange data, the water consumption efficiency indicator (the ratio of photosynthesis intensity to transpiration intensity) was calculated. Measurements of the water retention capacity of the leaves were carried out in dynamics .

The results were mathematically processed, and the tables show arithmetic averages and standard errors.

Results. The most general and integral characteristic of the influence of various factors on a plant can be obtained by studying the growth processes. The conditions of insufficient water supply have led to a significant decrease in the level of accumulation of dry biomass by all types of miscanthus (fig.1).

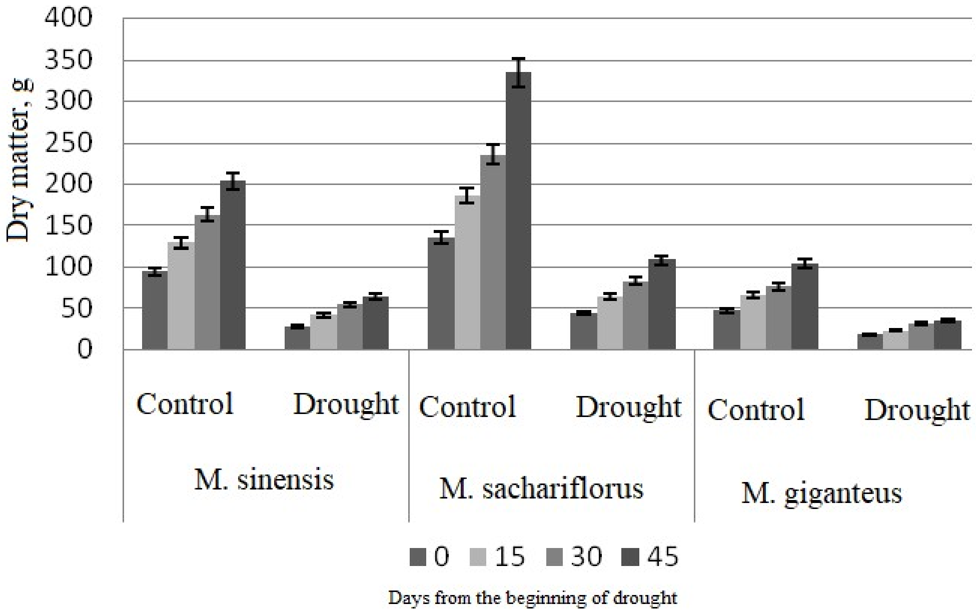

Figure 1. – Dry matter accumulation by different Miscanthus species under the drought conditions

Drought caused a stable decrease in the relative growth rate in all studied miscanthus species. According to the net productivity of photosynthesis in plants (NPP) of various species and hybrid forms, differences in reactions were also revealed (Table 1).

Table 1. Relative growth rate and net photosynthesis productivity of miscanthus grown in drought conditions

Variant		RGR, g/g of dry matter per day			NPP, g/м^2*day		
		0 – 15**	15 – 30	30-45	0 – 15	15 – 30	30-45
M. sinensis	C***	0,018+0,004	0,015+0,003	0,016+0,003	3,42+0,11	2,42+0,2	3,35+0,8
	D	0,022+0,003	0,017+0,004	0,009+0,002	10,32+0,09	14,34+3,8	1,14+0,2
M. saccharif.	C	0,019+0,003	0,014+0,003	0,020+0,002	3,85+0,09	6,31+1,3	9,35+1,4
	D	0,020+0,008	0,016+0,004	0,014+0,002	2,91+,0,5	6,32+1,2	5,46+1,2
M. giganteus	C	0,019+0,004	0,019+0,005	0,018+0,003	10,02+1,5	4,04+0,9	9,48+2,1
	D	0,013+0,002	0,008+0,002	0,007+0,002	3,91+0,8	6,21+1,3	1,84+0,4

time interval, days from the beginning of drought. * C. – Control, D. – Drought

The lack of water in the soil significantly affected the parameters of photosynthetic gas exchange of miscanthus plants, From the very beginning, drought conditions led to a significant suppression of the process of visible photosynthesis, which may indicate both the occurrence of disorders in the photosynthetic apparatus and increased respiration under the influence of drought. Similarly, lack of water affected the intensity of transpiration. In conditions of insufficient water supply, miscanthus plants of all studied genotypes were forced to reduce moisture consumption in order to use it as efficiently as possible. Soil drought caused a steady decrease in the degree of stomata opening in plants, which, apparently, was one of the reasons for the parallel decrease in the intensity of photosynthetic gas exchange processes (Table 2).

According to the change in the efficiency of water consumption under the influence of drought, the miscanthus plants of the studied genotypes can be divided into several groups with different strategies.

Table 2. Indicators of photosynthetic gas exchange of miscanthus plants of various genotypes in drought conditions

Variant		Photosynthesis intensity, мкмolCO₂/м²*sec			Transpiration intensity, ммolH₂O/м²*sec			Stomatal conductivity,ммol/м²*sec		
		45/15	60/30	75/45	45/15	60/30	75/45	45/15	60/30	75/45
1	C.**	1,68±0,09	1,54±0,05	1,50±0,08	1,38±0,11	1,43±0,12	1,28±0,18	0,046±0,011	0,043±0,012	0,044±0,012
	D.	1,11±0,05	1,01±0,09	0,91±0,04	0,44±0,12	0,40±0,08	0,43±0,04	0,029±0,008	0,028±0,007	0,027±0,004
2	C.	1,85±0,04	1,81±0,15	1,75±0,08	1,35±0,08	1,42±0,17	1,30±0,21	0,046±0,012	0,044±0,012	0,041±0,013
	D.	0,88±0,04	0,80±0,04	0,69±0,04	0,62±0,04	0,60±0,6	0,52±0,10	0,023±0,007	0,022±0,004	0,021±0,07
3	C.	1,60±0,12	1,61±0,14	1,55±0,12	1,40±0,14	1,34±0,14	1,38±0,14	0,049±0,012	0,048±0,012	0,049±0,014
	D.	0,95±0,09	1,01±0,09	1,06±0,09	0,69±0,03	0,62±0,9*	0,63±0,09	0,029±0,07	0,030±0,08	0,029±0,009

*in the numerator – the number of days from the beginning of the growing season, in the denominator – the number of days from the beginning of the drought. ** C. – Control, D. – Drought, ***Types:1 – M. sinensis, 2 – M. sacchariflorus, 3 – M. giganteus

In conditions of optimal water supply, due to the absence of stress factors, there are no significant changes in the efficiency of water consumption in all studied plants. In m. sinensis and m.giganteus, drought conditions caused a stable increase in water consumption efficiency, while in m. sacchariflorus, it remained at the control level. Thus, plants have the ability to adapt to drought conditions has been demonstrated in both by optimizing photosynthesis processes and by increasing the efficiency of water consumption.

Table 3. Indicators of the water metabolism of miscanthus plants when grown in drought conditions

Variant		Water consumption efficiency,мсMolCO₂/ мMolH₂O			Water retention capacity, % of lost moisture per 30 min.		
		45/15	60/30	75/45	45/15	60/30	75/45
M. sinensis	C.**	1,22±0,12	1,09±0,09	1,19±0,22	7,4±0,8	9,2±1,5	8,8±1,2
	D.	2,55±0,21	2,54±0,22	2,14±,024	12,1±1,3	14,2±2,5	14,8±2,6
M. saccharif.	C.	1,32±0,14	1,23±0,15	1,32±0,09	8,4±0,7	7,2±1,3	7,6±1,5
	D.	1,44±0,23	1,35±0,19	1,36±0,14	6,9±0,5	7,7±0,8	7,5±1,0
M. giganteus	C.	1,18±0,14	1,22±0,14	1,12±0,12	10,9±1,1	12,4±2,0	11,9±2,6
	D.	1,54±0,18	1,60±0,21	1,70±0,13	7,3±0,7	7,5±1,4	8,7±1,4

in the numerator – the number of days from the beginning of the growing season, in the denominator – the number of days from the beginning of the drought. ** C. – Control, D. – Drought

Discussion. At the initial stage of the action of insufficient moisture supply in plants of all variants, no differences in the values of relative growth rate (RGR) were found. This indicates the ability of miscanthus plants in the early stages of drought to actively adapt metabolic processes and thus minimize the effect of an adverse factor. However, the plants of M. giganteus show an earlier decrease in RGR under the influence of drought compared with other species and hybrid forms. In the future, as the duration of the conditions of lack of water in the soil increases, the ability of plants to adapt decreases, which is expressed in a decrease in RGR.

Drought conditions do not cause significant changes in Miscanthus sinensis plants according to net productivity of photosynthesis (NPP). It should be noted that over the entire observation period, the net productivity of photosynthesis of Miscanthus sinensis plants in drought conditions was an order of magnitude higher than that of plants in the control group, which, along with a more intensive level of accumulation of dry biomass, may indicate a successful adaptation of the photosynthetic apparatus to the action of an unfavorable factor. The plants of miscanthus sacchariflorus and miscanthus giganteus show similar dynamics of NPP under the influence of water deficiency. During the initial stages of drought, the net productivity of photosynthesis in these genotypes increased, but by the 45th day, the productivity of photosynthesis decreased significantly, especially in miscanthus giganteus. Thus, plants of miscanthus sacchariflorus and miscanthus giganteus with a prolonged lack of moisture are not able to fully adapt photosynthesis processes to conditions of water scarcity, which in turn can lead to a decrease in final productivity.

In most of the studied miscanthus genotypes, the conditions of lack of water in the soil did not cause significant changes in the water retention index. Significant differences were noted only in the case of plants of M. sinensis, in which, under drought conditions, it is possible to distinguish a tendency to an increase in

VUS. These data also indicate that the plants of M. sinensis are able to adapt to the conditions of prolonged soil drought due to the widest range of physiological reactions.

Conclusion. The results indicate a wide species-specificity of the reaction of miscanthus plants to drought conditions. Insufficient water availability leads to a decrease in the relative growth rate as the duration of the adverse factor increases. In some species and hybrids, such as Miscanthus sacchariflorus, water scarcity conditions led to a decrease in photosynthesis productivity, however, plants were able to maintain water consumption efficiency at the level of the control group that did not experienced the lack water. In plants of miscanthus giganteus and especially miscanthus sinensis the wider range of responses to drought was found. It which includes not only maintaining photosynthetic productivity, but also optimizing it, as well as increasing the efficiency of water utilization. Thus, in miscanthus plants of the studied genotypes, two strategies for adaptation to conditions of lack of moisture were confirmed – the preservation and maintenance of vital processes in conditions of water scarcity, along with the presence of mechanisms that optimize the efficiency of water consumption.

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Information about authors:

Anisimov Aleksandr Alekseyevich – Candidate of Biological Sciences, Senior Lecturer of the Department of plant physiology, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Russian Federation, 127434, Moscow, 49 Timiryazevskaya Str., tel.: 84999762054, e-mail: anisimov_a@rgau-msha.ru.*

Skorokhodova Anastasiya Nikolayevna – Candidate of Biological Sciences, Senior Lecturer of the Department of plant physiology, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Russian Federation, 127434, Moscow, 49 Timiryazevskaya Str., tel.: 84999762054, e-mail: red-green216@mail.ru.

Skorokhodov Dmitriy Mikhailovich – Candidate of Technical Sciences, Associate Professor of the Department of materials resistance and machine parts, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Russian Federation, 127434, Moscow, 49 Timiryazevskaya Str., tel.: 84999762054, e-mail: d.skorokhodov@rgau-msha.ru.

Анисимов Александр Алексеевич – кандидат биологических наук, старший преподаватель кафедры физиологии растений, Российский государственный аграрный университет – Московская сельскохозяйственная академия имени К.А. Тимирязева, Российская Федерация, 127434, г. Москва, ул. Тимирязевская 49, тел. 84999762054, e-mail: anisimov_a@rgau-msha.ru.*

Скороходова Анастасия Николаевна – кандидат биологических наук, старший преподаватель кафедры физиологии растений, Российский государственный аграрный университет – Московская сельскохозяйственная академия имени К.А. Тимирязева, Российская Федерация, 127434, г. Москва, ул. Тимирязевская 49, тел. 84999762054, e-mail: red-green216@mail.ru.

Скороходов Дмитрий Михайлович – кандидат технических наук, доцент, доцент кафедры сопротивление материалов и детали машин, Российский государственный аграрный университет – Московская сельскохозяйственная академия имени К.А. Тимирязева, Российская Федерация, 127434, г. Москва, ул. Тимирязевская 49, тел. 84999760673, e-mail: d.skorokhodov@rgau-msha.ru.

Анисимов Александр Алексеевич – биология ғылымдарының кандидаты, Өсімдіктер физиологиясы кафедрасының аға оқытушысы, Ресей мемлекеттік аграрлық университеті-К.А. Тимирязев атындағы Мәскеу ауылшаруашылық академиясы, Ресей Федерациясы, 127434, Мәскеу қ., Тимирязевская к-сі, 49, тел. 84999762054, e-mail: anisimov_a@rgau-msha.ru.*

Скороходова Анастасия Николаевна – биология ғылымдарының кандидаты, Өсімдіктер физиологиясы кафедрасының аға оқытушысы, Ресей мемлекеттік аграрлық университеті-К.А. Тимирязев атындағы Мәскеу ауылшаруашылық академиясы, Ресей Федерациясы, 127434, Мәскеу қ., Тимирязевская к-сі, 49, тел. 84999762054, e-mail: red-green216@mail.ru.

Скороходов Дмитрий Михайлович – техника ғылымдарының кандидаты, доцент, кафедра доценті материалдар мен машиналардың бөлшектеріне төзімділік, Ресей мемлекеттік аграрлық университеті-К.А. Тимирязев атындағы Мәскеу ауылшаруашылық академиясы, Ресей Федерациясы, 127434, Мәскеу қ., Тимирязевская к-сі 49, тел. 84999760673, e-mail: d.skorokhodov@rgaumsha.ru.

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ВНЕДРЕНИЕ ТЕХНОЛОГИИ ТОЧНОГО ЗЕМЛЕДЕЛИЯ В ТОО НПЦ «EURASIA FARM INNOVATIONS»

Бисетаев К.С. – магистр делового администрирования, заместитель директора Научно-производственного центра «Eurasia Farm Innovations», г. Лисаковск, Казахстан.

Плотников В.Г. – магистр сельскохозяйственных наук, главный агроном Научно-производственного центра «Eurasia Farm Innovations», г. Лисаковск, Казахстан.

Екатеринская Е.М. – доктор PhD, заместитель директора по науке Научно-производственного центра «Eurasia Farm Innovations», г. Лисаковск, Казахстан.*

Бенюх О.А. – к.т.н., доцент, и.о. профессора кафедры «Аграрной техники и транспорта», Костанайский региональный университет имени Ахмет Байтұрсынұлы, г.Костанай, Казахстан.

В 2023 году на полях Научно-производственного центра «Eurasia Farm Innovations» площадью 11 тыс. га были проведены работы по внедрению технологии точного земледелия.

В данной статье в качестве примера будут выступать исследования, проведенные на поле № 97.

На полях для оценки исходного состояния почв до посева определены основные элементы минерального питания с помощью агрохимического экспресс анализа почв прибором Stenon Farm Lab: содержание минерального азота (Nmin) и нитратного азота (NO_3), подвижного фосфора (P_2O_5), содержание органического вещества в слое 0-20 см, pH почвенного раствора.

Установлена очень низкая обеспеченность нитратного азота в слое 0-20 см (5-10 мг/кг почвы).

По содержанию подвижного фосфора в почве, следует отметить, что 74% от общей площади поля имели низкий уровень обеспеченности (10-15 мг/кг) и только 26% имели высокий и средний уровень обеспеченности (P_2O_5).

По содержанию органического вещества, почвы имели низкую и среднюю степень обеспеченности (2-6%). Все образцы почвы имели реакцию почвенного раствора средне-щелочную (7,3-8,5).

По данным агрохимического обследования рассчитана доза аммофоса 40-121 кг/га, составлены карты-заданий для дифференцированного внесения удобрений в осенний период.