Name of the program: Development of a decision-making system for the production of main types of agricultural crops based on the adaptation of the DSSAT model for crop growth and development with the formation of an information database of scientific and technical documentation on agro-technologies for agribusiness entities in order to create Smart systems in agriculture

Relevance: Nowadays, in the agricultural production of the Northern and Central Kazakhstan, the growth of gross output's mainly achieved due to extensive factors. This's one of the main reasons for the low yield of cultivated crops and low economic indicators. Today, the agro-industrial complex of these regions does not show a significant increase in productivity and labor efficiency. Naturally, overcoming these problem is possible only with the widespread introduction of new technologies into production. It's known that the digitalization of agricultural production helps to increase the productivity of agricultural crops, reduce costs and increase labor productivity. In this regard, the transition to digital agriculture in the Northern and Central regions of Kazakhstan should be considered as one of the strategic goals of the development of the agro-industrial complex of Kazakhstan.

On the basis of this program, the creation of a decision-making system is planned to be carried out on the basis of the DSSAT model. The development of a decision-making system and crop modelling based on this system will be carried out in three soil-climatic zones: steppe zone-ordinary chernozems; steppe zone – southern chernozems; dry-steppe zone – dark chestnut soils.

On the basis of this program, it's planned to conduct research in the field of creating an open-access database of scientific and technical documentation for agricultural enterprises (Open API). Based on the activities carried out in the field of crop production and animal husbandry, a package of ready-made technical documentation will be formed, which will allow forming a single Database for the subjects of the agro-industrial complex of Northern and Central Kazakhstan. The database and decision-making system will be tested in the conditions of farms production activities in Northern and Central Kazakhstan and set into use. The implementation of the program results will contribute to the growth of the educational level of specialists, the intensity of the use of IT-technologies in agro-technological processes.

Aims. Implementation of the concept of "Smart" agriculture, including high-tech products of crop production and animal husbandry, including on the basis of new technical decisions.

Expected results

Upon completion of the program:

- Experimental studies of the main types of agricultural crops (cereals, legumes, oilseeds and forage) with different sowing dates, seeding rates, fertilization of three different soil and climatic zones will be carried out;
- Simulation of the growth and development of crops will be carried out. Modeling of the main types of crops will be carried out in DSSAT in three different soil and climatic zones, including using retrospective data (previously conducted experiments);
- DSSAT models of major crops will be validated under production conditions. A decision-making system will be developed on the basis of the research carried out with the possibility of changing climatic and soil parameters in order to extrapolate to other soil and climatic zones of Kazakhstan. This system will be tested in agricultural enterprises;
- methodological recommendations will be developed for modeling the growth and development of agricultural crops within the framework of the created decision-making system. Based on this methodology, a module will be developed on an open-source solution with open access (openAPI) for the possibility of connecting and using its module by agribusiness entities in order to simulate the growth and development of crops within the framework of the created decision-making system;
- young specialists will be involved in research, incl. 5 undergraduates and 5 bachelors. At least 3 articles will be published in foreign cited databases (at least Q3) and at least 6 articles in journals recommended by KKSON.

At the end of the project, the system with all source codes, database and technical documentation must be transferred to state ownership.

In order to fulfill the set task - building a database of scientific and technical documentation (standards, reference books, classifiers, etc.) for the production of livestock and crop products with open access (Open API):

- a package of ready-made technical documentation will be formed for all types of agricultural technologies and the livestock sector (current standards, reference books, classifiers, etc.). A single Database will be created for agribusiness entities interested in introducing digitalization of production and management processes in animal husbandry and crop production (cereals, legumes, oilseeds and forage);

- a database will be developed, which will include registers, regulatory and reference information on types of agricultural crops (taking into account the species, phenophase, seed weight, optimal sowing parameters, sowing temperature, seeding rates, seeding depth, soil pH, etc.), types of fertilizers (taking into account the type of fertilizers, formulation, nutrients, etc.), types of soil, types of plant protection products (taking into account the types of pesticides, formulation, composition, cultivated crop, processing method, processing time, restrictions, multiplicity, consumption rates, etc.), by types of seeds (taking into account basic information, biological characteristics, disease resistance, seeding rates, zoning, etc.), by types of diseases and by types of weeds, as well as uniform classifiers, registers and normative and reference information on all types of livestock activities (including according to the "Statistical Classifier of Products (Services) of Agriculture, Forestry and Fisheries VK-003 RED" approved by the Order of the Chairman of the Committee on Statistics of the Ministry of National Economy of the Republic of Kazakhstan dated 05.12.2014 No. 69). All specified registers, classifiers, regulatory and reference information will be consolidated from officially registered according to sources, regulatory legal acts, regulatory reference information and other official sources of the Republic of Kazakhstan as of the final date of adoption, taking into account the use and application of international, uniform identifiers of world standards, divided into groups and subgroups for intuitive use of data in the database;

- young specialists will be involved in research, incl. 2 undergraduates and 2 bachelors. At least 2 articles will be published in foreign cited databases (at least Q3) and at least 3 articles in journals recommended by KKSON.

At the end of the project, the system with the created database with all the source codes, the database and technical documentation will be transferred to state ownership.

Results obtained in 2021

Test sites were organized in North-Kazakhstan Agricultural Experimental Station and “Naydorovskoe" LLP: 80.0 ha in North-Kazakhstan AES and 96.76 ha in "Naydorovskoye" LLP. On these test sites, against the background with various doses of mineral fertilizers, varieties of agricultural crops were studied under conditions of various sowing dates and seeding rates: spring wheat, peas, flax, sunflower. The conducted studies have shown that increased seed count resulted in higher density of planting. A similar pattern was observed in all varieties of agricultural crops without exception, regardless of the backgrounds and the timing of sowing. Productivity of crop varieties was largely determined by the sowing time and seeding rate. The use of mineral fertilizers had a significant impact on the productivity of varieties of various crops. For example, increase in yield of spring soft wheat varieties, when cultivated with the use of fertilizers, in comparison with the control, ranged from 2.3 c/ha to 4.9 c/ha, oil flax by 2.9-4, 2, peas 21.6-3.2. At the same time, it should be noted that the highest level of increase in yield against a fertilized background was observed in the varieties of spring soft wheat in the late sowing period (May 25) at a seeding rate of 4.0 million viable seeds per 1 ha. In agronomic practice, there is a notion of optimal seeding rate, which contributes to the formation of crops with a sufficient number of productive stems to obtain a potential yield under various weather conditions. In our studies, the productivity of spring soft wheat and spring triticale varieties in

LLP "North-Kazakhstan AES" and LLP "Naidorovskoye" did not decrease at higher seeding rates. This indicates that in subsequent years, on the basis of test sites, it is necessary to conduct additional research of increased seeding rate, which will allow to establish the optimal seeding rate for the studied varieties of spring soft wheat and spring triticale, which in turn will contribute to obtaining the maximum yield under various weather conditions. Plant density in the germination phase of the Baiterek sunflower hybrid in the experiment increased with an increase in seeding rates. A similar pattern was observed both on fertilized sites and those without fertilization. Preservation of sunflower hybrid plants before harvesting, regardless of sowing dates and cultivation backgrounds, was also determined by the seeding rate. This indicator in the conducted studies reached the highest value, regardless of the sowing period, at a seeding rate of 65 thousand germinating seeds per 1 ha. The seeding rates influenced the height of Baiterek sunflower hybrid plants. The height of plants in this hybrid increased with an increase in the seeding rate. The tallest plants in the experiment were plants grown with a high seeding rate of 65,000 germinating seeds per 1 ha. The plant height of the sunflower hybrid Baiterek decreased with a decrease in the seeding rate, however, the diameter of the basket and the number of seeds in the basket increased. A similar pattern was observed regardless of the timing of sowing and the background of cultivation of this crop. Based on monitoring surveys, it was found that on wheat crops in the tillering phase; and sunflower in the phase of 2-6 pairs of true leaves (precursor of pairs); triticale in the tillering phase (predecessor of oil flax); oil flax in the “Christmas tree” phase and peas in the phase of 4-8 true leaves (precursor wheat), a high degree of weed infestation with a perennial root shoot weed (the predominant species) was revealed - gray cumin (Cursium incanum), which formed clumps on experimental plots (the number reached 3 -10 species/m2). Weed infestation of agricultural crops was also found to be from medium to high degree by the following annual and minor weed species (the number reached from 20 to 100 pcs/m2): medicinal dandelion (Taraxacum officinale), common wild oats (Avenafatua), black velcro (Lappyla squarrosa), chicken millet (Echinochloa crusgalli), field weed millet (Echinochloa crusgalli), bindweed mountaineer (Fallopia convolvulus), upturned schiriza (Amaranthus retroflexus), tenacious bedstraw (Galium aparíne). In the reporting year, activities were carried out in full to develop preliminary theoretical and applied aspects for modeling the main parameters of varieties of various crops in the DSSAT system using the Aina spring soft wheat variety as an example. The results obtained are only preliminary, but very promising. They reflect the work that is currently being conducted at the University of Florida (USA) in cooperation with NAO “Kazakh Agrotechnical University. S. Seifullin”. On the basis of this program, preliminary parameters for modeling in the DSSAT system of varieties of other crops - cereals, legumes, oilseeds, fodder crops - were also obtained. Database of scientific and technical documentation (standards, reference books, classifiers, etc.) for the production of livestock and crop products with open access (Open API) has been created. An analysis of international experience in the formation of a database of regulatory and technical documentation was carried out. Separate aspects of the package of technical documentation on the main types of agricultural technologies and the livestock sector have been formed, and the concept of the structure of the Database for the subjects of the agro-industrial complex has been developed, taking into account classifiers, registers and reference information on the main types of agricultural technologies and the livestock sector. Separate aspects of the package of technical documentation on the main types of agricultural technologies and livestock sector have been formed (development of the concept of the structure of the Database for the subjects of the agro-industrial complex). Preliminary parameters of a unified database for agribusiness entities have been developed. On the basis of LLP "SPC of Grain Farming named after A.I. Barayev”, agrotechnical measures were taken to prepare the steam predecessor for the test site for 2022. The experimental data obtained on the basis of the test sites of North-Kazakhstan AES and Naidorovskoye LLP were processed mathematically in order to obtain the average values necessary to build the DSSAT system. In the reporting year, preliminary modeling of varieties for the climatic conditions of Northern and Central Kazakhstan was carried out on the basis of

the following indicators: soil NO_3 content (Nitrogen); soil NH_4 content (Ammonium); soil P (Phosphorus); soil moisture at different depths; dry plant biomass; leaf area index; plant productivity and its structural indicators.

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Results obtained in 2022

1) Soils of the examined plots located in three farms LLP “NK AES” and LLP «SPCGF named A.Baraev», LLP Naydorovskoye by physical and chemical indices are typical for the study areas. Farms are characterized by medium, high and low content of mobile phosphorus. On backgrounds with fertilizers on dark chestnut and chernozem soils there is a higher content of phosphorus than on the control. Provision of nitrate nitrogen is mostly low. Potassium content is high and very high. Soil pH values in LLP “NK AES” and LLP «SPCGF named A. Baraev» are neutral and slightly alkaline, in Naydorovskoe LLP - slightly alkaline and alkaline.

Humus content on common chernozems and southern chernozems - medium and low supply, on dark chestnut soils - low supply.

For farms the most effective method of increasing soil fertility is the introduction of nitrogen and phosphorus fertilizers, bringing them to the optimum value to increase crop productivity. In this regard, these farms should strictly comply with all elements of zonal agricultural technology, fertilizer systems, the order of alternation of crops in the rotation, it is widely practiced sowing perennial grasses, legumes, also need to strictly comply with the entire technological cycle of soil treatment.

2) On the basis of three farms located in different soil and climatic zones LLP “NK AES” (steppe zone, ordinary chernozems, North Kazakhstan region), LLP «SPCGF named A. Baraev» (steppe zone, dark-chestnut soils, Akmola region), " Naidorovskoye" LLP (dry steppe zone, dark- chestnut soils, Akmola region) were created test sites, where the influence of sowing dates, seeding rates on growth and development of plants, their productivity was studied on backgrounds with the introduction of different doses of mineral fertilizers. As a result of the conducted experiments and statistical analysis (multifactor analysis of variance) the reliability of influence of the studied factors on the crop yield was shown. However, the share of influence of these factors (terms and norms of sowing, background) in the current year was different in different agroclimatic zones. For example, the share of influence of feeding conditions was the highest in LLP “NK AES” and varied depending on the crop 51.3 - 72.5%, the share of

influence of seeding rates depending on the crop was 4.6 - 40.4%, the share of terms of sowing was 4.3 - 22.7%. In LLP «SPCGF named A. Baraev» the share of influence of different factors had the following maximum values: seeding rate - 70.9%, feeding conditions - 41.6% and sowing dates - 10.8%. In LLP "Naidorovskoe" the share of participation in variability of a crop of the studied factors was distributed as follows: terms of sowing - to 59,6 %, seeding norm - to 35,8 %, conditions of a food - to 29,6 %. Such distribution of influence of factors on crop yield is determined by soil-climatic conditions, which were formed in these zones in the current year, and availability of moisture during vegetation period of plants.

3) Phenological observations of plant growth and development were carried out for all crops, field seed germination and safety of plants depending on sowing dates, seeding rate, feeding conditions were studied. On all variants of the experiment insignificant fluctuations on these signs are marked. The correlation dependence between the elements of yield structure (number of productive stems per m2, productive bushiness, number of grains per spike, weight of grains per spike, weight of 1000 grains, plant height for grain legumes and oilseeds: number of plants at harvest per m2, number of bolls (seeds) per plant, number of seeds per plant, weight of seeds per plant, weight of 1000 grains), biometric indices (accumulation of dry biomass, leaf surface area) with yield of grain was shown. Weakly and strongly correlating traits were determined. For example, high correlation between the number of productive stems per m2 - r=0,6 - 0,8, leaf area - r=0,5 - 0,7, accumulation of biomass - r=0,7 - 0,8, weight of grains per plant - r=0,5 - 0,9 showed depending on the variety. Most of other studied traits had medium to low correlation. All phenological data, soil characteristics (soil properties and soil-agrochemical data), climatic indicators (daily minimum and maximum temperatures), agro- technologies of cultivation in each farm were used in parameterization and as input parameters in modeling plant growth and development, crop yield forecasting in DSSAT CMP.

4) To improve the DSSAT CSM system for gene modeling of wheat heading time prediction in the conditions of Northern Kazakhstan, molecular genetic studies on known adaptability genes (Vrn - vernalization and Ppd - photoperiod) were carried out. At the first stage, the wheat varieties under study were analyzed for homogeneity and typicality by the most informative gliadins spare proteins, and also their genotyping by the known genes of vorivation (Vrn) and photoperiod (PpD) was carried out. The genetic structure of cultivars with typical for the conditions of Northern Kazakhstan alleles of gliadin encoding loci: Gli-A1 (f, a), Gli-B1 (e, l), Gli-D1 (a, b), Gli-A2 (i, k, b), Gli-B2 (t, o) and Gli-D2 (p, l). The results of genotyping for the genes of vernalization and photoperiod showed the presence of Vrn-A1a and Vrn A1 (J) alleles in all varieties (except for cultivar Granny). Also in varieties Aina, Shortandinskaya-95 improved allele Vrn-B1c is found. The presence of dominant alleles of spring wheat genes indicates the spring type of development of these varieties of wheat, also for high latitude spring wheat varieties are characterized by strict sensitivity to the length of day and the presence of the allele Ppd-D1b.

5) In each farm, UAVs of both helicopter and airplane type, equipped with multispectral cameras, were flown and overflown over the fields at different phases of plant growth and development. Up to 1500 aerial images were acquired, divided into 5 channels (RGB, IR, NIR). All obtained images were loaded into the supercomputer for further processing. NDVI indices were calculated using these channels this year. Spectral signatures of healthy and damaged plants with different diseases were also collected and soil conditions were studied. According to the spectral curve, it was found that the effect of the disease on wheat is concluded in the interval between 700 and 1450 nanometers.

6) Based on the data collected during multifactorial field experiments conducted at test sites in Northern and Central Kazakhstan during the growing seasons of 2021 and 2022, preliminary parameters were determined for three models CERES-Wheat, CROPGRO-Pea and OILCROP- Sunflower from DSSAT CSM, i.e. for cereals, pulses and oilseeds, respectively. At this stage, to calculate these parameters, we used data on phenology (date of flowering and ripening), crop yield, yield components (number of grains, grain weight), weather data (daily

maximum and minimum temperatures, precipitation and solar radiation) in each zone, based on which we calculated genetic coefficients for each variety. Preliminary mathematical calculations using CERES-Wheat, CROPGRO-Pea and OILCROP-Sunflower models showed good agreement between the simulated and observed values on the dates of flowering and ripeness in all crops under study. Thus, wheat varieties Aina, Granny, Shortandinskaya-2012 and triticale Rossinka had reliable values of conformity index D and degree of dispersion between simulated and observed values of RMSE. In wheat they were D=0.74 - 0.98, RMSE = 0.7-1.0; in triticale they were D=0.97, RMSE = 0.7. The same correspondence (i.e. reliability) between these traits (observed and modeled) was observed in pea cultivar Aksaysky mustachy-55. However, analysis of OILCROP-Sunflower model calibration results shows relatively low correspondence between simulated and observed values (number of days) from sowing to flowering and maturity, as shown by low D value (0.1-0.2) and high RMSE 8-12.9 for Baiterek variety. For all crops on yield data, additional calculations with inclusion of other auxiliary parameters of the model are required.

7)The research carried out on flax within the framework of this program allowed us to introduce a new model for flax into the DSSAT CSM system. The program CSM-CROPGRO is used as a template. To adapt this program, data from field experiments on flax varieties Kustanaiskii Yantarnyi and Lirina for the two-year growing season (2021 - 2022) are collected, analyzed and processed. The collected data include phenology, growth, yield and yield components. Based on them, experimental files (Weather, SBuild, XBuild, ATCreate version 4.8.0.0) were prepared for model run, as well as measured data files for calibration.

8) Within the framework of this program, online and offline seminars were conducted by the developers of this model from Florida University (USA) to build human resources capacity on the use of DSSAT CSM simulation model for yield forecasting and as a decision support system. A total of 18 people from KATU named after S. Seifullin were trained.

9) System architecture, client-server part of the IS, database design has been developed, the knowledge base including normative-technical documentation on agroindustrial complex, reference information, classifiers to facilitate searching of appropriate materials, as well as methodological manuals on farming have been developed. Scenarios for the use of the system by different groups of users were distributed. Functionality of sending methodological recommendations for review by experts in the field of agriculture was developed. Cataloguing of the downloaded materials is provided, their ways of structured storage in a single place and visualization are taken into account.

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Results obtained in 2023

1 Meteorological observations conducted from 2021 to 2023 in three farms (NK AES, NPCZX, Naidorovskoye) located in different soil and climatic regions of Northern and Central Kazakhstan were compared with the previous 30 years of observations (1991-2020). The research revealed that the average annual air temperature in all the farms was slightly below the long-term average temperature. Average annual precipitation norms in all the farms were low in 2023 compared to 2021 and 2022, which significantly affected soil moisture levels in the farms. The Hydrothermal Coefficient (HTC) was higher in the study farms in 2022 compared to 2021 and 2023. According to the HTC data, the conditions were drier in SPCGF in 2023 compared to other farms. Overall, meteorological data indicates variable climatic conditions during the studied period and their potential impact on agriculture and crop yields in different farms.

2 Over the course of three years of research (2021 - 2023) in three farms (NK AES, Naidorovskoye, SPCGF), soil moisture in the meter-deep layer was satisfactory and low for all crops and experiments during the plant growing period, not exceeding 160-170 mm. In the upper soil horizons (up to 40 cm), soil moisture was low (not more than 40-50 mm). The best soil moisture levels for all crops over the three years were in the spring before planting, associated with greater precipitation during this period. The lowest field moisture content was observed after harvest for all treatments in the meter-deep layer. In all the studied farms (NK AES, Naidorovskoye, SPCGF), the year 2022 had the highest soil moisture levels in the meter-deep layer and upper horizons for all growing periods, contributing to better plant uptake of mineral nutrients (nitrogen, phosphorus, potassium, etc.). For NK AES, Naidorovskoye, and SPCGF, the year 2023 was characterized as the driest year with the least amount of precipitation, which affected the productivity of agricultural crops. The year 2021 had the lowest moisture levels, especially in Naidorovskoye.

3. Summary of Soil Assessment Results and Recommendations. In all farms, it is recommended to apply mineral nitrogen fertilizers before or at the time of sowing to achieve optimal nitrogen levels. The recommended annual nitrogen application for NK AES is 10-15 kg/ha. Phosphorus application: For farms NK AES, Naidorovskoye, and SPCGF, it is recommended to adjust phosphorus content to the optimal level (35 mg/kg) by applying phosphorus fertilizers, including differentiated ones, in the main tillage or in fallow. To mitigate soil heterogeneity in NK AES, the use of differentiated fertilizer application is recommended to correct the content of macronutrients and organic matter in the soil. Leguminous crops for nitrogen fixation: In NK AES, it is recommended to introduce more leguminous crops into crop rotations to enhance nitrogen fixation in the soil. Soil tillage: In farms NK AES, Naidorovskoye, and SPCGF, all soil tillage practices should be followed, including no-till cultivation to prevent wind and water erosion. Adaptive landscape farming system: It is recommended to implement an adaptive landscape farming system in all farms for more effective soil and resource management. Soil structure improvement: In Naidorovskoye and SPCGF, soil structure and density improvement is recommended through plowing and sowing perennial grasses.

4. Research Conducted in the North Kazakhstan Region. The research conducted in the North Kazakhstan Region emphasized the importance of moisture availability for crop cultivation. Precipitation timing and July rains had a significant impact on plant productivity parameters. Various agronomic practices, such as planting date, seeding rate, and fertilization, also influenced crop structure and productivity. This allows for adjustments to be made to the cultivation techniques based on specific climatic conditions. Different crop varieties and species respond differently to these agronomic practices in the dry steppe conditions of the North Kazakhstan Region, highlighting the importance of selecting the right agronomic solutions

depending on the specific conditions. Improving almost all yield structure parameters was facilitated by applying phosphorus (P90) compared to the control. Low moisture availability in crops reduced the efficiency of fertilizers, leading to the suppression of growth processes, decreased plant size, and reduced reproductive organ quantity. Crops with the application of ammonium phosphate (P90) showed significant productivity advantages. The soft spring wheat variety Shortandinskaya 2012 fully realized its genetic potential in drought years (2021, 2023) when sown on May 25 with a seeding rate of 3.5 million seeds/ha, yielding 29.7 and 26.4 c/ha, respectively. In the moderately wet year of 2022, the most productive crops were sown on May 20-25 with a seeding rate of 3.5 million seeds/ha, yielding 54.7 c/ha. The spring soft wheat variety Semenovna exhibited its high productive potential under fertilized conditions when sown on May 20-25 with a seeding rate of 4.0 million seeds/ha, with yields ranging from 24.1 (2023) to 35.9 c/ha (2022). The recommended agronomic practices for this crop and variety are sowing after May 20 with a seeding rate of 3.0-3.5 million seeds/ha under fertilized conditions. In the case of peas, the Aksai Usatyi 55 variety efficiently utilized moisture and produced higher yields when sown on May 15-20 with a seeding rate of 1.0-1.2 million seeds/ha, and this pattern was consistent throughout the years. Linseed yield almost independent of the seeding rate but influenced by sowing date and fertilization level, with later sowing dates resulting in higher yields. The hybrid Bayterek benefited significantly from the application of fertilizers when sown on May 20 with a seeding rate of 55,000 seeds/ha, with a yield of 9.5 c/ha. The same pattern was observed in 2021 and 2022.

5. Analysis of Meteorological Data in Naidorovskoye (Dry-Steppe Zone, Karaganda Region). The analysis of meteorological data collected at Naidorovskoye for the growing season (May-August) of agricultural crops in the years 2021-2023 indicated that these years presented unfavorable vegetative conditions. Two years, 2021 and 2022, were characterized by severe drought conditions, while 2023 was slightly less dry according to the Hydrothermal Coefficient (GTC) but still experienced insufficient precipitation in the early stages of plant development. Abundant rains during the harvest period and elevated temperatures during generative organ development contributed to unfavorable conditions for plant growth and development. The study showed a close relationship between field germination and plant survival and seedling density, both within the scope of the studied agricultural crop varieties and across experimental treatments. The field germination rate was influenced by sowing dates and cultivation conditions, particularly during the early stages of plant development. Plant survival depended on nutrient availability and the seeding rate of agricultural crops. All examined factors, such as seeding rate and cultivation conditions, had an impact on dry matter accumulation in plants. Increasing the seeding rate and improving nutrient conditions led to an 18-32% increase in dry matter accumulation compared to the control group, which did not receive fertilizers. Grain crop yields were primarily influenced by plant biomass, stem dry weight, greenness index, grain weight per spike, grain filling, and grain size. High grain crop yields were achieved with improved nutrient conditions and a maximum seeding rate of 3.5 million seeds/ha. Later sowing dates, regardless of nutrient conditions, reduced the yield of grain crop varieties. In the conditions of Central Kazakhstan, the spring wheat variety Granni demonstrated ecological plasticity distinct from other studied varieties. An analysis spanning 2021-2023 confirmed the influence of sowing dates, seeding rates, and fertilization on pea yields. Peas exhibited increased yields with an average sowing date (May 15) and mineral fertilization. A strong positive correlation was observed between pea yield, seeds per square meter, total biomass, and leaf surface area. For flax, late sowing dates and nutrient availability influenced yield formation. A high correlation was observed between yield and the number of bolls, 1000-seed weight, and seed mass per plant. Sunflower yield, particularly for the Bayterek 17 variety, during 2021-2023, was highly dependent on sowing dates and nutrient conditions, with early sowing dates (May 10) and improved nutrition resulting in yields of up to 15.66 c/ha. For triticale, critical yield-influencing factors included the number of plants before harvesting, productive tillering, and the number of grains per spike. Grain size remained relatively constant regardless of fertilization and

seeding rates. Maximum triticale yields were achieved by sowing on May 20 with a seeding rate of 3.5 million seeds/ha under conditions involving the application of Ammophos and ammonium sulfate in all experimental treatments.

6. Analysis of Meteorological Data in SPCGF, Akmola Region (Steppe Zone). The meteorological data analysis for the years 2022-2023 conducted in the steppe zone of the Akmola Region (NPCZX) revealed weather conditions characterized by a deficiency of precipitation during the autumn and winter periods, resulting in insufficient moisture during the growth and development stages of all agricultural crops. The growing season of 2023 was significantly drier (GTC 0.2) compared to 2022 (GTC 0.6). For grain crops, early sowing dates (May 15) and high seeding rates (4 million seeds/ha) increased plant yield, especially under limited moisture conditions. The application of fertilizers contributed to the accumulation of more substantial above-ground biomass compared to the control (no fertilizers). In grain crops, yield was highly correlated with yield structure elements such as grain filling, grain weight per spike, and 1000-seed weight. The spring wheat variety "Shortandinskaya 2012" was found to be the most sensitive to various factors affecting yield, underscoring the importance of selecting suitable varieties for specific agroclimatic conditions to ensure high yields in variable weather conditions. For peas, it is also recommended to consider optimal sowing dates, seeding rates, and to focus on water management to overcome the adverse effects of high temperatures and drought. The positive correlation between the number of pods and 1000-seed weight is crucial when selecting varieties and managing nutrient levels. Plant nutrient status and sowing dates had a significant impact on flaxseed yield. Early sowing (May 10) and good nutrient conditions contributed to higher flaxseed yields. In the case of forage millet, the analysis revealed the plants' vulnerability to drought, necessitating the adaptation of agronomic practices, including fertilizer application and seeding rates. Key factors influencing yield in forage millet included grain size, number of seeds per plant, and 1000-seed weight, providing the basis for the development of more effective cultivation methods. Consideration of yield structure elements, especially the number of grains per primary spike and grain weight from the primary spike, is essential in the development of agronomic practices and variety selection to increase triticale yields.

7. Digital Material and Decision Support System for Agricultural Technologies (DSSAT). The digital material obtained during the research serves as the foundation for the Decision Support System for Agricultural Technologies (DSSAT). Using DSSAT, the production process of cultivated crops was modeled. Based on the research conducted, a decision support system was adapted for three farms located in different soil and climate zones. Multifactorial field experiments (27 variants - 3 fertilizer levels x 3 sowing dates x 3 seeding levels) were conducted in three climatic zones (steppe and dry steppe) in the Northern and Central parts of Kazakhstan. Data was collected on phenology, growth, yield, and its components, as well as weather and soil data throughout the 2021-2023 cultivation of five agricultural crop types. Genotype-Specific Parameters (GSP) for models, including CERES-Wheat, CROPGRO-Pea, and OILCROP-Sunflower DSSAT, were determined for cereals, legumes, and oilseed crops. This allowed for the modeling of these crops/varieties in various climatic conditions in Kazakhstan, utilizing local weather, soil, and management data. Different management scenarios were studied, including combinations of fertilizer levels, sowing dates, seeding levels, and varieties, to select the best option based on long-term modeling. To predict the growth and yield of oil flax, a model of canola (genetically modified rapeseed) was selected as a template based on their similar growth and development patterns. A flax growth model was developed based on three years of field experiment data. Further steps in this regard include more rigorous testing of the flax model before its broader use in agronomic decision-making.

8. Model Validation and Future Development. The validation of DSSAT models for grain, legume, and oilseed crops in the studied farms has shown satisfactory overall performance and the potential for their use in other soil and climate zones in Kazakhstan. As empirical data accumulates and reaches a critical volume, dynamic models will be refined to provide accurate

data for decision support. Forecasts and recommendations will be based on the production process modeling. This process requires additional resources and coordination with stakeholders.

9. Development of an Information Portal and Open API. The initial stage of developing an information portal for farmers based on the DSSAT model has been completed. A module with open access (open API) has been created, allowing agricultural entities to connect and utilize it for the information portal. A database structure has been established, sample data provided for display on the website, relationships between tables developed, methods for loading the DSSAT model into the database, and their presentation to users on request. To enhance its functionality further, data must be collected from various natural-climatic zones and subzones, taking into account agricultural practices, phenotypic and genetic characteristics of cultivated crop varieties.

10. Comprehensive Database and Technical Documentation. A comprehensive database and technical documentation have been developed, covering various agricultural technologies in the fields of crop cultivation and animal husbandry. This is intended for the integration of information technologies into the production process and for use by agricultural product manufacturers, agricultural specialists in Kazakhstan, and other interested parties. Key characteristics of the developed comprehensive database and technical documentation include: i) Current standards, directories, and classifiers for various types of agricultural technologies and livestock activities. ii) Registries and normative-reference information encompassing various aspects of agronomic crops, fertilizers, soils, plant protection agents, seeds, diseases, and weeds, as well as information on livestock in accordance with standards and classification. Information has been consolidated from official sources and legislative acts of Kazakhstan, utilizing global standards and identifiers for easy data access. The plan is to finalize and transfer the project, including the database system, with all source code and technical documentation, into state ownership.

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