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# Influence of Sowing Dates, Soil Fertility and Crop Rotation System on Increasing the Yield Level of Various Varieties of Spring Wheat (*Triticum Aestivum* L.)

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**Abstract:** One of the most important branches of agriculture is crop production, from which people receive most of their basic foodstuffs, animal feed, and raw materials for the main industries. The most important goal of crop production is to increase yields in every possible way and, as a result, increase the production of grain, feed, and other products. The study aimed to analyze the influence of sowing dates, soil fertility, and crop rotation system on the yield level of various varieties of spring wheat (*Triticum aestivum* L.). To achieve this goal, field and production experiments, laboratory analyses, and phenological observations were carried out in Akmola and North Kazakhstan regions with different soil and climatic conditions. The following activities and experiments were carried out: Agrochemical survey of experimental and production fields, sowing and harvesting of various wheat varieties. The influence of sowing dates, fertility parameters, as well as various technical aspects of the use of crop rotations on the level of wheat yield has been analyzed. It has been concluded that it is possible to increase the yield of wheat in the current economic conditions under the condition of optimization and strict compliance with the basic agrotechnological requirements, such as compliance with optimal sowing dates, the introduction of scientifically based crop rotations and economically advantageous structure of crops and planned compensation of those nutrients that are at a minimum to increase soil fertility.

**Keywords:** Yield, Precision Agriculture, Agricultural Technologies, Remote Sensing, Sowing Dates, Soil Fertility Increase

## Introduction

In 2022, Kazakhstan saw a significant increase in the gross collections of grain products. This was the result not only of favorable weather conditions but also of a conscious restructuring of the structure of sown areas and the reorientation of agricultural production to modern intensive technologies for growing basic crops. The gross grain harvest, according to preliminary data from the ministry of agriculture of the Republic of Kazakhstan, amounted to 22.1 million tons, of which wheat accounted for 16.4 million tons. Over the past 10 years, this was one of the highest indicators (Fursov, 2021).

The increase in grain production is also due to significant demand on the global market since it is the basis of food for people and concentrated animal feed, i.e., the main source of food and feed protein (Elliott and McKitterick, 2013). Currently, almost all countries are trying to identify unused reserves and opportunities that would make it possible, based on the intensification of management methods, the widespread use of fertilizers and new high-yielding varieties, to increase the production of crop products (Tembo, 2021).

Crop-growing industries in agricultural production play an extremely important role in the formation of food security in Kazakhstan since they provide the population with basic foodstuffs and also make raw materials for the food, processing, and textile industries. Under these conditions, the issue of increasing the yield of commercial grain and other crops is important for Kazakhstan.

Yield is a qualitative, complex indicator that depends on numerous factors (Cassidy *et al*., 2013). Its level is greatly influenced by natural and climatic conditions (Waha *et al*., 2012; Zhao *et al*., 2022), terrain (Aparicio *et al*., 2002), air temperature regime (Barlow *et al*., 2015), and precipitation (Shortridge, 2019). Agriculture standards (Mohamed *et al*., 2000; Farooq *et al*., 2011), agricultural technology and crop cultivation technology (Turner *et al*., 2014; Voss-Fels *et al*., 2019), the number of fertilizers (Novoselov *et al*., 2013), high-quality performance of all fieldwork in a short time and other organizational and economic factors (Dobor *et al*., 2016; Minoli *et al*., 2019) also have an equally significant impact on yield.

Insufficient yield is explained by many factors, although the main reason is that producers do not adhere to scientifically sound agrotechnological requirements that require timely updating (Gulyanov *et al*., 2020).

The agrotechnological requirements can be updated provided that precision farming systems are used in the crop industry, which is a complex high-tech agricultural management system based on technologies of differentiated land use, considering the intra-field variability of soil fertility factors (Jägermeyr and Frieler, 2018) and using modern technology and software (geoinformation systems) support (Panesh and Tsalov, 2017; Bekezhanov *et al*., 2022) and remote sensing of the state of soils and crops (Oxukbayeva *et al*., 2023). Precision agriculture ensures the maintenance and improvement of soil fertility (Gulyanov and Chibilev, 2019), increasing sustainability and reducing material and energy costs of agricultural production (Polishchuk *et al*., 2021), obtaining high-quality products and reducing the burden on the environment (Gulyanov and Chibilev, 2019).

Remote sensing significantly reduces financial investments and the time required to obtain the necessary information compared with the use of ground-based equipment and traditional methods (Fritz *et al*., 2019). Satellite information is characterized by efficiency, reliability, and objectivity. Therefore, it is extremely in demand in the agricultural industry (Wójtowicz *et al*., 2016). The remote sensing system of farmland allows for obtaining information about the physical, chemical, and biological composition of the soil and the condition of crops using satellites or Unmanned Aerial Vehicles (UAVs) (Whitcraft *et al*., 2015). Such information is effectively used for monitoring and agricultural forecasts, effective management of soil and plant resources, and control over adverse environmental factors.

As the results of the analysis of scientific literature have shown, a significant number of research papers have focused on various aspects of increasing the yield level, thoroughly considering the factors of effective cultivation of individual crops, but not enough attention has been paid to agrotechnological factors.

The study aimed to study the influence of such agrotechnological factors as sowing dates, soil fertility, and crop rotation system on increasing the yield level of various varieties of spring wheat.

## Materials and Methods

The study was conducted in 2022 at two operating enterprises of Kazakhstan (A.I. Baraev grain farming research and production center (NPTsZKh) Limited Liability Partnership (LLP) and North Kazakhstan agricultural experiment station (SKhOS) LLP) in two regions (Akmola region, North Kazakhstan region) with different soil and climatic conditions.

Thus, studies on the influence of the sowing dates of spring wheat on the yield level were carried out against the background of contrasting sowing dates:

- In the Akmola region, at the A.I. Baraev NPTsZKh LLP in the subzone of southern carbonate chernozems (a variety of spring wheat of Kazakhstan selection; 3 replicates: May 10, 20, 30)
- In the North Kazakhstan region, at the North Kazakhstan SKhOS LLP (five varieties of spring soft wheat of different types of ripening of Kazakhstan selection; 6 replicates: May 10, 15, 20, 25, 30, June 5)
- Studies on the influence of various technical aspects of the use of crop rotations on the yield level were carried out in the Akmola region at the A.I. Baraev NPTsZKh LLP.
- The study also used methodological approaches for the use of Geographical Information System (GIS) technologies and the Big Data database

A comparative analysis was carried out when studying the duration of the growing season and the yield of wheat varieties depending on the sowing period and yield in various crop rotations. Five wheat varieties were studied: Astana, 2012, Semyonovna, Taimas, and Aina.

Studies on the influence of soil fertility parameters on the yield level were conducted at 20 accounting sites of experimental field No. 30 at the North Kazakhstan SKhOS LLP in the conditions of the North Kazakhstan region, where soil samples were selected and agrochemical analysis was carried out for six indicators of soil fertility (pH, Nitrogen (N), Phosphorus (P), Potassium (K), organic matter and sulfur).

In the course of the study, the following main activities and experiments were planned: Agrochemical inspection of experimental and production fields, crop sowing, and harvesting. The primary source of information for the study was the results of field observations, laboratory analysis of soil and plants, generalization, and analysis of scientific data.

Phenological observations and records of the phases of plant development were carried out according to the methods of the state crop variety testing. Based on the obtained indicators, the following types of ripening were identified: Middle-early, midseason-ripening, and middle-late.

Studies on the productivity of agrobiocenoses of crops (grain and oilseed yield) were carried out in the main phases of plant growth and development in dynamics. The structure of the crop was determined before harvesting using the GSI method for crops. In soil samples, the following indicators were determined: Humus according to I.V. Tyurin; mobile forms of NPK: Nitrate N ($N\text{-}NO_3$) according to Grandval-Lajoux, ammonia N with the Nessler reagent, mobile P in 1% ammonium carbonate extract according to the method developed by B.A. Machigin with subsequent determination on a photocolorimeter and mobile P according to Chirikov.

Statistical analysis of data on the duration of the growing season of wheat varieties and the yield of wheat varieties was performed using StatTech v. 3.1.6 (Stattech LLC, Russia). Quantitative variables following a normal distribution were described using Mean (M) and Standard Deviation (SD), and a 95% Confidence Interval (95% CI) for the mean was estimated. The data processing of the relationship between soil fertility and yield indicators at the accounting sites was carried out using methods of variance and correlation analysis in statistica 10 and ANOVA software.

## Results

When choosing the sowing dates, it is necessary to take into account the meteorological conditions of the agricultural year. The year 2022 was characterized as arid, with an elevated temperature background. The average daily air temperature in August was at the level of the long-term average and in May, June, and July it exceeded the long-term average values by 3.2, 1.9, and 1.2°C, respectively. The amount of precipitation for the entire vegetation of plants was lower than the average annual data, regardless of the month, and in general, 100 mm of precipitation fell during the period, while the total amount of average annual precipitation for the same period was 136 mm.

The period from sowing to germination, in pairs, under the influence of an increase in temperature in the sowing layer of the soil from 10-24°C, decreased from 13 days in the early stages to 7 days in the late stages. A similar situation was observed in the background with wheat as the preceding crop. The soil temperature was 12-27°C and the germination time was 10-6 days.

Observations of the phenology of the development of spring wheat in the Akmola region showed the relationship between the amount of productive moisture in the soil before sowing and precipitation from May to August with the duration of the growing season of spring wheat (Fig. 1).

In general, the period from germination to full ripeness was ambiguous. Precipitation that fell in the first decade of August led to an extension of the period of milk-wax ripening of grain with the sowing on May 20. Another trend in the development of plants is the increase in the interphase period from germination to tillering and the reduction in the phase of ontogenesis from tillering to stem elongation from early sowing dates to late dates.

The meteorological conditions of the year also influenced the long-term trend of increasing yields from early sowing dates to later dates. Depending on the sowing period, the yield of wheat sown on May 10 was 20.0 c/ha, on May 20 22.6 c/ha, and on May 30 21.0 c/ha. The best yield was obtained during sowing on May 20 (Fig. 2)

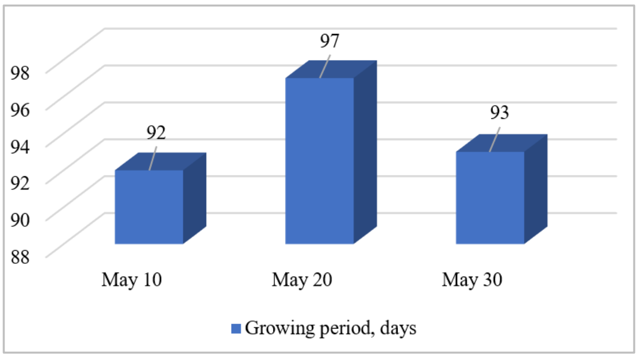


**Fig. 1:** The duration of the growing season of spring wheat depending on the sowing period, NTsPZKh, 2022

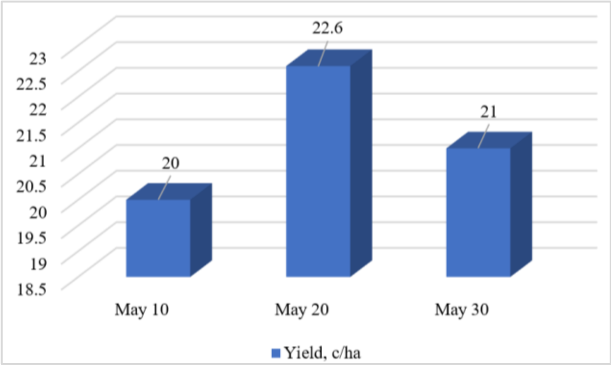


**Fig. 2:** Yield of spring soft wheat depending on the sowing period, c/ha

In the North Kazakhstan region, wheat seedlings during sowing on May 10 were obtained after 12 days. With the further advance of the sowing campaign, the sowing to sprouting period was significantly reduced; in June crops, it was only 3-5 days.

The calculation of the plant density of wheat varieties on the fixed sites was carried out. On average, there were from 206-285 plants per 1 $m^2$. This indicator is optimal for obtaining the necessary number of productive ears. The duration of the growing season of wheat, based on long-term observation periods, corresponded to the average level (Kunanbayev *et al*., 2022). This allowed the plants to realize their potential and get grain yields above average. Changes in the duration of the growing season depending on the variety and type of ripeness are presented in Table 1.

The distribution of the growing season of wheat, depending on individual varieties, ranged from 77-81 days (Astana variety) to 83-87 days (Aina variety). On average, the values of the indicator for the varieties were the following: Astana: 79 days, Shortandinskaya 2012 variety: 79 days, Semyonovna: 81 days, Taimas: 80 days and Aina: 84 days. In the context of the type of ripeness, the vegetation period for middle-early varieties was 77-81 days, for midseason-ripening ones 79-83 days, and for middle-late ones 83-87 days. Changes in yield depending on the wheat variety, the type of ripening of the variety, and the timing of sowing are shown in Table 2.

Wheat yield, on average, depending on the sowing period varied in the range of 22.5-27.9 c/ha. There was a tendency for an increase in the yield from the first term to the next one and a decrease in the case of sowing in June. The yield level in the case of sowing on May 10 was the lowest one, equaling on average 22.5 c/ ha, with a minimum yield of the Astana variety. The highest yield of wheat was obtained during sowing on May 20-30, in the range of 24.3-27.9 c/ha. Thus, the increase in yield in comparison with sowing on May 10 was +1.8+5.4 c/ha. In the context of varieties, the maximum yield was noted in the Aina variety (26.3-31.1 c/ha).

When cultivating varieties, the type of ripening is very important (Kunanbayev *et al*., 2022). In the conditions of the year, the varieties of the middle-early and midseason-ripening groups were characterized by very close yields, on average 23.6-23.9 c/ha, with a variation from 20.5-27.3 c/ha, depending on the sowing period. The middle-late wheat variety had the highest yield in the experiment, on average 27.7 c/ha with a variation of 26.3-31.1 c/ha.

The relationship between the yield level and fertility parameters (pH, N, P, K, organic matter, and sulfur) is presented in Table 3.

**Table 1:** Duration of the growing season of wheat varieties, including different types of ripening, depending on the sowing period, 2022

| Sowing dates, variety, type of ripening | The duration of the growing season of varieties, including different types of ripening, days | | | | | | |
|---|---|---|---|---|---|---|---|
| Sowing dates | May 10 | May 15 | May 20 | May 25 | May 30 | June 5 | M ± SD |
| Astana variety | 81 | 81 | 78 | 77 | 78 | 78 | 79±2 |
| Shortadinskaya 2012 variety | 81 | 81 | 78 | 77 | 78 | 78 | 79±2 |
| Semyonovna variety | 83 | 82 | 79 | 80 | 80 | 80 | 81±2 |
| Taimas variety | 83 | 83 | 79 | 80 | 79 | 79 | 80±2 |
| Aina variety | 87 | 87 | 83 | 84 | 84 | 84 | 85±2 |
| Type of ripening (evaluation criterion depending on the duration of the growing season of varieties) | | | | | | | |
| Middle-early | 81 | 81 | 78 | 77 | 78 | 78 | 79±2 |
| Midseason-ripening | 83 | 83 | 79 | 80 | 80 | 80 | 81±2 |
| Middle-late | 87 | 87 | 83 | 84 | 84 | 84 | 85±2 |

**Table 2:** Yield of wheat varieties and types of ripening depending on the sowing dates, 2022

| Sowing dates, variety, type of ripening | The yield of varieties and types of ripening, c/ha | | | | | | |
|---|---|---|---|---|---|---|---|
| Sowing dates | May 10 | May 15 | May 20 | May 25 | May 30 | June 5 | M ± SD |
| Astana variety | 17.1 | 24.1 | 24.3 | 23.1 | 26.5 | 22.4 | 22.9±3.2 |
| Shortadinskaya 2012 variety | 23.8 | 23.9 | 24.1 | 25.9 | 28.1 | 23.1 | 24.8±1.9 |
| Semyonovna variety | 23.1 | 22.4 | 23.5 | 24.6 | 26.4 | 20.1 | 23.3±2.1 |
| Taimas variety | 22.4 | 21.2 | 22.9 | 26.1 | 27.8 | 23.6 | 24.0±2.5 |
| Aina variety | 26.3 | 26.7 | 26.8 | 26.8 | 31.1 | 28.3 | 27.7±1.8 |
| Type of ripening (evaluation criterion depending on the duration of the growing season of varieties) | | | | | | | |
| Middle-early | 20.5 | 24.0 | 24.2 | 24.5 | 27.3 | 22.8 | 23.9±2.2 |
| Midseason-ripening | 22.7 | 21.8 | 23.2 | 25.4 | 27.0 | 21.9 | 23.7±2.1 |
| Middle-late | 26.3 | 26.7 | 26.8 | 26.8 | 31.1 | 28.3 | 27.7±1.8 |

**Table 3:** Results of the correlation analysis of the relationship between soil fertility and yield indicators at the accounting sites

| Indicator | Characteristics of the correlation relationship: Correlation coefficient between X and Y (rxy)/ ρ | The Correlation ratio on the cheddock scale | p |
|---|---|---|---|
| pH-biological yield p | 0.041 | No correlation | 0.862 |
| Humus content-biological yield (rxy) | 0.479 | Moderate | 0.033* |
| $N\text{-}NO_3$ content-biological yield (rxy) | 0.048 | No correlation | 0.842 |
| Mobile forms of sulfur-biological yield p | 0.178 | Weak | 0.454 |
| Mobile P compounds-biological yield (rxy) | -0.156 | Weak | 0.511 |
| Mobile K compounds-biological yield (rxy) | -0.052 | No correlation | 0.828 |

**Table 4:** Grain yield by various preceding crops of spring wheat

| Preceding crop | Grain yield, c/ha |
|---|---|
| Wheat after black fallow | 19.8 |
| Wheat after oats | 17.3 |
| Wheat after lentils | 15.6 |
| Wheat after peas | 14.8 |
| Wheat after chickpeas | 16.6 |
| Wheat after annual grasses | 13.4 |
| Wheat after sunflower | 15.0 |
| Chickpeas after stubble | 13.5 |
| Peas after stubble | 12.8 |
| Lentils after stubble | 09.5 |
| Oats after stubble | 15.9 |
| Barley after stubble | 22.0 |

**Table 5:** Agricultural production in various crop rotations

| Crop rotation | Grain and oilseed yield, c/ha: Cereals | Legumes | Oilseeds | Feed | Output of feed units, c | Output from 1 ha of crop rotation area, c |
|---|---|---|---|---|---|---|
| Four fields Fallow-wheat-wheat-barley | 20.2 | - | - | - | - | 15.1 |
| Four fields Peas-wheat-flax-barley | 18.3 | 12.8 | 8.1 | - | - | 14.4 |
| Four fields Chickpeas-wheat-flax-barley | 18.3 | 13.5 | 8.6 | - | - | 14.7 |
| Four fields Lentils-wheat-flax-barley | 16.4 | 9.5 | 7.8 | - | - | 12.6 |
| Four fields Oats-wheat-wheat-barley | 17.6 | - | - | - | - | 17.6 |
| Four fields Annual grasses-wheat-Wheat-barley | 17.3 | - | - | 160.8 | 30.5 | 12.5 |

According to the analysis, there was no connection with the content of nitrate N, exchangeable K, and pH, and a weak direct connection was found with the content of mobile forms of sulfur, possibly because three plots related to a low degree of availability of this element were localized in the zone of low productivity. When assessing the relationship between biological yield and the content of mobile P compounds, a weak correlation was established, i.e., in some plots, an additional application of P fertilizer reduced the yield. Thus, it was demonstrated that the humus content had the greatest impact on productivity among fertility indicators. To a lesser extent, the content of mobile forms of sulfur and P influenced the situation.

The influence of various preceding crops in the crop rotation on the yield level of spring wheat is presented in Table 4.

The alternation of profitable crops in crop rotation makes it possible to steadily increase the yield of some crops and the productivity of crop rotations in the structure of arable land. Despite the dry year 2022, black fallow with a yield of 19.8 c/ha, and leguminous crops with 14.8-16.6 c/ha proved to be the best-preceding crop conditions for spring wheat (Table 4). The yield of grain crops (oats and barley) was obtained in the range of 15.9-22.0 c/ha. For the rest of the preceding crops, the grain harvest was obtained in the range of 17.1-17.6 c/ha. Leguminous crops gave yields in the range of 9.5-13.5 c/ha (Table 4).

Grain crop rotations were distinguished by the highest productivity. The calculations show that the largest grain yield from 1 ha of arable land was provided by a four-field grain crop rotation with the rotation of oats-wheat 2-barley, which amounted to 17.6 c/ha from 1 ha of arable land using smart agriculture tools (Table 5).

## Discussion

As the results of the study showed, one of the main factors affecting wheat yield was non-compliance with sowing dates and crop rotations, lack of humus content in the soil, etc. These results are largely consistent with the data obtained earlier (Mohamed *et al*., 2000; Novoselov *et al*., 2013; Dobor *et al*., 2016). According to Shortridge, (2019), adverse weather conditions during the growing season also add to the negative results. All the factors listed above are the main reason for the large gap between the potential and actual wheat yield.

However, not only weather conditions can cause low yields. Agricultural producers have increased non-compliance with agrotechnological requirements for wheat cultivation (Kunanbayev *et al*., 2022). Therefore, in recent years, weather conditions have become an indicator of the agriculture standards and the ability to grow high yields of wheat on our fertile soils.

From the results of studies (Barlow *et al*., 2015), it can be concluded that precipitation indicators directly affect the yield. However, even with the optimization of these indicators, yield may decrease if significant precipitation falls during the harvest period. The greatest stress factor affecting plant development is a sharp temperature fluctuation during the growing season (Barlow *et al*., 2015). High and low temperatures during the growing season negatively affect the physiological processes of plants. The consequences vary depending on the phase of plant development, the duration of exposure, and the actual air temperature. Frost resistance and drought resistance are significantly influenced by the conditions of soil nutrition, especially in the autumn period (Novoselov *et al*., 2013).

Manifestations of weather anomalies, which other researchers have noted in recent years, have been observed in Kazakhstan. They require increasing the resistance of wheat to these phenomena by developing comprehensive organizational measures to protect against adverse natural conditions (Kashina *et al*., 2022). The resistance of plants to frost increases when K-P fertilizers are applied to winter crops, while excess N fertilizers, contributing to the growth processes, make winter plants more sensitive to frost. Microelements have a positive effect on frost resistance, as well as on the cold resistance of plants (Novoselov *et al*., 2013).

High yields also lead to faster depletion of soils. The resumption of soil fertility can be carried out, in our opinion, by a combination of two measures: The introduction of fertilizers and scientifically based crop rotation (Turner *et al*., 2014). Thus, by using fertilizers that meet agrotechnological requirements and productive crop rotations, it is possible to increase crop productivity.

## Conclusion

As the results of the study showed, the level of the yield of various varieties of spring wheat is determined by the quality indicators of the soil, the number of fertilizers applied, the meteorological conditions of the year, the quality and grade of seeds, methods, and timing of sowing. Thus, it is possible to stabilize or increase the yield of cultivated wheat varieties in the current economic conditions, provided that the basic agrotechnological requirements are optimized and strictly observed. The least costly of them are compliance with optimal sowing dates, the introduction of scientifically sound crop rotations and economically advantageous crop structure, planned compensation of those nutrients that are at a minimum to increase soil fertility, preventive measures to control phytosanitary conditions, timely harvesting, etc.

Considering all of the above, the use of precision farming technologies in soil cultivation and wheat cultivation will help to increase the efficiency of agricultural production and reduce the impact of unfavorable environmental factors on the economy of enterprises.

Considering the technical organizational and economic factors contributing to the stabilization and increase in the efficiency of grain production can become a prospect for further research, which will allow us to develop a specific set of measures aimed at solving the problems of the development of the industry.

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## Author’s Contributions

All authors equally contributed to this study.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues are involved.

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