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Enhancing the Effectiveness of Feed Production in Arid Areas, Northern Kazakhstan, Considering the Utilization of Soil Moisture Resources

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Abstract: The problems of sustainability of crop production in arid regions are actual. Moreover, often the aridity factor is combined with other stress factors, such as elevated temperatures and soil salinity. The article evaluates the effectiveness of the use of moisture and heat resources when growing fodder crops in arid conditions with a short growing season. In order to compare the yields of different crops, their yields were converted into feed units. The nutritional value of one kilogram of oats was taken as one feed unit. As a result of the research, it was concluded that for Northern Kazakhstan the most optimal period for sowing annual crops is the period from May 20-31. This ensures that the period of their maximum water consumption coincides with the maximum amount of precipitation in July. In this case, when growing spring wheat or barley, the land is empty for 34-47 days, with an average loss of 63 mm of productive moisture. In addition, the process of soil salinization is provoked. This does not happen when barley or wheat is replaced by perennial sainfoin. When comparing the yields of sainfoin and barley in feed units, the yield of sainfoin in the 2nd and 3rd years of life exceeded the yield of barley by 32.9-47%. Therefore, in order to minimize losses and rational use of water and heat resources of the region, it is proposed to diversify the structure of crops by increasing the share of crops of perennial leguminous grasses in the structure of the main crops. This will significantly increase the efficiency of the industry not only in Northern Kazakhstan but also in other regions of the world with similar conditions.

Keywords: Food Production, Drought Conditions, Efficiency, Feed Units, Soil Moisture

Introduction

Problems of crop production sustainability in arid regions are acute. All the more so the drought factor is often combined with other stressors such as increased temperatures and soil salinity. These abiotic factors work together to significantly reduce crop productivity (Jacobsen *et al*., 2012).

The search for technologies to overcome abiotic stresses has led to the conclusion that it is necessary to develop and combine cropping strategies for specific conditions (Matthews *et al*., 2013; Huang *et al*., 2022). This includes adjustments in crop rotations, planting densities, feeding regimes, etc. In order to ensure high crop yields. In addition, the stimulation of adaptation tolerance to stress breeding of varieties with increased resistance the and use of crops with increased drought and salt tolerance are promising avenues (Syzdykova *et al*., 2018; Anikina *et al*., 2021). According to Traore *et al*. (2017); Liu *et al*. (2022); Matthews *et al*. (2013) the use of modeling in agricultural crop production can facilitate adaptation to climate stresses. Crop redistribution based on spatial patterns of crop suitability and water availability can help reduce water scarcity and increase food production (Haouari and Azaiez, 2001; Osama *et al*., 2017; Boustani and Mohammadi, 2010). According to Osama *et al*. (2017), this will increase gross net returns in arid regions without additional costs.

Water scarcity and drought have become a problem not only in North Africa and the East but also a frequent and widespread phenomenon in Canada, America, the European Union, southern Russia, Central Asia, and

Central Asia (Corbeels *et al*., 2018; Seminchenko, 2021; Lobunskaya *et al*., 2021; Liu *et al*., 2022).

Rainfed agriculture is still a common crop production practice in many regions, e.g., in the Mediterranean countries, Australia, Russia, and also in northern Kazakhstan, especially for grain crops (Anderson, 2010; Malitskaya *et al*., 2020; Giller *et al*., 2021; Seminchenko, 2021).

In Northern Kazakhstan, agricultural production is mainly cereal-based, with a predominance of spring wheat (Kunanbayev *et al*., 2024), and the region also specializes in livestock farming, as it has vast areas not occupied by cities. Spring wheat crops occupy about 60% of the total sown area. Cereal crops (spring wheat) in Northern Kazakhstan are grown in areas with 270-340 mm of precipitation per year. The areas with 340 mm of precipitation occupy less than 50% of the total sown area of spring wheat (Irmulatov *et al*., 2021).

Shortridge (2019), crop yields directly depend on the amount of precipitation during the growing season.

There are few lakes and rivers in northern Kazakhstan and hot air masses often come from the south, from the desert area. This creates conditions of high evaporation from the soil surface and considerable dryness of the air. High air temperatures with low humidity during the growing season negatively affect the physiological processes of plants (Barlow *et al*., 2015; Kunanbayev *et al*., 2024). This leads to low yields, especially for annual crops. For example, in spring wheat, grain yields vary from 0.45-2.72 t/ha, with average yields of 1.4-1.8 t/ha (Syzdykova *et al*., 2018). Low yields of fodder crops have a negative impact on the development of animal husbandry.

The area of arable land in the northern part of Kazakhstan is approximately 19.2 million hectares and a huge amount of thermal solar energy is supplied to this area of arable land, which is empty for a month during the cultivation of spring crops. Most of which is wasted. According to the law of nature, these significant amounts of energy must be transformed and condensed by the organic mass of plants in this large area.

This would have a positive impact on soil fertility and the agroecological system of the region as a whole and increase the yield of all crops. However, this leads to the development of a complex of negative processes in the region. A climatic peculiarity of the spring period is a rapid increase of high air temperatures on open steppe spaces in combination with high wind activity (Konopyanov, 2004). In the background of these conditions, the incoming energy to these spaces, especially when the arable land is empty for 34-47 days before sowing annuals, has a negative impact on these areas. Firstly, it increases the evaporation of moisture from the soil surface, as mentioned above, and increases aridity. Secondly, the loss of moisture and heat resources in arid conditions leads not only to low yields and low profitability of production but also provokes the development of soil salinization processes (Eleshev and Konopyanov, 2012; Issanova *et al*., 2017).

It is characteristic for regions, where at the depth of 80-160 cm and below there are toxic salts NaCl and Na_2CO_3. These salts, easily soluble in water, rise to the upper soil layers with the evaporated moisture (Fig. 1) and in non-irrigated conditions cause the development of soil salinization processes. This leads to problems in farming crop production, as the salts are toxic to plants (Almaganbetov and Grigoruk, 2008; Ismukanova and Merzlyakov, 2013; Issanova *et al*., 2014).

Based on the above, we believe that the current concept of feed production with the predominant cultivation of spring crops in Northern Kazakhstan is extremely ineffective for arid climatic conditions and requires significant improvement.

During the analysis of growing conditions and the results of research, including our own (Konopyanov, 2004; Arystangulov, 2010), it was suggested that to improve the strategy of agricultural development in the arid regions of northern Kazakhstan, to combat soil salinity and ensure high efficiency of crop production, it is necessary to change the structure of crops by including perennial leguminous grass, sainfoin, alfalfa and other their analogs in the crops.

The role of perennial legumes in crop rotations has been demonstrated by many researchers (Abraham *et al*., 2019). Symbiotic with rhizobial bacteria, they fix atmospheric nitrogen and saturate the soil with it. Their use in crop rotations with cereals increases cereal yields and mitigates environmental impacts (Nemecek *et al*., 2008).

Legume-grass-based animal feed systems are now widespread agroecosystems of critical ecological and social importance (Sebastià *et al*., 2024).

At the same time, there is increasing interest each year in the wider use of alternative forage legumes such as sainfoin (*Onobrychis viciifolia*) (Şakiroğlu, 2021; Kelln *et al*., 2021; Karabulut *et al*., 2023). Many researchers have shown the advantages of sainfoin in terms of high fodder quality and good adaptability, especially in regions with limited soil fertility resources and increased aridity (Delgado *et al*., 2005; Khalilvandi-Behroozyar *et al*., 2010; Biligetu *et al*., 2021).

Fig. 1: Bringing to the soil surface of toxic salts during evaporation under arid conditions (Pavlodar district, Pavlodar region, June 20, 2021)

It is not inferior to alfalfa in terms of yield and crude protein content (*Medicago sativa*) (Malisch *et al*., 2017). At the same time, sainfoin, due to the presence of condensed tannins, has significant advantages over lucerne, namely longevity, resistance to gall nematodes, reduced frothy bloat in ruminants, also antihelminthic protection against intestinal parasites (Biligetu *et al*., 2021). In addition, when feeding sainfoin-based forages, ammonia, and enteric methane emissions are reduced (Wang *et al*., 2015; Sheppard *et al*., 2019).

According to the conclusions of many scientists, sainfoin among forage grasses is the most favorable crop for sustainable agriculture in dry conditions (Delgado *et al*., 2005; Sakhraoui *et al*., 2023).

In Kazakhstan, there is interest in sainfoin as a forage crop and there are studies confirming its positive effects on livestock productivity and soil characteristics (Chekalin, 2009; Kantureyev, 2019; Sagalbekov *et al*., 2022).

However, these grasses are currently absent from the cropping pattern of cereal crops in Northern Kazakhstan, while they can simultaneously address the above-mentioned problems. Thus, the problem of crop area diversification is overdue, taking into account the potential of local soil and climatic resources.

The research on this topic has novelty, as it has not been conducted in Kazakhstan before.

Currently, these grasses are absent in the structure of cereal crops in Northern Kazakhstan, but they can simultaneously solve the two above-mentioned problems.

The purpose of the research was to study the factors of increasing the efficiency of feed production in arid regions in the example of Northern Kazakhstan, taking into account the use of soil moisture resources.

Materials and Methods

Research work was carried out in 2019-2021 on the fields of the village Shortandy, Akmola region, and on the experimental farm "Irtyshskoye" of the Pavlodar region of Kazakhstan.

The objects of research were forage crops of sainfoin and barley, as well as soil and climatic conditions of the zone. The conditions of the growing season during the research period were within the range of the average long-term data on humidity and temperatures (Table 1).

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The objects of research were fodder crops of sainfoin (variety Peschanyi improved) and barley (variety Donetskiy 4), as well as soil and climatic conditions of the zone. Growing season conditions during the study period were within the range of average multiyear data for moisture and temperatures (Table 1).

Soil moisture was determined by the method of thermal weighing every 10 cm at a depth of 1 m according to the method of Bakayev and Vasko (1975) in a six-fold repetition 2 times a decade, then the average value was deduced. The amount of precipitation was determined using rain gauges installed in the experimental plots.

At the same time in the experimental plots, yield measurements were carried out in three repetitions in plots of 100 m^2 each.

Sainfoin does not produce a productive crop in the year of sowing, so its yield was not counted in the first year. Sainfoin was sown under spring wheat cover. Soils of experimental plots are chestnut, sandy loam, with humus content in 0-20 cm layer within 1.0-1.3 %, gross nitrogen 0.07-0.022 %, phosphorus 0.09-0.19 %, potassium 1.4 %. Absorption capacity is 14-38 mg/eq per 100 g of soil. Nutrient content: N-NO_3 5-12 mg kg^{-1}, P_2O_5 52-90 mg kg^{-1}, K_2O 150-280 mg kg^{-1}, pH 6.7-7.0.

Fertilizers and Artificial Irrigation were not Applied

Barley yields were measured once a year, sainfoin yields were measured twice a year and sainfoin results were summarised.

In order to compare the yields of different forage crops, their yields were converted into a single indicator feed unit, which allows for comparison of their feed value.

The nutritive value of 1 kg of oats is taken as one feed unit, i.e., 1 kg of oat grain is equal to 1 feed unit (f.u.), which corresponds to 0.6 starch equivalents or 5.92×10^6 J (1414 kcal) of net energy (Kukusheva and Stepanov, 2016). Thus, 1 kg of barley grain corresponds to 1.17 feed units (f.u.) and 1 kg of barley straw corresponds to 0.32 f.u. 1 kg of hay or dry above-ground matter of sainfoin corresponds to 0.53 f.u.

Statistical processing of the data was carried out using Microsoft Excel 2007. The data in the table are presented as averages over the three years of the study (2019-2021). Pearson correlation coefficients, errors, and significance criteria were calculated (not all results are presented). Differences were statistically significant at the $p<0.05$ level.

Results

In the spring period, the loss of water resources is as follows. In spring the snow on the main area of arable land melts by April 3-16 (Table 1).

The data obtained on the change in the amount of productive moisture in the soil in a layer of 0-100 cm during the sowing period of spring crops are presented in Table 2.

Table 1: Soil and climatic conditions of the early spring period of Northern Kazakhstan

Region	End of snowmelt	Date of steady onset of air temperature +5°C	Date of soil thawing to a depth of 30 cm	Average soil temperature between 1 and 10 May at a depth of 10 cm
Akmola region, Shortandy station	16 April	15 April	30 April	+12°C
Pavlodar region, Ertis station	28 March-3 April	16 April	15 April	+14°C

Table 2: Productive moisture content in soil in 0-100 cm layer

No.	Moisture content	Year of Research 2019	2020	2021	Average, mm
1	Moisture content in the soil in 0-100 cm layer in the 2nd decade of April, mm	82,6	94,7	124,2	100,5
2	Precipitation from the 2nd decade period of April to the 3rd decade period of May, mm	31,8	22,2	39,0	31,0
3	Sum of moisture in the soil in the 0-100 cm layer during the 2nd decade of April and precipitation during the period 10 April-30 May, mm	114,4	116,9	163,2	131,5
4	Moisture content in soil in 0-100 cm layer in the 3rd decade of May, mm	51,4	64,3	89,7	68,5
5	Total moisture loss for the period from 10 April to 30 May, mm	63,0	52,6	73,5	63,0

Fig. 2: Height of sand sainfoin (90 cm, 1 June 2020)

Fig. 3: Height of sandy sainfoin second growth (swath) 25 July 2020

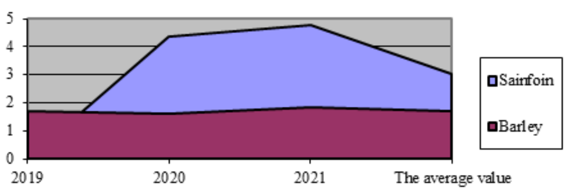

Fig. 4: Yield of air-dry mass (14% humidity) of spring barley, in comparison with sandy sainfoin, tons/ha

Table 3: Yields of spring barley compared to sandy sainfoin in the conditions of Northern Kazakhstan in feed units

Crop name	Yield in feed units By year 2019	2020	2021	Average value in 3 years	An increase in feed units during the cultivation of sainfoin compared to barley + in 2 and 3 years, % 2 year	3 year
Barley	16,8	16,0	18,2	17,0	-	-
Sainfoin	-	23,5	24,2	15,2	47	32,9

Mean values in each column followed are significantly different (p<0.05)

During the study, it was found that the sainfoin grows early after snowmelt and effectively uses moisture and heat in early spring and by the period from May 25-June 1 forms a good harvest, reaching a height of 80-90 cm (Fig. 2).

After the first mowing in early June, then after 55-60 days, sainfoin forms a second growth of at least 50 cm in height due to rainfall in July (Fig. 3).

In the course of the research, the yield of forage crops was studied: Barley and sainfoin. When comparing the yield of the dry mass of the sainfoin (14% humidity) with barley, even taking into account the fact that in the first year the sainfoin, as a perennial grass, did not yield, subsequently in 2 and 3 years due to the increase in biomass during the growing season, the yield indicators of the sainfoin were much higher than those of barley in 3 years. The Fig. 4 shows the yield indicators for 3 years in tons per ha.

Table 3 shows the yields of barley and sainfoin converted to feed units, allowing a comparison of their productivity.

Discussion

During the study of Soil and climatic conditions of the early spring period, it was found that. The growing season conditions in Northern Kazakhstan are characterized by low moisture supply and elevated temperatures.

To improve agricultural efficiency, the region has the following potential resources:

- High soil moisture after snowmelt
- A large amount of incoming heat in the spring period in April-May
- Relatively favorable conditions of the second half of the vegetation period due to rainfall in July in the amount of 49-57 mm
- Often humid conditions in the autumn period

These data show that in the region, against the background of high aridity, such a major factor as water resources is distributed at different times and is strongly separated during the growing season. Due to the fact that the months of May and June are dry in the region, farming is mainly focused on the efficient use of favorable conditions in the second half of the growing season, especially the rainfall in July. But under conditions of acute water scarcity, such a farming system has significant disadvantages because, firstly, it does not ensure the rational use of moisture resources accumulated for the spring period, due to which a significant part of them is lost uselessly; and secondly, it allows violation of laws of natural system development.

In this zone, spring crops are sown on May 20-31. In the conditions of the region, sowing at this time is the most optimal, because in cereal crops the period of maximum moisture consumption is the end of the booting stage (Litovchenko and Dolgopolova, 2022; Kunanbayev *et al*., 2024). Therefore, this period must be water availability, otherwise low yields are formed.

During the growing season, the region receives the greatest amount of rainfall in July (Table 1). Therefore, sowing spring wheat and other annual crops between 20 and 31 May ensures that their period of highest moisture consumption coincides with the maximum rainfall in July. Only in this case is it most likely to produce economically profitable yields. The soil and climatic conditions of the region allow spring wheat, barley, and other crops to be sown between 25 and 30 April, when there is plenty of moisture in the soil.

As can be seen from Table 2, during this period the air temperature steadily becomes higher than +5°C, and the arable layer of soil also warms up to a suitable condition for sowing. However, in this case, the period of maximum moisture consumption of spring barley and other crops comes in the highly arid conditions of June, when precipitation is low and air temperature is high. This leads to the formation of low yields. Thus, when studying Altybaeva and Zharkova (2020) yields of 15 varieties of spring wheat in the Pavlodar region in 2017-2019, the yields ranged from 0.95-1.68 t/ha.

From the data given earlier, it can be seen that in the Northern part of Kazakhstan, arable land after snowmelt and before the sowing of crops is empty for 34-47 days and possibly even more (Konopyanov, 2004).

The present studies have established that during this period, firstly, 63 mm of productive moisture is lost on average as a result of evaporation from the meter layer of soil and inefficient use of precipitation (Table 2).

Similar results were obtained in other studies conducted in Northern Kazakhstan (Irmulatov *et al*., 2021; Litovchenko and Dolgopolova, 2022). Thus, over 3 years these losses reached 189 mm. Approximately the same amount of productive moisture in the region is spent to form an annual average yield of spring wheat grain of 1,0-1,2 t/ha, or 1,1 t/ha. On the basis of calculation for the formation of 0.1 tons of grain in region 13,5-17 mm of moisture is spent (Irmulatov, *et al*., 2021). The same losses occur on the sowing of other annual crops, including Lentils, rape, oilseed flax, chickpeas, etc.

Sainfoin and other perennial grasses have a complex positive impact on soil and agroecology (Nemecek *et al*., 2008). For example, after 3-4 years of cultivation and use as animal fodder, they leave a large mass of organic residues in the soil in the form of roots and stubble. The organic residues of perennial legumes are rich in nutrients and in turn, enrich the soil with them. Their complex positive effect on soils increases the yields of crops placed after them, including spring wheat, barley, and others (Ozlu *et al*., 2022; Babur *et al*., 2022; Poyda *et al*., 2022). In other words, the second task mentioned above increasing the yields of annual crops is solved.

As a result of the efficient use of available moisture and heat resources, perennial legumes produce higher and more consistent annual yields than annual crops cultivated in the region (Konopyanov, 2004; Sagalbekov *et al*., 2022).

Among grain crops in the region, the most productive is barley, which under the same conditions forms a grain yield 0,2-0,4 t/ha higher than that of wheat (Irmulatov *et al*., 2021). Therefore, barley was chosen for comparison with the sainfoin crop. As can be seen from Table 3, the yield in feed units of sainfoin in the 2^{nd} and 3^{rd} years of life is significantly higher than barley by 7.5-6 feed units/ha respectively, or 47-32.9%. Moreover, financial costs in the 2^{nd} and 3^{rd} years on the sainfoin crops were 2,5-3 times less than on the barley crops. The reason is that in these years there are no costs for seeds, sowing, and herbicide treatments against weeds on the sainfoin crops. These costs are available for barley and other annual crops.

Thus, perennial leguminous grasses under regional conditions produce significantly higher yields at lower financial costs than annual crops. Under these conditions, sainfoin steadily forms two harvests, i.e., its green mass is

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mown twice during the growing season. At the same time, leguminous grasses are high-quality forages, rich in protein and vitamins (Ates *et al*., 2013). Therefore, these crops can play a major role in the development and efficiency of livestock production (Nyfeler *et al*., 2009; Tomić *et al*., 2023), which is also important because by 2030 global meat and milk consumption is expected to increase by 68 and 57% respectively (Abraham *et al*., 2019). In this regard, for example, the EU has developed Common Agricultural Policy (CAP) measures that support the cultivation of legume crops.

Thus, the inclusion of alfalfa, sainfoin, and their counterparts in the cropping pattern solves many problems simultaneously, increasing the efficiency of grain and livestock production, which will contribute to the overall efficiency of agriculture in the region.

In addition, in dry climates, the sowing of barley and other cereals leads to a reduction in soil organic carbon, which is crucial for maintaining many soil functions (Babur *et al*., 2022; Ozlu *et al*., 2022). These circumstances, repeated year after year, contribute to a further decrease in soil fertility in arable land, which is currently occurring everywhere in agricultural production (Giller *et al*., 2021).

Thus, based on the analysis of the identified problems and by including perennial legume grasses in the structure of the main crops, there is an opportunity to switch to a new agricultural development strategy in the North of Kazakhstan and other regions with similar conditions, ensuring higher efficiency.

The introduction of sainfoin into crop rotations of northern Kazakhstan, as well as other arid regions, will also contribute to solving agronomic and environmental problems. Since sainfoin is a good precursor and contributes to the accumulation of available nitrogen in the soil up to 100-200 kg/ha, it has the greatest adaptive properties to abiotic factors of arid northern regions of Kazakhstan in comparison with other leguminous grasses. It contributes to the prevention of soil degradation, i.e., due to its powerful root system it forms a strong sod layer in a short time.

Conclusion

From scientific studies conducted in regions with less than 340 mm of precipitation per year and the maximum amount of precipitation during the growing season in July, the following conclusions can be drawn:

1. The cultivation of annual spring crops in arid conditions with a short growing season has low efficiency since arable land is empty for 34-47 days or more before the optimal sowing period, which leads to significant losses of moisture and heat resources in the spring period. As a result, the average yield of spring barley is 17 feed units
2. The cultivation of perennial legumes, such as sainfoin, allows for greater use of soil moisture reserves and positive spring temperatures. The yield of sainfoin in feed units for the 2nd and 3rd years of life is significantly higher than that of barley, by 7.5-6 feed units/ha, respectively, or by 47-32.9%. When comparing the yield of the dry mass of the sainfoin (humidity 14%) with barley, even taking into account the fact that in the first year the sainfoin, as a perennial herb, did not yield, subsequently for 2 and 3 years due to an increase in biomass during the growing season, the yield indicators of the sainfoin were on average for 3 years 77% higher than that of barley in 3 years. Thus, in the conditions of this region, the sainfoin produces a significantly larger volume of products in feed units, at lower financial costs. The inclusion of the sainfoin in the structure of the sown areas of Northern Kazakhstan will create good prerequisites for the development of animal husbandry. Obtaining high-quality livestock products will allow producers to enter foreign markets, as well as meet the needs of domestic producers for high-quality raw materials for the production of cheeses and other food products

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Author’s Contributions

Kudaybergen Konopianov: Organized the study, and participated in all experiments.

Irina Anikina: Coordinated the data analysis and contributed to the writing of the manuscript.

Karina Omarova: Contributed to the writing of the manuscript and translation assistance.

Semby Arystangulov: Designed the research plan and organized the study.

Marat Omarov and Temirbolat Kabykenov: Participated in all experiments.

Bakhyt Tuganova: Coordinated the analysis of literary data and contributed to the writing of the manuscript.

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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