

## Article

# Development of Sustainable Production of Rainfed Winter Wheat with No-Till Technologies in Southern Kazakhstan

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**Abstract:** The production of rainfed crops in arid regions is an extremely difficult task, especially without tillage. In southern Kazakhstan, in 2020–2021, the approbation of various nutrition regimes for winter wheat grown in conditions of no-tillage rainfed lands has been studied. The effect of different doses and terms of application of growth stimulators, micronutrients, bio-fertilizers and mineral fertilizers, as well as their economic efficiency, was studied in ten variables. The use of a combination of growth stimulators and microfertilizers produced the highest grain yield and was the most cost-effective. The greatest value of the nominal net profit of 223.25 euro and 244.10 euro from one hectare was provided and calculated with the recommended target grain yield of 2.0 t/ha dose of mineral fertilizers, respectively; however, the production cost of one ton of grain in these treatments was also highest. Further research is continuing with a wider range and combination of amendments and various crops in a rainfed no-till winter wheat farm in southern Kazakhstan.

**Keywords:** bio fertilizer; drought; micronutrient; no-till; phenological phases; plant growth stimulator; winter wheat

## 1. Introduction

To feed the ever-growing population of the Earth, it is necessary to obtain higher grain yields per unit area. This requires intensive exploitation of arable land against the background of a reduction in their area, which ultimately leads to soil degradation [1,2].

At the same time, given the dual pressures of the food crisis and global warming, there is an urgent need to increase organic carbon sequestration in agricultural soils while ensuring crop yields. In order to meet goals of environmentally friendly crop management, sustainable soil management [3], and land degradation and restoration assessment [4], target 15.3 of the Sustainable Development Goals [5], “A Farm to Fork” (COM (2020) 381),

developed a zero pollution action plan for further strategies emphasizing the importance of soil health in future agricultural policies, environmental protection and climate change [6,7]. These documents prescribed reducing nutrient losses in soil by at least 50% and the use of fertilizers by at least 20% by 2030, while ensuring that there is no reduction in soil fertility [8].

Currently, about 75% of the territories of the Republic of Kazakhstan are subject to an increased risk of desertification, more than 30.5 million hectares are subject to wind and water erosion, and 54% of these territories are located in the southern part of the country [9]. The physical load on soil due to repeated soil cultivation under CT leads to soil compaction and destruction of soil aggregates leading to an impaired soil pore network [10,11]. This in turn contributes to the initiation or intensification of wind and water erosion, changes in soil chemical and biological properties [12,13].

In the arid climate of southern Kazakhstan, the main limiting factor of crops is the lack of soil moisture [14]. Ref. [15] simulated process-based crop growth by a mechanistic model and reported the impact of climate variability on wheat productivity in the steppe zone of Kazakhstan, highlighting that average wheat production from 2000 to 2010 was 1 ton ha<sup>-1</sup>, with high inter-annual fluctuations due to a shorter growing season, lower water supply and higher heat stress. Ref. [16] computed that climate change has reduced wheat and barley yields between 1980 and 2015 in Kazakhstan. Ref. [17], in reviewing the climatic-dependent grain production of Kazakhstan, emphasized the potential susceptibility of Kazakhstan wheat yields to any future reductions in precipitation and increases in drought occurrence and intensity. In Kazakhstan, the moisture-resource-saving technology of cultivation of spring grain crops was first introduced in the northern part of the country, where modified no-till technologies were successfully applied [18]. In southern Kazakhstan, the resource-saving cultivation of winter wheat with direct sowing has been studied since 2006 [19–22]. The latter established that direct sowing of winter wheat provided a decrease in direct costs by 28–44%, fuel by 36.5–38.6%, and net cost by 24.3–26.3%, with an increase in nominal pure income by 16.7–31.5%.

One of the limiting factors regulating the productivity of grain crops is plant nutrients in soil. Particularly, in arid climates, nutrient uptake is limited under heat and drought stress, which affects each phenological phase of plant development [23]. Drought and temperature extremes are the major abiotic constraints to cereal production worldwide, particularly in rain-fed dry agriculture systems [24,25] such as southern Kazakhstan. Many works are devoted to various aspects of the use of mineral fertilizers, micronutrients and growth regulators as well as to the study of their effectiveness under various treatments and conditions [26–32]. Experience shows that the reduction of conventional soil tillage (CT) and the appropriate use of herbicides can significantly increase the effectiveness of weed control, reduce the cost of chemicals, and reduce the risk of environmental pollution.

Nearly 25% of the emissions of greenhouse gases are attributed to agriculture [33]. Other benefits of reduced tillage have been demonstrated by a number of researchers, who have suggested that agricultural soil can mitigate the increase in greenhouse gas emissions to the atmosphere [34] by sequestering approximately 5500–6000 Mg CO<sub>2</sub>-eq. yr<sup>-1</sup> by 2030 [35]. Moreover, conversion to no-tillage systems may improve the soil's physical properties [36] and increase the soil's water retention in rainfed environments [37]. In addition, savings on operating costs and reductions in machinery emissions are expected [38].

Wheat is a strategic crop in the economy of the Republic of Kazakhstan. Issues of resource-saving technology for the production of winter wheat in southern Kazakhstan is one of the strategic priorities under development, testing and adjustment. This requires more detailed study, particularly in an arid climate with an erratic pattern of precipitation and air temperature. For the first time in the region, a technology is being developed for cultivating winter wheat by direct sowing without the main and pre-sowing tillage in a three-field crop rotation under rainfed agriculture.

The main hypothesis was that a diversified application of plant growth stimulators (PGRs), micronutrients, biological fertilizers (bio-F) and mineral fertilizers would have a

positive effect on crop productivity in the highly stressful arid climate of South Kazakhstan, especially in rainfed no-tillage (NT) winter wheat cropping. The main goal was to contribute to developing a grain production system that would provide both a profitable level of grain yield and rational use of soil resources. This includes testing of various doses and timing of seed and foliar treatments with growth stimulators, microelements, as well as the use of biofertilizers in the NT cultivation of winter wheat. Monitoring of various phases of growth and development of plants under NT cultivation of rainfed winter wheat was carried out, taking into account the biological need for nutrition in these soil and climatic conditions of South Kazakhstan. The tasks included:

- (1) Testing different doses and timing of plant growth stimulators, micronutrients, bio-F and their combinations as well as mineral fertilizers.
- (2) Revealing the effect of the applied amendments on the formation of the productivity elements of the winter wheat
- (3) Calculating the criterion for the economic efficiency of the amendments on the market under NT cultivation of rainfed winter wheat.

## 2. Materials and Methods

### 2.1. Field Experiments

The research was carried out in 2020–2021 on an area of two hectares of the experimental non-irrigated lands of the South-Western Research Institute of Livestock and Crop Production, Shymkent, Turkestan region (42°42'21" N and 69°21'50" E). Field experiments were laid by the split plot method with a single-tier systematic placement of treatments with direct sowing (no-till) of winter wheat in 4-fold replications, with a plot size of  $5.6 \times 10 \text{ m}^2$ . The crop tested was the zonal variety of winter wheat (*Triticum durum* L.), "Steklovidnaya 24". The study soil was southern ordinary grey soil developed on a medium loam loess that corresponds to *Calcisols* according to the IUSS soil classification system [39]. The possibility of direct sowing of winter wheat in a three-crop rotation including alfalfa and safflower was studied. Direct sowing of winter wheat was performed with the FANKHAUSER 2115 seeder (Tuparendi, Brasil) on 26 October 2020 after safflower sowing. The grain yield was determined by threshing with a Sampo-500 harvester. All measurements and analyses were performed in four replications. The details of the dynamic and doses of application of the amendments are given in Table 1.

### 2.2. Amendments Applied

- (1) Plant growth stimulator "Vypel" is a complex natural-synthetic fertilizer of contact-systemic action for processing seeds and vegetative plants. Contains: polyethylene oxides (PEO)—770 g/L; washed salts of humic acids up to 30 g/L. Indications: growth stimulator, adhesion, adaptogen, cryoprotector, thermal protector, antistressant, disease inhibitor, soil activator, antioxidant
- (2) Micronutrient fertilizer for seed treatment "Oracul" is a complex liquid micronutrient fertilizer for seed treatment. It contains: N—20 g/L; P<sub>2</sub>O<sub>5</sub>—99 g/L; K<sub>2</sub>O—65 g/L; SO<sub>3</sub>—57 g/L; Fe—15 g/L; Cu—5.4 g/L; Zn—5.4 g/L; B—1.8 g/L; Mn—15 g/L; Co—0.01 g/L; Mo—0.4 g/L.
- (3) Micronutrient fertilizer for top dressing "Oracul" multi-complex is a complex universal liquid micronutrient fertilizer for top-dressing crops. Contains: N—100 g/L; P<sub>2</sub>O<sub>5</sub>—66 g/L; K<sub>2</sub>O—44 g/L; SO<sub>3</sub>—36 g/L; Fe—6 g/L; Cu—8 g/L; B—6 g/L; Mn—6 g/L; Co—0.05 g/L; Mo—0.12 g/L.
- (4) Biofertilizer "Biobars M" is a complex-mixture bio-fertilizer with microelements. Contains: macro elements: N, P, K, Ca, Mg, Fe and S and microelements: Cu, Z, Sn, Mo, Mn, B, Co, I, Si, Cl, as well as protein-chlorophyll-vitamin-phytoncide of plant origin
- (5) Fungicide "Bunker" water-suspension concentrate. Active ingredient: tebuconazole; Chemical class of the active substance: Triazole

- (6) Herbicide “Ballerina” is a systemic herbicide as an emulsion against annual dicotyledons, including those resistant to 2,4-D and MCPA, and some perennial root weeds, contains: 2,4-D, complex 2-ethylhexyl; ether 410 g/L; florasulam 7.4 g/L

**Table 1.** Treatments studied in winter wheat rainfed no-till cultivation in southern Kazakhstan.

	Treatment	Doses, L/t	Terms of Application	Designation
1	Control without any amendment	n.a.	n.a.	Con
2	PGS seed treatment	0.5	Pre-sow seed treatment	PGS seed
3	PGS + micronutrient seed	0.5 + 1.0	Pre-sow seed treatment	PGS + mN seed
4	PGS + micronutrient + fungicide PGS + micronutrient dressing	0.5 + 1.0 + 0.4 0.5 + 2.0	Pre-sow seed treatment Tillering	PGS + mN + Fseed/PGS + mN dress
5	PGS + micronutrient + fungicide PGS dressing Micronutrient dressing	0.5 + 1.0 + 0.4 0.5 2.0	Pre-sow seed treatment Tillering Flag-leaf	PGS + mN+Fseed/PGS and mN dress
6	Bio-fertilizer + fungicide seed	1.0 + 0.4	Pre-sow seed treatment	Bio + F seed
7	Bio-fertilizer + fungicide seed Bio-fertilizer + herbicide dressing	1.0 + 0.4 1.0 + 0.5	Pre-sow seed treatment Tillering	Bio + F seed/Bio + H dress
8	Bio-fertilizer + fungicide seed Bio-fertilizer + herbicide dressing tillering phase heading phase	1.0 + 0.4 0.5 + 0.5 0.7 + 0.5	Pre-sow seed treatment Tillering Heading	Bio+F seed/Bio + H dress <sup>2</sup>
9	Recommended dose of NP fert.	P45 kg ha <sup>-1</sup> N70 kg ha <sup>-1</sup>	45 kg P <sub>2</sub> O <sub>5</sub> at sowing 70 kg N at tillering	N <sub>70</sub> P <sub>45</sub>
10	Calculated dose of NP fert. for the targeted yield of 2 t/ha	P20 kg ha <sup>-1</sup> N60 kg ha <sup>-1</sup>	20 kg P <sub>2</sub> O <sub>5</sub> at sowing 70 kg N at tillering	N <sub>60</sub> P <sub>20</sub>

**Note:** PGS—plant growth stimulator; Seed treatment was carried out before sowing together with the fungicide; dress<sup>2</sup>—two phase foliar dressing. Calculation of the dose of mineral fertilizer for the targeted grain yield is given in the Supplementary Table S1.

### 2.3. Laboratory and Field Methods

The initial soil characteristics were analyzed before the start of the experiment in October 2020 from two depths. Soil pH was determined with a glass electrode pH meter in 1 mol L<sup>-1</sup> KCl (pH KCl; in ratio 1:2.5 (*w/v*)) and in distilled water (pH in H<sub>2</sub>O with ratio 1:20 (*w/v*)). The content of soil humus was determined by the wet combustion Tyurin method, based on the oxidation of a small portion of the soil with potassium dichromate, followed by titration of the excess potassium dichromate with Mohr’s salt [40]; total nitrogen was determined by the Kjeldahl titration method [40]. The content of carbonates was determined in an aqueous extract by titration with a solution of sulphuric acid to pH 8.3 and bicarbonate to pH 4.4. The end point of the titration is set using a pH meter or by changing the color of phenolphthalein (pH 8.3) and methyl orange (pH 4.4); particle size distribution (PSD) was determined by the densimeter method based on sedimentation governed by Stokes’ law, which relates the size of the particle to the sedimentation velocity in a liquid [41]. Soil moisture content was determined every 10 cm to a depth of 1 m by the thermostat-weight method after sampling with a 100 cm long drill at the ends of the first, second and third 10-day periods of each month of the wheat vegetation [42].

Plant density was determined on the test plots with a size of 0.25 m<sup>2</sup> for each replication, and the standing density was calculated for each phase. The content of dry matter was determined by grinding the green mass of the test grain with two weighed portions of 50 g each and drying at a temperature of 100–105 °C until a constant weight was reached. The species composition of weeds and the load of weed infestation were determined according to [42].

Phenological observations were carried out according to the date of the onset of the phases: sprouting, tillering, booting, earing, milk maturity, wax maturity and full maturity. The sprouting phase was recorded when an awl or the first true leaf appeared on the soil surface. The tillering phase was observed when 3 lateral shoots appeared. The booting

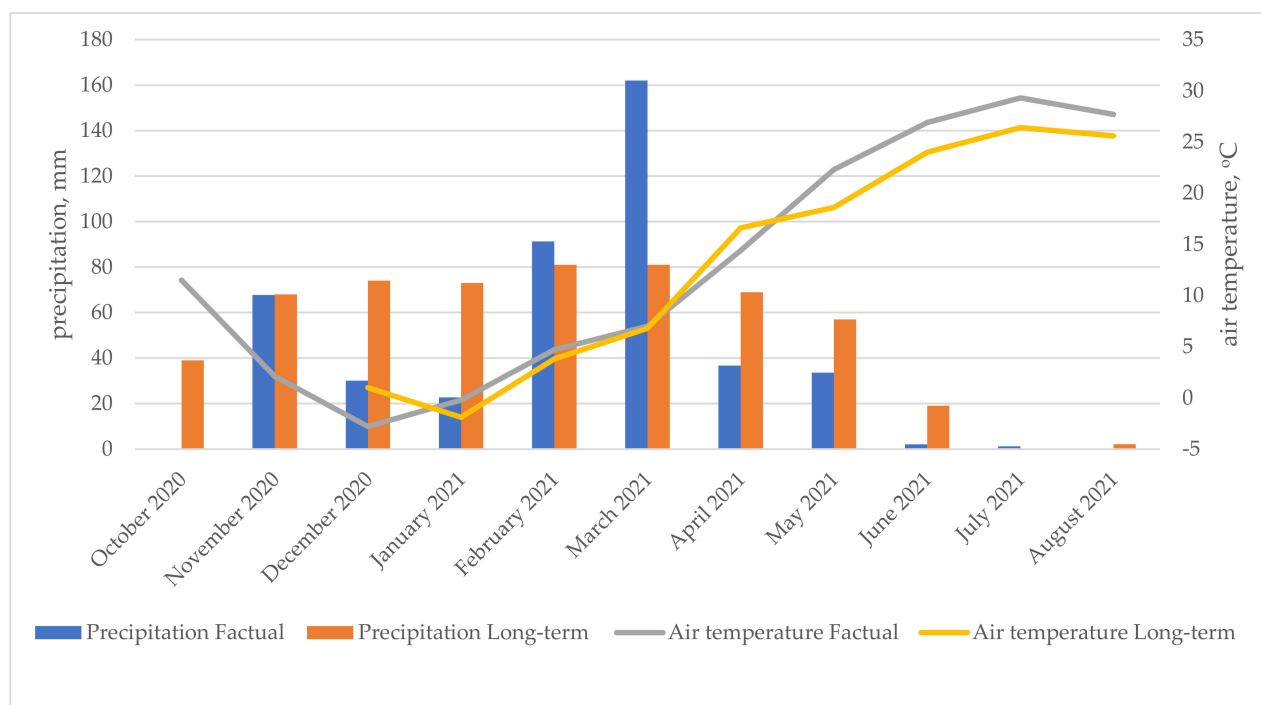
phase was recorded with the growth of the lowest internode of the stem. The heading phase was recorded when inflorescences of an ear appeared from the axils of the upper leaf.

Biometric and productivity parameters were determined according to the standardized methodology for variety testing [43]. Determination of the biomass of wheat was carried out for each of the main phases by taking plant samples from 1 m<sup>2</sup> from two non-adjacent field plots. Biological and structural analysis of the yield, depending on the factors studied in each plot was performed in every plot in four replications. The content of dry matter was determined by grinding with two weighed portions of 50 g each and dried at a temperature of 100–105 °C until a constant weight was reached.

The economic efficiency of no-till cultivation of rainfed winter wheat with the use of various doses of fertilizers was calculated on the basis of technological maps and taking into account the actual costs of labor and resources for all types of work at market prices of the Turkestan region for 2021. The results are presented as average values. Parametric estimation (one-way analysis of variance) was performed at a probability level ( $p \leq 0.05$ ) to detect significant differences.

#### 2.4. Climatic Conditions and Soil Moisture Reserves during the Observation Period

In a 2021 study, the dynamics of soil moisture showed that the amount of autumn–winter precipitation (Figure 1) resulted in a sufficient reserve of soil moisture (162 mm) (Table 2) accumulated in the meter layer in early March that was maintained until the start of the booting phase in early April (184 mm). With the onset of the phenological phase with a high demand for water, the amount of soil moisture quickly decreased and by the heading phase amounted to 100 mm (end of May). Subsequently, with the onset of the phase of grain filling, milk, wax and full ripeness, moisture reserves sharply decreased due to the lack of precipitation and a sharp increase in air temperature from the end of May to the end of June, that is, until full ripeness. Despite the low amount of precipitation in April, the productive moisture in the meter layer was 121 mm, which is a satisfactory indicator for the study area. Wheat plants did not suffer from moisture deficiency; however, the top layer of soil, where the main mass of plant roots is concentrated, was very dry.



**Figure 1.** Amount of precipitation and air temperatures for the studied vegetation months in Shymkent, South Kazakhstan from the nearest meteorological station.

**Table 2.** Reserves of the soil productive moisture on the rainfed winter wheat grown with no-till technology in the period of March–June 2021.

Sampling Date	Depth of Sampling (cm) and Moisture Reserves (mm)				Average in 100 cm	Moisture Reserves, mm
	0–10	10–20	20–30	30–40	0–100	0–50
18 March	24.9	22.1	20.7	19.2	162	105
28 March	22.6	22.3	19.8	18.9	196	102
08 April	19.6	20.0	18.9	18.7	184	92
18 April	13.2	13.8	14.6	15.3	141	61
28 April	10.4	11.1	11.7	13.0	121	44
08 May	11.8	12.1	11.9	12.9	116	46
18 May	9.5	11.3	11.6	12.0	101	40
28 May	7.7	9.4	10.6	11.6	100	32
08 June	3.0	5.0	5.0	7.0	83	28
18 June	8.0	3.0	3.0	5.0	68	19
28 June	1.0	2.0	1.0	2.0	49	11

### 2.5. Initial Agrochemical and Physical Properties of the Soil before Start of the Experiment

The initial soil characteristics were determined before sowing winter wheat and after harvest of the preceding crop (safflower) from the two depths (Table 3). Supply with soil humus and mineral nitrogen was low. Particle size distribution indicated that the study soil was dominated by silt and clay fractions, which is typical for this type of soil formed on a loess parent material. According to the textural class, the study soil was on the border of silty-clay and silty-clay loam classes.

**Table 3.** Fertility and physical properties of *Calcisol* on the rainfed lands of southern Kazakhstan before sowing winter wheat.

Depth, cm	pH	Humus	Total N	CO <sub>2</sub> Carbonates	Sand, %		Silt, %		Clay, %		Physical Clay, %
		%	mg/kg	%	1.0–0.25, mm	0.25–0.005, mm	0.05–0.01, mm	0.01–0.005, mm	0.005–0.001, mm	<0.001 mm	<0.01 mm
0–20	7.78	1.16	30.8	8.29	0.570	15.342	43.631	3.570	15.469	21.419	40.457
20–50	7.79	0.47	12.4	3.24	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

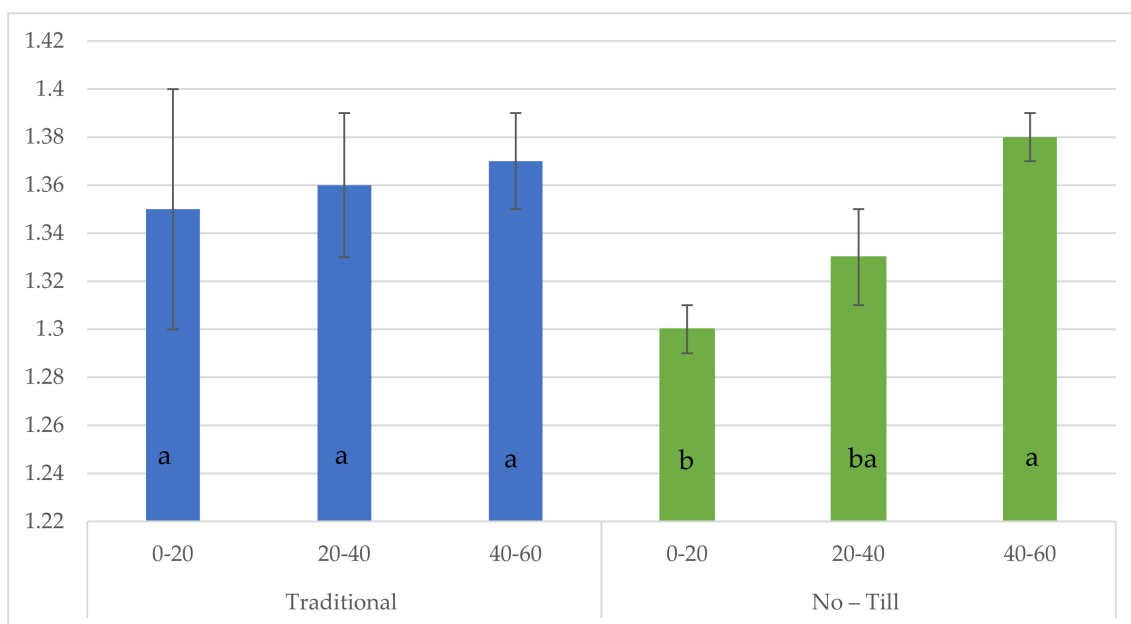
## 3. Results and Discussion

### 3.1. Soil Bulk Density in the Studied Conventional (CT) and No-till (NT) Fields

Values of the bulk density were between 1.30 and 1.38 g/cm<sup>3</sup> (Figure 2). The most optimal bulk density for silty clay loam soil is <1.40 g/cm<sup>3</sup>, while 1.65 g/cm<sup>3</sup> restricts root growth [44]. However, according to [45], soil bulk density higher than 1.30 g/cm<sup>3</sup> may result in yield loss due to inadequate soil aeration. In our study, a bulk density of around 1.3 g cm<sup>-3</sup> was recorded only for the surface layer in the no-till system. Generally, under no-till systems, the bulk density has a trend of lower soil compaction in the upper soil horizons. This is due, first of all, to the mulching effect of crop residues on the soil surface upon the direct sowing of wheat, which prevents physical evaporation of soil moisture, thus reducing its compactness, since root channels are not destroyed by tillage and water movements are not interrupted [35,46]. Furthermore, secondly, the lower impact of machinery on no-till areas has a lower load on the soil [20,47]. However, these results are not entirely consistent with other studies that found an opposite or absent effect of no tillage on the change in soil bulk density compared to CT on loamy and clayey grain production soils [48,49]. These disagreements may be related to differences in soil type, agronomic practices, duration of no-till and conventional tillage, and climatic conditions.

Safflower as a preceding crop produces a high amount of straw. About 80% of the safflower total yield remains in the form of straw [50]. No-till farming of wheat plays a huge role as a mulching substrate that protects the soil from moisture loss through evaporation, regulates the temperature regime of the soil, and protects against wind

erosion [46]. Probably, under arid rainfed agriculture, the traditional cultivation of silty-clay soil leads to greater destruction of soil aggregates, rupture and clogging of soil pores. The response to no-till (NT) largely depends on climatic conditions, the amount of mulch on the soil surface, and soil management [48,51]. Less mechanical stress and more mulching in a no-till system maintains a better water-to-air ratio in the soil [48]. The findings of this investigation should be treated with relative caution as they cover only a few years of investigation, from 2019 to 2021.



**Figure 2.** Bulk density ( $\text{g}/\text{cm}^3$ ) under CT and NT farming of winter wheat cultivation on the rainfed lands of southern Kazakhstan. Different letters indicate statistically significant difference at  $p < 0.05$ .

### 3.2. Growth and Development of Winter Wheat

The spring resumption of the vegetation of winter wheat was observed in early March at an average ten-day air temperature of  $+6.5\text{ }^\circ\text{C}$ , then in the second decade of March, it slowed down due to a decrease in temperature to  $+4.5\text{ }^\circ\text{C}$ . The tillering phase of winter wheat continued from the third decade of March, at an air temperature of  $+10.1\text{ }^\circ\text{C}$  and March rainfall of 162.0 mm, which made it possible to accumulate 196 mm of soil moisture by the end of the month.

However, the number of plants in spring fluctuated between 148.1 and 241.3 pcs/ $\text{m}^2$  (Table 4), which indicates the sparsity of plant standing, which is associated with unfavorable climatic factors in the autumn–winter period of 2020–2021. As expected, the smallest number of plants was observed in the unfertilized control. The largest number of plants per square meter was 233.8, 235.9 and 241.3 for PGS + Mn + F/PGS and mN dress and both NP variants, respectively. Furthermore, visual observations showed that the fertilized plots and plots treated with PGS, microelements and biofertilizers developed and grew more evenly and intensively compared to the control plots. So, when using the calculated doses of NP fertilizer, the booting phase began on 4 April 2021, and when using PGS and microelements, on 5 April 2021, while in the control plots, the booting phase was delayed and was recorded on 9 April 2021 (Table 5). High air temperatures persisted throughout all phases of earing, anthesis and grain filling until the full ripeness of winter wheat. An increase in air temperature for one degree of Celsius may lead to total yield loss of wheat up to 60% [52]. In our experiment, daily temperatures and precipitation were the same for all variants, while visual observations and phenological records showed that the formation and maturation of the grain were more uniform in the fertilized plots.

**Table 4.** Phenological parameters of winter wheat with no-till technology under rainfed conditions in southern Kazakhstan.

	Treatments	Number of Plants † per 1 m <sup>2</sup> , pcs	Plant Height, cm	Productive Tillering, pcs	Spike Length, cm	Number of Grains per ear, pcs	Weight of Grains from an ear, g	Weight of 1000 Grains, g
1	Con	148.1a	69.5a	1.00	7.0	17.0	0.69a	27.0
2	PGS seed	167.0b	71.8a	1.01	7.4	18.8	0.81b	28.0
3	PGS + mN seed	166.9b	74.8a	1.02	7.6	19.8	0.89b	28.5
4	PGS + mN + F/PGS + mN dress	214.8c	79.8ab	1.08	8.0	20.5	0.93b	29.2
5	PGS + mN + F/PGS and mN dress	233.8c	80.3b	1.10	8.1	21.3	0.95b	29.5
6	Bio + F seed	170.1b	70.6a	1.01	7.3	18.2	0.80b	27.3
7	Bio + F seed/Bio + H dress	183.0b	75.4a	1.03	7.8	18.8	0.92b	28.2
8	Bio + F seed/Bio + H dress <sup>2</sup>	199.1c	78.6ab	1.05	7.9	19.1	0.94b	28.5
9	N <sub>70</sub> P <sub>45</sub>	235.9d	80.7b	1.10	8.0	21.2	0.94b	29.8
10	N <sub>60</sub> P <sub>20</sub>	241.3d	81.0b	1.10	8.1	21.7	0.96b	29.8
	<i>t</i> -test at <i>p</i> < 0.05 for Tukey HSD	**	*	n.d.	n.d.	n.d.	*	n.d.

†—number of plants before harvesting per 1 m<sup>2</sup>; Con.—control without any amendments; PGS—plant growth stimulator; mN—micronutrient fertilizer; F—fungicide; Bio—biofertilizer; H—herbicide; dress<sup>2</sup>—two-phase foliar treatment; N<sub>70</sub>P<sub>45</sub>—recommended dose of nitrogen and phosphorus fertilizer; N<sub>60</sub>P<sub>20</sub>—calculated dose of nitrogen and phosphorus fertilizer; seed—pre-sow seed treatment; dress—foliar treatment. Different letters within a column indicate statistically significant difference at *p* < 0.001 and *p* < 0.05, for \*\* and \*, respectively.

**Table 5.** Phenological observations on winter wheat crops depending on the use of fertilizers 2020–2021.

Treatment	Sowing Date	Timing of the Phenophase							
		Shooting	Tillering	Booting	Earing	Anthesis	Milky Ripeness	Wax Ripeness	Full Maturity
Control	26 October 2020	17 January	07 February	09 April	25 May	27 May	06 June	17 June	25 June
PGS seed	26 October 2020	13 January	02 February	05 April	23 May	25 May	04 June	17 June	26 June
PGS + mN seed	26 October 2020	12 January	03 February	05 April	22 May	24 May	04 June	17 June	26 June
PGS + mN + F/PGS+mN dress	26 October 2020	13 January	03 February	05 April	21 May	23 May	04 June	16 June	27 June
PGS + mN + F/PGS and mN dress	26 October 2020	16 January	05 February	05 April	21 May	23 May	04 June	14 June	27 June
Bio + F seed	26 October 2020	16 January	05 February	05 April	21 May	23 May	04 June	15 June	28 June
Bio+F seed/Bio + H dress	26 October 2020	17 January	06 February	05 April	22 May	24 May	05 June	16 June	29 June
Bio + F seed/Bio + H dress <sup>2</sup>	26 October 2020	17 January	06 February	06 April	22 May	24 May	05 June	16 June	29 June
N <sub>70</sub> P <sub>45</sub>	26 October 2020	14 January	03 February	04 April	21 May	23 May	03 June	13 June	28 June
N <sub>60</sub> P <sub>20</sub>	26 October 2020	14 January	03 February	04 April	21 May	23 May	03 June	14 June	28 June

Con.—control without any amendments; PGS—plant growth stimulator; mN—micronutrient fertilizer; F—fungicide; Bio—biofertilizer; H—herbicide; dress<sup>2</sup>—two phase foliar treatment; N<sub>70</sub>P<sub>45</sub>—recommended dose of nitrogen and phosphorus fertilizer; N<sub>60</sub>P<sub>20</sub>—calculated dose of nitrogen and phosphorus fertilizer; seed—pre-sow seed treatment; dress—foliar treatment.

The preceding crop for winter wheat was safflower, which is responsive to water supply [53,54] and nitrogen availability [55] since it needs a large amount of water and nutrients to build a large biomass [56]. Safflower straw contains high amounts of ligno-cellulosic compounds [50], which do not decompose quickly, and therefore winter wheat plants following the crop rotation may be deficient in nitrogen. This probably explains the fact that the variants with mineral fertilizer (no. 9 and 10) showed significantly higher yield formation parameters compared to other options (Tables 5 and 6).

### 3.3. Yield of Winter Wheat with No-Till Technology under Rainfed Conditions in Southern Kazakhstan

Under the prevailing climatic conditions of the reporting year, the seed treatment with PGS led to a slight increase in the yield of winter wheat grain (by 0.19 t/ha) compared to the control (Table 6). The largest grain yield was obtained with mineral fertilizer treatments (1.5 and 1.56 t/ha for P<sub>45</sub>N<sub>70</sub> and P<sub>20</sub>N<sub>60</sub>, respectively), followed by PGS and seed and foliar treatment with microfertilizer at a higher dose.

A good grain yield of 1.46 t/ha for a dry year was ensured by seed treatment and double treatment of winter wheat crops with PGS in the tillering phase and the flag leaf and with mN in the 6th treatment. The treatment of seeds with biofertilizer gave an increase in grain yield by 0.16 t/ha compared to the control, and the joint treatment of seeds and plants with biofertilizer significantly increased the grain yield to 0.97 and 1.08 t/ha with single and double feeding, respectively (No. 7 and No. 8).



**Table 6.** Grain yield of winter wheat with no-till cultivation, depending on the use of fertilizers, grown after safflower.

	Treatments	Average Grain Yield	Variation Form Control
		t/ha	
1	Con	0.68a ± 0.03	-
2	PGS seed	0.87b ± 0.04	+0.19
3	PGS+mN seed	0.94b ± 0.03	+0.26
4	PGS + mN + F/PGS+mN dress	1.28c ± 0.05	+0.60
5	PGS + mN + F/PGS and mN dress	1.46d ± 0.04	+0.78
6	Bio + F seed	0.84b ± 0.03	+0.16
7	Bio + F seed/Bio + H dress	0.97b ± 0.03	+0.29
8	Bio + F seed/Bio + H dress <sup>2</sup>	1.08b ± 0.04	+0.40
9	N <sub>70</sub> P <sub>45</sub>	1.50d ± 0.03	+0.82
10	N <sub>60</sub> P <sub>20</sub>	1.56d ± 0.05	+0.88
LSD, $p \leq 0.0001$		0.121	
$t$ -test at $p < 0.05$		*	

Con.—control without any amendments; PGS—plant growth stimulator; mN—micronutrient fertilizer; F—fungicide; Bio—biofertilizer; H—herbicide; dress<sup>2</sup>—two-phase foliar treatment; N<sub>70</sub>P<sub>45</sub>—recommended dose of nitrogen and phosphorus fertilizer; N<sub>60</sub>P<sub>20</sub>—calculated dose of nitrogen and phosphorus fertilizer; seed—pre-sow seed treatment; dress—foliar treatment. Different letters indicate statistically significant difference at  $p < 0.05$  \*.

In the variants with single seed treatment, the grain yield was at the average annual level, and the combined use of both seed and foliar treatment, as well as mineral fertilizers, significantly increased the grain yield. It should be mentioned that the booting and anthesis of winter wheat, i.e., the formation of reproductive organs, as well as the phases of grain filling, was accompanied by atmospheric and soil drought. In this regard, the grains formed were puny and lightweight, with smaller ears, a smaller number of grains per ear, and a mass of 1000 grains. As a result, the grain yield turned out to be slightly lower than the potential productivity of the studied variety Steklovidnaya 24. However, with the improvement of nutritional conditions due to the application of PGS, microelements and biofertilizers, the yield of grain gave a significant increase compared to the control.

Pre-sowing treatment of seeds with PGS and mN provides the plant with available nutrients, starting from the earliest phases of growth and development. Only four weeks after the start of germination, the plant switches to self-feeding from the soil. Due to the presence of available microelements in the seeds of field crops, enzymatic processes are activated to the maximum.

The splitted treatment with microfertilizers (as seed treatment and foliar feeding) provided the highest level of grain yield, as well as mineral fertilizers (treatments No. 5, 9 and 10, respectively, Table 6). Splitted applications might increase the likelihood of matching application dates with the corresponding growing conditions and phenological stage [57]. In addition, the composition of the microfertilizer includes macro- and microelements in chelated and other readily available forms, such as etidronic acid, which regulates the movement of water in cells and reduces the formation of insoluble compounds in them [58]. These readily available microelements optimized the nutritional regime of growing plants, allowing plants to save energy and increase the pace of their development, especially in critical times of plant development [59,60]. On the other hand, the addition of mineral fertilizers compensated for depleted nutrients in the soil after the preceding safflower plants, thus greatly contributing to the yield of winter wheat in NP treatments.

### 3.4. Economic Efficiency of No-Till Farming of Winter Wheat

The criterion for the effectiveness of a particular agricultural technique for the cultivation of agricultural crops is their economic assessment. To this end, we have determined the cost of funds per hectare of winter wheat crops with zero tillage and for the production of one ton of grain, depending on the cost of PGS, microfertilizers, biofertilizers and mineral

fertilizers, as well as direct costs per hectare for each type of work associated with their use, pest and weed control, harrowing, as well as nominal net income. Economic calculations were carried out at the prevailing market rates in the wage system for 2021 at South-Western Research Institute of Livestock and Crop Production LLP and in the southern region of Kazakhstan as a whole (Table 7).

**Table 7.** Economic efficiency of no-till farming of winter wheat depending on the use of PGS, microfertilizers, biofertilizers and calculated doses of mineral fertilizers, prices in euro for 2021.

	Treatments	Grain Yield, t/ha	Production Cost, 1 ha	Price of Grain, per ton	Net Profit per 1 ha	Cost of 1 ton
1	Con	0.68	56.13	240.54	107.44	82.55
2	PGS seed	0.87	60.58	240.54	148.78	69.63
3	PGS + mN seed	0.94	67.71	240.54	158.40	72.04
4	PGS + mN + F/PGS + mN dress	1.28	105.12	240.54	202.76	82.12
5	PGS + mN + F/PGS and mN dress	1.46	113.14	240.54	238.04	77.49
6	Bio + F seed	0.84	70.38	240.54	131.67	83.78
7	Bio + F seed/Bio + H dress	0.97	85.70	240.54	147.53	88.36
8	Bio + F seed/Bio+H dress <sup>2</sup>	1.08	96.39	240.54	163.39	89.25
9	N <sub>70</sub> P <sub>45</sub>	1.50	137.19	240.54	223.25	91.46
10	N <sub>60</sub> P <sub>20</sub>	1.56	131.14	240.54	244.10	84.06

Con.—control without any amendments; PGS—plant growth stimulator; mN—micronutrient fertilizer; F—fungicide; Bio—biofertilizer; H—herbicide; dress<sup>2</sup>—two phase foliar treatment; —recommended dose of nitrogen and phosphorus fertilizer; N<sub>60</sub>P<sub>20</sub>—calculated dose of nitrogen and phosphorus fertilizer; seed—pre-sow seed treatment; dress—foliar treatment.

Under current market conditions, the lowest direct costs were under control (EUR 56.13/ha), which included the cost of seeds, fungicides, herbicides, direct seeding and grain harvesting. In treatments with the use of PGS and microfertilizers, depending on the dose and frequency of treatment, direct costs increased from EUR 60.58 to 113.14/ha. The direct costs of biofertilizer treatment per hectare ranged from EUR 70.38 to EUR 96.39, depending on the dose and frequency of application. The highest direct costs of EUR 137.19/ha were for the application of the recommended dose of mineral fertilizers P<sub>45</sub>N<sub>70</sub> kg/ha, which is associated with a high market value and additional costs for transportation and their application during the growing season of winter wheat.

In the reporting year, the use of PGS and microfertilizers increased the nominal net income per hectare of winter wheat from 138.5% to 221.6%, depending on the dose and frequency, compared with the control. An increase in the number of treatments in the main phenological phases of wheat contributed to an increase in grain yield and the level of nominal net profit while reducing the cost of grain compared to the control. When using the biofertilizer, the nominal net income increased from 122.55% to 152.07% depending on the dose and frequency compared to the control.

The highest nominal net returns were obtained from treatments using NP fertilizers of 207.8% for N<sub>70</sub>P<sub>45</sub> and 227.2% for N<sub>60</sub>P<sub>20</sub> compared to the control. However, the cost of grain in N<sub>70</sub>P<sub>45</sub> was 110.8% of the control. The highest nominal net income per hectare and close to the control cost of grain was obtained for the calculated doses of mineral fertilizers (N<sub>60</sub> P<sub>20</sub> kg/ha) with a target grain yield of 2.0 t/ha.

#### 4. Conclusions

In southern Kazakhstan, most farmers, due to financial difficulties in the grain wedge, at best use nitrogen fertilizers as top dressing in early spring or leave winter wheat crops without fertilizers. Growing no-till winter wheat without irrigation in a dry climate is an extremely difficult task. For the first time in this region, we have tested plant growth stimulators, micro-, bio- and mineral fertilizers to develop an agronomic system that will contribute to both sustainable grain production and soil quality.

The results showed that unirrigated no-till winter wheat cultivation is possible in arid climates, provided that appropriate agricultural practices are used. Among the studied treatments, the most positive effect on the growth and development of winter wheat was

exerted by the splitted use of PGS and microfertilizers, as well as the use of NP mineral fertilizers. In addition, treatments with the use of PGS and microfertilizers turned out to be the most cost-effective.

Further research using various combinations of PGS, microfertilizers and mineral fertilizers should be continued in many years of field trials. Further trials should include more variables to establish an agronomically and ecologically sustainable way to grow no-till winter wheat in the rainfed arid conditions of South Kazakhstan.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agronomy12040950/s1>, Table S1. Calculation of the doses of mineral fertilizers for the targeted harvest of winter wheat grain for rainfed areas of southern Kazakhstan.

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