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# Impact of energy saving cultivations on soil parameters in northern Kazakhstan

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ABSTRACT

Recently the cost of soil processing for agricultural production has been rapidly increasing because of expensiveness of agricultural machinery, energy, and agricultural chemicals. Intensive soil cultivation is costly and adversely affects soil fertility due to accelerated mineralization of soil organic matter. By minimizing mechanical disturbance to the soil, costs can be reduced and the environment enhanced. About half of the global $CO_2$ emissions from the soil come from decomposition of the annual plant litter including agricultural crops. We studied methods of soil tillage that would help stabilize the yield of crops while maintaining soil fertility and saving energy and labour at the same time. Three types of crop cultivation experiments were studied: 1) cultivation intensity (simplified ST, common CT, and intensive IT); 2) tillage depth (shallow S, and deep D subsoil till), and 3) minimum MT, and zero till ZT. The results showed that under ST the soil biological parameters were more favourable than under CT and IT. Shallow subsoil till maintained higher levels of soil nutrients, and reduced $CO_2$ emission compared with the deep subsoil till. The minimum and zero tills positively influenced soil physical and biological properties through improvement in soil aggregate stability and soil enzymatic activity.



## 1. Introduction

Energy input and output differs widely among crops, production systems and management intensity. Yield of primary agricultural production is positively correlated with energy input. Differences in cropping practices, such as tillage, have considerable effects on energy efficiency of crop production systems. The most energy-consuming process in crop cultivation is soil processing that consumes an average 30–40% of the energy input in agriculture [1–3]. Total input of energy used per hectare increases with the increase of management intensity [4]. Therefore, selection of the appropriate tillage method includes assessments of the system's efficiency control [5].

Also, mechanical disturbance of soil is one of the most significant factors that determine deterioration of soil fertility. Losses of humus under agricultural use are determined by biological (domination of mineralization processes over humification) and mechanical (reduction of thickness of humus layer caused by erosion and destruction of soil aggregate stability) factors [6,7,33].

Continuous intensive mechanical disturbances can cause both soil environmental (depletion of soil fertility; compactness of soil etc.), and energy related problems (higher input of human and mineral resources, etc.) [8–17]. About half of the globally $CO_2$ output from soil comes from the decomposition of the annual plant fall [18] including agriculture. Therefore, minimization of soil tillage can also contribute in another key environmental issue as carbon sequestration.

Traditional technology of cultivation of crops with spring moldboard till and repeated seasonal harrowing is characterized by high energy and labour cost. Therefore, one of the ways to save energy and sustain soil environment is introduction of the

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technologies with reduced mechanical operations on soil, both in the number of operations and the depth of plough.

Dry-steppe areas of northern Kazakhstan are characterized by very low precipitation (mean annual rainfall is 350 mm) and by strong winds causing soil erosion. Therefore, the cropping technologies that could maintain soil moisture and prevent soil erosion were introduced in the area. The crop requirements for water have being solved via moisture accumulation through introduction of snow retention. The wind derived problems were solved by replacing the traditional moldboard till by subsoil till. The nutrient accumulation problems were solved through bare-fallowing.

Retention of snow through making snow ridges is very effective measure for moisture accumulation during the winter. In spring the water from snow ridge is better absorbed into soil and less evaporated. The subsoil till greatly protects soil from wind erosion because of the crop stubbles left after harvest on the field. Bare fallow is the field in a cropping sequence that is not planted but is actively cultivated during the whole vegetation season. Therefore, such intensive mechanical disturbance might result in decrease of soil fertility via intensified mineralization of soil organic matter.

Where soil is often intensively manipulated, the effect on soil organic matter (SOM) is especially pronounced [19]. On one hand, intensive soil cultivation ensures better oxidation conditions for soil microbes, thus intensifying mineralization processes in soil and ensuring plant nutrients and thus crop yield. On the other hand traditional cultivation consumes much more energy, resources and labour inputs, as well as an accelerated mineralization leading to the depletion of natural SOM. The labile fractions of SOM (mineralizable carbon and nitrogen; microbial biomass) proved to be reliable indicators to respond to subtle changes in cropping technologies [19]. Variable direct energy costs (1–6%) depend on cropping system and increase to 7–10% when indirect consumption (e.g. fertilizers and seeds sown) is included [3].

The goal of this study was to research the optimum soil cultivation intensity in terms of preservation of soil fertility and saving energy through studying the physical and biological properties of soil in dry-steppe of northern Kazakhstan.

## 2. Materials and methods

The long-term field experiments were carried out at the Kazakh Research Institute of Grain production in Shortandy, Astana, northern Kazakhstan (51°35′36″, 54N; and 71°10′15″, 40E) on *Typic Haplustolls* [20].

Three experimental cropping scenarios were studied: 1) *cultivation intensity* (simplified, ST; common, CT; and intensive, IT); 2) *tillage depth* (shallow till, S, and deep till, D); and 3) *minimum and zero till* technologies in the standard wheat production system.

The ST implies no additional agronomic inputs; the CT includes making 35 cm snow ridges in winter and phosphorus fertilization in spring; the IT implies making 40 cm snow ridges and phosphorus and nitrogen fertilization (Table 1).

In the tillage depths experiment soils were sampled from the two phases of fallow-wheat cropping cycle. Both the shallow (S) till and deep till (D) were sampled immediately after fallow year (S1 and D1) and in 4 years after fallow or just before fallow (S4 and D4).

**Table 1**
Cultivation intensity experiment.

| Treatment | Snow retention | Fertilization, kg $ha^{-1}$ $year^{-1}$ |
|---|---|---|
| Simplified (ST) | No | No |
| Common (CT) | 35 cm | Phosphorus: 20 |
| Intensive (IN) | 40 cm | Phosphorus: 20<br>Nitrogen: 40–50 |

**Table 2**
Tillage depth experiment in fallow-wheat cropping.

| Rotation | Shallow till (S), cm | Deep till (*D*), cm |
|---|---|---|
| Fallow year | | |
| **1st year wheat after fallow**[a] | 12–14 | 25–27 |
| 2nd year wheat after fallow | 10–12 | 20–22 |
| 3rd year wheat after fallow | 10–12 | 20–22 |
| **4th year wheat after fallow**[a] | 10–12 | 20–22 |

[a] Samples years, bolded: Fallow – **Wheat** – Wheat – Barley – **Wheat**.

This experiment was initiated to study the effect of tillage depth and fallowing on soil properties and $CO_2$ fluxes (Table 2).

The soils were sampled and examined during 2000–2001 for the experiment no. 1 *cultivation intensity* and 2 *tillage depth*; and during 2012–2013 for the experiment no. 3 *minimum and zero till*. The sampled soil were analysed for soil physical properties, content of soil organic matter (SOM), content of labile fractions of SOM, soil microbial biomass and soil enzymatic activity.

Among proposed treatments the simplified technology (ST) in the cultivation intensity experiment and the shallow till (S) in tillage depth experiment are the least energy-consuming treatments versus intensive and deep tillage treatments. Also, the new soil processing concept such as minimum and zero till (direct planting) technologies was studied in this research.

All analytical and data processing methods were performed by internationally certified methods by using the modern laboratory instruments and apparatus [21–27].

## 3. Results and discussions

### 3.1. Soil physical characteristics

Soil water-physical properties influence directly the growth and development of plants. Therefore the regulation of these parameters is one of the most important issues. The dynamics of soil moisture, density and moisture reserves are shown in Table 3.

Comparative analysis of water-physical properties under minimum and zero till systems has shown that under the zero till in 0–50 cm soil layer the average values the soil moisture in spring was 15.89%, soil density was 1.17 g/$cm^3$; total porosity was 53.6 % and total moisture capacity was 46.1 $m^3$; while under the minimum till these parameters were: 16.65, 1.25, 49.8 and 40.3, respectively (Table 3).

Table 4 shows that to the end of vegetation season the dynamics of soil water-physical parameters changed. After dry summer soil moisture content was by 2.28% higher and moisture reserves were by 0.8 $m^3$ greater under the minimum till versus zero till. The soil

**Table 3**
Water-physical properties in 2013 (*spring*).

| Depth, cm | Moisture, % | Density, g/$cm^3$ | Porosity, % | Moisture capacity, $m^3$ |
|---|---|---|---|---|
| Minimum tillage | | | | |
| 0–10 | 16.40 | 1.09 | 56 | 51.4 |
| 10–20 | 19.64 | 1.20 | 52 | 43.3 |
| 20–30 | 19.08 | 1.25 | 50 | 40.0 |
| 30–40 | 16.25 | 1.33 | 47 | 35.3 |
| 40–50 | 11.87 | 1.40 | 44 | 31.4 |
| **Average** | **16.65** | **1.25** | **49.8** | **40.3** |
| Zero tillage | | | | |
| 0–10 | 15.63 | 1.08 | 57 | 52.8 |
| 10–20 | 17.38 | 1.18 | 53 | 44.9 |
| 20–30 | 17.67 | 1.21 | 52 | 42.9 |
| 30–40 | 14.12 | 1.18 | 53 | 44.9 |
| 40–50 | 14.63 | 1.18 | 53 | 44.9 |
| **Average** | **15.89** | **1.17** | **53.6** | **46.1** |