FIELD PERFORMANCE OF THE ROTARY PRICKLE CHAIN TILLAGE TOOL

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ABSTRACT

One of the effective farm practices of moisture accumulation is the pre-seed harrowing in early spring. A rotary prickle chain tillage tools are the most suitable for this agricultural practice. However, the process of their interaction with the soil has not been drawn a research attention. Hence, this research was aimed to field investigation of the performance of the developed rotary prickle chain tillage tool for the pre-seed harrowing. In this paper the field performance of the developed tillage tool in terms of the work quality and specific draught resistance are presented. The obtained data allowed us to determine the parameters and operation modes of the developed tillage tool under which the required quality is provided. The research results will be used in the development of the implement for the pre-seed harrowing.

Keywords: pre-seed harrowing, rotary chain harrow, soil tillage quality, rotary prickle chain tillage tool, field performance.


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1. INTRODUCTION

One of the main factors, limiting and determining the crop yields in Northern Kazakhstan is the soil moisture. It is as important for plants life as heat or light and plays a leading role in future crop yield formation, especially in the initial period of plant growth and development [1–2]. In Northern Kazakhstan, the soil moisture reserves at the time of sowing are accumulated due to the winter precipitation, the average annual amount of which is 300-350 mm [3–4]. Moreover, the warm weather with the positive temperature and draining winds in the pre-sowing period, i.e. from snow melting to the sowing in this region lasts about 30 days. During this period a significant loss (up to 30%) of productive soil moisture by evaporation occurs [2]. In doing so, the maximum retaining of crop residues on field surface to reduce soil moisture loss is ineffective. So, it is revealed that with an average crop yield of 10-15 hundreds kilograms per hectare, the scattered straw does not provide full coverage of the soil surface and, as a result, it contributes to the formation of soil surface crust and cracks, through
Field Performance of the Rotary Prickle Chain Tillage Tool

which the soil moisture is intensively evaporated by the convection-diffuse method [5]. It is also revealed that even with full coverage of the field surface with crop residues, the process of soil moisture evaporation does not stop; it only slows down for a period of 7 to 20 days [6–7].

In this regard, one of the effective farm practices of moisture accumulation in the period prior to the sowing process is the pre-seed harrowing in early spring. This operation is carried out when the soil workability is achieved for breaking up the top layer of the soil to the tilling depth of 4-6 cm (in order to destroy the soil capillarity) and smoothing out the surface with maximum retaining of crop residues. The fast drying and friable top layer and crop residues on the soil surface significantly slow down and reduce the evaporation of moisture from the lower soil layers [4, 8]. The research results of the Kostanay Scientific Research Institute of Agriculture show that without pre-seed harrowing in early spring, by the time of sowing about 30% of available moisture is lost in the layer of 1 m, and only 10-12% is lost during harrowing [4].

The following quality parameters for the process of the pre-seed harrowing in early spring are required [9]:
- tilling depth should be 5 ±1 cm;
- breaking up the soil surface crust should be at least 75%;
- should be provided finely and crumbly clod size distribution with a clod content of at least 80% of clod size from 1 to 25 mm, while the clod size of larger than 50 mm is not allowed;
- after passing of the implement, on the field surface should be retained not less than 70% of stubble and crop residues from initial amount;
- after the passage of the implement, the amount of the erosion-hazardous particles of soil less than 1 mm in the layer of 0-5 cm should not be increased against initial amount;
- the field surface after the passage of the implement should be smoothed, the average height of the ridges and the depth of the furrows is allowed no more than 3 cm;
- tillage tools should not accumulate the crop residues and soil mass.

For the pre-seed harrowing of fields cultivated in autumn with a small amount of stubble as well as the summer fallows a heavy and medium tine harrows BZTS-1.0 and BZSS-1.0 and on stubble fields a rotary hoe harrows BIG-3A and BMSH-15, heavy and medium spring tine harrows are used. However, harrows BZTS-1.0 and BZSS-1.0 accumulate crop residues, the rotary hoe harrows BIG-3A and BMSH-15 have high power consumption and low working capacity, and the spring tine harrows have a poor penetration ability and accumulate crop residues as well [10].

At present for the operation of pre-seed harrowing in early spring implements with the rotary prickle chain tillage tools are widely used. They are harrows of Russian (BTSD-12) and Kazakhstan production (BZTS-12, BZTS-24) with the tillage tools in the form of round link of chains rotating in bearing assemblies, at each link of which there are two oppositely oriented and sharpened teeth [11–12]. The tillage tools are set on the frame of harrow at an angle of attack with the «diamond-shaped» scheme. However, the tillage tools of such harrows due to the low weight of the chains do not sufficiently break up the top layer of the soil and do not provide the required tilling depth when the soil hardness is above 1 MPa [13].

The rotary prickle chain tillage tools have been developed by V.I. Taranin, N.I. Bezdolnyj, V.M. Kotenov, A.A. Kem, L.C. Phillips, R.K. Clark, G.A. Sauder and etc. [14–20]. However, the process of their interaction with the soil has not been drawn a research attention.
Hence, the purpose of the research is to assess the effect of parameters and operation modes on the work quality produced by the rotary prickle chain tillage tool and its power requirement.

2. MATERIALS AND METHODS
In the Kostanay department of «Scientific Production Center of Agricultural Engineering» LLP a new rotary prickle chain tillage tool with the setting load on the tooth for pre-seed harrowing in early spring has been developed and manufactured, Figure 1.

![Figure 1. Rotary prickle chain tillage tool with the setting load on the tooth](image)

The tillage tool is made in the form of a round link chain, consisting of connected consistently identical links 1. In each link 1 there are X-shaped two double-ended teeth 2 of circular section. The ends of the tillage tool are fixed in the bearing assemblies in stretched position with the possibility of rotation. Tillage tools set at an angle of attack to travel direction. The load on the tooth and tilling depth can be adjusted depending on the hardness of the treated soil layer. The spacing of the teeth is \( L = 0.102 \, \text{m} \), the radius of the circumscribed circle at the ends of the teeth is \( R = 0.18 \, \text{m} \), the radius of the section of the teeth is \( r = 0.01 \, \text{m} \), the number of teeth on one chain link is \( n = 4 \), the angle between adjacent teeth in link is equaled to \( \gamma = 45^\circ \).

Field experimental studies were conducted in the Kostanay region of the Republic of Kazakhstan to assess the effect of the parameters and operation modes on the work quality produced by the developed rotary prickle chain tillage tool and its power requirement.

As a laboratory-field setup the BTSD-12 harrow frame was used, on the side sections of which were installed the investigated tillage tool sections with the ability to adjust the angle of attack and the vertical load on the teeth, Figure 2.

The soil tillage process occurred as follows. During movement across the field, the teeth of the tillage tools under the action of a fixed load are penetrated into the soil at a set tilling depth and rotated due to their interaction. In doing so, the teeth of the tillage tools performed the soil pulverization in the top layer, breaking up the soil surface crust, uprooting the weeds, redistributing crop residues over the surface, smoothing out the soil surface and mulching its top layer.

The main investigated parameters and operation modes were the angle of attack, specific vertical load on the tooth and travel speed. The work quality produced by the tillage tools to
be studied was assessed in terms of changing in tilling depth, clod size distribution, breaking up the soil surface crust and roughness of the soil surface. The soil parameters characterizing the field conditions and work quality were determined and assessed according to the Standards [21, 22]. Draught resistance of the tillage tools was determined by the method of the strain gage measurement and measured using a tensometric unit with the data acquisition unit and transducer of the company «Tenso-M». All instrumentations were installed in the MTZ-80 tractor cab.

Figure 2. Laboratory-field setup with the rotary prickle chain tillage tool sections

The experiments were conducted on a fallow field in the following soil conditions: soil type is chernozem with the texture of medium loam; soil moisture content was in the layer of 0-5 cm – 21.7%, 5-10 cm – 19.2% and 10-15 cm – 18.3%; the mean penetrometer resistance is 0.35, 0.82 and 1.12 MPa respectively. During the experiments the angle of attack was 30°, 35° and 40°. The specific vertical load on the teeth was adjusted by the weight of the section and was 50, 70, 90 and 110 N/unit. The magnitude of the travel speed varied from 6 to 15 km/h.

3. RESULTS AND DISCUSSION

In Figure 3 the research results of determining the effect of the specific vertical load on one tooth and travel speed on the tilling depth are presented.
Analysis of the results shows that the increase in the vertical load on the tooth from 50 to 110 N/unit causes an increase in the tilling depth for all range of travel speeds. So, at the speed of 6 km/h, the tilling depth increases from 3.7 to 8.1 cm, at the speed of 9 km/h – from 3.4 to 7.1 cm, at the speed of 12 km/h – from 3.0 to 6.6 cm and at the speed of 15 km/h – the tilling depth increases from 2.7 to 6.1 cm. With the increase in the travel speed from 6 to 15 km/h the tilling depth decreases for all values of the vertical load on the tooth by 2.2-2.3 times, which is associated with the increase in the dynamic component of the soil resistance force. From Figure 3 is seen that the tilling depth of 5 ±1 cm (green zone), corresponding to quality requirements, is provided with the vertical load on the tooth 70-80 N/unit for the range of travel speeds of 6-15 km/h.

![Figure 3. Effect of the specific vertical load on the tooth and travel speed of the tillage tool on the tilling depth](image)

**Figure 3.** Effect of the specific vertical load on the tooth and travel speed of the tillage tool on the tilling depth

Figure 4-6 show the results of the assessment of the effect of the angle of attack and travel speed on the work quality produced by the tillage tool in terms of clod size distribution, breaking up the soil surface crust and roughness of the soil surface at the value of the vertical load on the tooth, providing the required tilling depth.

From the graphs in Figure 4 is seen that with increasing the angle of attack from 30 to 40° clod size distribution increases by 1.1-1.2 times for all travel speed range. With the increase in travel speed from 6 to 15 km/h clod size distribution also increases due to the higher dynamic effect of the teeth on the soil. The clod size distribution satisfied the quality requirement (clod content at least 80% of clod size from 1-25 mm, the green zone on the graph) is provided at the angles of attack of 35-40° for all travel speed variations.
Field Performance of the Rotary Prickle Chain Tillage Tool

**Figure 4.** Effect of the travel speed and angle of attack of the tillage tool on the clod size distribution at the specific vertical load on the tooth 70 N/unit

**Figure 5.** Effect of the travel speed and angle of attack of the tillage tool on the breaking up the soil surface crust at the specific vertical load on the tooth 70 N/unit

From the graph in Figure 5 is seen that the increase in the angle of attack from 30 to 40° leads to the increase in the breaking up the soil surface crust from 71.8 to 78.7% at the speed of 6 km/h and 79.2 to 91.1% at the speed of 15 km/h. With the increase in speed from 6 to 15 km/h the breaking up the soil surface crust also increases by 1.1-1.2 times due to the growing in intensity of the impact of the teeth on the soil. Breaking up the soil surface crust satisfied the quality requirements (not less than 75%, the green zone on the graph) is provided at the angles of attack of 35-40° at any given travel speed.

It is revealed that the rotary prickle chain tillage tool has high level of smoothing of the soil surface – for all range of the angle of attack and travel speed the roughness of soil surface meets the quality requirements – not more than 3 cm, Figure 6.
Figure 6. Effect of the travel speed and angle of attack of the tillage tool on the roughness of the soil surface at the specific vertical load on the tooth 70 N/unit

Figure 7 shows the results of the assessment of the effect of the travel speed and angle of attack of the tillage tool on the specific draught resistance at the value of the vertical load on the tooth, providing the required tilling depth.

From the graphs is seen that with the increase in the angle of attack from 30 to 40° the specific draught resistance increases by 1.7-1.8 times. With the increase in the travel speed from 6 to 15 km/h the specific draught resistance also increases by 1.2 times, which is associated with the increase in the dynamic component of the soil resistance force.

Figure 7. Effect of the travel speed and angle of attack of the tillage tool on the specific draught resistance at the specific vertical load on the tooth 70 N/unit

Thus, the obtained data allowed us to select the parameters and operation modes of the tillage tool to be studied, providing the required quality of the pre-seed harrowing process in early spring. The research results will be used in the development of the implements for the pre-seed harrowing in early spring.

4. CONCLUSION
1. Field experimental studies show that the specific vertical load on the tooth should be 70-80 N/unit to provide the required tilling depth.

2. It is revealed that the required quality in terms of the clod size distribution, breaking up the soil surface crust and roughness of the soil surface is provided at the angle of attack of the tillage tool of 35-40° for the range of the travel speed of 6-15 km/h.

3. Experimental studies show that at the angle of attack of 35-40°, travel speed of 6-15 km/h of the investigated tillage tool and vertical load on the tooth, providing the required tilling depth, the specific draught resistance is 0.65…1.0 kN/m.

4. The obtained data allowed us to select the parameters and operation modes of the tillage tool to be studied, providing the required quality of the pre-seed harrowing process in early spring. The research results will be used in the development of the implement for the pre-seed harrowing.

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REFERENCES


