Optimization Parameters of Innovative Harrow for Sorgo Production in Burundi

Boris Tarasenko¹, Eric Havyarimana¹, Irina Troyanovskaya²,³*, Abdal-Mudalif Dzjasheev⁴, Evgeny Tikhonov⁵, Ramil Zagidullin⁶, and Linar Sabitov⁶,⁷

¹Kuban State Agrarian University, Krasnodar, Russia
²South Ural State Agrarian University, Troisk, Russia
³South Ural State University, Chelyabinsk, Russia
⁴North-Caucasian State Academy, Cherkessk, Russia
⁵Petrozavodsk State University, Petrozavodsk, Russia
⁶Kazan State Agricultural University, Kazan, Russia
⁷Kazan State Power Engineering University, Kazan, Russia

Abstract. Sorghum is one of the staple foods in the world's poorest regions, where food security is of the greatest concern. Sorghum is capable of growing even in the poorest soils, but it is very demanding on surface treatment. For drought-tolerant sorghum, the soil must be loose and breathable. The aim of the study was to select the means of mechanized tillage for growing sorghum and optimize its parameters. To obtain a crop, a new design of a universal disc-chisel harrow was developed. The harrow consists of two modules: disc and chisel. It allows you to perform various surface treatment operations: cultivating at a depth of 100 mm, loosening at a level of 200 mm and plowing at a level of 300 mm. The novelty of the structure is protected by a patent of the Russian Federation. A prototype was assembled and full-scale experiments were carried out. As a result of significant optimal values of the speed of the unit and an increase in the speed of the disks, the best quality of surface treatment is achieved.

1 Introduction

The Republic of Burundi belongs to the developing countries of Africa [1]. According to the Ministry of Agriculture, 90% of the republic's population lives in rural areas [2]. The standard of living of the population of the country strongly depends on the development of the agro-industrial complex. Agriculture in Burundi provides 35% of the gross domestic product [3]. The main problem of the inefficiency of agriculture in the Republic of Burundi is its low mechanization.

In June 2012, the first business forum "Russia-Burundi: opportunities for economic partnership" was held in the city of Bujumbura. The agenda included questions on expanding the partnership between Russia and the Republic of Burundi [4]. Russia is currently one of Burundi's trading partners. It imports coffee, tea and spices from the republic. About 60% of the republic's needs for grain crops are exported from outside [5].
Sanctions against Russia have led to a significant decline in grain exports. This could lead to starvation in poor African countries. Against the background of the alleged food crisis, ensuring the food security of the republic is becoming increasingly important [6-8]. To solve the food problem, it is necessary to increase the cultivation of agricultural crops on its territory.

The climate of Burundi is semi-arid and is characterized by low annual rainfall (1000–1200 mm). The average annual temperature ranges from +21°C to +24°C [9]. Poor acidic (5–6 PH) soils prevail in the republic [10-11]. The soil, climate, and topography characteristics of Burundi are favorable for growing the sorghum crop (figure 1). Sorghum culture is well adapted to the hot and dry climate of the republic [12-13].

Fig. 1. Sorghum crop.

Sorghum is the fifth largest food crop in the world after wheat, rice, corn and barley [14-16]. Sorghum grains are widely used for the preparation of highly nutritious feed mixtures for animal nutrition. The green mass of sorghum is used for silage, which is slightly inferior in quality to corn [17].

The underdevelopment of the agrarian sector of the Republic of Burundi requires the introduction of mandatory labor mechanization. The poor economic condition of the republic requires the creation of a universal agricultural unit capable of combining several tillage operations at once. This will allow you to achieve a high yield with minimal cash and labor costs.

The aim of the study is to choose a means of mechanized tillage for growing sorghum and optimize its parameters to obtain a high yield.

2 Material and methods

The sorghum plant can grow in any poor soil [18]. The high drought resistance of sorghum contributed to the development of a powerful root system of the plant. For a good harvest, the soil must be loose, with good breathability. Therefore, the cultivation of sorghum requires good soil preparation [19]. The main requirement for mechanization in soil preparation is to provide a wide range of loosening depths (from 10 cm to 40 cm).

Existing disc harrows [20-21] or soil-loosening separating machines [22] provide high quality soil crushing (figure 2a). However, their processing depth is limited to 8–18 cm. The processing depth is regulated by changing the angle of at-tack of the discs. Deeper non-moldboard tillage is carried out by means of a chisel plow [23-26] (figure 2b).
The chisel plow has one or two rows of subsoiler shares with height-adjustable side knives. With deep loosening (up to 30-40 cm) side knives. Such a depth of processing is necessary for the accumulation of moisture in the pre-sowing period. Deep loosening is carried out once every 2–3 years. Most often, chisel plows are trailed. As a result, uncultivated soil remains in the corners of the sowing fields. In addition, adjusting the depth of the chisel working bodies is quite laborious [26-27].

In order to avoid the shortcomings of the considered means of mechanization, we proposed a universal mounted disc-chisel harrow (figure 3).

Universal mounted disco-chisel harrow can be aggregated with tractors of various classes. Its distinctive feature is the content of two modules at once: disk 2 and chisel 3, fixed on frame 1 [28]. Each spherical disk had the ability to smoothly adjust the angle of attack in the range from 0° to 30°. The disc diameter was 560 mm. Paws-subsoilers are equipped with side knives and had the ability to adjust in height. The frame of the chisel module was a swinging link of the parallelogram mechanism for raising and lowering the subsoilers [29].

The versatile mounted chisel disc harrow allows you to perform various agricultural tillage operations (figure 4). For this, the following setting is made:

- peeling is carried out after harvesting grain crops (figure 4a). To do this, the frame of the chisel module is raised and the subsoilers do not participate in soil cultivation. Spherical disks 2 and a slat-helical roller 4 participate in the work. The processing depth of spherical disks is no more than 100 mm;
- loosening is a seedbed operation (figure 4b). It involves both modules at a depth of 200 mm. Spherical discs 2 cut the stubble, crush plant residues and mix it with the soil. Paws-subsoilers 3 with side knives create a smooth subsoil sole. The slatted spiral roller 4 crushes clods, levels the soil surface and creates a finely cloddy surface layer;
- the plowing operation is carried out also by two modules (figure 4c). First, the angle of attack of each row of spherical disks 2 necessary for plowing is set. Then the chisel module with subsoilers 3 is lowered. The processing depth of spherical
disks 2 is 150 mm. Subsoiler tines with side knives work the soil at a depth of up to 300 mm.

Fig. 4. Scheme of setting up a universal harrow when performing various tillage operations: (a) peeling; (b) loosening; (c) plowing.

Based on the proposals made, a prototype of a universal mounted disco-chisel harrow was made. When conducting experimental studies, the harrow was aggregated with a John Deere wheeled agricultural tractor. The tractor was equipped with a GPS navigation system and a display for recording parameters (figure 5).

Fig. 5. Experimental soil-cultivating unit with a universal disc-chisel harrow.

Nine experiments were carried out. Soil cultivation was carried out in the plowing mode. During the experiment, two main parameters were changed:
- speed of movement of the unit in the range \( V = 6; 9; 12 \text{ km/h} \);
- angle of attack of disks in the range \( \alpha = 15; 30; 45 \text{ degrees} \).

Processing of experimental data was carried out using a mathematical package Mathcad.

3 Results and discussions

The results of experimental studies are presented in table 1.

<table>
<thead>
<tr>
<th>V (km/h)</th>
<th>( \alpha ) (degree)</th>
<th>( Y_1 )</th>
<th>( Y_2 )</th>
<th>( Y_3 )</th>
<th>mean ( Y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>45</td>
<td>62.66</td>
<td>62.81</td>
<td>62.33</td>
<td>62.60</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>65.10</td>
<td>64.10</td>
<td>65.46</td>
<td>64.89</td>
</tr>
<tr>
<td>12</td>
<td>15</td>
<td>63.90</td>
<td>60.48</td>
<td>62.10</td>
<td>62.16</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>55.50</td>
<td>53.73</td>
<td>52.40</td>
<td>53.88</td>
</tr>
</tbody>
</table>
Based on the results of the table, a response surface was constructed (figure 6).

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>30</td>
<td>73.00</td>
<td>72.50</td>
<td>72.80</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>69.20</td>
<td>70.90</td>
<td>69.22</td>
</tr>
<tr>
<td>9</td>
<td>45</td>
<td>77.50</td>
<td>78.90</td>
<td>78.50</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
<td>71.70</td>
<td>72.50</td>
<td>73.50</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
<td>85.30</td>
<td>86.80</td>
<td>85.35</td>
</tr>
</tbody>
</table>

Fig. 6. The surface of the response of the quality of tillage according to agricultural requirements $\bar{Y}$ to the speed of movement $\bar{V}$ and the angle $\alpha$ of inclination of the disks.

To determine the optimal values of $V$ and $\alpha$ based on the average response values, a regression equation was compiled.

$$ Y = -112.77 + 31.36V + 3.49\alpha - 0.059V\alpha - 1.62V^2 - 0.05\alpha^2 $$

(1)

partial derivatives are taken

$$ \begin{align*}
    \frac{dY}{V} &= -3.23V - 0.06\alpha + 31.36, \\
    \frac{dY}{\alpha} &= -0.06V - 0.09\alpha + 3.49, \\
\end{align*} $$

(2)

and equated to zero [30-31]. The coordinates of the extremum points corresponding to the maximum value of the response surface were $V=9.1$ km/h and $\alpha=32$ degrees.

4 Conclusion

The characteristics of the soil, climate and topography of the Republic of Burundi are favorable for the cultivation of drought-resistant sorghum. For a high yield of sorghum, it is necessary to ensure good pre-sowing soil preparation. For soil cultivation, a design of a universal disc-chisel harrow was pro-posed. The novelty of the proposed harrow model is confirmed by a patent of the Russian Federation [32]. The advantage of the new design of the harrow is the ability to implement various technologies for tillage: peeling, loosening and plowing. The harrow includes two modules: disc and chisel. Various combinations of
the work of these modules make it possible to provide a depth of tillage from 10 cm to 30 cm. A prototype of a disk-chisel harrow was assembled for experimental studies. As a result of experimental studies, the optimal values of the working speed of the unit \((V = 9.1 \text{ km/h})\) and the angle of attack of the discs \((\alpha = 32 \text{ degrees})\) were determined, providing 86% of the quality of tillage.

References

2. R. Manirakiza, Mining information and analytical bulletin 6, 399-401 (2012)
4. O. Konstantinova, Bulletin of the University 4, 70-76 (2016)
9. J.M. Ndayiragije, F. Li, Water (Switzerland) 14(16), 2511 (2022)
16. L.M. Pereira, C. Hawkes, Frontiers in Sustainable Food Systems 6, 786151 (2022)
17. J.G. Boonman, Tasks for Vegetation Science, 29 (1993)
19. C.M. Musafiri et al., Soil and Tillage Research 223, 105473 (2022)
20. V. Zubko et al., Engineering for Rural Development 20, 1193-1199 (2021)
22. Y. Syromyatnikov et al., Journal of Terramechanics 98, 1-6 (2021)
30. V.V. Tsybulevsky et al., IOP Conference Series: Earth and Environmental Science 1010(1), 012038 (2022)
32. B. Tarasenko et al., Journal of Terramechanics 99, 29-33 (2022)