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Article

Engineering development of a specialized seeder for the mechanized restoration of degraded pastures in Uzbekistan.

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Abstract: This study aimed to develop and evaluate a mechanized approach for restoring degraded natural pastures in the arid regions of Uzbekistan through the sowing of native drought-resistant desert plants.The study focused on saxaul, cherkez, and izen (prutnyak), selected for their adaptation to dry conditions and potential for improving vegetation cover and stabilizing degraded sandy soils. Field and laboratory investigations were conducted to assess seed quality and evaluate a specialized seeder developed for the mechanized sowing of saxaul and izen seed material. The proposed seeding technology and technical solutions are protected by Republic of Uzbekistan Patents No. FAP 2670 and FAP 3044. The experimental results showed that the prepared seed material had a purity of 20–25% and a germination capacity of 40–45%. The developed seeder was designed to provide continuous seed flow, controlled seed placement, and uniform distribution under sandy-soil conditions while accounting for the specific physical and mechanical properties of the seed material. The findings demonstrate the technical feasibility of using specialized mechanized seeding equipment for establishing native desert vegetation on degraded pasturelands. The proposed approach provides a technological basis for improving vegetation establishment, reducing soil exposure to degradation, and supporting the restoration of arid and semi-arid pasture ecosystems.

Keyword: desert ecosystems; semi-desert areas; pastureland degradation; restoration of natural pastures; sandy soils.

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Introduction

Arid pastures occupy millions of hectares and serve predominantly as grazing lands for livestock. However, substantial portions of these ecosystems are currently affected by varying degrees of degradation across almost all regions [1]. Approximately 40% of desert pasturelands are affected by degradation, resulting in a 20-30% decline in their average productivity [2]. In the Republic of Uzbekistan, approximately 8.0 million hectares of degraded pasturelands have been identified as requiring improvement and restoration [1].

Globally, arid and semi-arid regions cover approximately 66.7 million km² and support the livelihoods of nearly 2 billion people [3]. According to the United Nations, drylands account for approximately 30% of the Earth's terrestrial surface and extend across more than 100 countries, supporting the livelihoods of nearly 2 billion people [4]. The continuing expansion of desertification and land degradation represents a major environmental and socioeconomic challenge, particularly for regions that depend heavily on natural pasture resources. Projections cited by the United Nations indicate that continued severe land degradation may substantially increase the proportion of the global population living in degraded areas [5].

Land degradation has already affected more than 2 billion hectares of productive land worldwide, while approximately 12 million additional hectares are degraded annually [6]. Changes in the spatial distribution, density, and structural characteristics of vegetation are closely associated with desertification processes, particularly in areas exposed to intensive livestock grazing [7]. Degradation develops especially rapidly in pasturelands subjected to continuous or year-round grazing, where vegetation does not have sufficient time to recover naturally [8].

Unregulated livestock grazing and excessive grazing pressure are important factors contributing to the deterioration of pasture vegetation and soil resources, as well as to the formation and accumulation of wind-driven sand deposits [9]. The vulnerability of pasture ecosystems increases considerably during dry periods, when vegetation cover and soil moisture decline substantially [10]. Prolonged and severe drought can further accelerate land degradation and desertification, resulting in reduced vegetation productivity, declining soil stability, and weakened ecological resilience of natural pasture ecosystems [11].

Under these conditions, the restoration and sustainable management of degraded arid and semi-arid pastures require scientifically substantiated technologies and efficient mechanized approaches for establishing native, drought-resistant vegetation [12]. The use of appropriately adapted desert plant species in combination with specialized sowing technologies can provide an effective basis for increasing vegetation cover, stabilizing degraded sandy soils, and restoring the ecological and productive functions of natural pasture ecosystems [13]. Therefore, the development and application of specialized seeding technologies for establishing drought-resistant forage vegetation represent an important technological component of degraded pasture restoration in arid regions.

Materials and Methods

Study Area and Research Design. The study was conducted to develop and experimentally evaluate a mechanized sowing technology for the rehabilitation of degraded desert and semi-desert pasturelands in the Republic of Uzbekistan. The research was focused on establishing native drought-resistant plant species capable of surviving under conditions of limited soil moisture, high temperatures, and unstable sandy substrates. The experimental studies were carried out on degraded natural pastures and sandy soils characteristic of the arid and semi-arid regions of Uzbekistan [14]. The research methodology combined field observations, laboratory analyses, determination of seed quality parameters, theoretical assessment of the sowing process, and experimental testing of a specially developed desert seeder. The experimental design was aimed at determining the technological suitability of mechanized sowing for establishing vegetation on degraded pasturelands and evaluating the stability and uniformity of seed delivery under conditions representative of arid environments.

Plant Material and Seed Characteristics. Three native desert and semi-desert plant species were considered as biological materials for the study: saxaul (Haloxylon spp.), cherkez (Salsola spp.), and izen (Kochia prostrata). The selection of these species was based on their natural distribution in arid ecosystems, adaptation to severe climatic conditions, drought tolerance, and potential contribution to the rehabilitation of degraded pasture vegetation [15]. These plant species are adapted to environments characterized by low precipitation, high evaporative demand, and sandy or weakly structured soils. Their establishment is considered important for increasing vegetation cover, reducing wind-induced soil erosion, improving the stability of sandy surfaces, and restoring the ecological and productive functions of degraded natural pastures. Prior to the experimental sowing trials, the principal quality characteristics of the seed material were determined. Particular attention was given to seed purity and germination capacity because these parameters directly influence the amount of viable seed entering the metering system and the subsequent establishment of plants under field conditions [15]. The analyzed seed material had a purity of 20–25%, while its germination capacity ranged from 40 to 45%. The obtained seed-quality characteristics were considered when evaluating the performance of the developed sowing mechanism.

Development of the Specialized Seeder. A prototype of a specialized seeder was developed and manufactured for mechanized sowing of desert plant species, particularly saxaul and izen. The design was developed taking into account the specific physical and mechanical characteristics of desert seed material, including its low flowability, heterogeneous composition, and tendency to form unstable aggregates within the hopper and seed-metering zone [16]. The main technological objective of the developed seeding system was to provide a continuous and controlled supply of seed material from the hopper to the metering mechanism and to ensure its uniform distribution during sowing [14]. Particular attention was given to preventing seed bridging, arching, blockage, and interruption of seed flow, which may occur when non-free-flowing seed material accumulates above the metering elements. The developed seeder incorporated a hopper, a seed-metering and distribution mechanism, and a working element designed to improve the movement of seed material toward the metering zone.

The operating parameters of the mechanism were selected on the basis of theoretical calculations and preliminary experimental investigations. The developed technical solutions are protected by patents of the Republic of Uzbekistan, including Patent No. FAP 2670 and Patent No. FAP 3044.

Experimental Procedure. Laboratory and field experiments were conducted to determine the operational and technological characteristics of the developed seeder. The experimental procedure included assessment of seed movement through the hopper, stability of seed delivery, uniformity of seed distribution, and the ability of the machine to maintain a continuous sowing process under conditions corresponding to sandy and degraded pasture soils. The experimental setup was based on a modified seeding machine equipped with the developed seed-metering system. The rotational parameters of the metering mechanism could be adjusted during the experiments, allowing the influence of operating conditions on seed delivery and distribution to be evaluated. The hopper and metering zone were configured to reproduce the conditions under which arching and interruption of seed flow may occur when using poorly flowing desert seed material. Field trials were performed under conditions representative of degraded desert and semi-desert pastures. During the experiments, the operation of the seeder was monitored and the stability of seed delivery was evaluated throughout the sowing process. The experimental observations were focused on the continuity of seed movement, uniformity of seed distribution, and the ability of the developed mechanism to operate without significant blockage or interruption.

Evaluation of Sowing Performance. The effectiveness of the developed technology was assessed using a set of technological indicators characterizing the quality and stability of the sowing process. The principal indicators included the uniformity of seed distribution, stability of seed delivery, continuity of operation, and suitability of the seeder for sandy and degraded pasture conditions. The uniformity of seed distribution was evaluated by analyzing the quantity and distribution of seeds delivered by the metering mechanism during a defined operating interval. Seed delivery stability was assessed by monitoring variations in the amount of seed supplied during consecutive operating intervals. Particular attention was given to the occurrence of interruptions, bridging, or blockage within the hopper and metering system. The experimental results were processed and compared to identify the operating conditions that provided stable seed movement and consistent distribution. The obtained data were used to determine the technological suitability of the developed seeder for mechanized establishment of drought-resistant vegetation in degraded arid pasturelands [16].

Data Analysis. The experimental observations and measured parameters were systematically recorded and analyzed to establish relationships between the operating conditions of the seeder and the resulting quality of seed distribution. The obtained results were interpreted in terms of the technological requirements for establishing native desert vegetation under arid soil and climatic conditions. The combined laboratory and field investigations provided an experimental basis for evaluating the applicability of the developed mechanized technology to the rehabilitation of degraded desert and semi-desert pasturelands. The methodology enabled assessment of the ability of the proposed seeding system to provide stable seed delivery and uniform distribution while reducing technological problems associated with the handling of poorly flowing desert seed material.

Results

The operating principle of the proposed seeder for sowing the seed heap of desert forage plants, particularly izen, is based on the controlled loosening, displacement, and continuous feeding of the seed material within the hopper. Before operation, hopper 7 is filled with the prepared seed mixture. Once the seeder is coupled to the tractor and begins forward movement, the ground wheels 2 rotate and transmit the resulting mechanical motion to the left 4 and right 5 horizontal drive shafts. The rotational motion from the horizontal drive shafts is subsequently transmitted to the seed-mixture loosening mechanisms located in the lower part of hopper 7 and supported by bearings 8. The left horizontal drive shaft 4 drives the two left shafts 9 of the loosening mechanisms, while the right horizontal drive shaft 5 drives the corresponding two right shafts 9 (Fig. 1). Thus, the drive system ensures synchronized operation of the loosening mechanisms on both sides of the hopper and facilitates the continuous movement of the seed mixture toward the metering zone. The geometry and arrangement of the hopper walls also play an important role in maintaining stable seed movement. The side walls of the quadrangular hopper are positioned at an angle of 90°, which reduces excessive

contact between the seed mixture and the hopper surfaces and facilitates its downward movement. Under the action of gravity, the seed mixture moves from the upper section toward the lower part of the hopper, where it enters the operating zone of the loosening mechanisms. As the seed material reaches the lower section of the hopper, it comes into contact with the conical fingers 10 mounted on the rotating loosening mechanisms (Fig. 2). The rotating fingers actively loosen and redistribute the seed heap, promoting its gradual displacement toward the metering zone. This interaction prevents the formation of stagnant zones and reduces the likelihood of bridging, blockage, and interruption of seed flow. Consequently, the coordinated operation of the ground-wheel drive, horizontal shafts, loosening mechanisms, and conical fingers provides a continuous technological flow of the seed mixture from the hopper toward the metering system. The proposed operating principle is intended to maintain stable seed movement throughout the sowing process and improve the reliability and uniformity of seed delivery under field conditions

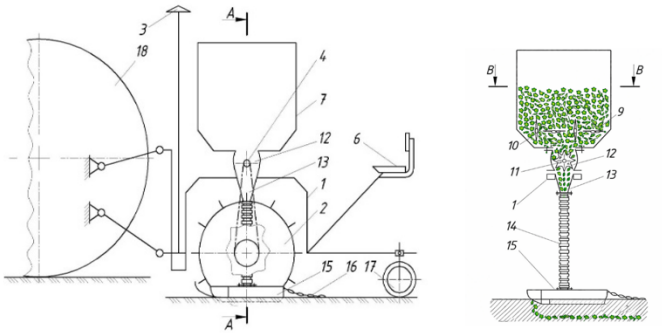


Figure 1. Diagram of the proposed unit for sowing a seed heap of desert forage plants (izen). 1-frame, 2-support wheels, 3-marker, 4-5-left and right horizontal shaft, 6-seat, 7-hopper, 8-bearing, 9-seed mixture softeners, 10-cone-shaped fingers, 11-drum distributor, 12-13-seeding apparatus, 14-seed tube, 15-coulter, 16-hedder, 17-compacting roller, 18-tractor chassis

Initially, the seed material is retained on the surfaces of the conical fingers 10 mounted on the seed-mixture loosening devices 9. When the loosening mechanisms start rotating, the conical fingers actively engage with the seed material and regulate its movement toward the distributing drum 11. Their configuration prevents the seed mixture from falling suddenly and directly onto the triangular grooves 12 of the distributing drum, thereby ensuring a gradual supply of material to the metering zone (Fig. 2). During rotation of the loosening devices, the conical fingers continuously disturb and separate the seed mixture, preventing excessive compaction and maintaining its mobility in the lower part of the hopper. This mechanical action is particularly important for seed material with poor flowability, as it reduces the tendency of the mixture to accumulate above the grooves and form stable arches that could interrupt the seed flow. The geometry and arrangement of the conical fingers provide a controlled transition of the seed mixture from the loosening zone toward the triangular grooves 12 of the distributing drum 11. As a result, the seed material is progressively supplied to the grooves rather than being discharged as a single compacted mass. This improves the consistency of seed supply and reduces the probability of localized accumulation, bridging, and blockage within the metering zone. Thus, the coordinated action of the rotating loosening devices 9 and conical fingers 10 ensures continuous displacement of the seed mixture toward the distributing drum. The resulting stabilization of seed flow contributes to more uniform filling of the triangular grooves 12 and, consequently, to stable and uniform seed distribution throughout the sowing process.

The proposed operating mechanism ensures continuous and stable movement of the seed material and contributes to a more consistent distribution of the seed mixture during the sowing process. The design facilitates the controlled displacement of poorly flowing seed material through the hopper while minimizing the formation of bridges, arches, and blockages that may disrupt the feeding process. The coordinated action of the loosening and feeding elements provides a continuous supply of seed material to the distributing drum, thereby maintaining stable operating conditions of the metering system. This function is particularly significant when sowing izen seed material, whose specific physical and mechanical properties may result in reduced flowability and irregular

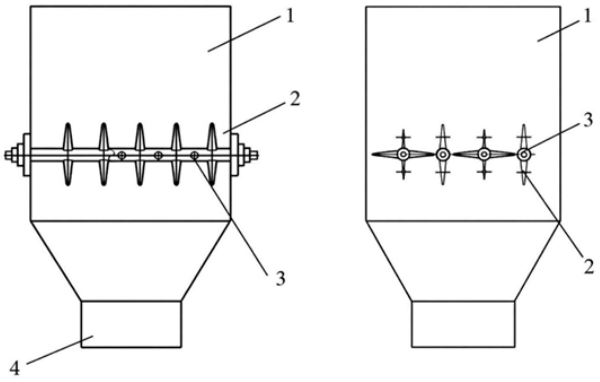


Figure 2. Layout of the conical working element inside the hopper. a – front view; b – side view. 1 – hopper; 2 – conical working element; 3 – shaft; 4 – housing

feeding under conventional hopper configurations. Accordingly, the integration of a specialized seed-mixture loosening and feeding mechanism creates favourable technological conditions for maintaining uninterrupted seed movement, stabilizing the feeding process, and achieving consistent and uniform sowing performance under field conditions.



Figure 3. General view of an innovative seeder for sowing seeds of desert forage plants. 1 – hopper, 2 – shaft (with a conical working section), 3 – drum, 4 – seed feed pipe, 5 – laboratory autotransformer, 6 – distribution panels, 7 – belt conveyor

The principal operating parameters of the proposed device were determined under controlled laboratory conditions using a DT-2236B digital tachometer. The calculated parameters were subsequently compared with the experimentally measured values, and the corresponding results are presented in Figure 3. Field experiments with the developed seeder were conducted in 2025 at the testing facilities of BMKB-Agromash Joint-Stock Company in Farish District, Jizzakh Region. Additional field trials were performed during the same year in Urtachirchik District, Tashkent Region. These experimental sites provided representative conditions for assessing the operational and technological performance of the seeder under actual field conditions. During the field trials, the developed seeder was aggregated with wheeled tractors belonging to traction class 0.9–1.4, including the T-40 and MTZ-80/82 models (Fig. 3). The selected tractor models provided the required traction force and operating conditions for conducting the experiments and evaluating the technological performance, stability, and operational suitability of the developed seeding system under field conditions.

As shown in the figure, an increase in the rotation parameter from 0.01 to 0.075 s is accompanied by a gradual increase in the number of sown seeds, from approximately 6 to 17 seeds. The most pronounced increase is observed within the range of 0.01–0.05 s, where the number of sown seeds rises from about 6 to 14. With a further increase in the parameter, the number of sown seeds continues to increase, reaching approximately 17 seeds at 0.075 s.

In contrast, the number of wingless seeds remains comparatively low throughout the investigated parameter range. At 0.01–0.02 s, their quantity is approximately 1 seed. Within the range of 0.03–0.05 s, this value increases to about 2 seeds, while at 0.06–0.075 s, it reaches approximately 3 seeds. The obtained results indicate that an increase in the operating parameter of the conical working element enhances the loosening and displacement of the seed mixture, thereby increasing the amount of seed material supplied to the distributing mechanism. At the same time, the relatively small increase in the number of wingless seeds suggests that the working element ensures a controlled and regulated movement of the seed mixture within the hopper.

Overall, the observed dependence confirms the effectiveness of the proposed conical working element in providing a stable and continuous supply of seed material to the distributing mechanism. This operating principle contributes to greater uniformity of seed delivery and improves the stability and reliability of the overall sowing process.

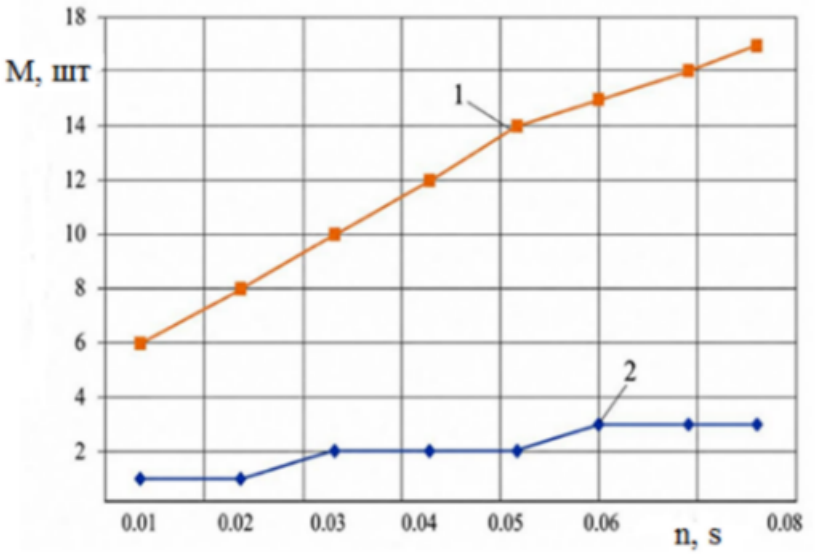


Figure 4. Graph of the dependence of the seed heap quantity on the number of revolutions of the cone-shaped working element. 1 sown seeds, 2 wingless seeds

Overall, the obtained dependence demonstrates a clear positive relationship between the operating parameter of the conical working element and the quantity of seed material supplied to the distributing mechanism. An increase in the rotational speed of the working element intensifies the loosening and displacement of the seed mixture, thereby increasing the amount of seed material delivered to the distributing drum. This dependence indicates that the rotational characteristics of the conical working element directly affect the continuity and intensity of the seed-feeding process. Analysis of the experimental results makes it possible to identify a rational operating range of the proposed device within which the required amount of seed material is supplied without excessive accumulation or interruption of the seed flow. Within this range, the conical working element provides sufficient loosening of the non-free-flowing seed mixture while maintaining controlled movement toward the distributing mechanism.

At the same time, the relatively limited increase in the number of wingless seeds indicates that increasing the operating parameter does not substantially impair the separation and distribution of the seed mixture. Thus, the experimental results demonstrate that the appropriate selection of the rotational operating parameter of the conical working element is an important factor in ensuring stable seed feeding and uniform seed distribution during sowing. The identified rational operating range provides an appropriate balance between the productivity of the seeding mechanism and the quality of seed distribution, while reducing the likelihood of bridging, clogging, and irregular seed flow within the hopper. Therefore, the obtained results can be used as a basis for determining the optimal operating parameters of the proposed device for the mechanized sowing of izen seed material under field conditions.

Discussion

The experimental results demonstrate that the operating characteristics of the conical working element have a direct effect on the stability and intensity of seed-material supply to the distributing mechanism [14]. The observed increase in the number of sown seeds with increasing rotational operating parameter can be attributed to the intensification of the loosening and displacement processes within the hopper [17]. As the rotational motion of the conical working element increases, the non-free-flowing seed mixture is subjected to more intensive mechanical action, which facilitates its movement toward the distributing drum. The obtained dependence is particularly important for seed materials such as izen, which differ from conventional free-flowing seeds by their relatively low flowability and tendency to form accumulations and bridges within the hopper. Under insufficient mechanical action, the seed mixture may remain stationary in certain zones of the hopper, resulting in an irregular supply to the distributing mechanism. The experimental results indicate that the proposed conical working element effectively reduces this tendency by continuously disturbing and redistributing the seed material. The increase in the number of sown seeds from approximately 6 to 17 over the investigated operating range confirms that the intensity of seed delivery can be controlled by varying the rotational characteristics of the working element. The most pronounced increase was observed at operating parameter values of 0.01–0.05 s, where the number of sown seeds increased from approximately 6 to 14. This indicates that the working element becomes increasingly effective in loosening and moving the seed mixture as its rotational activity increases. Further increases in the operating parameter resulted in a more moderate growth in the quantity of delivered seed material, reaching approximately 17 seeds at 0.075 s.

At the same time, the number of wingless seeds remained comparatively low throughout the experimental range. Their quantity increased from approximately 1 seed at 0.01–0.02 s to about 2 seeds at 0.03–0.05 s and approximately 3 seeds at 0.06–0.075 s. The relatively small increase in this indicator compared with the overall increase in the number of sown seeds suggests that intensified operation of the conical working element does not lead to a proportional deterioration in the separation and controlled movement of the seed mixture. From a technological perspective, these results indicate that the function of the conical working element is not limited to simply increasing the quantity of seed material delivered to the distributing drum. Its mechanical action also contributes to maintaining a continuous flow of the seed mixture from the hopper toward the metering and distributing zone. This is particularly relevant for the mechanized sowing of izen, where interruptions in seed supply can result in irregular seed placement and reduced sowing uniformity. The results also demonstrate the importance of selecting an appropriate operating range rather than maximizing the rotational parameter. Excessively intensive movement of the seed mixture is not necessarily required to achieve stable seed delivery. The experimental relationship suggests that, within a rational operating range, sufficient loosening can be achieved while maintaining controlled seed movement and a relatively low proportion of wingless seeds. Consequently, the operating parameter should be selected by considering both the quantity of supplied seed material and the quality and stability of its distribution. The observed behavior can be explained by the interaction between the conical working element and the physical structure of the seed mixture. During rotation, the conical fingers act on the accumulated seed material, breaking local zones of compaction and facilitating its downward displacement. This mechanical action prevents the formation of stable bridges above the triangular grooves of the distributing drum and promotes a more continuous replenishment of the metering zone. As a result, the distributing mechanism receives a more stable supply of seed material. An important practical implication of the obtained results is that the proposed design provides an adjustable method for controlling seed flow. By changing the rotational operating parameter of the conical working element, the intensity of seed-material movement can be adapted to the required sowing rate and operating conditions. Such adjustability is particularly valuable for desert forage seeds, whose physical and mechanical properties may differ considerably from those of conventional agricultural crops.

Overall, the experimental findings support the proposed design concept and demonstrate the technological role of the conical working element in stabilizing the seed-feeding process. The combination of intensified loosening, controlled displacement, and continuous replenishment of the distributing mechanism contributes to more stable seed delivery and reduces the probability

of bridging, clogging, and interruption of seed flow. Therefore, the experimentally established relationship between the operating parameter and seed supply can be used for the further determination of rational operating conditions and for field optimization of the developed seeder for izen sowing under arid conditions.

Conclusions

The experimental investigation confirmed the effectiveness of the proposed conical working element for stabilizing the supply of non-free-flowing izen seed material to the distributing mechanism of the developed seeder. The results demonstrated a clear positive relationship between the rotational operating parameter of the working element and the quantity of seed material delivered to the distributing drum. An increase in the operating parameter from 0.01 to 0.075 s resulted in an increase in the number of sown seeds from approximately 6 to 17. The most substantial increase was observed within the range of 0.01–0.05 s, where the number of sown seeds increased from approximately 6 to 14. At the same time, the number of wingless seeds remained comparatively low, increasing from approximately 1 to 3 seeds over the investigated range. This indicates that the intensification of the working element did not cause a substantial deterioration in the controlled movement and distribution of the seed mixture. The obtained results demonstrate that the conical working element effectively loosens and displaces the non-free-flowing seed mixture, reduces the tendency toward bridging and clogging, and ensures a more continuous supply of seed material to the distributing drum. The identified rational operating range provides a balance between the intensity of seed feeding and the stability of seed distribution. Thus, the proposed design can improve the reliability and consistency of the sowing process for izen under arid and semi-arid field conditions. The experimentally established relationships provide a basis for selecting the appropriate operating parameters of the conical working element and for further field optimization of the developed seeder to achieve stable seed feeding and uniform sowing.

Authors' contribution Conceptualization, E.Farmonov. and Sh.Mirzaeva.; methodology, E.Farmonov.; software, Sh.Mirzaeva.; validation, E.Farmonov., Sh.Mirzaeva.; formal analysis, E.Farmonov.; investigation, Sh.Mirzaeva.; resources, E.Farmonov.; data curation, Sh.Mirzaeva.; writing—original draft preparation, E.Farmonov.; writing—review and editing, Sh.Mirzaeva.; visualization, Sh.Mirzaeva.; supervision, E.Farmonov.; project administration, Sh.Mirzaeva. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest The authors declare no conflicts of interest.

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