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Achim Jesser "Development, Testing, and Optimization of a Prototype Seedball Machine for Sahelian Smallholder Farmers in Niger", University of Hohenheim, 2020

Supervisor: Prof. Dr. Joachim Müller

Problem Statement

Farmers in Niger, most of whom engage in small-scale subsistence farming, often face adverse growing conditions. Soils are sandy and nutrient-poor, the climate is hot and semi-arid with erratic rainfalls, leading to substantial yield gaps and yield variability. Pearl millet is a major staple crop in smallholder farming systems of the West African Sahel, well adapted to the challenging growing conditions and productive where most other crops would fail. However, a review of production practices indicates that there is untapped potential to increase average yields. (Mason et al, 2015).

Seedball is a seed-pelleting is such technology, that consistently increases yields and is tailored to traditional cropping systems (Nwakwo et al. 2018). Seedballs have higher germination rates, enhanced seedling establishment, and stronger early growth compared to common seeding. To prepare seedballs a mixture of soil materials, seeds and water is formed in a ball-like sphere. Further additives, such as fertilizers can be added.

Despite being a promising technology adoption rates are low. A crucial drawback is that seedballs are merely made by hand, which is time-consuming. It takes about forty hours to prepare the 10,000 seedballs required for one hectare. The mechanization of production would multiply the output significantly. Thereby the technology becomes more accessible and adoption barriers can be removed.

Objectives

The Institute of Agricultural Engineering in the Tropics and Subtropics at the University of Hohenheim constructed a prototype to address the issue of mechanization. This study bridges the crucial transfer stage from early prototype development to initial implementation. By testing, optimizing, and refining the prototype the overall aim is to achieve an optimized prototype for efficient production of seedballs, ready for service. To do so, the thesis defines three objectives that build on each other. The specific goals are:

1. Proof of Concept
   The prototype is operational, efficiently producing seedballs of similar or superior quality to manual production. Scientific experiments aim to optimize and increase understanding of production parameters
2. Practical Adaptions
   Building on the lessons learned and feedback from stakeholders, further adaption to local circumstances is necessary. These target the whole production process and make production more efficient while increasing the ease of use.
3. Implementation
   To support implementation and diffusion of the technology an operational strategy, a user manual, and training tools are designed.

Without adaptions to local circumstances, innovations in smallholder farming systems are prone to fail. Therefore, we defined three guiding principles that must be met by all three objectives. Construction and operation must be inexpensive. The prototype is decidedly low-tech, to ensure a high level of robustness and make modifications possible. Lastly, the prototype must be easy to operate.

Methodology

The prototype pictured in Figure 1 on the right consists of four major components. The drum on top, an electric motor, a metal framework, and appliances for power transmission.

Seedballs are formed in the drum, through rotation, comparable to a snowball rolling down a hill. The electric motor provides the energy to rotate the drum and is connected to the drum with V-Belts. The metal framework consists of tubes that are welded together but could also be made from other materials.

As outlined in the objectives above the thesis consists of a scientific the experiment followed by practical trial runs and modifications.

Figure 1: The prototype

The scientific experiment optimizes and investigates the influence of three production parameters, unique to mechanized production. These parameters are the substrate composition (amount of loam and sand in the mixture), the rotational speed of the drum (measured in rpm), and the materials' residence time in the drum (measured in minutes).

The study applies Box-Behnken experimental design, where the variables fluctuate between a fixed high, middle, and low value. Its' major advantage is a reduced number of trial runs compared to other designs. Response Surface Methodology is a collection of mathematical and statistical methods used to optimize multiple responses influenced by various variables.

Responses tracked in the study, measure production efficiency (seedballs produced, substrate usage rate) physical parameters (seedball diameter, rupture force), and quality indicators (amount and variability of seeds in seedballs). Germination rates of hand- and machine-made seedballs were compared as well. A desirable seedball is 20-25 mm in diameter and contains multiple seeds.

In the practical stage, the goal is to optimize the production process holistically. This means comparing factors like different operational modes like (semi-) continuous and batch production or the effect of additional tools to separate seedballs. Furthermore, an investigation of different substrate compositions to adapt to local or agronomic needs.

Results

The study validates the concept of mechanized seedball production. During all experiments, the prototype worked as expected and produced high-quality seedballs. Figure 2 on the left shows seedballs produced in the prototype, as well as a germinated seedball with multiple emerging seedlings.

Figure 2: Seedballs (right) and a germinated seedball (left)

Statistical analysis of the quadratic models required with response surface methodology shows that all three independent variables (substrate composition, rotational speed, and residence time) have a significant impact on the response variables. Further analysis of the responses shows that the number of seedballs produced, substrate usage rate, and variability of seeds are the most important indicators of machine success.

The number of seedballs produced appears to be positively correlated with the amount of loam in the substrate mix. However, there is a limit due to agronomic constraints. Residence time and rotational speed have an adverse relationship, impacting substrate usage rate and the variability of seeds per ball. Data analysis shows ideally speed is high, while residence times are short. Otherwise, negative influences on seedball size and quality are possible.

Machine settings for production are optimal at 74% loam in the substrate, 3 minutes residence time, and SO rounds per minute. Trial runs under these conditions produce 31 seedballs per minute compared to 4 seedballs in manual production.

The practical adaptions introduced a new mode of operations and additional tools to improve the production process. Tools, like a perforated shovel and a separation unit, increase production efficiency as fewer seedballs are wasted. The study's results and the experiences during the trial runs show that production with the prototype is most effective in semi-continuous production. Using this method raw materials can be mixed and prepared in advance. The machine is then loaded and started. With a perforated shovel seedballs that have reached adequate sizes can be taken out at any time. After some time, the remaining small seedballs will not grow further and new raw material must be added. This process can be repeated every one to three minutes.

The combination of semi-continuous production, the optimized production parameters, and the tools leads to an output of 44.4 high-quality seedballs per minute. This represents a tenfold increase over manual production. Substrate usage rate, a crucial factor for efficient and economic production is remarkably high with 97.1% (compared to 95% in manual production and 44.1% after the scientific experiment. Variability of seeds per ball is lowered substantially in mechanical production from 15.5 to 7.9.

In greenhouse tests mechanically produced seedballs more than 98% of seedballs had multiple germinated seeds. This is a strong indication that seeds are not damaged during production and further validation the viability of the concept. However, large-scale field tests are still necessary.

Power consumption was recorded during all trial runs. The prototype's consumption is around 140 W, with short peaks immediately after it is turned on. This allows the prototype to be connected to a solar panel, lowering costs, and making it functional in remote areas.

Outlook

In conclusion, was able to prove that mechanized seedball production is possible. The data and results support the advancement to further field tests. Currently, the prototype is transferred to a farmer cooperative in Niger, where it needs to undergo these tests. Further research should address the question of scalability. To support innovation diffusion, it will be necessary to develop new strategies to make seedball technology available to more farmers. One possible solution could be that cooperatives own the machine and farmers can buy either seedballs directly or bring their seeds to them to make seedballs. In any case through the mechanization of the production process, entry barriers can be removed, and adoption rates increased!

References:

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