Design, fabrication and assessment of direct seeder in Benin Republic

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Abstract: The need for efficient agricultural equipment that is compatible with the characteristics of farms remains a crucial issue in Africa. The work aimed to design, fabricate and test a seeder for direct seeding. The method used consisted of collecting the farmers' equipment needs and the weakness of some direct seeders in the literature review. Then, the design of the planter components was carried out based on the mechanical characteristics of soil types and physical, mechanical, and kinetical properties of seeds in Benin Republic. Finally, a technical drawing of the seeder was made on the computer. The seeder was manufactured in a local mechanical workshop and tested in the field. This equipment is capable of sowing on unplowed soil, with an average capacity of 0.90 ha h^{-1} for two rows, a working speed of 1.6 m s^{-1} and a percentage seed damage of 1.28%. This seeder sows an average of two seeds per hole with an average distance of 0.25 m between seeds and 0.80 m between rows for sowing depth around 0.03 m. The optimization of this direct seeder will allow to support the farmers for the success and the extension of the area of the direct sowing under vegetable cover in Benin Republic.

Keywords: Planter, design, agricultural mechanization, conservation agriculture.

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1 Introduction

Due to the constantly growing population of Benin (INSAE, 2013), food needs are also increasing. To cover this deficiency, the use of faster means of production becomes necessary. One of the fastest and shortest methods is the mechanization of agricultural systems (Touzard, 2009). Indeed, mechanization can increase output, enhance the economy and improve the living and working conditions of rural populations (Onwualu et al., 2006). In order to achieve this issue, farmers are gradually moving from the use of currently dominant hand tools to mechanized systems (Vall et al., 2017). This modernization of agriculture could attract young people to this occupation, improve their income and thus reduce poverty (Ohanyere et al., 2014). It is true that the use of mechanical equipment requires significant resources that few local farmers do not have (Olajide and Manuwa, 2014). However, not only their co-operative organization could mitigate this constraint (Zokpodo et al., 2017), but especially the design and manufacture of less expensive and easily accessible equipment to farmers would be a great contribution. The Benin Republic, with an annual rainfall distribution ranged from 900 mm to 1300 mm and temperature of 26°C - 28°C, is divided into eight agro-

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ecological zones, with various types of soil. The land use for agricultural production is already identified as factors affecting environmental quality (Zhang et al., 2007). With agriculture as the main sector of economic growth, many studies have shown in Benin a close link between soil degradation and farmers’ practices (Igué, 2009; Lawal et al., 2007) such as burning, conventional tillage. However, very little attention is given to the proper use of the environment. In the current context of environmental protection for sustainable agriculture, the use of appropriate equipment for no-tillage or minimum tillage to reduce the conventional agricultural practice impacts on natural resources is necessary. Compared to the traditional system, fuel consumption for example is significantly reduced for a conservation system (Tayel et al., 2015). One of the most common practices for this conservation agriculture is direct sowing under vegetal cover. And to achieve this goal and let manual practices, the equipment most concerned is the direct seeder (Coufourier et al., 2008). But, as well as the sensitivity of germination of most seeds in an excessively moist or dry environment (Abd El-Tawwab et al., 2007), the components of a seeder must adapt and provide a better performance in varied conditions (dry or wet). Direct seeder models exist and are tested in different regions of the world (Vadon and Marionneau, 2012). But some direct seeders are fragile, poorly crossed the mulch, and are prone to a clump of grass (Rachou, 1997), difficult to control seeding depth (He et al., 2014), usage costs are high in small areas. In order to be successful in zero tillage, it is essential to have a seeder that can cope with the variability of soil conditions on the same day, in the same plot, and between plots (Baker and Saxton, 2007). The technologies to accompany conservation agriculture are very poorly introduced in many African countries and are almost non-existent in Benin. The lack of appropriate materials and knowledge by producers are the main reasons for this (Karabayev et al., 2012). This study proposes to manufacture and test the performance of a direct seeder adapted to soil and climate conditions of Benin.

2 Material and methods

2.1 Stages of seeder design

Four steps were followed during the design of the seeder. The first step was an informational and conceptual design and involved the collection of farmers' needs in direct seeding and other problems associated with the mechanization of direct seeding in Benin based on field observation and literature review. This stage was also interested in the weakness of direct seeders in the world: jams, low residue cutting, the location of fertilizers in relation to seeds and the poor closure of furrows (Rachou, 1997; He et al., 2014). For this purpose, reflections were conducted to model technically adapted parts to meet these weaknesses of previous seeders. The second stage was a preliminary design by sizing the planter components. For this, the force exerted by each element of the seeder was evaluated. Penetrometer resistances of different types of soils were determined to size the parts that come into contact with the soil. The third step was the shaping of the seed distribution system. At this level, the physical, mechanical and kinetic properties of some cereals and legumes were noted. During the last stage, the detailed design, it was the technical drawing of the seeder and these components on the computer.

2.2 Calculating the components of the seeder

For the calculation of the thickness of the cutting disc, considering the vertical elementary section to buckling of the cutting disc, the maximal shearing force on a section is given by the relationship (Boucard, 2013):

$$\tau_{max} = K_{\tau} \frac{T}{A} \tag{1}$$

Where: τ_{max} is the maximal shearing force (N mm^{-2}), K_{τ} is the coefficient depending on the form of the section, T is the cutting force (N), A is the area of the section subjected to the shearing force (mm^2).

The bending moment for a recessed bar with a rotation equilibrium around point A is expressed by the relationship (Longeot and Jourdan, 1982):

$$M_{fA} = F \times L \tag{2}$$

Where: M_{fA} is the bending moment (N mm); F is the acting force (N) and L is the length of the bar (mm).

The allowable bending stress was obtained taking into account the safety factor concerning the yield strength

(Itterbeek, 2012):

$$\sigma_{adm} = \frac{R_e}{s} \quad (3)$$

Where: σ_{adm} is the allowable stress (N mm^{-2}); Re is the elastic limit resistance (N mm^{-2}) and s is the safety factor.

The choice of the type of bar for the frame was conditioned by the allowable stress and the minimum flexural modulus (Chevalier, 2004):

$$w_y \geq \frac{|M_{max}|}{\sigma_{adm}} \quad (4)$$

Where: w_y is the minimum flexural modulus (mm^3); M_{max} is the bending moment (N mm).

The shear stress for a rod having two sheared surfaces is obtained by the expression (Daidié and Paredes, 2010; Aulnoye, 2013):

$$\tau = \frac{T}{S} \quad (5)$$

Where: τ is the shear stress (N mm^{-2}); T is the load supported by the rod (N); S is the section of the rod (mm^2).

2.3 Assessment of the seeder's performances

The prototype of the seeder was manufactured within the International Society of Engineering for Development (S2ID) located in Cocotomey (Abomey-Calavi, Benin). According to the design scheme, almost all the parts are fabricated in this workshop. Other parts (bearing, chain) were bought on the market while waiting to develop their molding and forging. After assembly and fabrication; distribution, transmission and seed flow, soil opening and burial systems were evaluated at the station to ensure good theoretical performance.

The field tests are carried out respectively on site 1 in Sékou (Municipality of Allada) and site 2 in Kpétou (Municipality of Comè). Both sites are in an area characterized by a Sudano-Guinean climate with two rain seasons of 600 to 1200 mm/year (MAEP, 2010; Gbemavo et al., 2014). The soil of the first site is ferralitic with a sandy loam particle size while the second site is characterized by sandy soil. The speculation sown is maize. Maize cultivation was chosen for the experiment because it plays an important role in the diet of Benin's populations, in animal feed and in industry. The maize grown is the variety 85 TZSR-W. It is early with a vegetative cycle of fewer than 90 days. The sowing equipment consists of the direct seeder designed and trailed by a 33.12 kW tractor on site 1 and 22.08 kW on site 2.

During sowing, it was observed and measured: the distance between the sowing lines, the effective sowing depth, the seed coverage efficiency, the distributed grain yield and the behavior of the working parts. The spacing between maize plants on the sowing lines was measured after the seeds had emerged.

2.4 Statistical analyzes of the data

Data obtained from the study were analyzed using descriptive statistics such as tables and charts. The mean and standard errors were calculated using the statistical software R.

3 Results

3.1 Description of the seeder

The direct seeder is composed of six main parts: the frame, the cutting system of residues and grasses, the opening and burying devices of seeds and fertilizers, the distribution organs, the hoppers of seeds and fertilizers; and the drive wheel of the system.

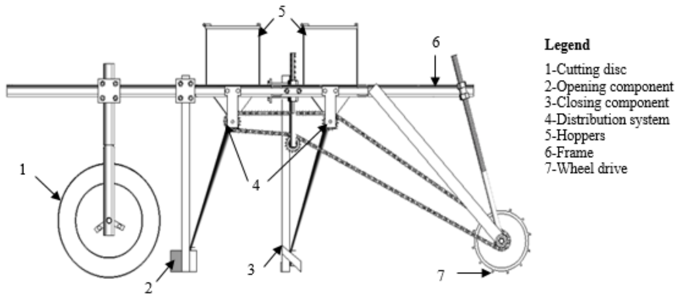

Figure 1 One unit of the direct seeder drawn with the TopSolid software

Figure 2 Direct seeder model fabricated

Figures 1 and 2 show the model of the direct seeder designed. Some details and views of the seeder drawn on TopSolid software are shown in the Appendix.

3.2 Operation of the seeder

When the pulling force (tractor) pulls the seeder, the disc starts with a rotational movement about its axis and sinks into the soil under the effect of the weight of the equipment. Then, it cuts residues thanks to the two cages located on its either side, which support and maintain horizontal and tangent weeds and / or crop residues to be cut. This disc after cutting residues sinks into the soil and opens a sowing line while crushing the clods of soil. In its translational movement, the organ opening the soil and planting the seeds passes in the previous line by enlarging it with its front face sharp and its thickness. The progress of the seeder also rotates the rear wheel which transmits the rotational movement to the driven sprockets of the distribution components through a chain and its drive shaft with a driving pinion. This rotation transmitted to the seed distributor allows the drum to select the seed and send it into the down tube. The seed thus falls into the line left by the opening organ. Subsequently, the furrow closer, in its translational movement, scrapes the soil and covers the seeds. The rear wheel passes over the sowing line while tamping the sand. The sowing is finished and the movement begins again.

3.3 Sizing of the main organs of the seeder

The sizing of the seeder's components is based on the efforts to be faced by each component. About the cutting, disc which met soil constraints and residues, the average maximum soil resistance in Benin measured by a penetrometer depth of 20 cm is about 21.07 kg cm^{-2} for almost dry soils. The force required to cut the residues (load at break) with the example of a wood 10 mm in diameter, or 78.57 mm^2 of section is estimated at 16.82 kg (Badour et al., 2010; Venet, 1958). Wood is taken here as the most difficult material to cut on plots, unlike grasses and crop residues. In total, an effort of 37.89 kg to overcome by the disc to succeed the operation of cutting of weeds and residues and tracing of the line of sowing. According to Equation 1, based on the total effort supported by the disc, and fixing a radius r = 200 mm, the cutting disc must have a thickness $t \geq 4.48$ mm. A sheet of a thickness of 5 mm was used (Figure 1 component 1).

The opening component is represented by a beam embedded at one end on the frame. It is exposed to stress evenly distributed over a height of 5 cm from its lower part (Figure 1 component 2). The contact surface of the opening component with the soil is 30 mm wide and 50 mm high, ie 1500 mm^2. The average soil stress is 5.25 kg cm^{-2} or 0.525 N mm^{-2}. The bending moment, based on Equation 2 is Mb = 374062.5 N mm. Given the width (30 mm) of the sowing line to be traced, the CAR730 stainless steel square bar of section 30 mm * 30 mm and 450 mm length in Prolians catalog is rigid enough to serve as an opening component (Descours and Cabaud, 2010). As for the fertilizer spreader component, its area of contact with the soil is 400 mm^2 (S = 10 mm * 20 mm * 2). The average soil stress being 0.525 N mm-^{2}, therefore F_2 = 0.525 * 400. The closure member exerts less than one-third (F_2 = 210 N << F_1 = 787.5 N) of the effort made by the opening component. However, given the additional effort to be provided by the closure component as that of the opening component. That is 30 mm * 30 mm and length 400 mm.

At the frame level (Figure 2 component 6) to be resistant, the maximum moment deduced from the diagram of shearing forces and bending moments, is 446655.308 N mm given by Equations 3 and 4. The allowable stress σadm = 101.43 N mm^{-2} and minimum bending modulus $wy \geq 4403.582$ mm^3. According to ArcelorMittal (2017) catalog of stainless steel tubes, there is a square tube, Reference standard: NF EN 10219 with an external dimension of 40 × 40 mm and a thickness of 4 mm respecting this condition. For uniformity and durability, the frame is made with a rectangular iron tube section 60 mm * 40 mm and thickness 4 mm.

A complete revolution of the seed distribution drum corresponds to two (2) sown grains. The space of maize is fixed 250 mm between crops on the same line, this complete turn corresponds to 250 * 2, which is 500 mm to be covered by the complete turn of the rear wheel (Figure 2 component 7). The sprockets are therefore chosen accordingly. For that, for a pinion of *n* teeth on the axis of the rear wheel, it will also be necessary a pinion of *n* teeth on the axis of the drums of distribution of seeds. Furthermore, the rear wheel is the second support of the planter after the disc, its thickness is also 5 mm, using Equation 5.

3.4 Assessment of the theoretical performance of the direct seeder with maize

After manufacture, the planter was arranged and dragged manually at the workshop and with the tractor to assess its theoretical performances in station (Figure 3).

Figure 3 Assessment at the station of the seeder

Table 1 shows the theoretical performances obtained in the station.

Table 1 Mean and standard error of station performances of direct seeder with maize

Parameters	Units	Average
Number of seeds distributed by each cell	Grains/cell	2.05±0.75
Seed damage	%	1.28±0.36
Seed spacing on a line	cm	23.08±0.25
Distance between sowing lines		80

3.5 Field performance of the direct seeder for sowing maize

Figure 4 shows the field test of the seeder. The seeder was evaluated on different types of soil cover, with plowing as a control treatment.

Figure 4 Field test of the direct seeder

Table 2 shows the results obtained during the field evaluation of the designed seeder.

Table 2 Mean and standard error of seeder performance in the field

Parameters	Units	Values
Distance between sowing lines	cm	80
Seed spacing on a line	cm	25.40±1.80
Depth of sowing	cm	3.07±0.22
Total width worked for sowing	cm	3.00±0.19
Number of seeds per hole	-	2.5±1.23
Quantity of seeds distributed per hectare	kg	25.06±1.2

3.6 Appreciation of specialists and users

The test was carried out in the presence of users and various stakeholders in agricultural mechanization. These are tractor drivers, members and leaders of Cooperatives of Agricultural Machinery Use, as well as teachers and high school students. After evaluation, most of those present congratulated the initiative through the design that appears new, the good seed distribution, the low breakage rate, and especially its adaptation to different tractors and small traction according to the number of rows. However, the poor grip of the wheels in too wet soil, the regularity of the inter-seed spaces and the covering of the seeds are the weaknesses noted by the assistance. Thus, the people present wished the continuation of the work by taking into account these weaknesses and especially advised to introduce the seeder to an agricultural cooperative for about three (3) years to better observe its behavior for successful long-term use.

3.7 Expenditures cost and economic performance of the seeder

This seeder is the prototype and there is no stock price for that. Table 3 describes and summarizes the expenses that occurred for the two rows seeder fabricated.

Table 3 Cost of expenditures for two rows of seeder

Parts and supplies	Cost (FCFA)	Percentage (%)
Main frame	102,300	41.29
Opener and closer components	12,000	4.84
Hopper and cutting disc supplies	35,500	14.33
Other supplies	97,950	39.54
Total	247,750	100

The frame is the most expensive component (41.29%) of the seeder, followed by the other supplies (39.54) of the total costs. By adding the workforce equal to 50,000 FCFA, the final cost of the direct seeder fabricated is 297,750 FCFA for two rows.

The economic performance of the seeder is given in Table 4.

Table 4 Economic performance of the seeder

Parameters	Values
Fixed cost (FC) per year (FCFA)*	37,220
Seeder maintenance (10% of FC)	3,725
Sub-total fixed and variable expenditure 1 per ha	*818.9*
Fuel cost (8 liters) for tractor/ha	4,400
Tractor driver per diem/ha	2,500
Sub-total variable expenditure 2 per ha	*6,900*
Number of ha/year**	50
Cost of providing 1 ha (FCFA)	15,000
Sub-total gain /year	*750,000*
Profitability/year	364,055

Note: * For 8 years; ** *Estimated*

4 Discussion

4.1 Mechanical resistance of the seeder components

Given the effort required to cut the residue, the cutting disc of our design has a radius of 200 mm and thickness increased to 5 mm. Which seems sufficient for the success of the work. The opening component is represented by a section beam 30 mm * 30 mm. This section is nevertheless superior to the characteristics of the opening share of several conventional seeders. For Ikechukwu et al. (2014), the design of seeder openers varies according to the needs of the soil conditions of the particular region. Most seed planters are provided with a pointed tool to form a narrow slot in the soil for seed depositions. The adjustable groove opener allows you to plant at every ideal soil depth of the variety. The used type of opener used by these authors for their design is a pointed bar, a mild steel flat iron of 50 mm side and 5 mm thickness. These types of furrow openers are used according to them to dig a narrow slot under heavy soils for seed placement at medium depths.

The frame of this seeder is made with a rectangular iron tube with a cross-section of 60 mm * 40 mm and a thickness of 4 mm. The frame is the platform on which the other components, these features are significantly superior to those used by Khurmi and Gupta (2005) consisting of mild steel angles of 30.2 mm on 30.2 mm on 3 mm thick. Our dimensions seem close to those of Soyoye et al. (2016) who manufactured the frame of their planter from a 50 mm * 50 mm angle. Also considering the main frame as the skeletal structure and based on the weight of the components and the force to be exerted, Ikechukwu et al. (2014) used a mild steel bar 50.8 mm × 50.8 mm and 4 mm thick to achieve their planter.

A complete rotation of the seed distribution drum corresponds to two grains sown for the spacing of 250 mm of maize on the same line, this complete turn corresponds to 500 mm to be covered by the complete turn of the rear wheel. This rotation of the drum conditioned by the movement of the rear wheel induces the flow of the seeds which depends on the size, shape, sphericity, actual density and angle of repose of the seeds (Jayan and Kumar, 2004). The distributor is an important link in the planter and its function is to distribute seeds evenly at the desired rate. According to Murray et al. (2006), the thickness of the seedbed should be between 3 and 6 mm to facilitate seed collection and to avoid seed damage. In their design, the measuring mechanism is a mild steel plate 100 mm in diameter and 5 mm thick with three equidistant cells close and flowing with the circumference of the plate. The cells are designed to pick at least one maize seeds and deposit them at a spacing of 25 cm.

The circumference of the rear wheel is 500 mm. For most manual and animal traction seed drills, the wheels are larger in diameter to reduce rolling resistance. Bharat and Sidharth (2014) design with a front wheel to improve movement on loose soil. It consists of a mild steel plate 6 mm thick folded into a circle 400 mm in diameter. Small pieces of V-shaped metal are alternately attached around the circumference of the wheel to provide lugs to ensure good adhesion on the soil.

4.2 Seeder performances

In general, the amount of seed used per ha is 25 kg. The average capacity is 0.90 ha per hour for two rows, against a working speed of 5.76 km h^{-1}. The seed breakage rate was 1.28%. The average difference between seeds is 25 cm and that between rows is 80 cm, with a sowing depth of 3.18 cm. The results are closer to those obtained by Soyoye et al. (2016) with an average seeding depth of 35 mm to 45 mm, an average spacing of 313.5 mm, an optimum speed of 1.38 m s^{-1} and a sowing efficiency of 89.7% with a seedling equal to 1.53 ha h^{-1}. The performance of the planter designed is in some ways different from that of the seeder realized by Ani et al.

(2016). Indeed, these authors obtained 3.7 hours as the time required to plant one hectare of agricultural land, so an effective field capacity of 0.27 ha h^{-1}. The average number of seeds planted is two per stand and the percentage of seed damaged is 1.71%. Adisa and Braide (2012) developed a planter model with a planting rate of 0.20 ha h^{-1}. Due to mechanical distribution, distributor cells are designed to pick an average of two maize seeds (Murray et al., 2006). Oduma et al. (2014) also developed and tested a hand-held cowpea precision planter giving a significant performance, and efficiency of 71.71% and an average capacity of 0.260 ha h^{-1}. The planting capacity of 0.0486 ha h^{-1} and an average speed of 0.15 m s^{-1} reported by Ikechukwu et al. (2014) appear weak, but the distribution mechanism showed no visible signs of seed damage. Also, the distribution system and the amount of seed sown appear approaches. This is because the wheel is connected directly to the seed metering device, and as long as the ground wheel rotates, the seed metering device at the bottom of the hopper rotates as well, releasing two or three seeds depending on the size of cells or the size of the seeds. Bashiri et al. (2013) developed and tested a prototype of a single hand seeder for maize. The test results showed that the planter has a dosing efficiency and accuracy of 96% and 58% respectively with a capacity of 0.5 ha h^{-1} versus 22 h per hectare if one person has to work. Olajide and Manuwa (2014) also designed, manufactured and tested a low-cost grain planter that can plant three types of grain: maize, soybean and cowpea. The planter had a mean-field capacity of 0.36 ha h^{-1} and a yield of 71% with a seed damage percentage of 2.58%, a spacing of 50.2 cm and an average depth of 4.28 cm. Thus, efforts continue on both sides to improve the performance of seeders for successful sowing.

4.3 Profitability

The use of this direct seeder appears to be profitable on several levels. Firstly, due to the lack of plowing, the expenses related to plowing are canceled, even if part of it has to be converted for the purchase of herbicides or gyro crushing. In all cases, the exposure of soil to climatic hazards is limited. Compared to conventional seeders, working time is reduced with this direct seeding machine because it saves 45% to 70% of the time (Bourarach, 1989; INRA, 2001). This reduction in work translates into savings only if some of the time is also valued. This can be used to cover more surface area, provide a service or develop another income-generating activity. More time available also allows for better observation and monitoring of crops and soil, for exchanges, information and training, and for meeting and visiting colleagues in order to think about even more efficient and economical strategies. Although the direct effects on final yield appear to be disputable, the amount of fuel in direct sowing is reduced; and soil protection and regeneration remain the best benefit for sustainable agriculture (Derpsch, 2001; Bourarach and Oussiblé, 2001). Less fuel means fewer hours of traction, less power consumption, less wear and tear and less breakage; the reduction of a number of jobs will, over time, lead to a reduction in the overall cost of mechanization.

The use of this seeder saved more time compared to manual sowing. Finally, it is expected that the final unit price of the seeder would decrease if multiple seeders were to be manufactured and purchased in a larger quantity.

5 Conclusion

A direct seeder was designed and developed to facilitate the direct sowing under vegetable cover for local communities in Benin Republic. This equipment differs from the imported seeders by the simplicity of the components fabricated locally at the workshop. The seed metering system is less complex and easily changeable by farmers. The design of the planter components takes into account the characteristics of soil types and seeds in the country. All the components were tested to enhance the durability and stability of the seeder. The field test showed an average capacity of 0.90 ha h^{-1} for two rows, a working speed of 1.6 m s^{-1} and a seed breaking rate of 1.28%. Moreover, in the field test, the study revealed an average of two seeds per hole with an average distance of 0.25 m between seeds and 0.80 m between rows for sowing depth around 0.03 m. Compared to manual sowing and other seeders, the equipment is economically profitable and more time can be saved for the users. The developed seeder could be optimized and introduced to the mechanized farms and agricultural cooperatives to supply the lack of adequate equipment for the success of the direct sowing system in Benin Republic.

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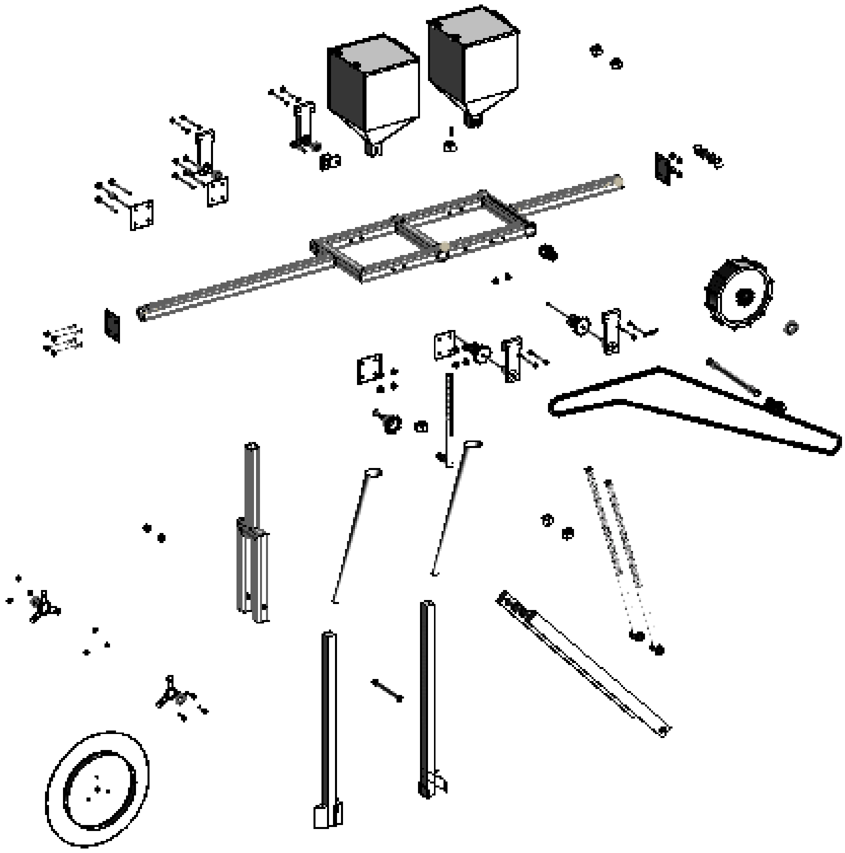
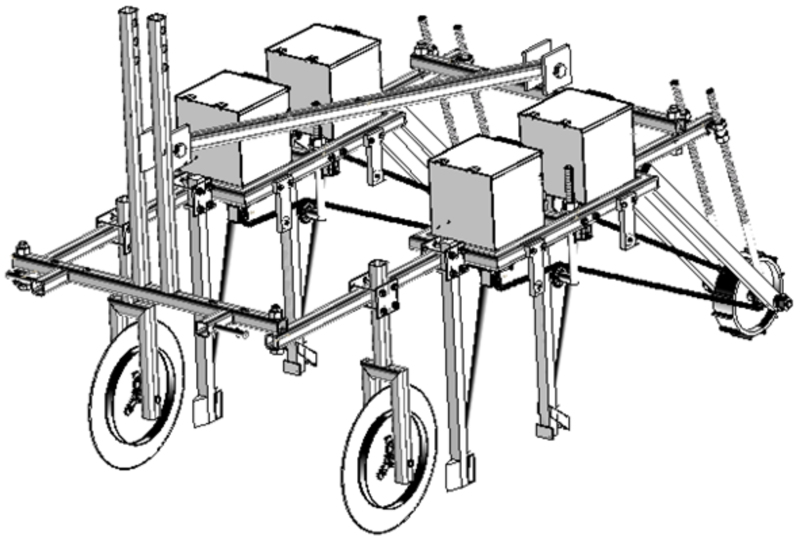
Appendix



Perspective view of one unit of the exploded seeder



Perspective view of two units of the seeder