Design and Evaluation of a No-Tillage Seeder for Small Scale Vegetable Production Using a Two-Wheeled Tractor in Coahuila, Mexico

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Abstract: Currently used conventional tillage systems for small-scale vegetable production in the region of Saltillo, Coahuila, Mexico require a considerable amount of hand labor, energy and materials for all activities. Seedbed preparation can require up to 60% of the total production cost in some systems in Mexico. Further, soil is degraded and eroded due to the system. Conservation tillage may reduce costs and prevent soil degradation, but appropriate tools, such as, no-tillage seeders for small-scale farmers are not available. This papers reports on the design and construction of a prototype of a no-tillage seeder for small-scale conservation tillage using a 2-wheeled tractor.

Three main functions received particular attention: opening of the soil, placing seed and/or fertilizer and closing the slot. Because of its vapor conservation and good seedling emergence, tools to create T-shaped slots were chosen, with adapted depth control and closing and covering devices. A systematic design process was applied in order to reach the required decisions. Function diagrams were defined from where morphologic charts guided the selection of the configuration of the seeder. A preliminary evaluation included testing of two furrow opener disc types (notched and fluted), and four crop residue levels, 0, 30, 60 and 100%, with respect to performance of the seeder.

An evaluation showed that with low cover amounts a consistent and firm seed cover was obtained, but emergence quality decreased due to insufficient residue cover. The notched disc had a better performance than the fluted disc. The inverted T-shape in the soil was not always sustained due to technical flaws.

It was possible to build a prototype under 2000 dollars with basic tools in a local workshop. Further research will focus on the biological performance and improvement of the mechanical components and performance.

INTRODUCTION

Currently used conventional systems for small-scale vegetable production in the region of Saltillo, Mexico involve a considerable amount of hand labor for all activities. The conventional method includes plowing, seedbed preparation and planting using two-wheeled tractors and small four wheel tractors. Seedbed preparation is the most energy demanding practice for establishing crops. In some production systems in Mexico the cost could represent up to 60% of the total production cost of the crops (*Baez, 2001*). The system also requires a considerable amount of materials, i.e., plastics and drip irrigation. Furthermore, due to intensive tillage practices and soil handling, risks for soil degradation and erosion are high.

Conservation tillage (CA) covers a wide variety of tillage methods, such as no-tillage, minimum, strip, and ridge tillage. The system is extensively used for grain crops, but only on a small scale for vegetable production (e.g. *Hoyt, 1999*). Apart from having a potential to reduce soil and water losses as compared to conventional tillage, CA may lead to a reduction of up to 50% in fuel consumption and time savings of up to 70%. CA requires different mechanical applications compared to conventional tillage systems. Seed has to be sown directly without plowing or preparing a seedbed and fertilizer generally is placed in the soil together with the seed. Many planters suitable for operating in undisturbed soils with residue at the surface have been developed in the last decades but not for small-scale use as required in the region of Saltillo.

No specialized equipment such as no-tillage seeders are available in order to establish a CA system on small-scale farms, using two-wheeled tractors. This makes the system beyond the reach of local farmers. *Morse (1999)* mentioned the lack of small-scale no-tillage equipment as a major cause of the slow adoption of no-tillage systems for vegetables. Therefore, small-scale equipment has to be developed.

This paper reports on the design and preliminary testing of a no-till seeder suitable for vegetable production by small scale farmers in Saltillo, Mexico.

DESIGN: BACKGROUND

The design process was focused on the three main functions of no-tillage seeders*; soil opening, seed and fertilizer placement and slot closing.*

Brief of requirements

The requirements that have to be fulfilled by the machine are shown in Annex B. Requirements were mainly determined by literature research and known demands of local farmers. They were divided into the following groups: cost, workability, opening of the soil, placing seed and fertilizer, closing the slot, agronomic and social acceptability. Requirements were used as a guideline for the design process and for a preliminary evaluation of the system.

Defining functions

By defining the correct functions of the system, the configuration of the machine can be more easily designed. The **main function** of the no-tillage seeder is: Consistently seed different types of vegetable seeds directly into a stimulating environment for germination and emergence with low soil disturbance.

Figure 1 presents the main function in IDEF0 format.

Sub functions were defined as:

- Cutting of the soil and residue, or removing residue, to create a path (row) where the seed and/ or fertilizer can be placed,
- Opening the soil and placing and pressing the seed and/or fertilizer for a stimulating seedling emergence environment and
- Closing the slot with soil and/or residue for seed protection and moisture conservation.

Function diagrams have been made in order to view different configurations. From these diagrams one main configuration was selected for further development using morphologic charts, as shown in Figure 2

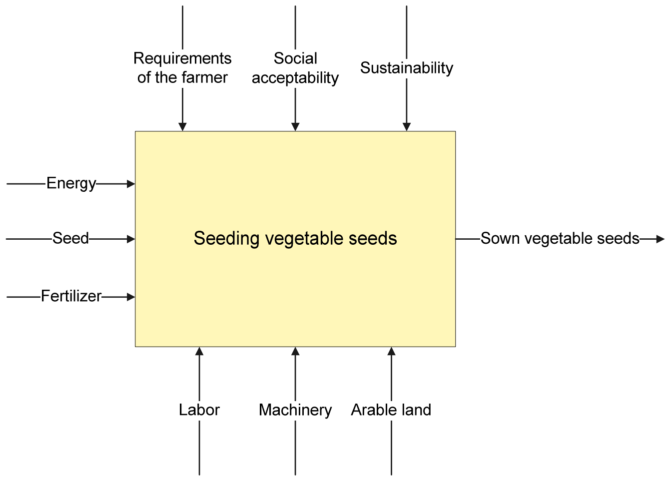

Fig. 1. Main function of the seeder in IDEF0 format with required inputs (left), mechanisms (bottom), controls (top) and output (right).

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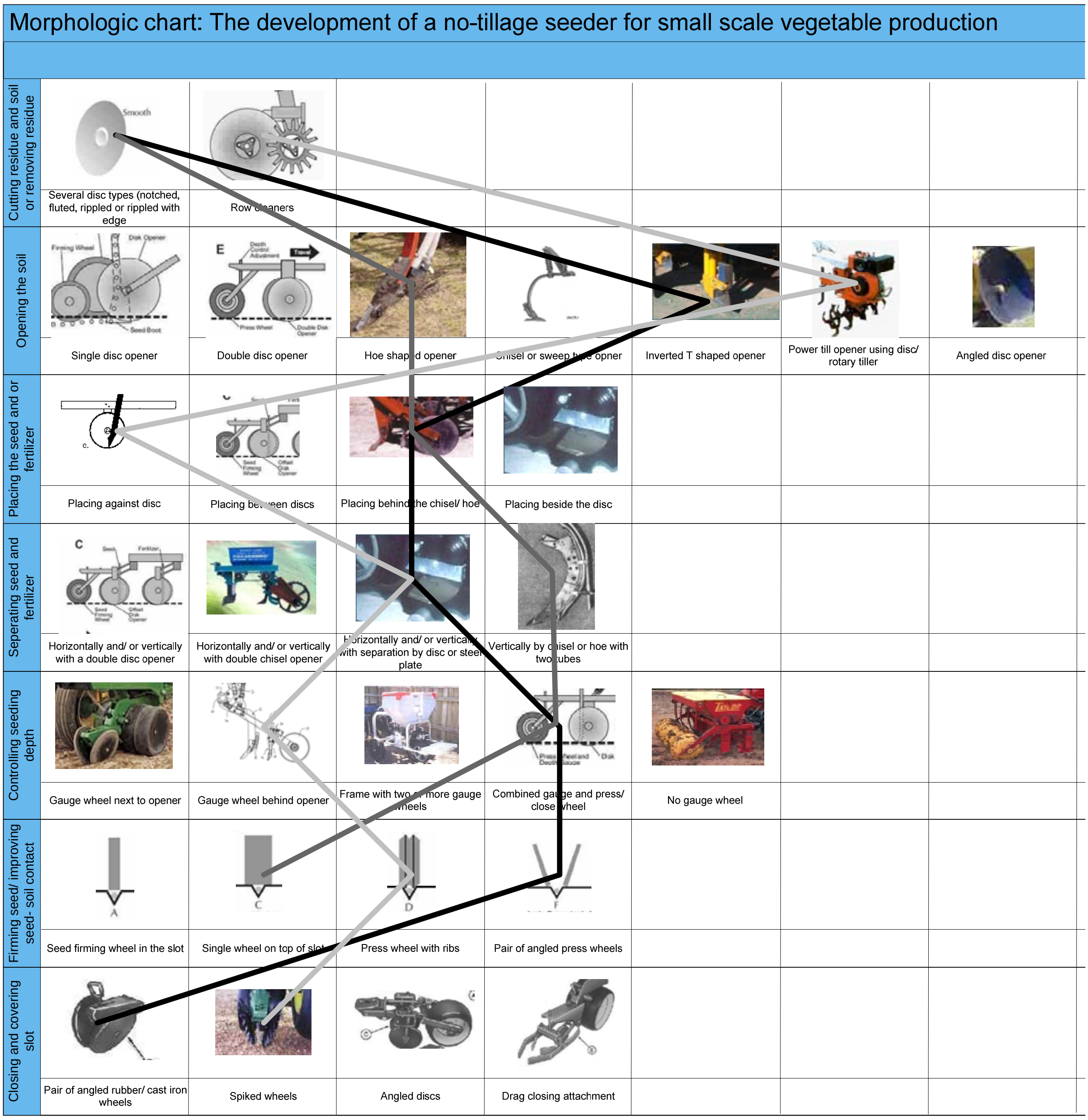

1. Cutting residue and soil with a disc→ Opening the soil with an inverted-T opener→ placing the seed and fertilizer behind/ inside the chisel with horizontal separation by a steel plate→ controlling depth, firming and closing and covering integrated in two angled press wheels running behind the opener.

2. Cutting residue and soil with a disc→ Opening the soil with a hoe type opener→ placing the seed and fertilizer behind the hoe with vertical separation by two outlet tubes→ controlling depth, firming and closing and covering integrated in one broad press wheel running behind the opener.

3. Removing residue with spiked row cleaners→ Opening the soil with a power till opener→ placing the seed and fertilizer beside a single disc with separation provided by the disc→ controlling depth, firming and closing and covering integrated in one press wheel with spiked wheels running behind the opener.

Fig. 2. Morphologic chart (function diagram) of the design components. Three configuration were considered. Configuration 1 was chosen.

Soil opening. V-shaped slots from double or triple disc type openers perform well mechanically (good residue handling), but they often perform worse compared to hoe type openers and inverted T-type due to compression of residue into the slot, compaction of seedling environment and extensive water vapor loss. U-shaped openers, such as hoes and chisels, require less down force and conserve more vapor compared to disc openers but will have difficulties handling residue. Inverted T-openers conserve moisture very well due to slot shape and create a biologically attractive environment for germination. With these openers, however, there is a chance of residue blockage and high penetration forces may be involved. Inverted T-openers in general require less down force in order to penetrate the soil (Mai, 1978) increasing the usability in the area of Saltillo where dry soils are generally expected to be present. On the other hand residue blockage is observed when using chisel type openers (Baker *et al*, 1996; FAO, 2007). However, depending on the type of residue used in vegetable production blockage may or may not occur.

Seed and fertilizer should be placed consistently regarding depth, distance and spacing and machine movement. Controlling depth is a main important characteristic determining this. Depth gauging should take place as close to the seed or fertilizer release point as possible in order to consistently apply depth control. According to the situation in the district of Saltillo the machine should be able to sow of a range of vegetable seeds with widely different characteristics, such as melon, spinach, tomato, chili peppers, coriander etc. Seeding depths of 1 to 5 cm, and distances between seeds of 5 up to 150 cm should be possible.

Slot closing and covering should be adequate and made feasible for the most common soil types on a range of cover conditions. Combined gauge and press wheels will improve the slot closing and covering capacity. The system will become more compact due to this feature and will require less material. Wheels need to be placed as close to the opener as possible.

The focus on above functions has led to these system boundaries: "the mechanical functioning of soil engaging components of a planter and their interaction with soil, residue and seed/ fertilizer placement". Seed and fertilizer dispensing units will solely be considered for dimensions. The system is to be powered by a 2-wheeled tractor and the machine should have the capability of effectively seeding 5 hectares or more since this is the typical farm size.

Construction

This was done in the workshop of the University with simple tools. Not all materials were new. The press wheels were taken from a John Deere Max Emerge planter, while the notched disc was taken from a John Deere MP-25 planter modified for minimum tillage, both available at the University.

Construction took place in steps and where needed, a field evaluation was performed, leading to adaptations in the design and construction. The sowing machine is shown in Annex A.

Field evaluation

The seeder was tested with two disc types, a notched disc and fluted disc, for four different amounts of residue: 0, 30, 60 and 100% coverage by sorghum straw. For each amount of residue three fields were prepared following a split plot statistical design with three repetitions.

During evaluation a 2 wheeled tractor was used, BCS (Italy), with a Briggs & Stratton Vanguard 14 HP engine. The machine was tested on several factors listed in Table 1.

Machine performance

Machine performance varied under the differing conditions. At low residue cover a good, consistent and firm coverage of seed with loose soil was obtained. However residue coverage was minimal reducing the quality of the cover.

At high residue conditions blockage at the opener was observed. Blockage of residue further caused problems with covering the seed due to keeping the opener from penetrating the soil.

At higher moisture conditions, the opener seemed to smear the soil at the bottom of the slot. This smearing has been observed by other authors as well (Baker *et al*, 1996; Iqbal *et al*, 1998) but was not considered to present a major problem in terms of emergence.

The cover of seed contained fine soil improving seed to soil contact. However, regarding the small width of the press wheels high pressure was applied to the soil increasing the risk of compaction. Due to this pressure the shape of the inverted T-shaped slot collapsed and was not sustained in most of the cases, although an improvement was seen under drier soil conditions.

Seed to fertilizer distance was observed to be constant when the opener performed well.

CONCLUSIONS

The construction can be done using only basic tools and materials allowing a low cost price (less than 2000 US$).

The methodological approach followed in the design process was successful and avoided many unnecessary steps or "trial and error" situations.

A compact design including a frame with lifting system was required due to the limited capabilities of a 2-wheeled tractor. This was achieved by the configuration of a cutting disc, a new type of inverted T- shaped opener and combined pressing, gauging, closing and covering wheels.

The inverted T-opener was considered a suitable opener requiring lower penetration forces than disc openers in hard soils as may be found in the area of Saltillo. The integrated press, closing and covering wheels were able to cover the see slot in a satisfactory way.

At relatively low cover residue, 0-30% and some cases 60%, a consistent and firm coverage of seed was obtained. However, the quality of slot cover decreased due to the covering of seed with only loose soil and no to low amounts of residue. This will decrease the biological performance of the seeder reducing vapor and temperature conservation.

At high residue conditions, 60% and more, machine performance decreases considerably due to blockage of sorghum residue at the opener or even preventing penetration of the soil by the opener resulting in no seed cover.

The shape of the inverted T in the soil was not sustained due to high pressure from the pressing wheels.

Additional experiments, leading to design modifications will be necessary, but a low-cost no-till sowing machine for a two-wheeled tractor is a viable option within reach of the small farmers in Saltillo.

Table 1. Factors considered during field evalution

Parameter	Evaluation method
Residue and soil cutting	
Residue cutting	Count the cut parts on 1m of length[a]
Soil cutting	Measure depth and width with a ruler
Amount and type of residue	0, 30, 75 and 100% cover application
Soil texture	Hydrometer method[b]
Soil humidity	Gravimetric method[c]
Soil resistance	Penetrometer
Furrow opening and seed/ fertilizer placement	
The establishment of the inverted T shape of the slot	Form sustained, moderately or not sustained
Blockage of residue at opener	Very much, much, medium, low, very low
Seeding depth	Ruler and measuring tape
Separation of seed and fertilizer	Measuring tape
Flicked out seed (lying outside the slot)	Counting seeds outside the slot
Slot closing	
Closing with soil and residue, slot cover	Various scales: between fully open, and closed[d]
Soil disturbance	Visual observation
Seed to soil contact	Visual observation

[a]: Cervantes Contreras (2001), [b]: Bouyoucus (1962) [c]: Black (1965) [d]: Baker *et al* (1996)

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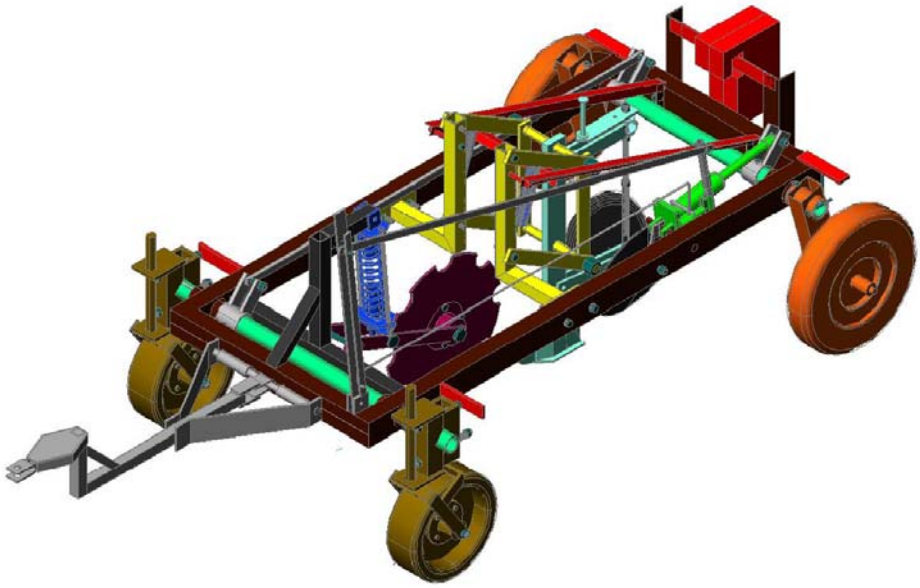
Annex A: The sowing machine



Annex B

Index	Aspect	Importance of Requirement	Fixed Req.	Variable Req.	Desirability		Min.value	Max.value	Desired	Unit	Reference
Brief of requirements for project: The development of a no-tillage seeder for small scale vegetable production							Quantify requirements				
1	***Cost***	The tool has to be low cost	X			>	0	2000		$ US Dollar	Estimated
2		The maintenace should be minimal, simple and low cost		X		>	0	200		$ Annual	Estimated
3	***Workability***	The construction process has to be simple and low tech		X		>					
4		The machine has to be reliable	X			>					
5		The machine should be easy to use		X		>					
6		The machine should require a maximum of 1 operator	X			>	0	1		Person	
7		Adjusting the machine should be simple and clear		X		>					
8		The machine has to seed different types of vegetable seeds	X			>	5	20	8	# of types	SAGARPA, 2006
9		The machine should not require too much draft force		X		>	0 / 0	2000 / 10		Newton/hp	*
10		The machine should be capable of handling sufficient speeds			X	>	2	10	4	km/h	
11		The machine should have sufficient field capacity	X			>	0.15	-	0.2	ha/hr	Ribeiro *et al*, 2006
12		There should be an ability to add weight if required		X		>	0	100	50	kg	Estimated
13		The machine should be compact as possible		X		>		2 x 1.2	<2 x 1.2	m	
14	***Opening soil***	The machine has to be able to cut the residue on the field without blockage		X		>					
15		The machine has to be able to create a slot in the soil	X			>					
16		The opener should not require too much down force		X		>	0	200	150	kg	**
17	***Placing seed and Fertilizer***	It has to be possible to separate the seeds in the slot	X			>					
18		It has to be possible to adjust the space between the seeds	X			>	0	60		cm	Stephens *et al*, 2003
19		The seeder should be capable of transfering the seed from the metering device to the opener without disrupting the seeding pattern		X		>					
20		The machine should be capable of following the soil surface in order to maintain a consistent seeding depth	X			>	300	500	400	mm	Baker *et al*, 1996
21		It has to be possible to regulate the seeding depth		X		>	10	70		mm	Baker *et al*, 1996
22		The machine should be able to separately place seed and fertilizer without seed to fertilizer contact			X	>					
23		The seed and fertilizer should be seperated horizontaly			X	>	20	40	30	mm	Baker *et al*, 1996
24		The seed or fertilizer should not be flicked out or taken out of the slot by the machine		X		>					
25	***Closing slot***	The machine should close the slot with soil and cover it with residue	X			>					
26		The closing and covering of the slot should stimulate the conservation of humidity			X	>					
27		Seed to soil contact should be improved by the machine		X		>					
28		Seed to residue contact should be avoided when closing the slot			X	>					
29		When closing the slot, compaction of soil should be avoided or be minimal		x		>					
30	***Agronomic***	The machine should disturb a minimal amount of soil		X		>					
31		The machine should leave residue intact as much as possible		X		>	30	100	70	%	Carter, 1994; Baker *et al*, 1996
32		The opener has to create a stimulating environment for germination	X			>					
33		When opening the soil, no to minimal compaction and smearing of soil should occur		X		>	0	900	640	kPa	***
34	***Social acceptability***	The machine has to be acceptable for local farmers		X		>					
Methodical approach to the development of a no-tillage seeder for small scale vegetable production							Quantify when possible				

* Reibiero *et al*, 2006; Mai 1978 in Baker *et al*, 1996 (1N = 0.2 lbs force)
** Grisso *et al*, 2006; Hoette, 1997; Mai, 1978 in Baker *et al*, 1996
*** Iqbal *et al*, 1998. This is the penetration resistance beneath the seed