DESIGN AND EVALUATION OF A PUNCH PLANTER FOR NO-TILL SYSTEMS

J. P. Molin, L. L. Bashford, K. Von Bargen, L. I. Leviticus

ABSTRACT. *A punch planter for corn was designed, prototyped, and evaluated for no-till conditions using a commercial seed metering unit. The seed meter was evaluated for seed spacing performance at the vertical position with 2.5 kPa of vacuum, as specified by the manufacturer, and at a 22° incline with 4.0 kPa of vacuum. The prototype punch planter was evaluated at a 22° incline with 4.0 kPa of vacuum. Only small changes occurred in the seed meter performance when speed varied from 1 to 3 m/s. The precision of seed spacing decreased approximately 6.0% when compared with the seed meter results. Field tests were conducted with several residue covers for testing the residue effect at a speed of 2.0 m/s. No significant difference was observed in the planter performance. The multiples index (more than one seed in one space) increased up to 5.0% when compared to laboratory results. Emergence may have been affected by environmental conditions, but the precision during field tests was better than in the laboratory tests.*
Keywords. *Punch planter, No-till, Seed spacing.*

Soil erosion has been identified as a major environmental problem in some farming areas. Conservation tillage systems have proven to control and reduce soil erosion. Research in many different areas has provided technology for developing conservation tillage systems such as no-till, but problems still remain.

This article describes the design and evaluation of a no-till, rotating punch planter. A John Deere MaxEmerge 2 commercial vacuum seed meter was extensively tested for use on the punch planter. A prototype punch planter was tested under laboratory and field conditions. Field experiments were conducted with several levels of residue covers.

Conservation tillage systems maintain crop residue on or near the surface to control soil erosion (Allmaras and Dowdy, 1985). Such systems require that at least 30% of the surface be covered with crop residue (Morrison and Allen, 1987; Jasa et al., 1991).

A comprehensive review by Morrison and Allen (1987) discussed performance characteristics required of planters and the challenges that must be addressed in conservation tillage systems. There are many accessories and attachments readily available for enhancing standard planters for no-till residue conditions. Another approach to planting uses a punch planter, which only penetrates the residue and soil to deposit seed (Adekoya and Buchele, 1987). A punch planter is conceptually ideal for no-till planting because it disturbs a minimal amount of soil and is useful for crops sensitive to precision spacing. However, research efforts have not sufficiently addressed all of the challenges.

A simple method of planting involves placing seeds into holes instead of furrows (Stout, 1971; Hauser, 1982). Punch planting is an old technique that still persists today in some countries, especially when manual devices are used.

Sugar beet crops require accurate seed spacing. Jafari and Fornstrom (1972) designed and constructed a punch planter specifically for sugar beets using a wheel with six conical punches on the circumference. A seed meter located behind the wheel dropped single seeds in each punched hole in a synchronized action with the wheel. Sawant (1972) and Heinemann et al. (1973) developed a different concept for punch planters using cylindrical plungers for opening holes. Wilkins et al. (1979) developed a punch planter for planting vegetables in crusted and salty soils using magnetic punches around a notched seed wheel. The seeds were coated with iron oxide and imbedded into the soil after initially being attracted by the punches.

Another special application of punch planting is associated with the plastic mulch system. Hunt (1961) developed a planter to punch through plastic mulch. The prototype had four radially arranged punches mechanically activated to open when dropping the seeds into the soil and metered by a horizontal plate seed meter. A punch planter, using only one punch, was designed for plastic mulch in Israel by Hezroni et al. (1986). The punch was controlled by an eccentric drive and activated by an electro-mechanic or pneumatic system. The prototype was tested up to a ground speed of 0.25 m/s. Punch planters with cam-activated punches have been tested by Bouchandira and Marley (1984), Adekoya and Buchele (1987), Shaw et al.

Article has been reviewed and approved for publication by the Power & Machinery Div. of ASAE. Presented as ASAE Paper No. 96-1046.

Published as Paper No. 11492, Journal Series, Agricultural Research Division, University of Nebraska-Lincoln. Mention of trade and company names are for the reader and do not infer endorsement of preferential treatment of the products by the University of Nebraska.

The authors are **José P. Molin, *ASAE Member,*** (former Graduate Student, Department of Biological Systems Engineering, University of Nebraska, Lincoln, Nebr.) Assistant Professor, University of São Paulo, ESALQ/USP, Av. Pádua Dias 11, Piracicaba, SP 13418-900, Brazil (Sponsored by CNPq–Brazil); **Leonard L. Bashford, *ASAE Member Engineer,*** Professor, **Kenneth Von Bargen, *ASAE Member Engineer,*** Professor, and **Louis I. Leviticus, *ASAE Member Engineer,*** Professor, Department of Biological Systems Engineering, University of Nebraska, Lincoln, Nebr. **Corresponding author:** Prof. Leonard L. Bashford, Department of Biological Systems Engineering, 203 L. W. Chase Hall, University of Nebraska, Lincoln, NE 68583-0726; tel: (402) 472-1627; fax: (402) 472-6338; e-mail: bsen052@unlvm.unl.edu.

(1978) and Kromer (1986). Similar ideas for manually pulled punch planters were proposed by Wijewardene (1978) and Molin and D'Agostini (1996).

Shaw and Kromer (1987, 1989) observed operational difficulties with a machine that used punches with cam-activated doors, especially when operating in wet soil or with a high accumulation of residue. The wet soil caused seeds to stick inside the punches, resulting in failure. Another problem was related to lubrication because of many moving parts. A different concept for punch planters was proposed where rigid tips were used with the punch wheel mounted at the same angle from the vertical and longitudinal planes. Each punch formed an elliptical hole in the soil as a consequence of the inclination and yawing of the wheel.

A dibber drill developed by Bufton et al. (1985) was described by Brown (1988). It was especially designed for planting vegetables in well prepared soils using an external seed meter. A new generation of this machine using an internal seed meter was discussed by Lawson (1988). Rogers and Baron (1987) designed a similar punch planter for small seeds using an air seed meter. The system had problems because many of the seeds were dropped on the soil surface. Simulations showed that an automatic propelled punch wheel with positive slip was necessary to aid in clearing of the punch tips. This same idea has been suggested by Srivastava and Anibal (1981) after designing and testing a punch planter for no-till.

Several measurement methods have been used for characterizing the spatial distribution of seeds or plants in the laboratory or field tests of planters. Kachman and Smith (1995) tested and compared the most widely used measures; mean, standard deviation, quality of feed index, multiples index, miss index and precision. Those measures were based on the theoretical spacing (x_{ref}), specified in ISO 7256-1 Standard (International Standardization Organization, 1984), and gave a good indication of the spacing distribution. The quality of feed index was the proportion of spacings between 0.5 and 1.5 x_{ref}. The multiple index was the proportion of spacings equal to or less than 0.5 x_{ref}, and the miss index represented the percentage of spacings greater than 1.5 x_{ref}. The precision was defined as the ratio between the standard deviation of the single spacing and the theoretical spacing (x_{ref}). The precision was not affected by missing or multiple spaces. It measured the degradation of performance within the target range. Kachman and Smith (1995) concluded that the mean spaces between seeds and the standard deviation of those spaces did not offer an appropriate evaluation of planter performance on seed distribution.

Data from the Prairie Agricultural Machinery Institute-PAMI (1984a) collected on a greased seed belt showed a feed index quality of 88% to 97% for a travel speed of 2.22 m/s and 87% to 96% for a travel speed of 3.06 m/s with a planter using a finger pickup metering unit. For a machine using an airflow seed meter, PAMI (1984b) reported a feed index quality of 91% to 97% for a travel speed of 2.22 m/s and 88% to 97% for a travel speed of 3.61 m/s.

Beyond the basic factors including soil moisture, fertility, and seed quality, the success of crop establishment depends on factors directly related to planter performance. Plant population, depth, and seed-soil contact depend on available machine adjustments.

Plant populations and spacing precision have been widely investigated. Glenn and Daynard (1974) tested plant spacing uniformity at a desired population. The reduced variability in spacing resulted in a 5.5% increase in corn yield. Pintér et al. (1978) tested corn plant populations and spacing uniformity and their relationship with grain yield. The highest yield resulted from the best space uniformities. Remussi et al. (1974) observed reductions in sunflower yields from 11.7% to 28.9% due to uneven spacing.

Jasa (1981) evaluated planter seed spacing performance for corn, soybean and sorghum. A maximum index of five points was given for less than 10% error in seed placement. Corn planters had an index of 1.21 to 4.22 with a mean at 2.41 which showed that even the best planters had a 20% to 30% error in seed placement.

The Design

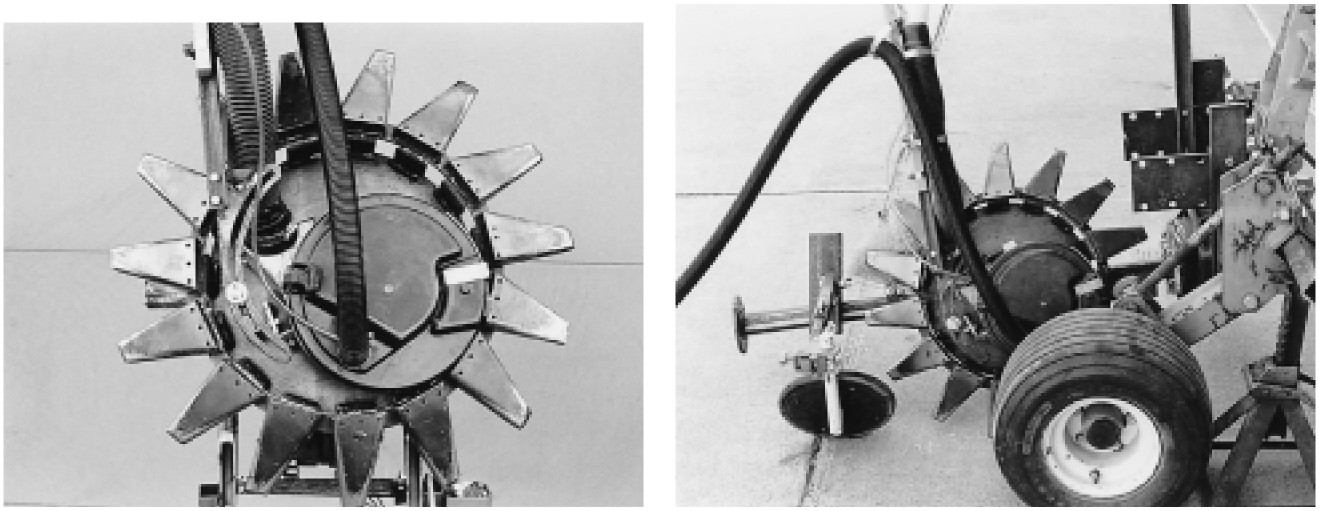
The idea of using a rotating punch planter has been more successful than other methods like intermittent punches. The success of a cycloidal hole made by an inclined wheel and aided by a yawing angle, as shown by Shaw and Kromer (1987, 1989), was adopted.

The prototype was designed for corn which has been shown to respond to precision in seed spacing. A base ring of 400 mm internal diameter was used as a support for 15 punches bolted radially to the ring as shown in figure 1(a). The punches were 125 mm long resulting in an external tip diameter of 650 mm. With this configuration, the prototype was capable of planting at a maximum depth of 100 mm. The spacing between centers of punches was 136 mm. This will be the x_{ref} or theoretical space between seeds. The theoretical population was based on a 0.76 m row spacing and 96,495 seeds/ha.

A commercial pressure seed meter using a vertical disk was first tested. The effect of the inclination angle of the unit and the dropping position of the seeds was the biggest concern. After a series of preliminary tests, the seed meter was replaced by a vacuum seed meter. Preliminary tests with the vacuum unit showed promising results when the vertical angle was varied between 0° and 30°.

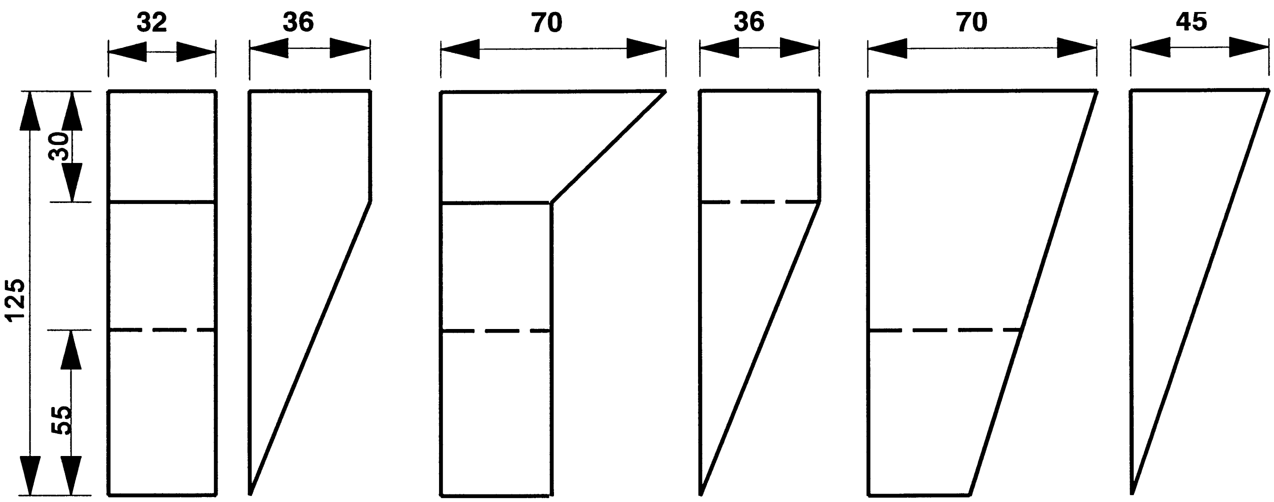
In a previous investigation into the shape of the punches and the force required for penetration, it was observed that force is linearly proportional to the width of the tip (Molin and Bashford, 1996). In the first trial, the punches were 32 mm wide (fig. 2a). The synchronization between seed meter and punch wheel for dropping the seeds at the exact time and position into the punch was not feasible at speeds higher than 1.0 m/s. Changing the width of the punches to 70 mm on the top, in an offset funnel shape (fig. 2b), improved the pairing, allowing much faster speeds. As this shape was not easily manufactured, the punches were redesigned to 70 mm wide on the top and 30 mm wide on the bottom (fig. 2c). The final shape of the punch wheel is shown in figure 1(a).

The punch wheel was mounted on a tool bar and tested in the field by adjusting its relative position to the ground. The best hole shape was obtained when operating at 22° off the vertical and 7° off the longitudinal. Even the tendency of soil adhering to the internal wall was avoided with the side movement. At lower yaw angles, soil adhesion was a problem. Figure 1(b) shows the machine at field working conditions.



(a) (b)

Figure 1–Punch wheel at its final configuration right before the laboratory tests (a); prototype set for field tests (b).



(a) (b) (c)

Figure 2–First punch tested (a); offset funnel shaped punch (b); final shape of the punches used in the prototype (c); dimensions in mm.

The vacuum pressure recommended by the seed meter manufacturer for the kind of disk and seeds used was 2.5 kPa. As the seed meter was originally designed for vertical operation, tests were conducted to evaluate the effect of the vertical inclination of the disk. The seed meter was evaluated at different angles for preliminary tests and it was observed that a vacuum of 4.0 kPa provided the same filling rate at a 22° inclination as 2.5 kPa did when the seed meter was vertical.

THE TESTS

LABORATORY TESTS

The seed meter and the prototype punch planter were evaluated using a greased belt which was adapted from a 2.3 m long conveyor belt. The methodology used was based on ISO 7256-1 Standard (International Standardization Organization, 1984). The objective was to evaluate the changes in seed metering as effected by position of the meter and the effect of speed. Three experiments were conducted at 1.0, 2.0, and 3.0 m/s of simulated forward speeds of the unit for each of the following situations:

1. Seed meter at the vertical position using the vacuum pressure as recommended by the manufacturer (2.5 kPa).
2. Seed meter at 22° from the vertical and at 4.0 kPa of vacuum pressure.
3. Planter working at 22° incline and 4.0 kPa of vacuum pressure.

In the first two experiments, the seed meter was mounted on the planter without the punches. The vertical distance between the bottom part of the seed meter and the greased belt was set at the minimum possible. When testing the planter in the third experiment, the distance was set at the minimum possible between the tip of the punches and the belt.

Pioneer 3417 seed corn, size CD5 and weighing 15.9 kg per 80,000 kernels, was used in all laboratory tests. The distance of each seed from a reference was taken and the frequency distribution of spaces calculated. The frequency distribution was based on the theoretical spacing between seeds, x_{ref} (136 mm). The first frequency distribution was based on intervals of 0.1 x_{ref}. A second distribution was based on intervals of 1.0 x_{ref}. In this case, the three frequencies represented the quality of feed index, multiples index and miss index, as referred in ISO 7256-1 standard (International Standardization Organization, 1984).

Each experiment was conducted in a completed randomized design with five replications of 50 spaces each. Each replication was obtained by running the greased belt once. A one-way statistical analysis was conducted for each experiment for quality of feed index, multiples index, miss index and precision. Those criteria were considered by Kachman and Smith (1995) as the appropriate measures for summarizing the distribution of spacing.

FIELD TESTS

The prototype was evaluated in the field in no-till conditions. The objective was to test the effect of different types and amounts of residue on the machine performance at a constant speed of 2.0 m/s. Residue amounts were determined using the line-transect method described by Dickey et al. (1986). The machine was set for field work using a laterally positioned depth control wheel and a press wheel behind the punch wheel [fig. 1(b)]. For generating vacuum to the seed meter, a commercial vacuum cleaner powered by a portable A-C generator was used.

The tests were conducted at the Rogers Memorial Farm east of Lincoln, Nebraska, in a silt loam soil with soybean residue from last season. The treatments were replicated in four blocks: soybean cover (30, 60, and 90%), corn cover (30, 60, and 90%), and no residue. The experiment was conducted as a complete randomized block design with one row of each treatment in each block. All original residue was removed from the plots and then the specific amount of each residue was added to each plot. The seed corn was Pioneer 3225, size CD5 and weighing 17.1 kg for 80,000 kernels. A sample of this seed was submitted for a germination test (Association of Official Seed Analysts, 1993).

The bulk density of the top soil was determined using 54 mm diameter by 60 mm high cylinders. Four replications of each block were collected. The same samples were used for determining moisture content using the oven method. The cone index of the top layer (between 35 and 105 mm) was also determined. An electronic cone penetrometer was used and the penetration resistance was measured at intervals of 35 mm. The tip was a standard cone of 12.83 mm diameter (ASAE, 1994). For each block, 12 data points were collected.

The planter was set to a depth of approximately 40 mm. The plots were planted and three weeks later the spaces between plants were measured. Seventy spaces were measured between plants on each block for each treatment, resulting in 280 spaces for each treatment. A two-way statistical analysis was conducted for quality of feed index, multiples index, miss index, and precision.

RESULTS AND DISCUSSION

The soil physical characteristics were determined and are summarized in table 1. The site of the field tests was managed as no-till for several years. The results of the cone index profiles are presented in figure 3. The cone index values were similar to those obtained in a laboratory study of punch penetration forces with soil from the same site as these field tests (Molin and Bashford, 1996). Estimation of the penetration forces for this field test were made with the assumption that no speed effect was involved and that the increase in penetration force, as stated before, was linearly proportional to the projected area of the punch. The penetration forces in the field ranged between 200 and 440 N under the test conditions.

Laboratory test results on the seed meter in the vertical position are presented in figure 4. The frequency distributions of seed spacing intervals equal to 0.1 x_{ref} show a very high concentration around 136 mm (x_{ref}). The same results are more clearly represented in the frequency distribution with intervals equal to 1.0 x_{ref}. Single seeds or quality of feed index varied between 98.0% and 95.6%. The statistical analysis of those results is shown in table 2. The speed did not affect the multiples index and the quality of feed index. Only the miss index had a significant increase with speed. The precision presented on table 2 did not differ significantly among the treatments with a good concentration of spacing around the target point, as shown by the histograms (fig. 4).

After setting the seed meter at a 22° inclined position and increasing the vacuum from 2.5 kPa to 4 kPa, similar results were obtained (fig. 5 and table 3). The multiples index was higher for the inclined than the vertical position, probably due to the increase in the vacuum level, but no significant difference was detected among speeds. The precision stayed at the same levels of those from the seed meter at the vertical position. A significant improvement in

Table 1. Soil characteristics observed for the field test site

Clay (%)	14.8
Silt (%)	75.4
Sand (%)	9.8
USDA textural class	Silt loam
Bulk density (Mg/m^3)	1.30 (σ = 0.134)
Gravimetric moisture (%)	21.0 (σ = 0.013)

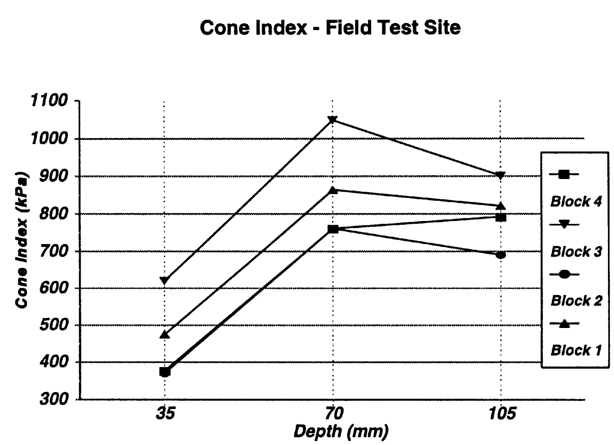


Figure 3–Cone index from the top layer (between 35 and 105 mm) of the field test blocks using an electronic cone penetrometer.

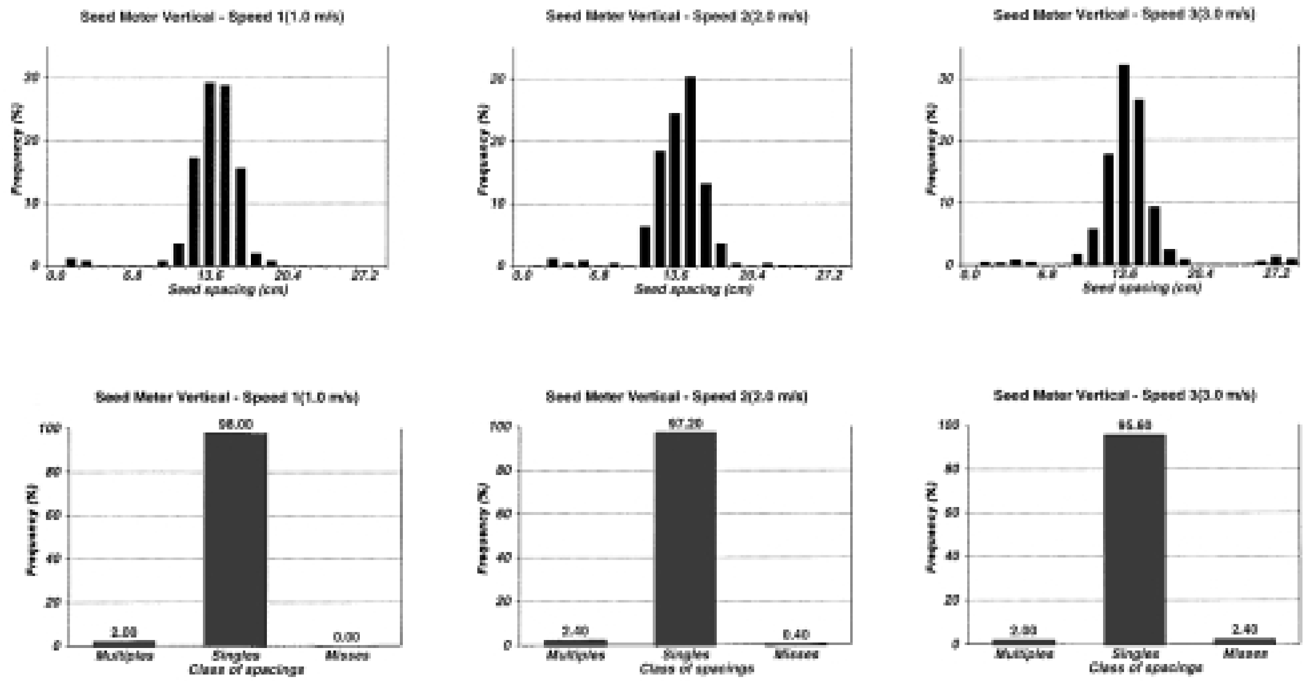


Figure 4–Frequency distribution of different speeds for the seed meter tested in the laboratory at standard working conditions using intervals equal to 0.1 x_{ref} on the top and intervals equal to 1.0 x_{ref} in the bottom.

Table 2. Seed space distribution of the seed meter tested on vertical position over greased belt using corn seeds at x_{ref} = 136 mm

Speed (m/s)	Multiples Index (%)	Quality of Feed Index (%)	Miss Index (%)	Precision (%)
1.0	2.0	98.0	0.0 b*	11.7
2.0	2.4	97.2	0.4 b	12.3
3.0	2.0	95.6	2.4 a	11.7
Pr > F (%)	0.848	0.101	0.010	0.726

* Means followed by the same letter are not significantly different by Fisher's Protected LSD (α = 0.05).

Table 3. Seed space distribution of the seed meter tested on 22° inclined position over greased belt using corn seeds at x_{ref} = 136 mm

Speed (m/s)	Multiples Index (%)	Quality of Feed Index (%)	Miss Index (%)	Precision (%)
1.0	4.8	94.8	0.4	12.6 a*
2.0	3.6	96.4	0.0	10.1 b
3.0	2.0	96.4	1.6	11.3 ab
Pr > F (%)	0.266	0.585	0.095	0.038

* Means followed by the same letter are not significantly different by Fisher's Protected LSD (α = 0.05).

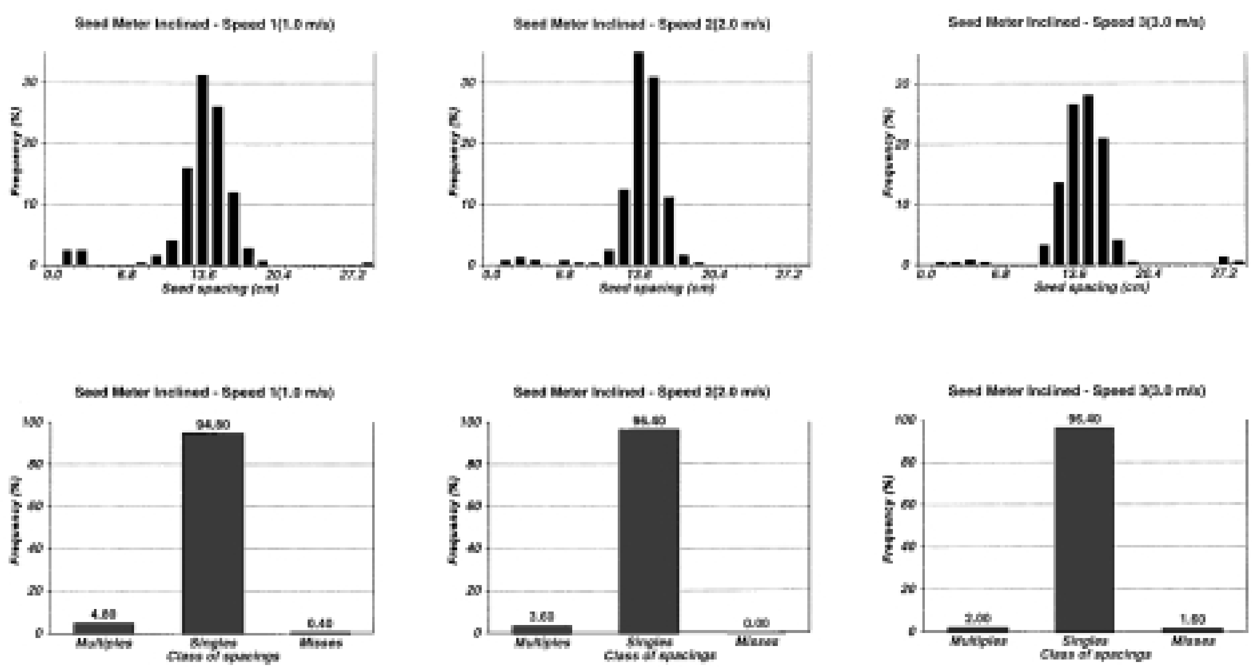


Figure 5–Frequency distribution of different speeds for the seed meter tested in the laboratory at at an inclination angle of 22°, using intervals equal to 0.1 x_{ref} on the top and intervals equal to 1.0 x_{ref} in the bottom.

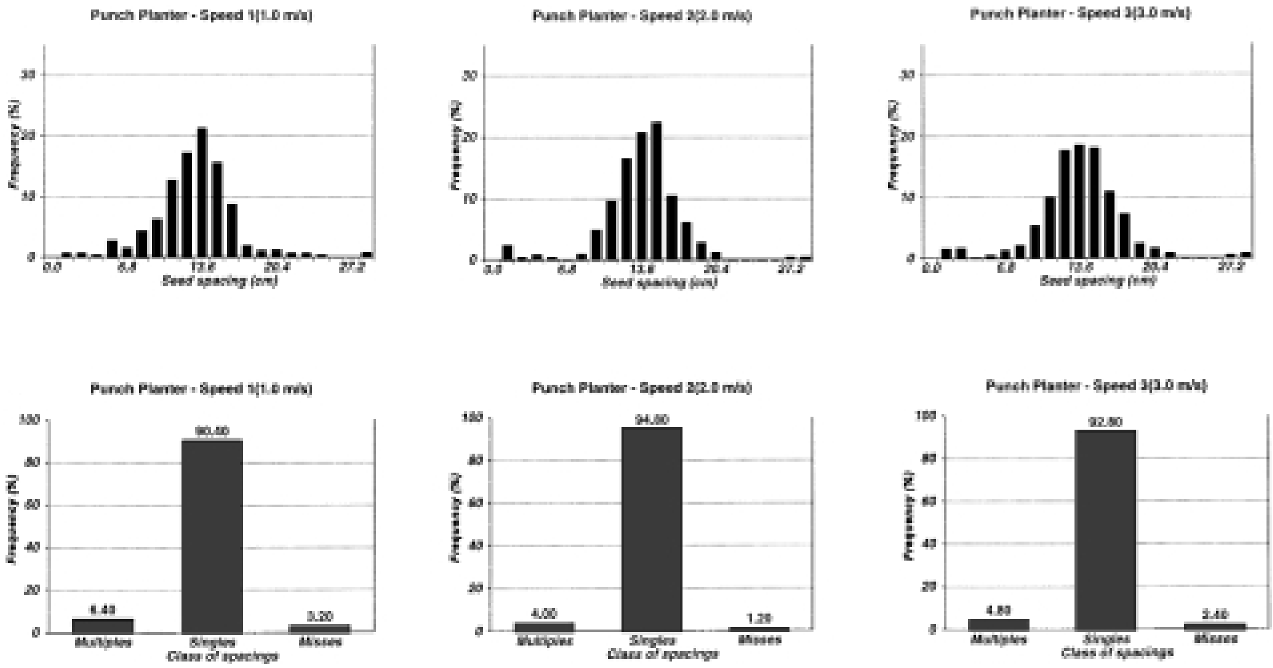


Figure 6–Frequency distribution of different speeds for the planter prototype tested in the laboratory using intervals equal to 0.1 x_{ref} on the top and intervals equal to 1.0 x_{ref} in the bottom.

precision was observed when the speed was increased from 1.0 m/s to 2.0 m/s. At 3.0 m/s the precision was not significantly improved.

The results from the laboratory tests of the prototype are shown in figure 6 and table 4. In addition to the seed meter performance, the synchronization between the action of the seed meter and the external wheel was measured. Each seed had to be caught by one punch as it passed under the dropping position of the seed meter and then dropped from the punch onto the greased belt. The time involved in this process was a function of the forward speed. Therefore, for each speed the dropping position of the seed meter had to be changed by rotating it with respect to the punch wheel. At the same time, the dropping position from the punch to the ground has to be almost the same for all speeds. From observations and experiences in the field, it was observed that a small difference in this dropping position as a function of speed was necessary to compensate for the centrifugal effect generated by the rotation of the punch wheel. With those adjustments made to the machine, no significant difference was observed in any of the measures used for evaluating the seed spacing distribution at a 5% probability level.

The seed spaces classified as singles were lower than tests of the seed meter. This means that some seeds did not go to the correct punch at the exact time. The reduction in the quality of feed index was between 1.6% and 4.4% for 2.0 m/s and 1.0 m/s, respectively. Overall, the precision index of the prototype increased when compared with that from the inclined seed meter. The precision levels were between 17.4% and 18.7% compared to precision between 11.7% and 12.3% when testing only the seed meter at the same conditions. The reason for the decrease in precision (increase in the values of precision index) may be due to some displacement in the seeds caused by interaction with the internal walls of the punches associated with the centrifugal effect when dropping over the greased belt. This difference is also reflected on the histograms (figs. 5 and 6), showing a less acute concentration of frequencies around x_{ref}.

Table 4. Seed space distribution of the prototype planter tested at working position (22° inclined) over greased belt using corn seeds at x_{ref} = 136 mm

Speed (m/s)	Multiples Index (%)	Quality of Feed Index (%)	Miss Index (%)	Precision (%)
1.0	6.4	90.4	3.2	18.2
2.0	4.0	94.8	1.2	17.4
3.0	4.8	92.8	2.4	18.7
Pr > F (%)	0.516	0.253	0.232	0.184

For the field tests, seeds were planted on 11 July and the spaces between emerged seeds were measured on 2 August The precipitation was 61 mm on 4 July and 12 mm on 19 July. Laboratory tests of germination for the cultivar 3225 used in the field tests were 98.5%.

Results of the field tests are shown in figure 7 and table 5. The treatments were based on two different residue types and three residue amounts. Residue types and residue amount had no significant difference at the 5% probability level in the results. The multiples index varied between 5.4% and 14.3% and had some tendency to increase with the increment of residue. In the laboratory tests (table 4), these values were between 4.0% and 6.4%. The reason may again be due to some limitation in synchronization between the seed meter and the external wheel combined with the dynamics generated by the bouncing of the unit in the field. The quality of feed index was comparatively lower than in the laboratory test, and the miss index was higher. Those values were directly related to the emergence and survival rates. Both were a function of several environmental and

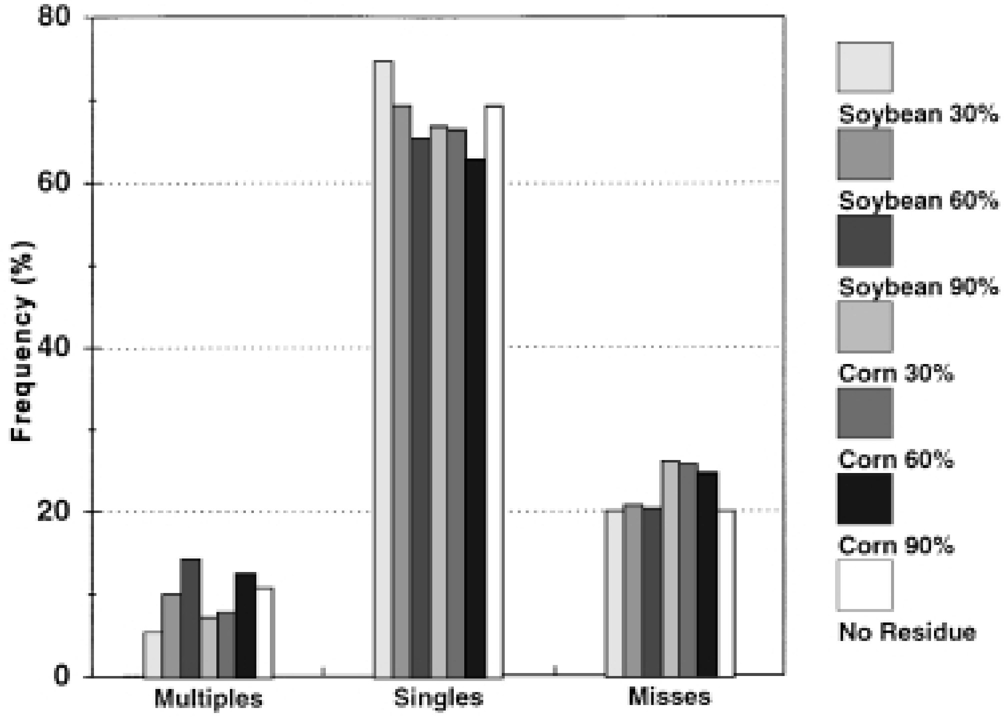


Figure 7–Frequency distribution of plant spacings for different residue types and amounts from field tests of the planter prototype using intervals equal to 0.1 x_{ref}.

Table 5. Field space distribution of corn plants from tests performed in a silt loam soil over different residues and amounts, at forward speed of 2.0 m/s, with the prototype planter at x_{ref} = 136 mm

Residue	Multiples Index (%)	Quality of Feed Index (%)	Miss Index (%)	Precision (%)
Soybean — 30 %	5.4	74.6	20.0	12.6
Soybean — 60 %	10.0	69.3	20.7	11.7
Soybean — 90 %	14.3	65.4	20.3	12.8
Corn — 30 %	7.1	66.8	26.1	11.1
Corn — 60 %	7.9	66.4	25.7	11.4
Corn — 90 %	12.5	62.9	24.6	12.8
No residue	10.7	69.3	20.0	12.2
Pr > F (%)	0.070	0.810	0.804	0.705

soil factors. Some of the most important environmental factors, like air and soil temperature and soil moisture, were not at optimum level due to late planting. An important soil factor was the kind of seed covering device and the pressure applied over the seeds. The press wheel was not extensively tested for this application. Thus, poor soil firming over seeds may have reduced emergence.

When compared with results from the laboratory tests, the precision values were consistently better (lower precision index) than those from the prototype (table 4) and similar to those from the seed meter tests (tables 2 and 3), varying between 11.1% and 12.8%. This indicates that considering only the seed spacing classified as singles, the placement of seeds into the soil was more precise than over the greased belt and was not affected by residue cover. The planter performance results from field tests suggest that the residue types and amounts tested did not result in differences in the performance of the punch planter prototype.

Conclusions

A punch planter was designed and constructed for planting corn in no-till conditions. A commercial vacuum seed meter was used and positioned such that it dropped each seed individually into each punch.

The seed meter was tested in the laboratory over a greased belt and at speeds of 1.0, 2.0, and 3.0 m/s at the conditions stated by the manufacturer. Four different criteria were used for evaluating the seed distribution; multiples index, quality of feed index, miss index, and precision. The seed meter resulted in no significant changes in performance, except a small increase in the miss index.

The same seed meter was then positioned at an inclination of 22° with the vertical axis, and the vacuum level increased. These results were almost the same, except that the resulting multiples index was higher, probably due to the higher vacuum. A significant improvement in precision was observed when increasing the speed from 1.0 m/s to 2.0 m/s.

The seed meter was synchronized with the punches. No significant difference was observed in any of the criteria used for evaluating the seed spacing distribution. The reduction in the quality of feed index was between 1.6% and 4.4% for 2.0 m/s and 1.0 m/s, respectively. The precision indexes were between 17.4% and 18.7% compared to between 11.7% and 12.3% when tested with only the seed meter. The precision decreased (precision index increased) due to an interaction between the seeds and punch walls.

Field tests were conducted with two types of residue and three different amounts in a no-till area at 2.0 m/s. No significant differences were observed in the seed spacing criteria due to type and amount of residue. The multiples index varied between 5.4% and 14.3% and had a tendency to increase as the amount of residue increased. In the laboratory those values were between 4.0% and 6.4%. This increase may be due to bouncing of the unit in the field that degrades the synchronization between the seed meter and the external punch wheel. Due to poor environmental conditions for planting and germination, high levels of miss index were observed. The precision did not differ significantly among treatments. The precision index values, varying between 10.3% and 12.8%, were similar and better than from laboratory tests.

REFERENCES

Adekoya, L. O., and W. F. Buchele. 1987. A precision punch planter for use in tilled and untilled soils. *J. Agric. Engng. Res.* 37:171-8.

Allmaras, R. R., and R. H. Dowdy. 1985. Conservation tillage systems and their adoption in the United States. *Soil & Tillage Res*. 5:197-222.

ASAE Standards, 41st Ed. 1994. S313.2. Soil cone penetrometer. St. Joseph, Mich.: ASAE.

Association of Official Seed Analysts. 1993. (rev. 1994) Rules for testing seeds. *J. Seed Technol.* 16(3):1-109.

Bouchandira, M., and S. J. Marley. 1984. Performance and synchronization of a vacuum metering system for a punch planter for corn. ASAE Paper No. MCR 84-102. St. Joseph, Mich.: ASAE.

Brown, F. R. 1988. Dibber seed drill: Design and experimental results. International Conference on Agricultural Engineering, Book of Abstracts, AG ENG 88 Paris, Paper No. 88-118:301-302. Antony, France: CEMAGREF.

Bufton, L. P., F. R. Brown, and P. M. Grundon. 1985. Crop establishment and seed drill design: Work during 1983 and 1984 with an experimental dibber drill. Div. Note DN. Silsoe, England: National Institute of Agricultural Engineering.

Dickey, E., P. J. Jasa, and D. Shelton. 1986. Estimating residue cover. NebGuide G86-793. Lincoln, Nebr.: University of Nebraska Cooperative Extension.

Glenn, F. B., and T. B. Daynard. 1974. Effects of genotype, planting pattern, and plant density on plant-to-plant variability and grain yield of corn. *Canadian J. Plant Sci.* 54:323-30.

Hauser, V. L. 1982. Punch planting to establish grass. *J. Range Manage.* 35(3):294-297.

Heinemann Jr., W. H., J. W. Cary, and A. E. Dilworth. 1973. Experimental machines for autodibble planting. *Transactions of the ASAE* 16(4):656-659.

Herzoni, A., Y. Alper, A. Antler, and I. Wolf. 1986. Mechanization of vegetable production. *Acta Hort.* 187:93-98.

Hunt, D. 1961. A vegetable seeder that plants through plastic and paper mulch. *Illinois Res*. 3(4):16.

International Standardization Organization. 1984. Sowing equipment—Test methods—Part 1: Single seed drills (precision drills), 7256/1. Geneva, Switzerland: ISO.

Jafari, J. V., and K. J. Fornstrom. 1972. A precision punch planter for sugar beets. *Transactions of the ASAE* 15(3):569-571.

Jasa, P. J. 1981. Corn seed spacing uniformity in various tillage systems. M.S. thesis. Lincoln, Nebr.: University of Nebraska.

Jasa, P. J., D. P. Shelton, A. J. Jones, and E. C. Dickey. 1991. Conservation tillage and planting systems. NebGuide G91-1046. Lincoln, Nebr.: University of Nebraska Cooperative Extension.

Kachman, S. D., and J. A. Smith. 1995. Alternative measures of accuracy in plant spacing for planters using single seed metering. *Transactions of the ASAE* 38(2):379-387.

Kromer, K. H. 1986. A bucket planter for seeding through mulch. *Acta Hort.* 187:159.

Lawson, G. 1988. Designs on direct drilling. *Grower* 14:24-25.

Molin, J. P., and L. L. Bashford. 1996. Penetration forces at different soil conditions for punches used on punch planters. *Transactions of the ASAE* 39(2):423-429.

Molin, J. P., and V. D'Agostini. 1996. Development of a rolling punch planter for stony soil conditions. *Agric. Mech. Asia, Africa and Latin America* 27(3):17-19.

Morrison Jr., J. E., and R. R. Allen. 1987. Planter and drill requirements for soil with surface residues. Paper presented at the Southern Region No-tillage Conf. on Conservation Tillage, Misc-Pub-MP-Agri-Exp-Stn (1636): 44-58. College Station, Tex.: The Station.

Pintér, L., J. Nemeth, Z. Pinter, and M. Szirbik. 1978. Trend of grain yield in maize (*Zea mays* L.) hybrids as a function of plant number per unit area and sowing uniformity. *Acta Agronomica Hungaricae* 27:398-404.

PAMI (Prairie Agricultural Machinery Institute). 1984a. John Deere 7000 Max-Emerge row crop planter. Evaluation Report 357. Humboldt, Saskatchewan, Canada.

________. 1984b. White Farm Equipment 5100 Seed Boss row crop planter. Evaluation Report 358. Humboldt, Saskatchewan, Canada.

Remussi, H. C., H. Saumell, and G. A. Vidal Aponte. 1974. Effects of sowing uniformity on sunflower yield. In *Proc. 6th Intnl. Sunflower Conf.*, 493-497. Bucharest, Romania: International Sunflower Assoc.

Rogers, B., and R. Baron. 1987. Cereal punch seeder; true zero till seeding. ASAE Paper No. 87-1615. St. Joseph, Mich.: ASAE.

Sawant, S. D. 1972. Design and basic studies of a plunger-type planter. Ph.D. diss. University Park, Pa.: Pennsylvania State University.

Shaw, L. N., R. C. Fluck, and H. H. Bryan. 1978. Energy conservation by recropping plastic mulch covered tomato beds. ASAE Paper No. 78-1509. St. Joseph, Mich.: ASAE.

Shaw, L. N., and K. H. Kromer. 1987. Revolving spade planter soil opener. ASAE Paper No. 87-1019. St. Joseph, Mich.: ASAE.

__________. 1989. A punch planter for vegetables on plastic mulch covered beds. In *Proc. 11th Intnl. Congress Agric. Engineering*, Vol. 3, *Agricultural Mechanization*, 1711-1715. Dublin Ireland. Rotterdam, The Netherlands: A. A. Balkema.

Srivastava, A. K., and M. E. Anibal. 1981. A punch planter for conservation tillage. ASAE Paper No. 81-1020. St. Joseph, Mich.: ASAE.

Stout, G. J. 1971. Plug-in for profits. *Am. Vegetable Grower* 19(3):20-21.

Wijewardene, R. 1978. Systems and energy in tropical farming. ASAE Paper No. 78-1511. St. Joseph, Mich.: ASAE.

Wilkins, D. E., P. A. Adrian, and W. J. Conley. 1979. Punch planting of vegetable seeds—A progress report. *Transactions of the ASAE* 22(4):746-749.