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Study of optimal design of parameters for spade punch planter of corn

In accordance with the development of agricultural cultivation systems a punch planter with revolving spade working part for soil opening was designed for use on soils covered with plastic film and agricultural waste materials. For investigation of sowing quality the parameters of the punch planter vertical decline angle, horizontal decline angle and working speed were tested with three varieties of corn and the relation between parameters and sowing quality was analyzed.

On the basis of experimental results and through regression analysis mathematical models describing sowing quality and its dependence on the parameters were developed. With Computer-Aided Design (CAD) the optimal parameter for spade punch planting were calculated and the test results were satisfactory.

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Keywords

Revolving spade, punch planter, maize, field test, precision seeding

Traditional corn planters with furrow soil opening cannot be used on soils covered with plastic films and agricultural waste materials. Therefore the development of a new punch planter with an improved working quality is very important for corn production. JAFARI and FORNSTROM [3] developed a precision planter that punches holes and meters seeds into the soil. The test results showed a higher precision of seed placement in the holes. But the test had been carried out on tilled ground, and it is not sure whether this planter can do satisfactory work on covered soil.

SRIVASTAVA and ANIBAL [7] designed a punch planter with hollow cones mounted radially on a punch wheel. The problem with this planter was that the hollow cones were plugged with soil. HEINEMANN et al [2] and WILKINS et al [8] had made similar research works on punch planters but the plugging problem of the soil opening element could not be solved completely. Besides, the precision of the seed placement was not really convincing on covered or untilled soils.

SHAW and KROMER [5] proposed a revolving spade to open the soil and they concluded that this kind of moving part was suitable for various types of soil coverings (see *figure 1*). SIEBERTZ [6] designed a precision punch planter with a revolving spade as soil opening part. The test results showed that this punch planter can operate under different soil conditions.

For the best combination of parameters for the design of punch planters with a revolving spade as soil opening element a further study was carried out to investigate the relationship between the parameters of the planter and of sowing efficiency with corn. In order to achieve a higher working quality an optimized combination of parameters was formulated by means of Computer-Aided-Design (CAD).

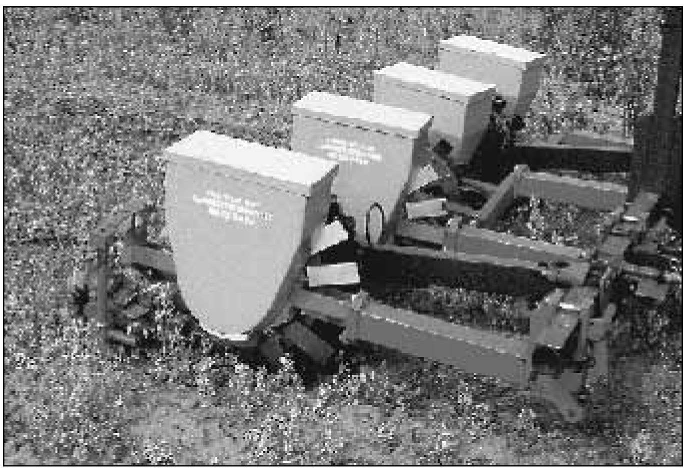

Fig. 1: Revolving spade planter

Selection of parameters

Through experiments with spade punch planters for corn we found the parameters, i.e. vertical decline angle b (*fig. 2*), horizontal decline angle g (*fig. 3*) and working speed to be the main factors affecting the precision of seed placement and the number of seeds per hole punched into the ground. One of the objectives of precision sowing is to reliably place exactly one seed in each hole. Aspiring for the optimal design of the punch planter these parameters were therefore selected to obtain a minimum percentage of holes containing more than one seed, with a given permission of variance of the corn placement within-the-row. According to the requirements of practical application of the planter and the permitted design space the range of the parameters for experimental design are: b = 15°-35°; g = 3°-15°, n = 1m/s - 2m/s.

Considering the need of square regression experimental design the parameters were changed linearly into variances x_j with the following dimension:

$$x_j = (Z_j - Z_{oj})/D_j$$

$$Z_{oj} = (Z_{j\,max} + Z_{j\,min})/2$$

with

$$D_j = (Z_{j\,max} - Z_{j\,min})/1.682$$

so that with

$$x_1 = (n - 1.5)/0.3$$

$$x_2 = (b - 25)/6$$

$$x_3 = (g - 9)/3.6$$

Tab.1: Levels of parameters for experimental design

Parameter	Variant	Zero level (Z_0)	Range D	Level of experimental variances -1.682	-1	0	+1	+1.682
n	x_1	1.5	0.3	1	1.2	1.5	1.8	2
b	x_2	25	6	15	19	25	31	35
g	x_3	9	3.6	3	5.4	9	12.6	15

we obtain the levels of the parameters for experimental design as shown in *table 1*.

Plan of the experiment

Three varieties of corn (Jidan 156, Jidan 159 and Zhongdan 2) were used for the experiment determining the effect of the parameters on the sowing quality. The criteria used to evaluate the sowing quality are:

- percentage of holes with more than one seed (D)
- percentage of holes without seed (M) and
- variance coefficient of seed distance within-the-row (V)

These criteria are defined as follows:

D = (number of holes with more than one seed)/(number of all holes tested)•100%

M = (number of holes without seed)/(number of all holes tested)•100%

V = (square root of standard variance)/(mean value of seed distance)•100%

Results and analysis

In accordance with the experiment plan field tests were carried out with the punch planter at a sowing depth of 50 mm. The results of the experiment are shown in *table 2* for each of the three corn varieties.

On the basis of the experiment plan matrix, test results and the corresponding coefficients for regression (b_0, b_i, b_j, b_{ij}, b_{jj}) equations, a mathematical model for influence of the parameters on the sowing quality of the punch planter was developed:

$$\hat{y} = b_0 + \sum_{j=1}^{3} b_{jj} x_j^2 + \sum_{j<i} b_{ij} x_i x_j$$

Variance analysis of the equations was significant (a = 0.1 to a = 0.01). The insignificant coefficients were removed from the equations through t-test. These calculations lead to the following results:

(1) Jidan156

$$D = 16.329 - 1.249x_1 + 0.621x_2 + 3.062x_1^2 + 1.693x_2^2 + 0.463x_3^2$$

$$M = 0.152 + 0.348x_1 - 0.414x_2 - 0.114x_3 + 0.876x_1^2 + 0.114x_3^2$$

$$V = 11.692 + 1.558x_1 + 0.833x_2 - 0.869x_1^2 - 0.971x_2^2$$

(2) Jidan159

$$D = 3.375 - 0.313x_1 + 0.281x_2 - 0.018x_1^2 - 0.291x_3^2$$

$$M = 0.416 + 0.043x_1 - 0.081x_2 - 0.018x_1^2 - 0.043x_2^2 - 0.013x_3^2$$

$$V = 7.599 + 1.23x_1 + 0.521x_2 - 0.542x_1^2 - 0.433x_2^2 + 0.709x_3^2$$

(3) Zhongdan2

$$D = 0.301 + 0.319x_1 + 0.958x_2 - 0.141x_1x_2 - 0.134x_1x_3 + 1.269x_1^2 + 1.245x_2^2 + 0.31x_3^2$$

$$M = 0.749 + 0.171x_1 - 0.085x_2 + 0.032x_1^2 - 0.125x_2^2 - 0.04x_3^2$$

$$V = 7.949 + 1.255x_1 + 0.654x_2 + 0.684x_1^2 + 0.715x_2^2$$

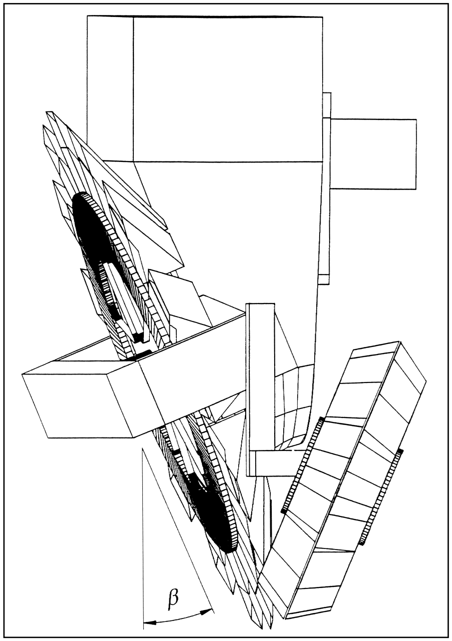

Fig. 2: Side view of revolving spade planter (indication of vertical decline angle b)

Optimal design of parameters

The optimal design of the planter's parameters aims at a minimized percentage of seed holes with more than one seed (D), a percentage of holes containing no seed lower than 0,5% (M < 0.5) and a variance coefficient smaller than 10% (V < 10). Based on these premises a mathematical model was developed describing the optimal design of the punch planter.

Using conjugate gradient method [1] and with the help of computer calculation the values of the variants under defined conditions were obtained. Through calculation for $x_1 = (n - 1.5)/0.3$, $x_2 = (b - 25)/6$, $x_3 = (g - 9)/3.6$ the optimal range of parameters of the punch planter for three varieties of corn were determined:

(1) Jidan156

n = 1.51 to 1.56 m/s
b = 18.2° to 20.5°
g = 8.1° to 9.8°

(2) Jidan159
n = 1.38 to 1.61 m/s
b = 22.1° to 26.3°
g = 7.9° to 10.1°

(3) Zhongdan2
n = 1.41 to 1.46 m/s
b = 23.0° to 24.0°
g = 8.1° to 9.8°

Conclusions

1) To achieve a minimized percentage of holes with more than one seed, the parameters of the punch planter must be adapted to the specific requirements of the different varieties of corn.
2) The vertical decline angle had the strongest effect on the number of holes with more than one seed, while the horizontal decline angle had only limited effect.
3) The working speed of the punch planter had a significant influence on the variance coefficient of the seed distance. To ensure a higher sowing precision, the working speed should therefore be limited.
4) The higher the working speed, the more must the vertical decline angle be decreased to maintain the minimum percentage of the holes with more than one seed.
5) Since the horizontal decline angle affected the variance coefficient of seed distance it should not be modified by more than 2°.

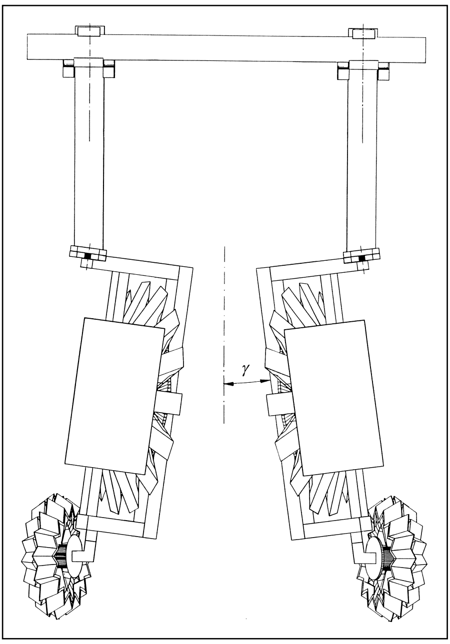

Fig. 3: Top view of revolving spade planter (indication of vertical decline angle g)

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Tab.2: Results of the experiment on the sowing quality of the punch planter

No.	Jidan 156			Jidan 159			Zhongdan 2		
	D %	M %	V %	D %	M %	V %	D %	M %	V %
1	21.4	0.9	10.1	2.0	0.1	6.3	4.0	0.6	8.0
2	20.8	1.9	9.0	2.5	0.1	6.1	4.2	0.6	8.0
3	21.2	1.8	8.7	2.9	0.04	5.9	3.1	0.5	8.0
4	21.1	1.8	8.6	2.6	0.04	5.8	3.9	0.5	7.9
5	22.3	1.2	7.6	3.0	0.02	5.5	4.4	0.4	7.5
6	22.5	1.1	7.5	3.0	0.02	5.5	4.2	0.4	7.3
7	22.3	1.5	7.9	2.8	0.02	5.9	3.0	0.5	7.6
8	22.4	1.5	7.5	3.0	0.03	5.3	3.2	0.5	7.5
9	21.6	3.3	15.4	1.9	0.3	12.3	4.1	1.5	16.3
10	27.9	1.3	7.3	3.2	0.01	4.2	1.9	0.5	8.1
11	23.3	0.02	13.7	5.4	0.01	10.4	5.4	0.3	14.7
12	18.4	0.2	8.4	2.9	0.2	6.7	0.5	0.9	9.8
13	17.8	0.1	14.2	2.8	0.2	11.6	0.4	0.8	10.3
14	17.0	0.2	13.6	2.9	0.2	12.1	0.2	0.8	10.0
15	17.6	0.2	12.9	2.4	0.1	8.4	0.4	0.8	6.6
16	15.0	0.2	10.2	3.1	0.1	7.2	0.4	0.6	8.4
17	16.3	0.1	12.4	4.1	0.2	7.3	0.5	0.8	9.6
18	15.5	0.2	11.9	3.8	0.1	6.1	0.2	0.9	6.8
19	16.6	0.2	11.3	2.7	0.1	8.9	0.3	0.7	8.0
20	17.0	0.2	10.8	4.1	0.2	7.0	0.3	0.6	7.5