



Title	EFFECTS OF COULTER SHAPE AND OPERATING VELOCITY ON THE PERFORMANCE OF PRECISION PLANTERS
Author(s)	Yisa, Mohammed G.; Walczyk, Jozef; TERA0, Hideo
Citation	Journal of the Faculty of Agriculture, Hokkaido University, 66(1), 79-98
Issue Date	1994-03
Doc URL	<a href="http://hdl.handle.net/2115/13132">http://hdl.handle.net/2115/13132</a>
Type	bulletin (article)
File Information	66(1)_p79-98.pdf



[Instructions for use](#)

## **EFFECTS OF COULTER SHAPE AND OPERATING VELOCITY ON THE PERFORMANCE OF PRECISION PLANTERS**

**Mohammed G. YISA, Jozef WALCZYK\* and Hideo TERA0**

Agricultural Vehicle System Engineering, Faculty of Agriculture,  
Hokkaido University, 060 Sapporo, Japan.

\*Faculty of Agricultural Technology and Energy, Academy of Agriculture,  
Ul. Balicka 104, Krakow, Poland

(Received December 28, 1993)

### **Introduction**

Large scale production of maize, vegetables, sugar beet, oil plants and leguminous plants calls for the use of precision planters. This is because apart from proper land preparation, adequate fertilizing and conducive environmental conditions, plant population and intra-row spacing play a vital role in the overall yield per unit area<sup>1)</sup>. For this reason the use of precision planters becomes very important.

To achieve the required effects of planting, that is, desired plant population, intra-row spacing, inter-row spacing and planting depth, a number of conditions must be satisfied<sup>2)</sup>. These conditions include: the land must be thoroughly prepared, intra-row distance must be correctly chosen, regulations for the use of precision planters must be religiously followed.

Precision planting allows the plants to have the same conditions for growth. These conditions allow them to achieve the same size, symmetric shape, better coloration and maturity at the same time which is very important during mechanical harvesting.

### **1. Precision Planting**

By precision planting it is meant placing of the seed at equal intervals and equal depths. The intra-row distance is usually between 4 to 35 cm. There are two methods of precision planting: (a) Planting at exactly the required intra-row distance, (b) Planting at smaller than required intervals. The first method is applied when a monogerm seed gives under every field conditions a minimum 60% germination, which is equivalent to 90% viability in the laboratory. This method is used for crops like sugar beet, corn, soybeans etc due to the fact that thinning which is labour intensive is completely eliminated<sup>3)</sup>.

In the second method excess germinated crops are reduced by singling. This method is used for sugar beat and vegetables which have field germination ability

of 35 to 70%. Very dense planting of intra-row spacing 6-9 cm is used to reduce the risk of not being able to obtain the required plant population. The singling operation is, of course less labour intensive than thinning. With regards to corn, the primary advantage of precision planting is improvement of nutritional value of corn grown for silage and increase in grain yield for corn grown for grains. During precision planting, proper operation of the planter is very important. One of the basic rules is that the maximum allowable operating velocity should never be exceeded. For mechanical planters the velocity is 4 to 5 km/h, while for pneumatic planters 7 to 8 km/h for corn. Exceeding these velocities result in the formation of empty holes and uneven intra-row distances caused by movement of seeds in furrows. Using precision planting requires proper land preparation most importantly, levelled field, broken clods and adequate pulverization to a depth of 5 to 8cm is required<sup>4),5)</sup>.

## 2. Research Methods

Studies on precision planters could be classified into: laboratory studies, laboratory/field studies and operation studies.

The following parameters are usually determined in the laboratory: (a) seed characteristics, i.e. seed dimensions (thickness, length, breadth) and viability, (b) measurement of the performance of the sowing mechanism, seed distribution, continuity of planting, planting depth, effect of velocity on planting and damage of seeds by metering mechanism.

Laboratory/field studies include, measurement of operating velocity, draft, planting depth, seed distribution, coverage of the seeds, straightness of the rows, quality of germination, length of the roots at the initial stage of growth and atmosphere of studies, that is, the type of soil, moisture content, cone index, depth of land preparation, quality of land preparation and meteorological conditions.

In laboratory and laboratory/field studies of precision planters the following methods have been widely used:

- measurement of seed distribution without consideration for the effect of the coulter. This method could be: (a) direct measurement of distance between seeds dropped to opened furrow in the field or in a soil bin. (b) direct measurement of distance between seeds planted on a sticky tape with automatic reading, recording and classification of distance between seeds into class groups.
- Indirect measurement with recording of seed distribution on a magnetic tape<sup>6)</sup>.
- Cinematographic method. The process of planting is recorded by a high speed camera. Analysis of the planting process is done using film analyzer under slow motion projection. This allows the whole process of seeding to be monitored up till the moment the seed is completely covered, but does not consider the effect of the coulter.
- Measurement of seed distribution with consideration for the effect of the coulter. There are three modifications of this method: (a) The method in which

the rows are covered with melted paraffin. (b) Isotopic method. In this method gamma rays are passed to the soil sown with seeds<sup>7</sup>.

- Direct measurement of distance between plants is used to determine longitudinal irregularities in sowing. The interested reader is referred to the senior authors thesis for detail information on the various methods<sup>8</sup>.

### **Literature Review**

Many researches have been done on the performance of precision planters. Dudzik<sup>6</sup>, studied the effect of the rotational speed of the metering disc on seed distribution on rows and concludes that too high speed of the disc brings about irregularities in seed distribution on rows. Bajak<sup>9</sup>, considers the relationship between seed velocity from metering mechanism to the soil and intra-row distance. The effect of coulter shape on seed distribution was studied by Nowocien<sup>9</sup>. No account has been given so far on how the shape of the coulter affects the planting depth, intra-row spacing and the distance between the center of gravity of the coulter and the seed as at the time the seed is completely covered, (which from now on shall be referred to as coverage distance).

The objectives of this study include:

1. Determination of the effect of coulter shape on planting depth and intra-row spacing
2. Study the effect of coulter shape on the coverage distance
3. Determination of the effect of planting velocity on the planting depth
4. Determination of the effect of operating velocity on the coverage distance
5. Study the effect of coulter shape on seed germination

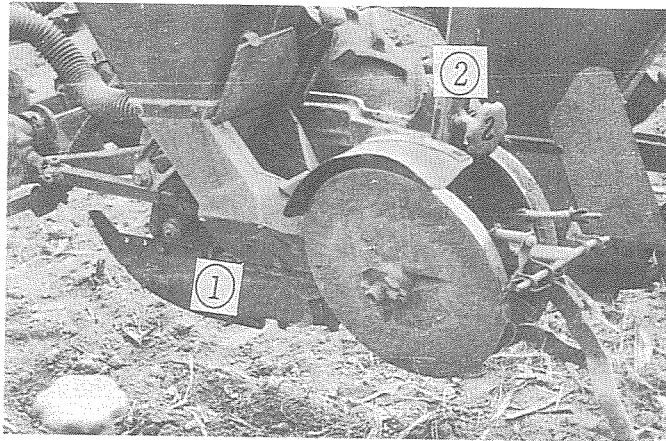
The study includes: construction of a modified coulter, comparative study of two coulters, original and modified coulter. Planting depth, soil pulverization and intra-row distances are considered. Construction of a new coulter "Nowa 85", construction of an experimental rig, determination of the coverage distance for three coulter shapes and four different operating velocities, determination of the effect of coulter shape on planting depth also constitute part of the study.

### **Construction of Precision Planters and Coulters**

Two types of precision planters were used in this studies, "Pneumasen II", an underpressure pneumatic planter and "PKV-6", a mechanical precision planter. "Pneumasen II" is equipped with disc type metering mechanism. The major components are: disc, fan, 3-step chain transmission mechanism, cutoff device for excess seeds, overload clutch, coulter, control/support wheel etc.

The metering mechanism is set using a table, making a choice of the right disc and drive depending on the type of seed and seeding rate required. The cutoff device controls the seeds. It has a toothed piece of metal sheet placed on

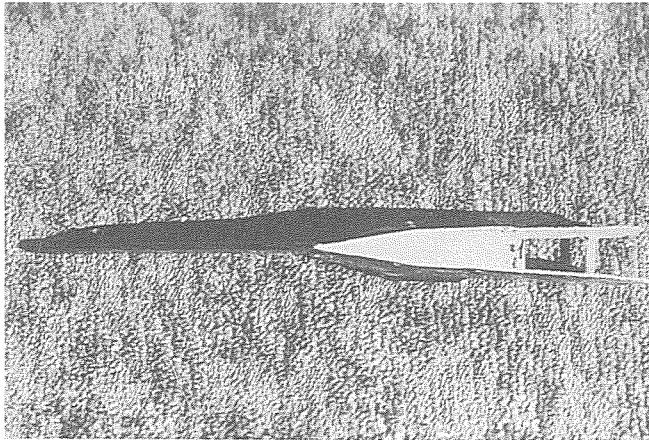
the disc from the side of the seed cells. Depending on the way the micrometric screw, has been set it covers the cells on the disc, figure 1. When it is placed too far from the cells on the disc, there could be planting of two seeds to one hole. If, however, it covers a large area of the cell, there could be holes without seeds<sup>10)</sup>. Positioning of the cutoff device with respect to the cells on the disc is controlled with the help of a pointer and scale. Once one of the units have been properly adjusted, others could analogically be adjusted by looking at the scale of the already adjusted unit. Every unit is equipped with an overload clutch mounted on a square shaft through which power is transmitted to the system. This clutch protects the metering mechanism against excessive loads that may result from the entrance of foreign materials like rope or stones into the system. Other elements of the planter are markers and press wheel. In this planter power from the support wheels is transmitted through the three step chain drive on to the central shaft. Respective units obtain power from the central shaft through universal shafts. Additional elements of the planter are adapters for granulated fertilizers and pesticides. It is usually made up of 6 or 8 units. A unit of the planter is shown in figure 1.



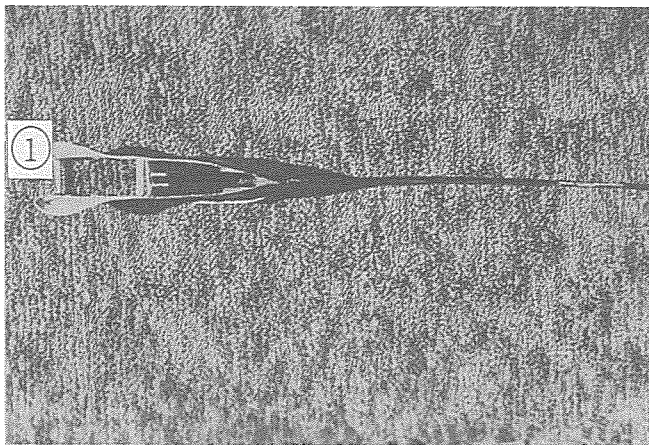
**Fig. 1.** A unit of precision planter "Pneumasem II"  
 ①coulters ②depth control screw

### Studied Coulters

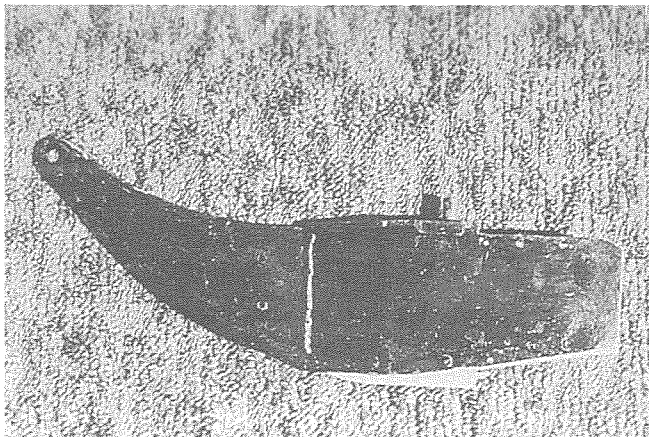
Previous studies on coulters have shown that furrow closing process actually starts before the seeds make contact with the soil. The effect of this was that seeds were placed at depths less than target depth. This is due probably to the fact that the wings of the coulters were shot and ended with straight wings above the furrow (Figure 2 and Figure 4, original coulters of "Pneumasem II" and "PKV-6" respectively). A decision was taken to make a modification of these coulters to eliminate this phenomenon. In the modified prototypes (Figure 3 and Figure



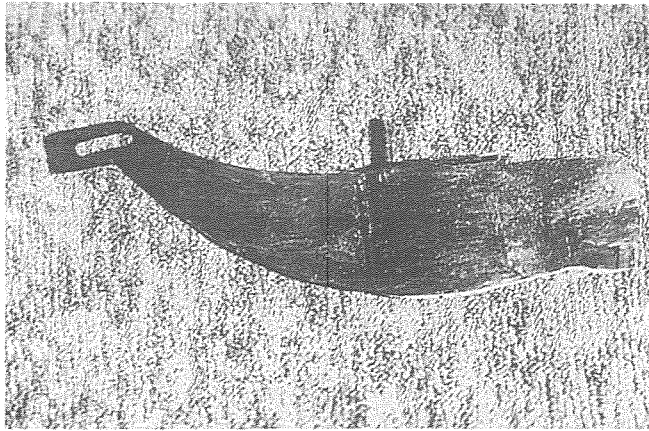
**Fig. 2.** Original coultter "Pneumasem II"



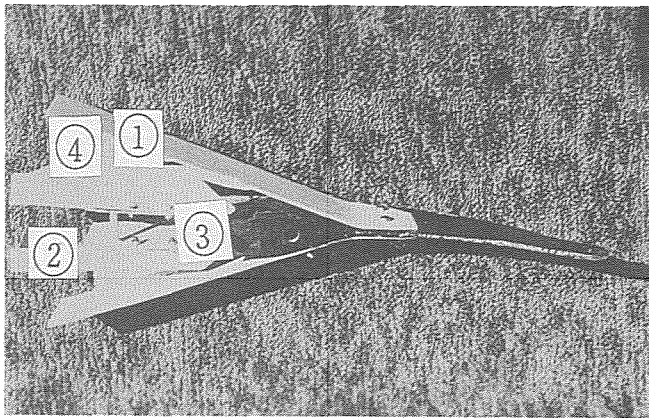
**Fig. 3.** Modified coultter "Pneumasem II"  
① curved wing



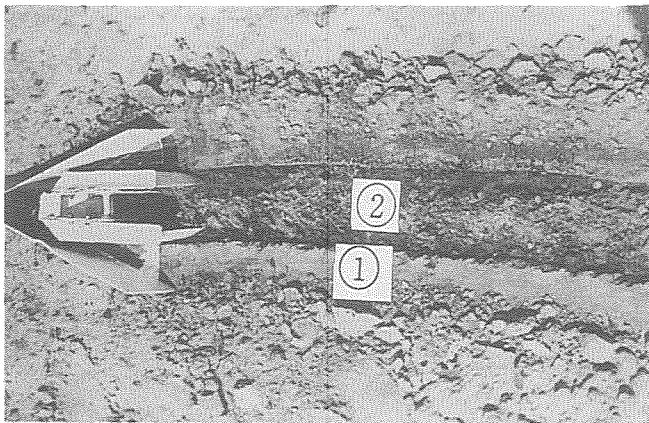
**Fig. 4.** Original coultter "PKV-6"



**Fig. 5.** Modified coultter "PKV-6"



**Fig. 6.** New coultter "Nowa 85"  
 ①slate ②curved wing ③roller ④metal sheet which serves as depth control device



**Fig. 7.** Operation of the new coultter "Nowa 85"  
 ①effect of slate ②planted row covered with moist soil

5) therefore, the wings were extended and curved at the end inwards.

After conducting multiple experiments on the coulters mentioned above, it was observed that there were variations between the target depth of planting and obtained depth. It was also observed that the depth varied with velocity even though a control wheel as well as a press wheel were used.

It became therefore necessary to design a coulters that will not be sensitive to variations in operating velocity, maintain as much as possible the set target planting depth. In view of forgoing a new coulters "Nowa 85", Figure 6 was designed, fabricated and tested. Figure 7 shows the new coulters in operation.

## Methodology

### 1. Study on Precision Planter "Pneumasem II"

In the field studies of precision planter "Pneumasem II" the following measurements were taken: soil particle distribution, soil moisture content, cone index, seed emergence rate, operating depth, root length, crop weight, intra-row spacing

Soil particle distribution was determined by sieve method, while the moisture content was determined by weighing method. Cone index was determined by measuring the force required to drive a cone penetrometer of cone 30° and diameter 10 cm to a certain known depth<sup>11,12</sup>. Germination rate was determined by counting the number of plants along a distance of 100 m at three different places for each of the coulters. The length of the roots was determined using Bohn's procedure<sup>13</sup>: On a square glass, squares of 2×2 cm were drawn. The roots were then placed in such a way that they don't overlap. The number of interceptions of the roots with the horizontal and vertical lines of the squares was then determined. The length of the roots was then calculated from:

$$L = 11/14 \times i \times k [\text{cm}]$$

where,

L is the length of the root in cm

i is the number of interceptions

k is a constant which is equal to 1.57 for squares of 2×2 cm.

The weight of crops was determined by weighing method. Intra-row spacing was determined by measuring directly the distances between plants after emergence.

The following laboratory studies were also conducted:

- dimension of the seeds
- force and energy of germination

The rate of germination was determined using the following procedure; to a container with wet sand, three samples of 100 seeds each were placed, the seeds were then covered with wet sand. Germination of the seeds was then observed and recorded.



## 2. Determination of Coverage Distance Under Field Conditions

Furrow covering takes place so fast that direct observation and measurement is difficult not to say impossible. During operation under lower travelling velocities it may be possible of course, to determine moment of covering but the accuracy of such measurements would certainly be low. With higher velocities taking measurements is impossible. Due to this difficulty filming technique was adopted and the film was later analysed during slow motion projection.

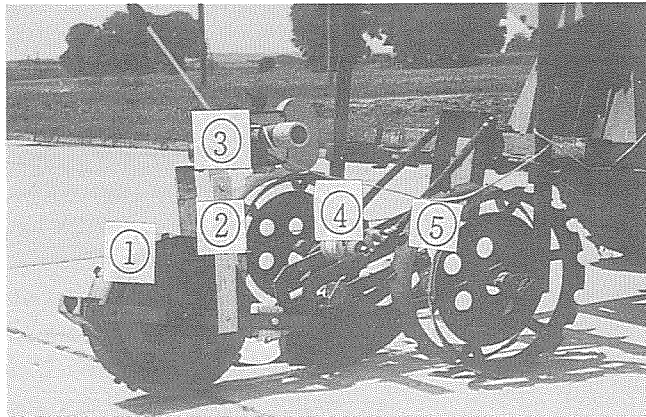
## 3. Description of the Experimental Rig

On the three point linkage of a tractor was mounted a unit of the PKV-6 precision planter without the hopper and sowing mechanism, since the purpose was to study coulters of different shapes working under different tractor velocities. An MF-235 tractor was used for the experiment. Over the planter unit was mounted a filming camera Pentaflex 16, a high speed camera. Its focal area includes a fragment of the coulter with a roller which direct a white belt in to the soil. It also covers the furrow opened by the coulter up to the press wheel. The camera is mounted to the unit by a stand made with flat bars. Since the bars are elastic enough they minimize vibration of the camera during planting. Additional weights have been added to the unit to take care of the weight of the hopper and the sowing mechanism which have been removed. A roller which passes a white belt to the bottom of the furrow through the coulter has been attached to the unit. The roller was mounted as low as possible to the soil so that it does not bring about changes in the work of the coulter.

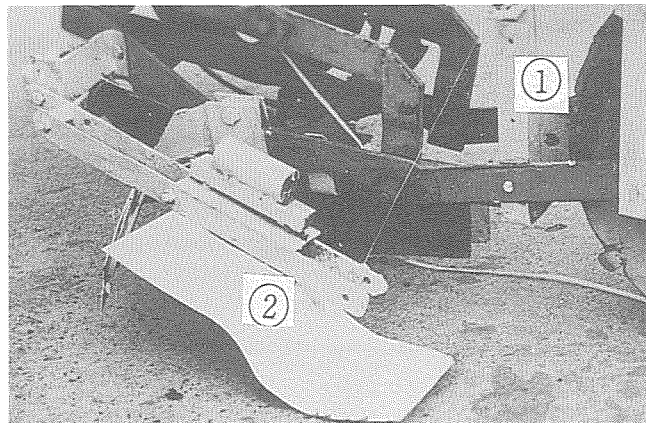
The white belt was passed to the soil so as to obtain contrast which allows easy analysis of the film. White belt on a film can easily be differentiated from soil, due to this it was possible to determine on a stopped film the point at which the first piece of soil falls on the belt and therefore, on the bottom of the furrow. Since the belt was placed at the depth where the seeds would have otherwise been, it was possible to measure manually the depth of operation. An instrument that measures the depth of operation of the coulter was also mounted on the unit. The camera obtain power from the tractor's battery, Figures 8 to 10. The process of furrow opening and closing was filmed for four operating velocities of 0.70, 0.95, 1.69, 2.08 m/s and three coulters of different shapes. The field for the experiment was first ploughed, then a cultivator and a roller were used. The field is a sandy, a little stony soil. Directly after sowing, soil samples were taken in order to determine moisture content. The operating depth of the coulter was measured (the depth at which the white belt was buried).

## 4. Film Analysis

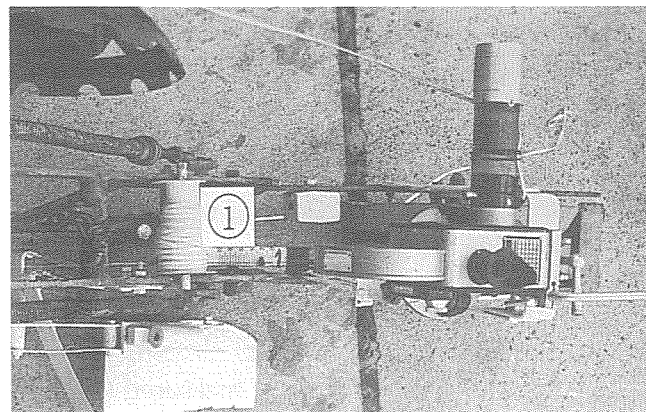
The film obtained during the studies was treated chemically and then analysed both quantitatively and qualitatively. Film analysis was carried out on a modified for the purpose 16 mm Kodak projector. The projector was addition-



**Fig. 8.** View of experimental rig  
 ①press wheel ②support for the camera ③high speed camera ④white tape on a roller ⑤control wheel



**Fig. 9.** View of experimental rig  
 ①added weight ②part of depth measuring system



**Fig. 10.** View of experimental rig  
 ①automatic depth measuring scale

ally equipped with:

- continuous speed regulator
- a device for steady regulation of light intensity
- instrument allowing for projection of the the film one segment at a time
- possibility of projection in both directions
- possibility of controlling the movement of the film with a foot switch.

At the beginning of every film appropriate enlargement was selected on the screen. On the screen was placed a scale which allowed reading of the distance between the roller directing the belt and the point of covering of the belt. The obtained data were extrapolated to the center of gravity of the metering mechanism to obtain coverage distance. The analysis was carried out on a tinted screen. This allowed clearer picture during backward projection. For every 5 frames of the film, the distance at which the belt was covered was read. About 250 readings were taken for each of the coulters. The depth of operation of the coulters was also read from the scale during projection. The results obtained were statistically treated.

## Results

### 1. Study with Precision Planter "Pneumasem II"

The experiment was to compare two coulters of different shapes. On the basis of the results obtained the following were determined:

- average soil moisture content  
 $W_{db}=8.9\%$ .
- cone index (Figure 11).
- rate of germination (Figure 12)
- particle size distribution for samples collected from rows planted by each of the coulters type (Figure 13).
- average root length (Figure 14).
- average depth of operation of each of the coulters was measured  
original coulters  $d_o=4.2$  cm  
modified coulters  $d_m=5.4$  cm.
- emergence was assessed (Table 1).
- crop weight obtained is shown in Figure 15.

In the laboratory experiments the following were determined:

- average dimension of the seed  
average length=9.38 mm  
average thickness=4.81 mm  
average width=8.32 mm
- the intra-row distances were manually measured (Figs. 16 & 17)
- average intra-row distances  $\bar{x}$  and standard deviation  $\sigma_x$  were calculated, Table 2.

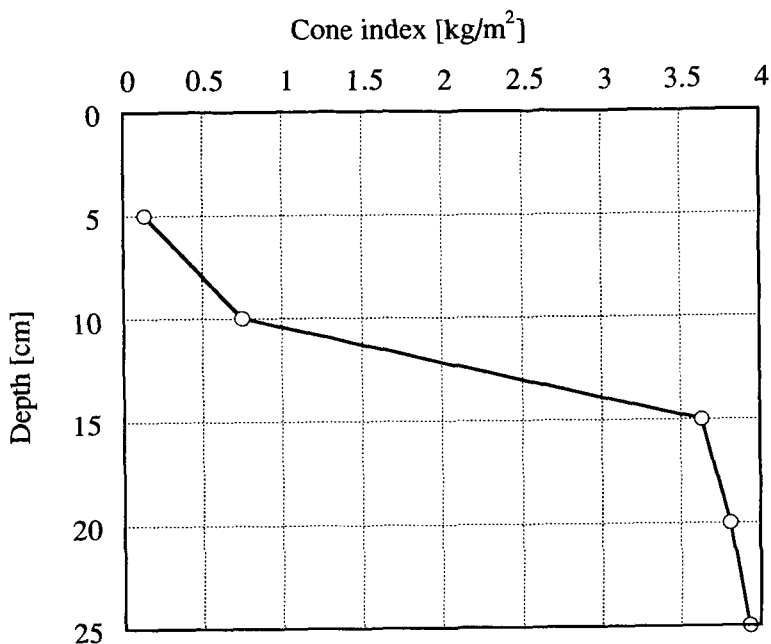


Fig. 11. Average cone index

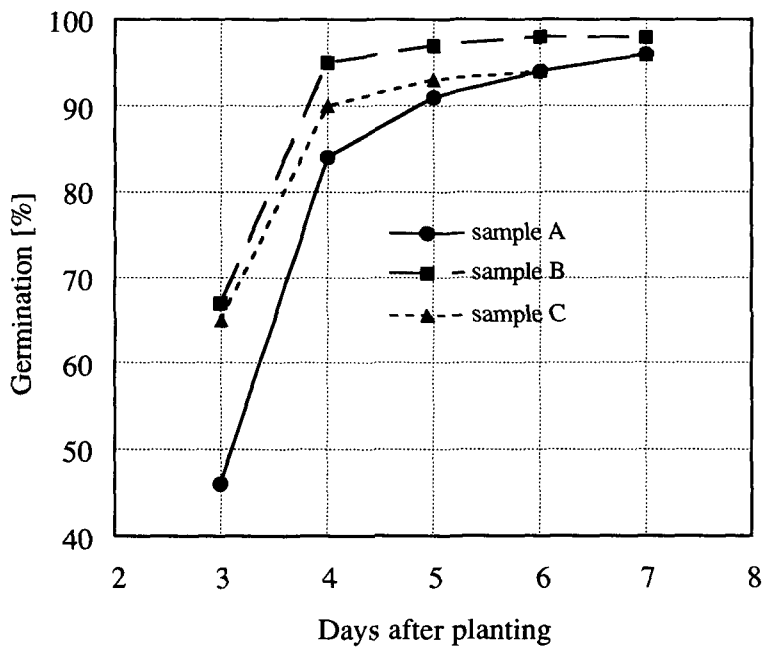


Fig. 12. Force and energy of germination

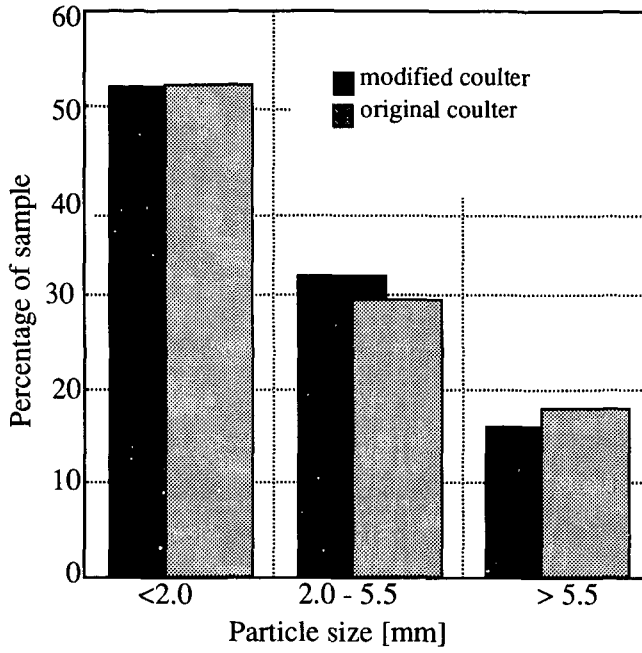


Fig. 13. Particle size distribution

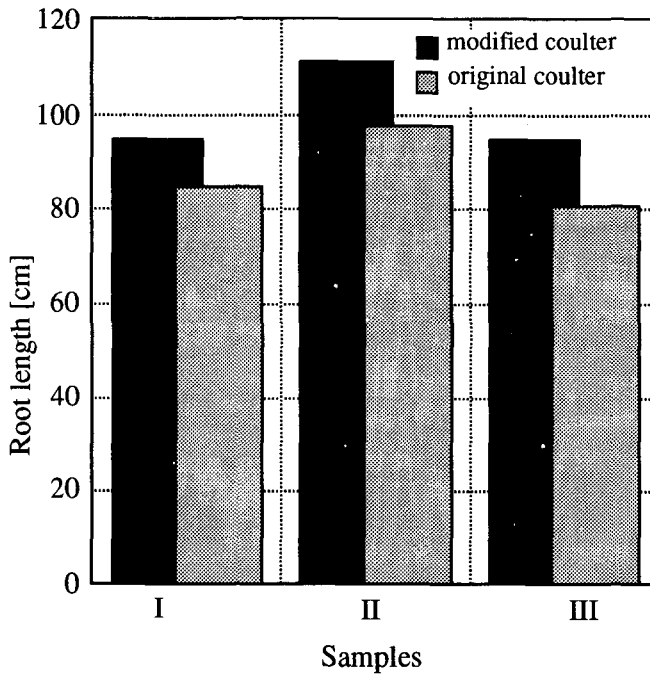


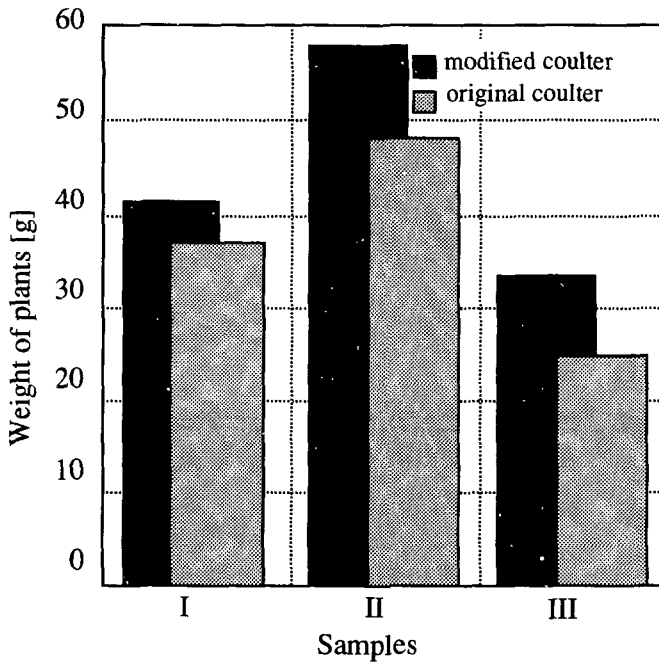
Fig. 14. Length of roots

**Table 1.** Emergence

Days after planting	Quantity of plants counted / day along each portion					
	Portion of the field 100 m					
	I		II		III	
	O	M	O	M	O	M
21	527	369	84	59	167	96
23	593	409	103	66	209	136
25	611	417	105	72	215	142
27	616	422	106	73	216	143
29	620	435	106	73	216	143
33	622	436	107	73	216	144
34	625	437	108	74	216	146

O original coultter

M modified coultter



**Fig. 15.** Weight of plants

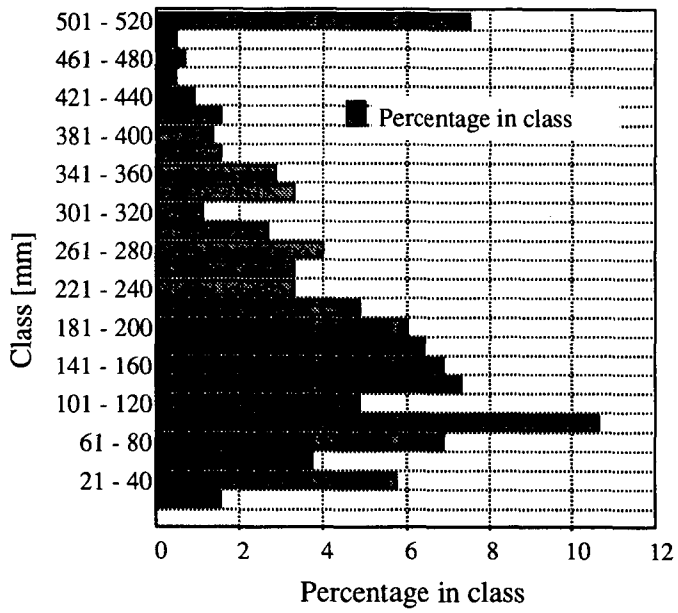


Fig. 16. Intra-row distances (original coulter)

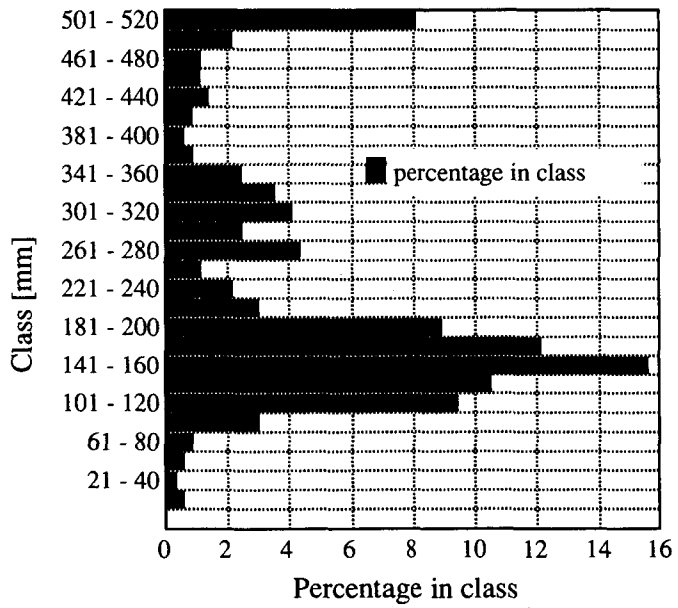


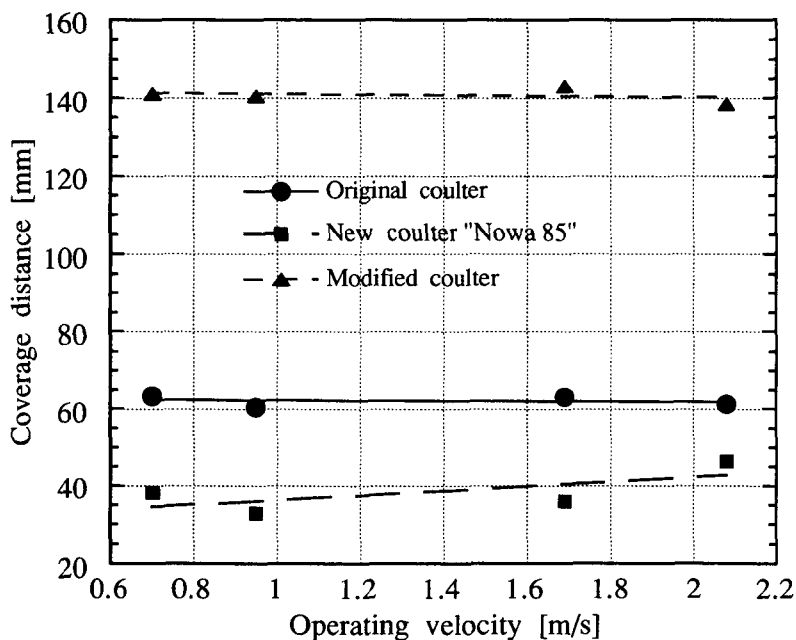
Fig. 17. Intra-row distances (modified coulter).

**Table 2.** Effect of Coultter Shape and Velocity on Coverage Distance

Type of coultter	V <sub>1</sub> = 0.70 [m / s]		V <sub>2</sub> = 0.95 [m / s]		V <sub>3</sub> = 1.69 [m / s]		V <sub>4</sub> = 2.08 [m / s]	
	$\bar{x}$	$\sigma_{\bar{x}}$	$\bar{x}$	$\sigma_{\bar{x}}$	$\bar{x}$	$\sigma_{\bar{x}}$	$\bar{x}$	$\sigma_{\bar{x}}$
Original coultter	63.30	6.79	60.45	8.95	63.11	8.13	61.25	7.75
Modified coultter	141.102	7.17	140.64	7.34	143.19	7.14	138.50	8.43
New coultter "Nowa 85"	38.23	8.17	32.78	8.59	36.02	8.57	46.39	8.99

**2. Determination of Furrow Coverage Distance Behind the Coultter**

During experiments, operating velocity as well as coultters were changed appropriately. The depth of operation was measured both manually and with the earlier described instrument. For every coultter shape and with different operating velocities, about 30 m of film was made. While analysing the film about 250 frames of film were randomly selected and treated statistically. Average values of furrow coverage distances as well as standard deviation were calculated<sup>14)</sup>. Figure 18 shows the relationship between the average coverage



**Fig. 18.** Effect of travelling velocity and coultter shape on coverage distance.



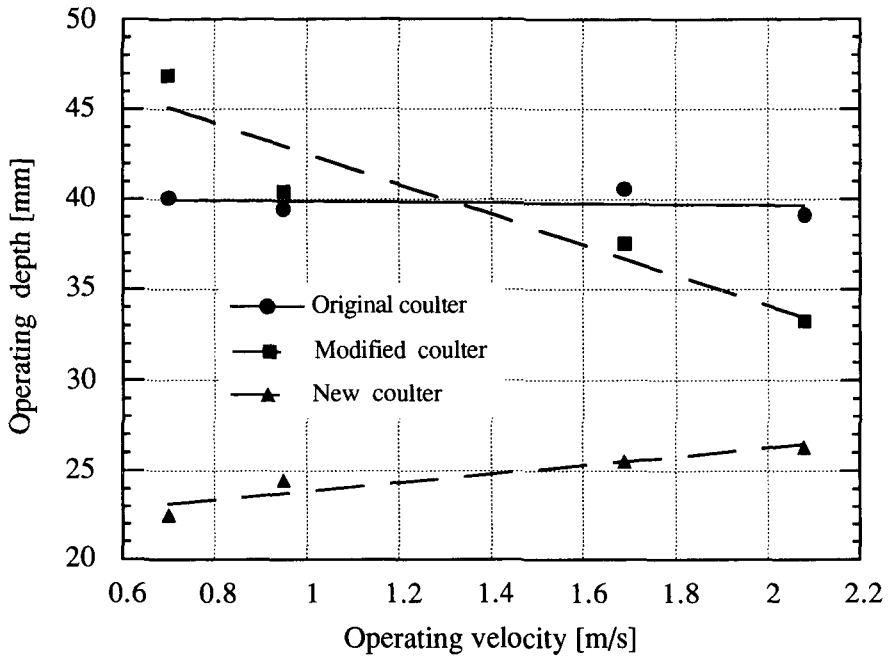


Fig. 19. Relationship between couler shape, travelling velocity and planting depth measured with instrument

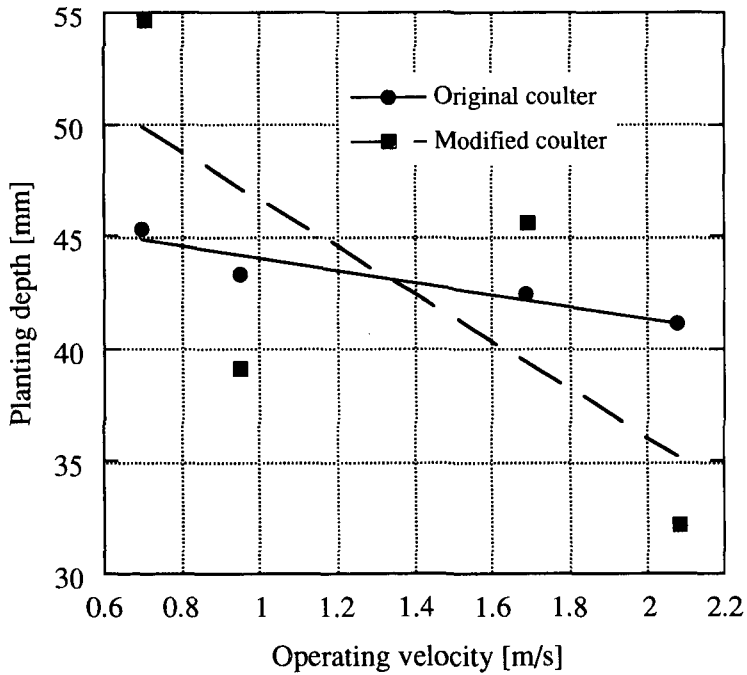


Fig. 20. Relationship between couler shape, travelling velocity and planting depth measured manually.

distances and travelling velocity. Figures 19 & 20 show the relationship between operating depth of the coulter and operating velocity (depth of operation measured both manually and with instrument).

### Discussions

During experiments performed using precision planter "Pneumasem II", it was discovered that the modified coulter covered the seeds with greater moist soil from the lower layer of the soil with the aid of its curved wing. From Figure 6, it can be observed that the particle size distribution of samples taken after the work of the two coulter types is not significantly different. From Table 2 it is evident that the expected plant population was not obtained considering the obtained laboratory germination of 96.7% and a target intra-row spacing of 12 cm. The reason for this low germination could be attributed to low temperature during planting ( $<8^{\circ}\text{C}$ ). This low temperature generally affected germination. Too early planting, in situations of late and cold autumn can reduce percentage of germination since seeds under these conditions are destroyed by organisms leaving in the soil and some may decay. This effect is not always taken care of by seed treatment<sup>15),16)</sup>. Few days after planting, there was heavy rainfall and part of the field was flooded. The action of birds and rodents is not ruled out. However, during counting of the germinated plants, more plants were counted on the rows planted by the original coulter. Nevertheless, the length of the roots of plants on the rows of the modified coulter were about 10% longer than those from the rows of the original coulter (Figure 14). The weight of 30 plants from the row planted by modified coulter was about 7 to 10% more than the weight of equal quantity of plants taken from the row planted by the original coulter (Figure 15). As evident from the data on root length and plant weight, the work of the modified coulter was more beneficial, due to the shape of its wing, which as stated earlier covered the seeds with more moist soil than the original coulter.

Therefore, it is assumed that this fact had an effect on the development of the plants at the initial stage of growth. Even though more plants were counted on rows planted by the original coulter, the roots were shorter and the weight less. It is important, however, to note the randomness of flooding of the field and action of birds and rodents. With a target intra-row spacing of 12 cm, the highest number of plants were found in the class 8-10 cm (10.7%, Figure 16), on the rows planted by the original coulter. It is, however, difficult to make any definitive conclusion about the accuracy of the work of the coulter, since as a result of the reasons advanced earlier the plant population after germination was lower than expected. For the modified coulter, Figure 17, the situation is as follows: with a target intra-row distance of 12 cm, the highest number of plants were found in the class 14-16 cm (15.6%). From the measurements of intra-row distances in this experiment it is difficult to establish the superiority of one

coulter over the other. From earlier analysis however, it is clear that coulter shape have effect on its performance. Figures 2 and 3 show the difference in the shapes of these two coulters. From Figures 19 and 20, we can conclude that the effect of operating velocity of the original coulter on the depth of planting is not much. In the case of the modified coulter the effect is substantial. For the new coulter "Nowa 85" the effect of velocity is also not much. The results of planting depth obtained for the three coulters show that both the original and modified coulters are characterized by high values of standard deviation, the fact that a control wheel was used in both cases notwithstanding. In the case of the new coulter "Nowa 85", no control wheel was used. This last coulter worked at the depth of between 2.3 and 2.6 cm, with the target depth at 2.5 cm. The deviation from target depth was not much which shows good performance of this coulter.

Advantages of the new coulter "Nowa 85"

- operation without control wheels
- maintains approximately the set planting depth
- possibility of adjustment of the blades
- possibility of adjustment of the curved wings.

Figure 19 and Figure 20 depict respectively the manually measured planting depth and those measured with instrument. There is no significant difference between the quantities presented in these two Figures. This shows the accuracy of the automatic measurement method used. From Table 2 we can establish that there exist a non proportional effect of working velocity of the original coulter of precision planter PKV-6 on the coverage distance. The operating velocity of both the modified coulter and the new coulter "Nowa 85" does not have much effect on the coverage distance. The curved wing of these two coulters, irrespective of the operating velocity, caused spontaneous covering of the furrow.

### Conclusions

1. Coulter shape and its operation affect the root system and growth of crops.
2. The process of furrow covering by the original coulter is affected by velocity of operation.
3. The process of furrow covering by both the modified and new "Nowa 85" coulters is not significantly influenced by the operating velocity.
4. Increase in operating velocity of a planter with either original coulter or modified coulter courses a slight decrease in planting depth.
5. Increase in operating velocity of a planter with the new "Nowa 85" coulter has however little effect on its planting depth.
6. The new coulter "Nowa 85" maintains the desired planting depth with just small deviations even though no control wheel was used. This provides the possibility of eliminating control wheels in future designs of precision planters, there by reducing the overall weight of the planters.

7. The results obtained from the automatic measurement of planting depth and manual measurements were close. This shows the usefulness of the automatic measurement system used in this studies. Its use in similar studies is therefore recommended.

### Summary

Variations in the shape, dimensions and the positioning with respect to the metering mechanism of coulters on precision planters show that manufacturers do not follow any specific standard. To assess the performance of coulters and the effect of their shape on the overall performance of precision planters, furrow opening and closing processes were studied. To this end, an experimental procedure for monitoring these processes was developed. Two coulters and their modifications were studied. On the basis of the findings of the above studies and theoretical assumptions, an entirely new coulters was designed, fabricated and tested. Results show that coulters shape affects the performance of precision planters.

### References

- 1) Soporysz, K. : Study on the Work of Coulters. M. Sc. Theses IMER AR Krakow (In Polish), 1983.
- 2) Domyslawska, E. : Precision Planting of Sugar Beet and Corn. *Mechanizacja Rolnicza* 3/77 (In Polish), 1977.
- 3) Bajak, R. : Study on Precision Precision Planters. Unpubl. M. Sc. Theses IMER AR Krakow, Poland (In Polish), 1984.
- 4) Kanofojski, Cz. : Theory and Construction of Agricultural Machines t. 1 cz. 3, PWRiL 1977 (In Polish), 1977.
- 5) Karwowski, J. : Precision Planting. *Mechanizacja Rolnicza*. 3/79 (In Polish), 1979.
- 6) Dudzik, A. : Studies on the Effect of the Angular Velocity of the Sowing Disc on the Distribution of Seeds. Unpubl. M. Sc. Theses IMER AR Krakow (In Polish), 1980.
- 7) Nowocien, L. : Studies on the Effect of Coulters Shape on Seed Distribution. M. Sc. Theses IMER AR Krakow (In Polish), 1980.
- 8) Yisa, M. G. : Performance of Precision Planters Taking into Account Coulters Shape. Unpubl. M. Sc. Theses, IMER AR Krakow, Poland (In Polish), 1985.
- 9) Chaniecki, E. : Pneumatic Planters. *Maszyny i Ciagniki* 9/78 (In Polish), 1978.
- 10) Glanze, P. : Grain Maize Mechanized Production In the Tropical and Subtropical Regions. Copyright 1972 by Edition Leipzig, 1972.
- 11) Dobrzanski, B. : Soil Science 4th Ed. PWRiL Warsaw (In Polish), 1983.
- 12) Oleksynowa, K., Tokaj, J. and Jakubiec, J. : Handbook of Experiments in Soil Science and Geology for Students of AR Cz. II Wyd. III, Krakow (In Polish), 1979.
- 13) Bohn, W. : Methods of Studying Root Systems. Springer- Verlag Berlin, 1979.
- 14) Platt, Cz. : Problems in Probability and Mathematical Statistics. Wyd. III PWN Warsaw 1978. (In Polish), 1978

- 15) Dubas, A. : Corn in Large Scale Production. PWRiL Warsaw (In Polish), 1981.
- 16) Walczyk, J. : Analysis of Metering Devices and Coulters of Precision Planters. Zeszyty Naukowe Akademii Rolniczej w Krakowie. (In Polish), 1987.