BUTTERWORTH HEINEMANN

0261-2194(95)00002-X

Crop Protection Vol. 14, No. 4, pp. 335–340, 1995
Elsevier Science Ltd
Printed in Great Britain.
0261-2194/95 $10.00 + 0.00

Weed control in sugar beet by precision guided implements

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A field experiment was carried out in sugar beet with a wide-span (12.2 m) tractor and laser guided implements. By means of a side-shift facility, implements were mounted on this vehicle for seedbed preparation, drilling, fertilizing, spraying and hoeing. Automatic laser guidance was possible with an accuracy of 0.6 cm on a track length of 220 m on arable land.

No inputs (soil cultivation, fertilizer, herbicide) were made at places where they were not needed, or even would potentially pollute the environment. The aim of the experiment, which was carried out in 2 successive years on fields of the same farm, was to investigate the influence on weed occurrence and efficiency of weed control.

Leaving out seedbed preparation between the future crop rows left already germinated weeds alive. In 1 year pre-emergence application of paraquat–diquat was necessary to stop growing of well developed weed plants. A crumbling operation had to be carried out to break the clods, otherwise inter-row hoeing was impossible. From the viewpoint of weed control restricting seedbed preparation to the future sugar beet rows was not of advantage.

Precision guidance allowed enlargement of mechanical weed control, i.e. interrow hoeing to 80% (40 cm wide at a row distance to 50 cm). Savings on herbicides were 75%, because little overlap was necessary of chemically and mechanically treated areas. The absence of fertilizers in these inter-row bands did not diminish the number of weeds, and speed of emergence of weeds. The effect of seedbed preparation and drilling the sugar beet crop in complete darkness (at night), made possible by the automatic guidance, on weed infestation was not different from daylight treatments. In these experiments this so called photo-control of weeds was only demonstrable after hoeing.

Keywords: weed control, precision guidance, photo control

Many agricultural crops are grown in rows with inter-row distances that vary between 0.25 and 0.75 m. Intra-row spacing is often far less, varying from 0.05 to 0.5 m. This means that on both sides of a crop row, there are bands of soil which serve as spacer bands only. Nevertheless, these spacer bands are crumbled, fertilized, sprayed and treated as part of the crop.

To lower the dependency of farmers on the use of chemicals, and to decrease the overall use of chemicals by half in the year 2000 (MJP-G, 1992), research has to be done on alternative weed control methods. Band spraying is an option by which a reduction in the chemically treated surface of a sugar beet field can be achieved by enlarging the mechanically treated part. The normal practice nowadays is an inter-row treatment with a hoe that covers 60–67% of the total surface (Kouwenhoven, Wevers and Post, 1991).

There are two possibilities of enlarging the mechanically treated area: one is an intermittent weed killing action inside the sugar beet row, and the other, a broadening of the mechanically treated area between the rows. Both ways require some form of intelligence and automation, the first to detect the spots where the sugar beet plants are growing, the second to guide the hoe very closely along the sugar beet rows. Bontsema, Grift and Pleyzier (1991) did research on how to distinguish the sugar beet plants from weeds, to make it possible to swing a hoeing knife through the row of sugar beet plants. Laser guidance of the hoeing implement, and prior to that of the sowing machine used in this experiment, make it possible to approach the row of sugar beet plants very closely without risk of damaging them.

The aim of this research was to investigate the possible economy on fertilizer and herbicide inputs by applying them only where needed, aided by the use of a precision guidance system. Also the effect of creating different situations inside the row and between the rows, related to the absence or availability of fertilizer in the inter-row bands and the absence or presence of a germination bed at the same place, is of influence on the emergence and development of weeds. The option of doing the various activities in complete darkness (at night), or in the daylight, is of influence on the germination of the weed seeds in the soil (Hartmann

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and Nezadal, 1990). Band fertilizing not only saves costs (De Wit, 1953), but also has an effect on the germination of weeds in the non-fertilized spacer bands (Bouwmeester, 1990).

The objectives of the experiment requires a very accurate guidance system for all the implements used, to be able to re-find the growing regions or bands in the field each time, and to make it possible to create a field build-up as a collection of alternating growing bands and spacer bands.

Materials and methods

Airborne navigation systems such as the Global Positioning System (GPS) using satellites as a reference are unlikely to provide the accuracy and the speed needed for guiding an implement over the field in a row crop (Tillett, 1991). Shmulevich, Zeltzer and Brunfeld (1987) described a laser scanning positioning system on the subject of automatic guidance of vehicles in the field. Accuracy of this method (0.15 m) is inadequate with respect to the objective required for this application.

Therefore, a field-bound guidance system was developed using a laser transmitter which emits a laser beam rotating in a vertical plane. The transmitter was positioned at the end of the field and had to be repositioned for each next double pass of the implement.

The research project was carried out in 1991 and 1992 on the 'Oostwaardhoeve' experimental farm in Slootdorp. The soil type, though slightly varying over the field, was mainly a highly calcareous loamy sand type of approx. 20% silt, 1.5% organic matter and a pH (KCl) level of 7.6. The 20 ha field was split up into two 10 ha fields, each with a 5-year rotation. The 5-year rotation was made up with cereals, potatoes, sugar beet, broccoli and iceberg lettuce. This resulted in two × five plots, each of 73.2 m × 200 m. All tests were restricted to sugar beet because of the availability of mechanization for this crop on the special-type vehicle.

The vehicle used was a Dowler gantry, a wide-span (12.2 m) vehicle with four wheels. On each side there is a main wheel with hydrostatic drive and a pivoting rear wheel in a parallelogram-type suspension. The vehicle has a 70 kW (90 hp) turbo diesel engine that makes it suitable for secondary tillage and nursing activities only, the implements having a 12 m working width and working in between the tracks of the wheels on 12 m wide beds.

The main tillage was carried out in November of the previous year with a four-furrow reversible plough drawn by a 108 kW (145 hp) tractor on wide tyres with a maximum air pressure of 1 bar. The ploughing depth was 0.28 m.

For preparing the full field seedbed, a 81 kW (110 hp) tractor was used, driving a 4.5 m wide rotary tiller of the type 'Lelyterra' for full-field plots. The tractor was equipped with wide-section tyres (0.42 m) at a tyre pressure of 1.0 bar. The row-type seedbed preparation was carried out with the gantry and a 24-element Stanhay Webb row crumbler. This implement exists of 24 parallelogram-mounted elements, each carrying three vertical round teeth and a cast iron spiked roller. A V-shaped clod mover was mounted in front of the teeth.

Fertilizing was done in the first year with a Nodet-Gougis pneumatic fertilizer spreader with 12 double outlets, one outlet for each row. By lifting the machine the full-field treatment was effected, because the fertilizer grains bounced in all directions when hitting the ground resulting in an even distribution. As the fertilizer grains were also bouncing sideways in row application, because of the airstream from the pneumatic transport system of the spreader, this machine was replaced by a Stegsted cereals drill in the second year. On the latter, every fourth outlet was used to obtain a row distance of 0.5 m. Because this machine uses coulters instead of an airstream, the fertilizer was dosed in neat bands of about 7 cm wide, with the coulters just touching the surface during application. The amount of fertilizer was 130 kg N ha^{-1} when dosed full field and 35 + 60 kg N ha^{-1} at the row application, given in two times: the first 1 week before sowing, the second 11 weeks after sowing. The first dose was, as was the full field application, mixed with the soil top layer when preparing the seedbed, the second dose was given in a 2 cm deep furrow about 5 cm next to the crop row.

Drilling the sugar beet was done with a 24-element Vicon-Fähse (Monopill) precision drill, which is almost a standard implement for this purpose.

In 1991 band spraying of herbicide was carried out by adjustment of the permanent spray boom on the gantry 15 cm above ground level. In this position the spraying width per nozzle was limited to approx. 12.5 cm, with the flat fan nozzles (Teejet 4003E; 40 degrees top angle, even spray variety, spray pressure 2.1 bar) being spaced 0.5 m apart and thus spraying right over the future crop rows. Due to the very low height of the spray boom, the drift of droplets by wind was also limited to almost zero. Two post-emergence sprayings were carried out with so called low dosage mixtures of phenmedipham, metamitron, ethofumesate and mineral oil (0.5 l or kg ha^{-1} of the commercial products, in 200 l water). In 1992 one full field application pre-emergence was carried out with metamitron (2.8 kg ha^{-1} a.i., in 300 l water using nozzles Albuz green at 2.3 bar). In both years the fixed quadrats used for counting the number of weeds were not treated with herbicides.

When weed control became necessary in the 'spacer bands' between the crop rows, hoeing was executed with a Kongskilde Vibra-Beta hoeing equipment (23 elements). These elements each existed of a parallelogram-mounted frame, that carried three spring tines, each equipped with a duckfoot chisel. By sliding the outer teeth to the side, the working width of the set of three could be adjusted by increasing or decreasing the overlap of adjacent chisels. Each crop row was protected by teethed, concave protection discs that shielded the crop from moving soil and clods when the chisels passed.

The two opposite oriented trial fields were approx. 1.5 ha each and separated by a field road and a ditch. Along this road the adaptors for the laser transmitter pedestal were present. The fields were ploughed in autumn and cultivated once with a rigid tine cultivator with duckfoot chisels during wintertime.

The experimental plots were 12 m wide and had a length of 45 m each. Four factors were investigated in two variations. In 1991 all variants and factors were combined in one experiment. This gave 2^4 combinations; in three replications this means a total of 48 plots. In 1992, variants A and B were combined (see below), and so were variants C and D, resulting in 24 plots for 6 repetitions. The variants were:

(A): Band application of fertilizer, compared with full-field application.
(B): Seedbed preparation in bands, compared with full-field cultivation.
(C): Seedbed preparation in the dark (on moonless nights; <0.1 lx), compared with seedbed preparation in daytime.
(D): Sowing and hoeing in the dark, compared with the same in daytime.

All treatments were done with the 12.2 m wide gantry, except the full-field seedbed preparation, which was done with a normal tractor with a rotary cultivator. The demands for the light level when working in darkness corresponded with previous research by Hartmann and Nezadal (1990). This made the use of an automatic guidance system, to guide the drilling machine, the hoe, etc., accurate over the field in complete darkness, so obligatory. The sugar beet variety was Lucy, the row distance was 0.5 m and the seed spacing in the row was 0.2 m.

In 1991 the numbers of weeds were counted 7 times at intervals of 1–2 weeks at 4 fixed places in the rows of sugar beet and on four fixed places between these rows to determine the effect of the various treatments. There were three repetitions of each treatment, resulting in 12 countings per treatment. Counting was done with the help of a rectangular steel bar framework of 0.125 × 0.8 m (0.1 m^2), on fixed quadrants. When the canopy closed, the countings were terminated. In 1991 the statistical software used to analyze the data was GENSTAT.

In 1992 the number of weeds was counted three times, 4 and 8 weeks after sowing and 6 weeks after hoeing. The countings were done at 10 fixed places in the row of sugar beet, and at 10 fixed places between the rows. The rectangular framework used to indicate the area to be counted was the same as in 1991. Statistical analysis of the data was done with SPSS this year.

Results

The most important weeds were *Polygonum aviculare*, *Matricaria chamomilla*, *Poa annua* and *Solanum nigrum*, but also 20 other species were observed, irregularly spread over the field. Because the number of individuals was low, it was not useful to present the results of the countings carried out per species. Therefore only the numbers of all weed plants are mentioned.

Presence or absence of seedbed

The number of weeds *between* the crop rows is of interest here for analysis. The comparisons can be made 'full-field seedbed' = seedbed present, and 'row-type seedbed' = untouched soil.

In 1991 the number of weeds was significantly lower on the prepared soil compared to the untouched soil, but only during the first 4 weeks after sowing (*Table 1*). The increase of the number of weeds on the prepared soil was much faster than on the untouched spots. The higher amount of biomass on the untouched soil is the result of bigger sized (older) weeds.

In 1992 weeds present on the ploughed land (before seedbed preparation) were rather well developed and had therefore been treated with a full-field dose of paraquat–diquat applied one week before sowing. This resulted in a lower number of weeds on the untouched soil compared to the soil cultivated for seedbed preparation, indicating also a faster development of the weeds on prepared soil as on untouched soil. The weeds were very small, resulting in low amounts of biomass.

Also in 1991 the two implement types for making a germination bed were compared in relation to the weed development on the treated surface. The number of weeds in the row were counted. Difference in the emergence of weeds was not measured. The weeds that grew in the rotavated seedbed were larger: biomass was almost double compared to the row type seedbed.

Presence and dose or absence of fertilizing

For this aspect, the availability of fertilizer for the germination of weeds, the results of countings *in the rows* and *between the rows* are used for analysis. Here, the comparison can be made 'full-field fertilized' =

Table 1. Number of weeds m^{-2} between crop rows. Average countings on 3 × 4 (1991) and 10 (1992) fixed spots. Biomass in g dry matter per m^2, at 10 weeks after sowing

Weeks after sowing	1991 Germination bed	1991 Untouched	1992 Germination bed	1992 Untouched
3	1.8**	10.3		
4	8.6*	14.1		
5	17.5	19.1	15.5**	3.8**
7	25.0	22.8		
8	24.7	23.4		
10	38.0	47.7	20.0**	5.3**
Biomass (g)	338	446	0.7	0.2

*$P < 0.10$; **$P < 0.05$

Table 2. Number of weeds m^{-2} in the crop rows. Average countings on 3 × 4 fixed spots. Biomass in g dry matter per m^2, at 10 weeks after sowing

Weeks after sowing	1991 Germination bed by rotavator	1991 Germination bed by row crumbler
3	0.9	1.4
4	12.3	7.8
5	16.7	20.0
7	26.4	27.4
8	22.6	25.9
10	41.5*	54.4
Biomass (g)	184	105

*$P < 0.10$

Table 3a. (1991) Fertilizing yes/no. Number of weeds m^{-2}. Average countings on 3 × 4 fixed spots. Biomass in g dry matter m^2

Weeks after sowing	In crop rows Fertilizer 130 kg N ha^{-1}	In crop rows Fertilizer 35 kg N ha^{-1}	Between crop rows 130 kg N ha^{-1}	Between crop rows 0 kg N ha^{-1}
3	0.9	1.4	4.4	4.2
4	4.4	10.8**	9.0*	13.4
5	17.2	19.6	16.6	20.1
7	25.8	28.0	21.5	26.5
8	22.6	26.0	23.1	25.0
10	46.8	48.2	40.6	44.3
Biomass (g)	138.	306	276**	546

*$P < 0.10$; **$P < 0.05$

Table 3b. (1992) Fertilizing yes/no. Number of weeds m^{-2}. Average countings on 10 fixed spots. Biomass in g dry matter m^2

Weeks after sowing	Between crop rows Fertilizer 130 kg N ha^{-1}	Between crop rows Fertilizer 0 kg N ha^{-1}
5	15.5	13.0
10	20.0	13.5
Biomass (g)	0.7	0.3

fertilized and 'band fertilized' = fertilized with the first dose (in the row) or not fertilized (between the rows). *Tables 3a and b* show that the number of weeds is not significantly different between fertilized and not fertilized treatments. After week 10 a supplementary dose of 65 kg N ha^{-1} was given (in the row fertilized object) to complete the 75% dose compared to full field fertilizing. This reflects on a full field dose, so actually only 25% of these amounts were supplied, on 12.5 cm wide bands with 37.5 cm wide inter-row spacings. The significant higher amount of biomass of the weeds on non-fertilized strips can not be made clear.

Photocontrol

To determine the influence of light during soil cultivation on the germination of weeds, the effect of seedbed preparation and also of hoeing during the day or at night can be measured *between* the sugar beet rows. Due to interactions between 'seedbed preparation' and 'sowing', carried out sequentially, the results of these treatments should only be judged together. These influences can be measured *in the rows* of sugar beet.

The results of these types of spoil cultivations in dark and in light on the emergence of weeds are already described in detail by Naber *et al.* (1992) and are summarized in this paper in *Figures 1–4*.

Figure 1 shows that the number of weeds after cultivation at night is not lower than after cultivation during the day, so no photocontrol effect on the weeds of seedbed preparation at night could be established.

The effect on the emergence of new weeds after hoeing in the dark (*Figure 2*) was only significantly different from hoeing in daylight in 1991, although also in 1992 a clear tendency towards fewer new weeds emerging after hoeing in the dark, so photocontrol, appeared to work.

After seedbed preparation in the daytime (*Figure 3*), the number of weeds in 1991 is lower when sowing is carried out at night compared to sowing at daytime; however, this was not confirmed in 1992.

Seedbed preparation in the dark (*Figure 4*) followed by sowing at night compared to sowing in the light did not show any difference in the number of weeds. This justifies the conclusion that seedbed preparation and sowing in darkness have no photocontrol effect on the weeds.

The results of the integrated chemical and mechanical weed control, outside the area where countings were conducted, were very good. Without

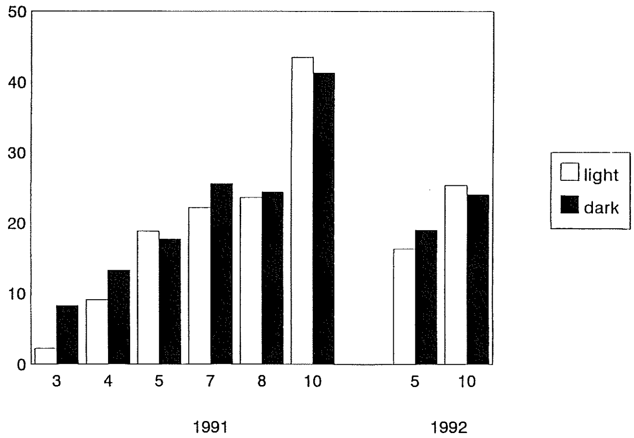

Figure 1. Seedbed preparation in light/in dark. Number of weeds m^{-2} – weeks after sowing.

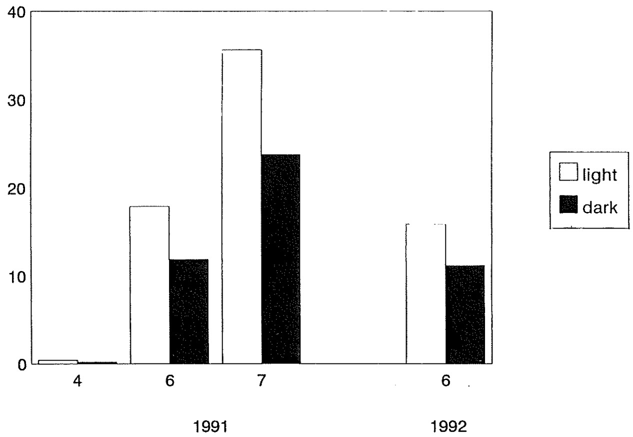

Figure 2. Hoeing in light/in dark. Number of weeds m^{-2} – weeks after sowing.

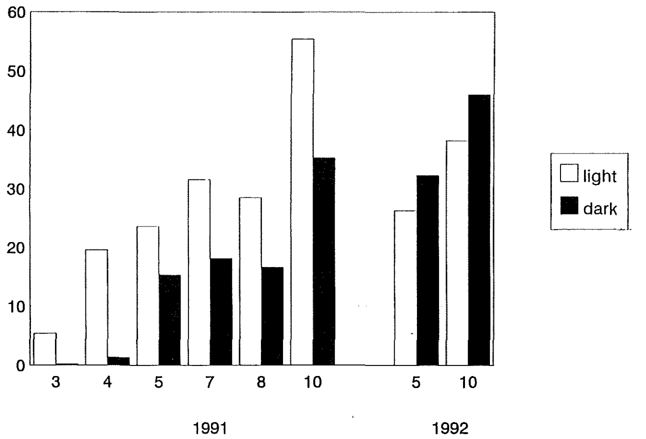

Figure 3. Seedbed preparation in light, sowing in light/in dark. Number of weeds m^{-2} – weeks after sowing.

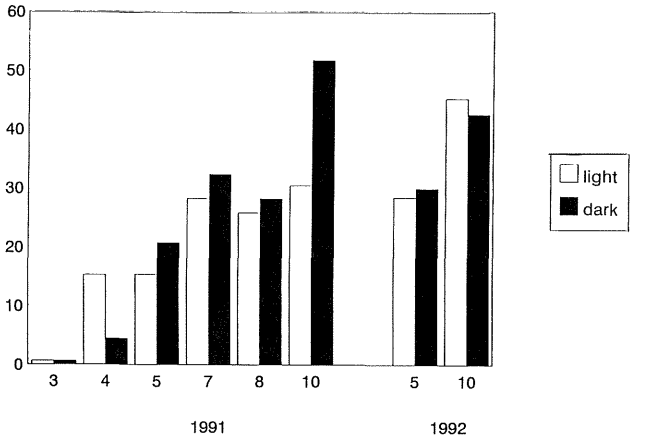

Figure 4. Seedbed preparation in dark, sowing in light/in dark. Number of weeds m^{-2} – weeks after sowing.

any technical problem herbicide application and hoeing could be carried out with the laser guided implements.

Discussion and conclusions

The aim of the 2 year field experiment was to investigate precision guided implements for crop management, focused on weed control in sugar beet.

The advantage of not making a germination bed between the rows of sugar beet to be sown is too small to justify practical application on this loamy sand soil. This mechanical effect can hardly be missed in the total weed control operations, unless herbicides are used to control them. Seedbed preparation has a killing effect on the weeds that had germinated during winter time and early spring. When the spacer bands between the sugar beet rows are not prepared as the rest of the seedbed, the soil is left in a very rough, cloddy state that is hard to hoe without damaging the small sugar beet plants by the big clods that are shifted sideways. The theory behind leaving out seedbed preparation between the rows to spare energy (fuel) was shown to be unrealistic either from the view point of weed control and from the point of crop management.

Avoiding the placement of fertilizer between the rows (in the 'spacer bands') by applying the fertilizer only in bands of 12.5 cm wide, is technically no problem with the laser-steered implements, either before sowing, before emergence or after emergence of the sugar beet crop. Not applying fertilizer to the spacer bands increases the efficiency with which the sugar beet plants use the fertilizer (the uptake) and minimizes the chance of leaching. It was expected also that the germination of weeds and their development would be less when these bands were not fertilized. In fact no difference was found in the numbers of weeds growing on fertilized or on non-fertilized spots. Theoretically, weed infestation, in number and in biomass, might be reduced by the placement of fertilizer out of reach of the weed seeds. It cannot be excluded that residual effects from the previous year (some nitrate left from the preceding crop) caused a nitrate level that was high enough to stimulate the germination of weeds between the rows.

Research into the effects of photocontrol was the third item of the field experiment in the 2 years. The laser-steered implements are ideal for this type of experiments as seedbed preparation (band cultivation), sowing and hoeing can be carried out in complete darkness without difficulty and with high precision.

Jensen (1992) obtained positive effects of photocontrol in his field trials in spring barley and winter wheat. Also Scopel, Ballare and Radosevich (1992) report about lower weed infestation after soil cultivation in the dark, even if they use the tractor's lights.

In our two year experiments seedbed preparation at night was not shown to be effective in decreasing the number of weed seedlings. Also the combination with sowing, both during the day and at night, does not produce a combination that was of advantage. Even if all the work is done in the dark, the number of weeds is the greatest.

It should be concluded here that the germination of weed seeds depends on more factors than on light alone. Post (1994) remarks that the need of the weed seeds for light to germinate can be compensated by dry weather conditions after soil cultivation. The seeds dry out under these circumstances and germinate without receiving light when the soil becomes moist again. The loamy sand soil used in our experiments easily dries out as was already mentioned under seedbed preparation.

The only positive effects of photocontrol in our field experiments were found after hoeing. In both years the amount of new germinating weeds after hoeing was lower, when this mechanical weed control was carried out in the dark.

The laser guidance of the implements on the wide span tractor has shown to be completely reliable even in the dark, so a straight course of all implements is guaranteed at any time, and hoeing the weeds close to the sugar beet plants is possible, increasing the percentage of mechanically treated surface. Reduction of the chemically treated area for weed control leads to a minimum band size of 12.5 cm. Combination with inter-row hoeing of 0.4 m wide (2.5 cm overlap) results in an optimum integration of chemical and mechanical weed control and an increase in the mechanically treated percentage of the surface from 60–67% in normal practice up to 80% in this system.

Acknowledgement

The authors want to thank the students Peter Baltus (1991) and Ilse Leeuwerik (1992) who did the observations on weed control.

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Received 29 December 1993
Revised 29 November 1994
Accepted 8 December 1994