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Effect of haulm destruction supplemented by cutting off roots on the incidence of black scurf and skin damage, flexibility of harvest period and yield of seed potatoes in field experiments

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Abstract

In field experiments, supplementing chemical haulm destruction (CHD) with cutting off roots resulted in a lower incidence of black scurf and skin damage (ripping off the skin) at harvest date than CHD alone. The lower susceptibility to skin damage at harvest allowed harvesting to begin on an earlier date, when only a few sclerotia of *Rhizoctonia solani* had developed. Furthermore, black scurf often developed more slowly after haulm destruction if roots had been severed and this enabled harvesting to be postponed.

At harvest, gross yield was highest if roots had not been cut through prior to CHD: the extra weight existed merely of water. Weight loss during storage, however, as well as grading losses resulting from black scurf were greater after CHD alone. This resulted in an equal or even lower net yield after CHD alone than after CHD supplemented by root severing. The favourable effects of supplementing CHD with cutting off roots almost equaled those of the mechanical removal, often called 'haulm pulling' or 'plant pulling'. Factors that may affect the development of black scurf are discussed.

Additional keywords: periderm, *Rhizoctonia solani,* sclerotia, *Solanum tuberosum,* tuber.

Introduction

In the search for the fundamental causes of black scurf it appeared to be useful to investigate the stimulatory effect of haulm destruction on the development of black scurf (Dijst, 1985).

In order to prevent virus transmission by flying aphids, haulm destruction is mandatory when growing seed potatoes in the Netherlands. The date of destruction is based on local counts of winged aphids and generally coincides with the second half of tuber growth. Haulm destruction of potato plants enhances the production of sclerotia on the tubers by *Rhizoctonia solani* Kühn. Chemical haulm destruction (CHD) is usually more stimulative than mechanical haulm removal, the so-called 'haulm pulling' or 'plant pulling' (Reestman and Schepers, 1955; Bouman et al., 1983).

Therefore, haulm pulling is recommended instead of CHD. However, under certain circumstances only CHD can be used; this results in high grading losses because of black scurf. It was therefore decided to ascertain why CHD stimulates black scurf much more than haulm pulling and whether this can be prevented.

CHD differs from haulm pulling in at least two aspects, which may account for the different impact on black scurf development of these two techniques. First, tuber physiology is affected differently: haulm pulling breaks the stolon whereas after CHD the tubers are still connected to the roots, which continue to function for several days after the treatment (Dijst, 1985). Second, the two measures affect the environment around the tuber differently: haulm pulling disturbs the soil of the ridge and CHD does not. Supplementing CHD with cutting off the roots eliminates both differences, for root severing terminates sap flow from the main root system to the tubers and disturbs the soil. In greenhouse experiments, supplementing CHD with root severing was found to be fairly successful, often giving black scurf ratings equal to those after haulm pulling and lower than after CHD alone (Dijst, 1985). However, the effect of root severing on black scurf development had not been evaluated in the field. We believed that by preventing tubers from swelling with water and by stimulating soil aeration, cutting off roots in the field might reduce skin damage at harvest as well.

The objectives of this study were twofold: to evaluate the efficacy of root severing in the field as a measure for controlling black scurf after haulm destruction and to examine what factors might favour black scurf development. The field experiments reported in this paper investigated the effect of different plant treatments with or without cutting off roots on (1) the incidence of black scurf, (2) skin damage at harvest, (3) the duration of the harvest period, (4) yield at harvest, (5) water content of the tubers and (6) the decrease of fresh weight during storage. Preliminary reports on this research have been published (Dijst et al., 1985).

Material and methods

Experimental design. Details on experimental conditions are given in Table 1. Disinfected seed was used for all trials. In the first experiment with cv. Arjan, samples of tubers were taken from different sites in a grower's field. The other experiments were carried out on research farms according to block designs. In the split-split-plot trials two varieties were planted on the main plots and treatments were on subplots. The four sampling times were randomly allocated to four small 'sample-plots' within each subplot. The sample-plots consisted of 40 (in 1982) or 24 (in 1983) plants and were surrounded by two buffer rows of plants.

Plant treatments. All the treatments of one trial were applied on the same day (day 0) In some experiments the 'E' or 'A' date was chosen to be day 0. The 'E' date and 'A' date are the dates on which haulms must be killed when cropping for seed potatoes grade E or A, respectively. In the Netherlands, basic seed potatoes are classified as SE (highest quality) or E. Basic seed potatoes can produce certified seed potatoes of class A (highest), B or C. If a higher classification is decided haulm destruction must be earlier. Since E-class potatoes are thus higher qualified than A-class potatoes, the 'E' date of haulm killing is some days earlier than the 'A' date on each location.

Haulm pulling and cutting off the shoots were done by hand. In earlier work (Dijst,

Table 1. Details of the experiments.

Year	Cultivar	Location	Soil type	Planting time	Experimental block design	Number of replicates	Weather during			Date of haulm killing (day 0)
							spring	summer	experiment	
1982	Arjan	Assen	reclaimed peat	April	none	3	wet	normal	very dry	26-07
1982	Prominent	Haren	sand	April	randomized	3	wet	normal	very dry	29-07
1982	Prominent	Rolde	diluvial/ loamy sand	April	randomized	4	wet	normal	very dry	19-07 (E)
1983	Astarte	Rolde	diluvial/ loamy sand	end of April	randomized	4	very wet	dry	dry	18-07 (E)
1983	Astarte/ Prominent	Rolde	diluvial/ loamy sand	end of April	split-split-plot	4	very wet	dry	dry	25-07 (A)
1983	Astarte/ Bintje	Creil	alluvial/ loamy sand	May	split-split-plot	4	very wet	dry	rain once on day 9	12-08

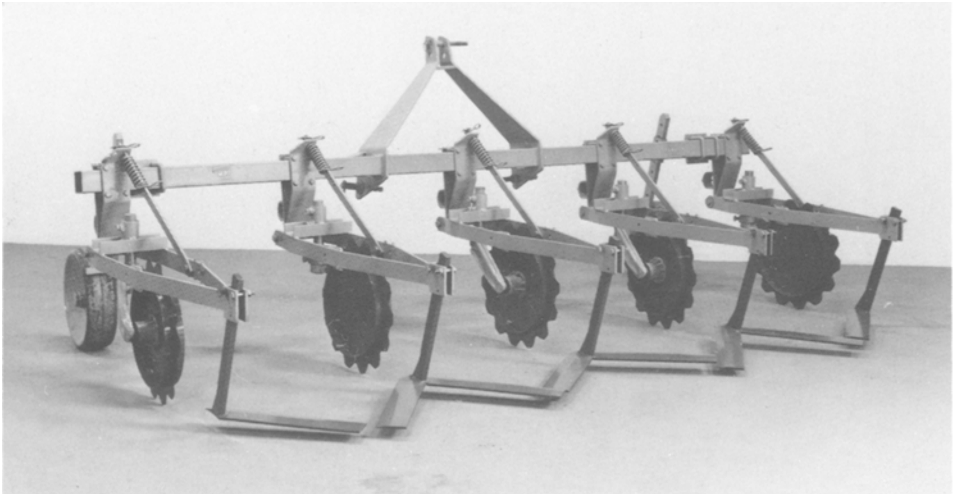

Fig. 1. The root-severing implement.

1985) the term 'plant pulling' was preferred to 'haulm pulling', because most of the plant (viz. above- and underground stems) is removed by this treatment, leaving the tubers. But since 'plant pulling' has already been used for another technique the term 'haulm pulling' has been reinstated in this report.

For CHD, dinoseb (Chimac Loofdood, 250 $g.l^{-1}$) was applied at a rate of 15 litres in 600 litres water per hectare. Where indicated, haulms were stripped prior to CHD with a flail-type haulm shredder which reduces shoots to almost leafless stems. After haulm stripping, lower amounts of chemicals are needed to kill the haulms completely and harvesting is also facilitated. In the fields at Haren the roots were cut through lifting the plant with a fork. In all other experiments a root-severing implement was used (Fig. 1). This tractor-mounted implement cuts the roots of four rows with two adjustable knives per ridge. The roots were cut through in the morning, followed by CHD either immediately or six hours later, when shoots had lost turgor.

Harvest and yield. Prior to harvest on days 3 and 10, soil water content in the centre of the ridge was determined. Tubers were harvested by hand, except for those of cv. Arjan, which were harvested by machine. Where the root-severing implement had been used, no complications occurred during mechanical harvesting, regardless of the depth of cutting. Immediately after harvest the tuber fresh weight (fw) and tuber dry weight (dw) of 32 (in 1982) or 16 (in 1983) plants per sample-plot were determinded.

Rating of black scurf. In order to estimate the amount of black scurf, samples of 100 tubers from at least eight plants were harvested per sample-plot and each sample was stored in a separate box to prevent skin damage. Three weeks later the tubers were graded. When unwashed tubers that had been classified as being free from sclerotia were subsequently washed, 10% still appeared to be lightly covered with sclerotia. Therefore, in all trials tubers were washed carefully prior to grading. The index (0-100) was calculated from the number of tubers in each of five severity classes as described previously (Dijst, 1985).

Rating of skin damage. In order to measure skin damage at harvest, tubers from 12 plants per sample-plot were wounded in a rotating drum designed for this purpose (Bouman et al., 1983). They were then incubated for two minutes in an aqueous solution of pyrocatechol at 1.9 $g.l^{-1}$ and the damaged surface turned black within five minutes. These tubers were graded in six classes according to the amount of blackened surface area: 0% (a), 0-5% (b), 5-20% (c), 20-40% (d), 40-75% (e) and more than 75% (f). The index (I) for skin damage (0-100) was calculated using the formula:

$$I = 100. (0.a + 1.b + 2.c + 3.d + 4.e + 5.f)/ (5.t)$$

where the characters a to f stand for the number of tubers in each class and t is the total number of tubers in the sample.

Yield loss. From each sample-plot at least 25 skin-damaged tubers and 25 undamaged tubers were weighed at harvest and weighed again after 30 and 90 days of storage, in order to estimate weight loss in storage. Yield loss caused by black scurf was measured by grading according to the requirements for class A seed potatoes: heavily and moderately covered tubers and some of the lightly covered tubers were eliminated until no more than 25% of those that remained were lightly covered.

Statistical analysis. All data were compared by analysis of variance using Genstat programming (V release 4.04 B, copyright 1984 Lawes Agricultural Trust, Rothansted Experimental Station). Differences between percentages (P) were analyzed after arcsinus transformation: $\arcsin (P \times 10^{-2})^{1/2} \times 57.296$.

Results

Ten days after haulm destruction the shoots were completely dead. On that date the shoots of untreated control plants were still green, and the shoots of plants where only the roots had been cut through were wilting and yellowing. There was great variation between replicates at Creil, possibly because of unequal distribution of irrigation water.

Black scurf. Analysis of variance showed a significant difference in black scurf development between cultivars: tubers of cv. Astarte being covered by sclerotia significantly less than those of cvs Prominent and Bintje (Table 2). At Creil in 1983 only few sclerotia developed on tubers of cv. Astarte and even fewer on those of cv. Bintje. Differences in incidence of black scurf between plant treatments did not become visible until 7 to 10 days after haulm destruction. The treatment effects were the same in all experiments. At Rolde in 1983 differences among treatments were more pronounced for cv. Astarte than for cv. Prominent.

During the first two experiments in 1982 black scurf increased more slowly after CHD supplemented by root severing as compared with CHD alone (Table 3). At Rolde in 1982 cv. Prominent showed only slight difference in black scurf development between the various treatments (Table 4). Nevertheless both haulm pulling, and to a lesser

Table 2. Effects of cultivars, treatments and date of sampling on severity of black scurf and skin damage in 1983, estimated by analysis of variance.

	Black scurf development		Skin removal at harvest	
	Rolde	Creil	Rolde	Creil
Cultivar[1]	*[2]	**	*	**
Treatment	***	NS	***	***
Cultivar × Treatment	NS	NS	NS	*
Day number	***	***	***	***
Cultivar × Day	NS	NS	***	**
Treatment × Day	***	*	**	***
Cultivar × Treatment × Day	NS	NS	NS	NS

[1] Rolde: cvs Astarte and Prominent haulms killed on A-date; Creil: cvs Astarte and Bintje.
[2] Significances at P = 0.05 (*), P = 0.01 (**) and P = 0.001 (***) level; NS = non-significant.

Table 3. Black scurf indices (0-100) of tubers after chemical haulm destruction (CHD) with or without cutting off the roots or after haulm pulling, in two experiments in 1982.

Method of haulm destruction	Number of days between treatment and harvest				
	cv. Prominent (1982) on sand			cv. Arjan 1982 on reclaimed peat	
	7	14	21	17	30
Haulms pulled	1	4 b[4]	9		
Shoots stripped + CHD	1	19 a	16	53 b	51
Roots cut off 250 mm deep + CHD[1]				60 b	53
Roots cut off 180 mm deep + CHD	0.1	5 b	13	35 a	36
Significance[2]	NS	**	NS	*	NS
LSD[3]	–	11	–	18	–

[1] Depth measured from the top of the ridge.
[2] Significances at P = 0.05 (*), P = 0.01 (**) level; NS = non-significant.
[3] LSD = Least Significant Difference for the above-mentioned P value.
[4] Values followed by the same characters are not significantly different.

extent, CHD supplemented by root severing gave a slightly lower incidence of black scurf than CHD alone. This also held for the experiments in 1983, but then the effects were more pronounced and differences were found to be significant.

At Rolde in 1982 when shoots were cut off either with or without root severing black scurf developed to the same extent as compared to CHD with or without root severing respectively (data not shown). An interval of six hours between root severing and CHD did not improve the effect of the supplementory root severing (data without an interval

Table 4. Incidence of black scurf (index 0-100) at different intervals after various treatments of the crop and haulm destruction on day 0.

Cultivar	Treatment[1]	Number of days between treatment and harvest					LSD[2] P = 0.05
		0	3	10	17	24	
Prominent-E	*Rolde 1982*						12.7
	S + CHD	—	11[3]	14	32 bc	42 bc	
	S + RC + CHD	—	8	19	30 bc	43 c	
	RC + 6h + CHD	—	7	20	25 abc	32 abc	
	Haulms pulled	—	10	15	15 a	31 abc	
	RC	—	13	15	20 ab	29 ab	
	Control (untreated)	10	14	14	16 a	26 a	
Astarte-E	*Rolde 1983*						12.4
	S + CHD	—	2	4	37 b	33 b	
	RC + 6h + CHD	—	1	5	10 a	28 b	
	Control (untreated)	1	2	3	3 a	13 a	
Astarte-A	*Rolde 1983*						11.5
	S + CHD	—	6	10	29 c	48 d	
	S + RC + 6h + CHD	—	2	4	23 bc	31 c	
	RC (+ 6h) + CHD	—	2	5	14 ab	27 c	
	Haulms pulled	—	2	11	13 a	18 abc	
	RC	—	4	8	10 a	9 a	
	Control (untreated)	3	3	3	12 a	15 ab	
Prominent-A	*Rolde 1983*						
	S + CHD	—	11	11	29 d	45 c	
	S + RC + 6h + CHD	—	6	12	25 cd	42 bc	
	RC (+ 6h) + CHD	—	7	9	19 abcd	31 b	
	Haulms pulled	—	12	16	22 bcd	32 b	
	RC	—	5	12	11 a	11 a	
	Control (untreated)	5	8	9	11 ab	17 a	
Astarte	*Creil 1983*						17.9
	S + CHD	—	4	4	4 a	8 b	
	RC (+ 6h) + CHD	—	2	3	9 a	15 b	
	Haulms pulled	—	3	3	1 a	5 b	
	RC	—	4	4	4 a	1 a	
	Control (untreated)	3	3	1	19 a	1 a	
Bintje	*Creil 1983*						
	S + CHD	—	7	13	27 ab	24 bc	
	RC (+ 6h) + CHD	—	12	4	25 ab	6 a	
	Haulms pulled	—	7	17	10 a	14 ab	
	RC	—	3	6	30 b	41 c	
	Control (untreated)	8	18	16	26 ab	13 ab	

[1] The treatments included: S = shoots reduced by stripping; CHD = chemical haulm destruction; RC = roots cut through; 6h = shoots destroyed chemically in the afternoon, six hours after root severing; (+ 6h) = identical results werd found when there was no time interval.
[2] LSD = least significant difference.
[3] Per date, values followed by identical characters are not significantly different. No characters per date means that there were no significant differences on that date.

Table 5. Skin damage at harvest (index 0-100) at different intervals after various treatments of the crop and haulm destruction on day 0.

Cultivar	Treatment[1]	Number of days between treatment and harvest					LSD[2] P = 0.05
		0	3	10	17	24	
Prominent-E	*Rolde 1982*						4.87
	S + CHD	—	49 d[3]	23 b	10 ab	4	
	S + RC + CHD	—	45 bcd	17 a	7 a	2	
	RC + 6h + CHD	—	41 b	15 a	9 a	3	
	Haulms pulled	—	42 b	17 a	8 a	4	
	RC	—	34 a	15 a	6 a	3	
	Control (untreated)	53	48 cd	31 c	14 b	6	
Astarte-E	*Rolde 1983*						9.98
	S + CHD	—	28 ab	24 a	13 ab		
	RC + 6h + CHD	—	20 b	8 b	5 b		
	Control (untreated)	48	33 a	32 a	21 a		
Astarte-A	*Rolde 1983*						7.60
	S + CHD	—	38 a	23 a	12 abc		
	S + RC + 6h + CHD	—	25 bc	8 b	5 c		
	RC (+ 6h) + CHD	—	20 cde	8 b	6 bcd		
	Haulms pulled	—	15 def	10 b	4 d		
	RC	—	12 f	4 b	4 d		
	Control (untreated)	24	32 ab	21 a	15 a		
Prominent-A	*Rolde 1983*						
	S + CHD	—	19 a	9 ab	4 b		
	S + RC + 6h + CHD	—	17 ab	6 b	2 b		
	RC (+ 6h) + CHD	—	11 b	4 b	3 b		
	Haulms pulled	—	11 b	3 b	1 b		
	RC	—	9 b	3 b	1 b		
	Control (untreated)	12	13 ab	14 a	15 a		
Astarte	*Creil 1983*						7.04
	S + CHD	—	48 ab	28 b	23 b		
	RC (+ 6h) + CHD	—	45 abc	17 c	11 c		
	Haulms pulled	—	40 c	19 c	13 c		
	RC	—	44 bc	13 c	14 c		
	Control (untreated)	44	52 a	44 a	52 a		
Bintje	*Creil 1983*						
	S + CHD	—	43 ab	16 b	10 b		
	RC (+ 6h) + CHD	—	43 ab	19 b	6 b		
	Haulms pulled	—	48 a	17 b	10 b		
	RC		45 ab	18 b	9 b		
	Control (untreated)	44	49 a	41 a	43 a		

[1] Legend see Table 4.
[2] LSD = least significant difference.
[3] Per date, values followed by identical characters are not significantly different. No characters per date means no significant differences on that date.

not shown in Table 3). In 1982, cutting through the roots at smaller depths resulted in lower black scurf ratings on cv. Arjan (Table 3), but no such effect was shown at Creil in 1983 on cvs Astarte and Bintje (data not shown in Table 4). Reducing shoot volume by stripping prior to root severing cancelled the effect of additional root cutting on black scurf, except in the case of cv. Astarte (A) at Rolde in 1983 (Table 4).

Skin damage at harvest. When skin set has not yet been completed the periderm rips off during harvesting and transport from the field when the tubers rub against each other. Here the amount of damage differed very little between replicates (Table 5). In 5 out of the 6 trials, skin damage at harvest decreased more quickly after haulm pulling or root severing plus CHD, than after CHD alone. This more rapid skin hardening allows harvesting to begin on an earlier date when only few sclerotia are present, thus indirectly preventing the development of black scurf.

In 1982, the skin damage at harvest of tubers cv. Prominent from plants whose shoots had been cut off appeared to be the same as that from plants that had undergone CHD. Furthermore cutting off shoots supplemented by root severing resulted in the same amount of damage as CHD supplemented by root severing (data not shown). In all split-split-plot trials in 1983 an interval of six hours between cutting roots and CHD had no effect on tuber damage at harvest (data not shown).

Table 6. The 'favourable harvest period' i.e. the number of days on which tubers could be harvested with acceptably low amounts of black scurf and skin damage at harvest (both indices below 20).

Treatment[1]	Cultivar, location and year of the trial					
	Prominent-E Rolde 1982	Astarte-E Rolde 1983	Astarte-A Rolde 1983	Prominent-A Rolde 1983	Astarte Creil 1983	Bintje Creil 1983
S + CHD	2 (12)[2]	2 (15)	5 (11)	11 (4)	6 (24)	11 (14)
S + RC + CHD	3 (9)	—	—	—	—	—
S + RC + 6h + CHD	—	—	13 (5)	14 (3)	—	—
RC + 6h + CHD	—	21 (4)	17 (4)	17 (3)	20 (9)	15 (10)
RC + CHD	—	—	22 (3)	19 (3)	20 (9)	12 (10)
RC deep + CHD	—	—	—	—	23 (10)	11 (12)
Haulms pulled	11 (8)	—	24 (3)	13 (4)	20 (10)	17 (11)
RC	10 (7)	—	27 (3)	27 (3)	18 (8)	8 (10)
Control (untreated)	5 (15)	4 (26)	18 (11)	24 (3)	0 (30)	0 (30)
Significance[3]	*	*	**	***	*	NS
LSD[4]	9	9	11	14	6	—

[1] Legend see Table 4; deep = roots cut through 50 mm deeper than in other trials where the roots were severed just below the tubers.
[2] In brackets: first day of harvest after treatment on day 0.
[3] Significances at P = 0.05 (*), P = 0.01 (**) and P = 0.001 (***) level; NS = non-significant.
[4] LSD = Least Significant Difference for the above-mentioned P value.

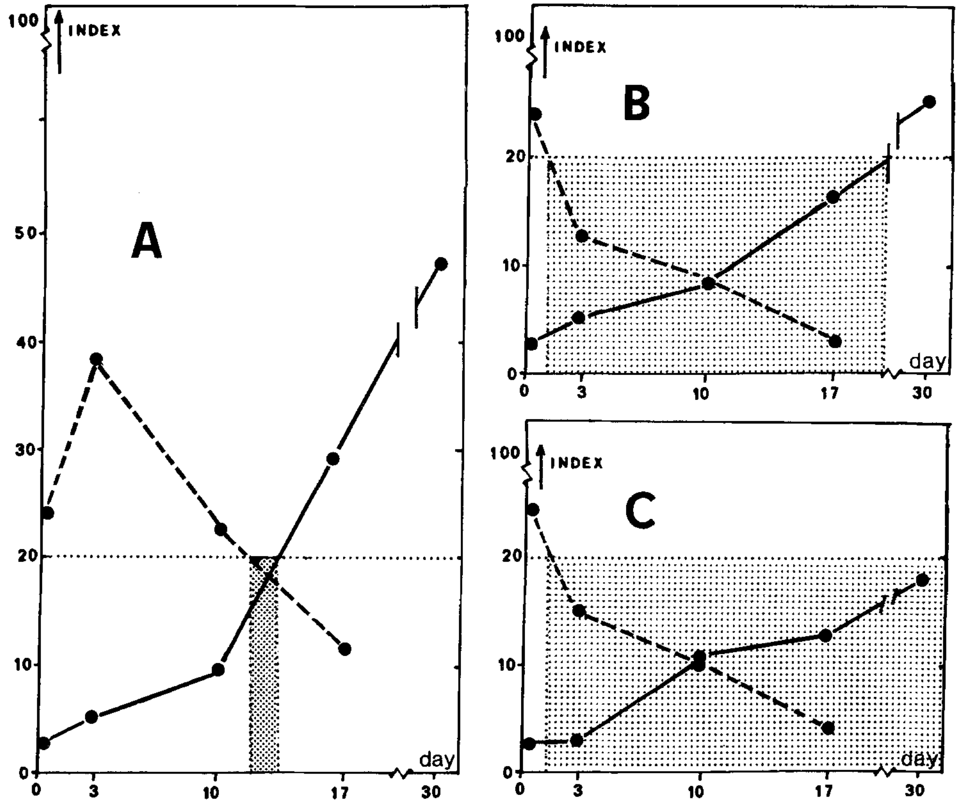

Fig. 2. The duration of the 'favourable harvest period' (shaded area) (i.e. both black scurf index (solid line) and skin damage index (broken line) below 20) as a result of haulm pulling (C), roots cut off plus chemical haulm destruction (B) as compared with shoots stripped plus chemical haulm destruction (A), for cv. Astarte in loamy sand at Rolde, 1983.

Harvest period. Tubers cannot be harvested until the skin is firm enough to withstand handling at harvest. On the other hand, tubers have to be harvested before too many and big sclerotia have developed. The mandatory limits set by the Dutch Inspection Service for the amount of sclerotia permitted on seed potatoes classes E and A are comparable with our indices 7 and 15, respectively. Thus we assumed that the skin damage and black scurf before grading were acceptably low if both indices did not exceed 20 at that moment (Fig. 2). The number of days on which both indices were below 20 were calculated and called the 'favourable harvest period' (Table 6). CHD supplemented by root severing as compared with CHD alone extended the favourable harvest period from a few days to at least two weeks, a period of time almost equal to that after haulm pulling.

Soil water content in the ridge. Soil water content in the ridge was measured at 3 and 10 days after treatment. No significant differences occurred and water content was generally very low, because the weather was very warm and dry during the experiment

Table 7. Average soil water content in the ridge, expressed as percentage of dry weight.

Year	Cultivar	Location	Soil type	Number of days between treatment and harvest	
				3	10
				$\bar{x}$ SD[2]	$\bar{x}$ SD[2]
1982	Prominent-E	Rolde	sand	— —	7.8 ± 0.5
1983	Astarte-E	Rolde	diluvial loamy sand	3.9 ± 0.2	4.2 ± 0.6
1983	Astarte-A	Rolde	diluvial loamy sand	4.8 ± 0.1	4.4 ± 0.5
	Prominent-A	Rolde	diluvial loamy sand	5.1 ± 0.3	4.4 ± 0.4
1983	Astarte	Creil	alluvial loamy sand	7.4 ± 0.7	15.0 ± 1.0
	Bintje	Creil	alluvial loamy sand	7.0 ± 0.4	15.2 ± 1.4

[1] The average was calculated from the results of four treatments: (1) control (untreated), (2) chemical haulm destruction (CHD), (3) roots severed plus six hours later CHD and (4) haulms pulled (all trials, except for 1983 Astarte-E, where haulm pulling was not tested).
[2] SD = standard deviation.

(Table 7). At Creil in 1983 soil water content increased after heavy rainfall on day 9. No relation was found between soil water content and black scurf development.

Tuber water content. Tuber water content was determined for cv. Prominent at Rolde in 1982 (Table 8). Tuber dry weight of untreated control plants increased from 0.63 kg.m^{-2} to about 0.85 kg.m^{-2} as a result of continued photosynthesis, and their tuber water content decreased from 79% to 74% (Table 8). If only the roots had been cut through tuber dry weight increased only slightly to 0.68 kg.m^{-2} in the first week. However, tuber water content decreased then because, until they died the wilting shoots continued to withdraw water from the tubers.

After haulm pulling or root severing plus CHD, both tuber dry weight (0.60 kg.m^{-2}) and tuber water content (79%) remained constant. After CHD alone or after cutting off the shoots, tuber dry weight remained constant (around 0.60 kg.m^{-2}, data not shown) but tuber fresh weight had increased from 2.91 to 3.12 kg.m^{-2} by day 17 (Table 8). As a result, tuber water content slightly increased during the first 10 days. This demonstrates that the roots continued to function for some days after CHD. Roots did not visibly decay until the second week after haulm destruction. However, no relation was found between tuber water content and black scurf.

Gross yield at harvest and net yield after storage and grading. Of the various methods of haulm destruction, only two, CHD alone or cutting off the shoots, increased gross yield at harvest during the first week after destruction. Thus CHD resulted in the yield at harvest being higher than that of crops where further growth had been terminated by haulm pulling or root severing plus CHD. Most of this extra yield, however, was lost during storage (Table 9). Weight loss in storage was found to be correlated with the amount of skin damage at harvest. After root severing plus CHD as well as after

Table 8. Tuber yield (kg.m^{-2}) and tuber water content (percentage of tuber fresh weight) of cv. Prominent (1982) on loamy sand at Rolde in various treatments and when harvested at different intervals after haulm destruction or cuttung off the roots on day 0.

Treatment[1]	Number of days between treatment and harvest				
	0	3	10	17	24
Tuber yield					
S + CHD	—	2.99 b[2]	3.01 cd	3.12 bc	2.98 cd
S + RC + CHD	—	2.96 b	2.86 bc	2.74 a	2.82 bc
RC + 6h + CHD	—	2.55 a	2.67 a	2.75 a	2.63 a
Haulms pulled	—	2.86 b	2.83 ab	2.77 a	2.68 ab
RC	—	2.68 a	2.80 ab	2.76 a	2.76 b
Control (untreated)	2.91	2.92 b	3.19 d	3.19 c	3.28 e
Tuber water content					
S + CHD	—	79.5 d	80.2 d	80.6 d	80.1 e
S + RC + CHD	—	78.7 bc	78.1 b	78.9 c	79.0 d
RC + 6h + CHD	—	78.6 bc	78.4 bc	78.0 b	78.1 c
Haulms pulled	—	79.2 cd	78.4 bc	78.9 c	79.2 d
RC	—	77.1 a	75.4 a	75.3 a	75.8 b
Control (untreated)	78.9	77.2 a	74.9 a	75.3 a	74.1 a

[1] Legend see Table 4.
[2] Per date, values followed by identical characters are not significantly different: Least Significant Difference for tuber yield (P = 0.05) = 1.73 and for tuber water content (P = 0.05) = 0.7.

haulm pulling, tubers were less damaged and lost less weight during storage than after CHD alone.

Finally, tubers were graded for black scurf according to the mandatory requirements for class A seed potatoes. When harvested on day 10, both grading and weight loss in storage reduced yield after CHD to the same net yield as that obtained by haulm pulling or CHD supplemented by root severing. When harvested on day 17, grading losses became more severe and net yield after CHD alone was generally (in 4 out of 5 trials) less than net yield after haulm pulling or CHD supplemented by root severing. This result was found for all three trials at Rolde (Table 9). At Creil these results were found for cv. Bintje, but not for cv. Astarte (data not shown). There was great variation between replicates at Creil.

With respect to both yield at harvest and yield after storage, analysis of variance showed that cultivars and treatments had significant effects (P=0.001), and no interaction was found between cultivars and treatments.

Discussion

Cutting off the roots has long been known to prevent tuber cracking and to facilitate harvest in certain soils (Werner and Dutt, 1941; Finney and Findlen, 1967). Until the present research, the efficacy of root severing on black scurf had not yet been ascer-

Table 9. Gross tuber yield (kg.m^{-2}) at harvest on day 17 after haulm destruction, tuber gross weight after storage and tuber net weight after storage plus grading for black scurf, Rolde 1983.

Cultivar	Treatment[1]	Tuber yield (kg.m^{-2})					Gross yield loss (%)		
		at harvest	after storage				by storage		by black scurf[3]
		gross	30 days		90 days		30 days	90 days	
			gross	net[2]	gross	net[2]			
Astarte-E	Shoots stripped + CHD	1.99	1.91	1.11	1.77	1.04	4	11	42 a[5]
	Roots cut off + 6h + CHD	1.85	1.81	1.66	1.70	1.55	2	8	8 b
	Control (untreated)	1.92	1.82	1.80	1.75	1.74	3	8	1 b
Significances[4]:	Treatments	*	*	* * * *	NS	* * * *	NS[5]	NS[5]	* * * *[5]
	LSD (P = 0.05)	0.13	0.09	0.30		0.24			
Astarte-A	Shoots stripped + CHD	1.83	1.71	1.07	1.67	1.04	6 a[5]	9 a[5]	36 a[5]
	Roots cut off + 6h + CHD	1.91	1.85	1.68	1.81	1.65	3 bcd	4 abc	9 bc
	Haulms pulled	1.80	1.80	1.69	1.70	1.62	3 de	6 bc	7 bc
	Roots cut off	1.55	1.48	1.46	1.43	1.41	5 ab	8 ab	1 c
	Control (untreated)	1.88	1.78	1.72	1.73	1.67	5 ab	8 ab	3 bc
Prominent-A	Shoots stripped + CHD	2.40	2.33	1.56	2.28	1.53	3 bcde	5 bc	33 a
	Roots cut off + 6h + CHD	2.17	2.13	1.83	2.10	1.80	2 de	3 c	15 ab
	Haulms pulled	2.03	1.99	1.53	1.96	1.52	2 cde	3 c	22 ab
	Roots cut off	2.08	2.05	2.02	2.02	1.99	1 e	3 c	2 c
	Control (untreated)	2.27	2.17	2.09	2.15	2.07	4 abc	5 abc	4 bc
Significances[4]:	Treatments	* *	*	*	* *	*	*[5]	*[5]	* *[5]
	Cultivars	* * * *	* * * *	* *	* * * *	* *	* * * *	* * * *	NS
	Tms × Cvs	NS	NS	NS	NS	NS	NS	NS	NS
	LSD (P = 0.05)	0.24	0.22	0.52	0.21	0.51			

[1] CHD = chemical haulm destruction.
[2] Tuber weight (kg.m^{-2}) left after storage during 30 and 90 days and grading for black scurf in order to obtain A class seed potatoes (at least 75% free and 25% not more than lightly covered with sclerotia).
[3] Percentage of gross weight lost by grading for A-class seed potatoes.
[4] Significance at P = 0.05 (*), P = 0.01 (* *), P = 0.001 (* * *), P $\leq$0.0005 (* * * *); NS = non significant; LSD = Least significant difference; comparing 3 treatments for the E trial and 7 treatments for the A trial.
[5] Analysis of variance after arcsinus transformation; values followed by identical characters are not significantly different (p = 0.05).

tained. Our results show that compared with chemical haulm destruction (CHD) alone, CHD supplemented by root severing often delayed the development of black scurf and always accelerated skin hardening, confirming previous observations (Dijst, 1985). The favourable effect on skin damage at harvest time of supplementing CHD by cutting off the roots increased its positive effect on the incidence of black scurf: harvesting could be started earlier, i.e. when only small amounts of sclerotia had developed. The consequent extension of the 'favourable harvest period' may give the farmer more flexibility in planning his harvest.

Our data on tuber water content are not in line with those obtained by Werner and Dutt (1941) or Finney and Findlen (1967). However, their experimental designs differed considerably from ours in the time of haulm destruction and of harvest. In our experiments tuber water content increased slightly after CHD. This indicated that sap flow from roots continues during the first week after CHD, confirming previous findings (Dijst, 1985). The reason that gross yield (at harvest) was higher after CHD than after haulm pulling was merely the extra water content.

In most experiments, CHD supplemented by root severing prevented both an increase in tuber water content and a high incidence of black scurf. However, no relation was found between incidence of black scurf and tuber water content, confirming previous results (Dijst, 1985). The weather was very dry and warm on haulm destruction day. Nevertheless, a six-hour interval at midday between root severing and CHD did not consistently change the effects of root severing on tuber water content and black scurf. In cv. Prominent at Rolde in 1983 stripping shoots prior to cutting off the roots completely negated the effect of root severing. These results suggest changes in tuber physiology resulting from the fall-off of sap flow from shoots to be more important for the development of black scurf than changes resulting from sap flow from the roots.

When CHD was supplemented by root severing the tubers did not swell with water and skin resistance to damage at harvest may have increased, regardless of the stage of skin set. Root severing also increases soil aeration, and this may have enhanced skin set. In the literature (Spencer and Fox, 1979; Braue et al., 1983) skin set has been used as a measure of tuber maturity. This may be justifiable after haulm pulling but not after CHD, where continued water uptake may cause extra pressure on the periderm.

Supplementing CHD with cutting off the roots ultimately favoured tuber yield: first, because it often lowered grading losses because of black scurf and second, it reduced weight loss in storage. In our study, lower ratings of skin damage at harvest coincided with less weight loss in storage, confirming earlier results obtained by Meijers et al. (1982). Less skin damage also lowers the sensitivity to storage rot. When harvested at 17 days after treatment, in 4 out of 5 trials net yield after storage and grading was higher after root severing plus CHD, or after haulm pulling, than after CHD alone. Grading losses accounted for most of this result, so that differences were smaller if harvest took place earlier. Comparisons with untreated control plants showed that, contrary to what Braue and his colleagues predicted (1983), haulm killing did not reduce weight loss in store.

In this study smaller amounts of black scurf were found on cv. Astarte than on cvs Prominent or Bintje. When grown in steamed soil in the greenhouse, no differences in black scurf development were found between seven cultivars, including Astarte and Prominent (Dijst, 1985). Factors in the field may account for this ambiguity.

The second objective of this study was to examine what factors might favour black scurf. Earlier data for plants grown in steamed soil had shown that the development of black scurf was mainly influenced by the tuber itself. This suggested an effect from changes in the periderm and/or tuber exudates, probably as a result of accelerated tuber maturation (Dijst, 1985). Our results demonstrate that other factors can interfere, for although CHD usually stimulates black scurf more than haulm pulling, sometimes both methods give equally low rating of black scurf. This was even found in steamed soils (Dijst, 1985).

In order to better understand why haulm destruction stimulates black scurf development, differences in effects of CHD and haulm pulling will be discussed. These differences concern: (1) the sap flow from the main root system to the tubers, (2) the disturbance of the ridge and (3) the amount of underground stems and stolons left behind in the ridge.

(1): Tuber physiology depends on the amount and quality of the supply of water and nutrients from shoots and roots. Sap flow from the roots is terminated by haulm pulling but after CHD it still continues for a week. The effects of our various treatments on the development of black scurf suggest that the crucial causal changes in tuber physiology may be induced less by continuation of sap flow from the roots than by termination of sap flow from the shoots. Since both CHD and haulm pulling terminate sap flow from the shoots, the cessation of this flow may be responsible for the basic stimulation of black scurf but cannot explain any difference in effect between the two treatments. Previous suggestions that the extra stimulation of black scurf after CHD as compared with that after haulm pulling is merely the results of tubers swelling with water (Dijst, 1985) are not strongly supported by the results presented in this paper. No relationship was found between tuber water content and incidence of black scurf. However, even slight swelling might induce other effective alterations in tuber physiology.

(2): Haulm pulling disturbs the ridge, but CHD does not. Results of additional field experiments (Dijst et al., 1985) support the idea that increased aeration prevents black scurf development. In 1984 in three of the four experiments, haulm pulling supplemented by root severing resulted in even less black scurf than haulm pulling alone (Dijst et al., 1985). Soil disturbance affects both soil aeration and soil moisture. We found no relationship between soil water content in the vicinity of the tuber and black scurf development, but this does not prove that soil water content had no effect on black scurf: may be any visible effects were obscured by the interfering influences of volatiles. In the vicinity of the tuber the production, consumption and diffusion of volatiles will depend on moisture, soil compaction, soil disturbance and the physiological state of the underground tissue (Blair, 1943; Brown et al., 1965; Cary, 1985). Increasing concentrations of carbon dioxide have been found to affect *R. solani* both negatively and positively and these effects were not consistent for different isolates (Sherwood, 1970). Tuber respiration and periderm permeability for volatiles decrease during maturation of tubers (Burton, 1966). Tuber maturation seems to be an important factor in black scurf development, especially if accelerated somehow (Dijst, 1985). Mature tubers, whether harvested from field or greenhouse experiments, often have big sclerotia where the growing tuber was pressed against pieces of clay, plastic, stones or the pot wall, i.e. sites where minimal diffusion of volatiles can be expected. These observations contradict the suggestions that high oxygen supply and good aeration are needed for sclerotial formation (Sherwood, 1970). Data from laboratory tests may wel differ from data in the field, where mixtures of volatiles change continuously in compositon.

(3): Supplementing CHD by root severing cancelled the two differences between CHD and haulm pulling mentioned above. However, it did not always completely eliminate the difference in black scurf rating between them. So far we have discussed a third difference between the effect of CHD and that of haulm pulling: the amount of underground plant tissue remaining after the treatment and thus the extent of possible effects during decay. Volatiles from decomposing plant tissue can often influence *R. solani* (Lewis, 1976). CHD with or without additional root severing does not affect the amount of underground plant tissue. Haulm pulling, however, eliminates underground stems and may thus reduce any effects arising from tissue decay. In these experiments, neither decay of all roots and stolons nor stimulation of black scurf could be observed until 7 to 10 days after haulm destruction. The effect of volatile exudates on black scurf therefore warrants for additional research.

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Samenvatting

De invloed van loofvernietigen en wortelsnijden op lakschurftbezetting, ontvelling, duur van de oogstperiode, opbrengst en gewichtsverlies van pootaardappelen in veldproeven

Pootaardappelen raakten minder bezet met lakschurft en werden minder ontveld bij de oogst na looftrekken of na wortelsnijden plus doodspuiten dan na loofklappen plus spuiten. Al vanaf de derde dag na trekken of wortelsnijden plus doodspuiten was de mate van ontvelling zo gering, dat met het oogsten kon worden begonnen. Op zo'n vroeg tijdstip na loofdoding konden knollen worden geoogst met nog weinig lakschurft, want de stimulering van lakschurft werd pas zichtbaar vanaf 7 à 10 dagen na loofdoding. Lakschurft ontwikkelde zich het traagst na looftrekken. Ook wortelsnijden bij het doodspuiten gaf meestal een tragere ontwikkeling van lakschurft dan klappen plus spuiten. Daardoor konden na wortelsnijden plus doodspuiten en vooral na looftrekken op nog latere tijdstippen knollen met weinig lakschurft worden geoogst.

Na klappen plus spuiten was het bruto gewicht bij de oogst het hoogst. Dat meergewicht bleek louter uit water te bestaan en het verloop in knolvochtgehalte leek erop te wijzen dat de wortels nog gedurende een week na doodspuiten blijven func-

tioneren. Dat gaf wel knollen met een hoger vochtgehalte die meer ontvelden en meer vocht en dus gewicht verloren. Dit groter gewichtsverlies bij bewaren en de hogere leesverliezen door lakschurft deden de meeropbrengst teniet: zo werd het netto knolgewicht na klappen plus spuiten, al naar gelang het moment van oogsten, meestal gelijk aan, of lager dan het netto knolgewicht na het trekken of na wortelsnijden plus doodspuiten. In dit artikel worden de factoren besproken, die mogelijk van invloed zijn op de ontwikkeling van lakschurft.

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