Neth. J. Agric. Sci., 15 (1967): 50—62

Effects of 2-chloroethyl-trimethylammonium chloride (CCC) on yield and lodging of wheat

N. M. de Vos, K. Dilz and J. Bruinsma

Research and Advisory Institute for Field Crops and Grassland Husbandry (P.A.W.), Wageningen, The Netherlands;
Institute for Soil Fertility (I.B.), Groningen, The Netherlands;
Plant Physiological Research Centre (C.P.O.), Wageningen, The Netherlands

Received 20 May, 1966

Summary

Results are presented from a number of field experiments on the application of CCC to winter and spring wheat at different rates, growth stages and levels of nitrogen fertilization.
Spraying with CCC could prevent lodging or at least delay its onset. Even at excessive levels of nitrogen the resistance to lodging could be markedly improved in most instances, although some bending could not always be prevented.
In several experiments a higher yield level could be reached with CCC and extra nitrogen than was obtainable with nitrogen alone. It is suggested that this may depend on soil fertility and particularly on the nitrogen mineralization pattern.
Spraying at later growth stages, up till stages 7 or 8 of the Feekes-Large scale, resulted in shorter culms than earlier applications and gave a similar improvement in lodging resistance. Practical application therefore seems possible over a fairly wide range of growth stages. The amount needed to prevent lodging will depend on the nitrogen pressure.

Introduction

Groups of chemicals with growth retardant properties have been known for some fifteen years. The characteristic effect of these chemicals is inhibition of stem elongation, other plant parts being less affected, if at all. Such an effect was first reported among nicotine derivatives (Mitchell et al., 1949) and later for other groups of chemicals as well. A survey of these compounds and their effects on plants has been given by Cathey (1964).
Only a few of the many chemicals capable of inducing growth retardation have become available commercially, mostly for use in ornamentals. A much larger field of application was opened when it was shown that lodging of wheat could be prevented by the stem shortening effect of the choline derivative 2-chloroethyl-trimethylammonium chloride, or CCC (Mayr et al., 1962; Jung and Sturm, 1964).
During the last ten years nitrogen rates applied to cereals have increased considerably. This has undoubtedly been made possible in The Netherlands through the introduction of new varieties with stiffer straw. Amounts of 70–80 kg N/ha on winter

wheat have become quite normal and rates of 100 kg N/ha are by no means exceptional.
However, even in these modern varieties the sturdiness of the straw is not quite adequate under all conditions, and there is still a risk of lodging at the nitrogen levels needed to give optimum production, particularly when all nitrogen is applied early. This is normal practice in The Netherlands, where winter wheat is given fertilizer in February or March and spring wheat at sowing. It may be true that split application improves standing ability to some extent, but this method has failed to become popular so far, except in certain regions with particular patterns of nitrogen mineralization (Jonker, 1964).
Investigations have therefore been conducted into the extent to which CCC can be used to reduce the risk of lodging in wheat crops grown at high levels of nitrogen fertilization. The botanical aspects of these studies have been reported earlier (Bruinsma et al., 1965; Arnold et al., 1965). The present paper concerns the agronomic aspects.

Description of the experiments

Some preliminary experiments were carried out in 1963 with winter wheat, spring wheat, winter rye and spring barley varieties. Since CCC gave promising results mainly when applied to wheat varieties, the results of the experiments performed with wheat in 1964 will be discussed below.

PAW 998 (with winter wheat var. Cleo) and *PAW 999* (with spring wheat var. Opal): The interaction between nitrogen and CCC was studied at 5 nitrogen levels, viz. 0, 30, 60, 90 and 120 kg N/ha, with 0 and 3 kg CCC/ha (active ingredient) on winter wheat and 0 and 2.4 kg CCC/ha on spring wheat. Spraying was also done at five different stages of development, ranging from the tillering stage up to the boot stage, using the concentrations mentioned above. The effect of rate of CCC was studied by applying 1.5, 3.0 and 6.0 kg/ha to the winter wheat and 1.2, 2.4 and 4.8 kg/ha to the spring wheat variety.

IB 827: The spring wheat varieties Peko, Carpo, Gaby, Orca and Opal, supplied with 80 and 200 kg N/ha, were sprayed with 5 or 20 kg CCC/ha (active ingredient) at stage 3 (Feekes-Large scale, see Fig. 1) or with 5 kg CCC/ha at stage 6. Since this experiment was mainly designed to obtain information on the influence of CCC on lodging resistance in different varieties, yield determinations were omitted.

IB 830: Winter wheat var. Stella grown at 7 nitrogen levels (0, 40, 80, 120, 160, 200 and 240 kg N/ha) was given 0 and 5 kg CCC/ha (active ingredient) at stage 3.

Interprovincial experiments: These were conducted with various varieties of winter and spring wheat at two nitrogen levels. At the lower level, the farmer's estimate of the optimum nitrogen rate, half of the plots were sprayed with 3 kg CCC/ha (active ingredient). At the higher level, 30–60 kg N above the farmer's estimate, winter varieties were given 3 and 6 kg CCC/ha at stage 5 or at stage 8; for spring varieties 2 and 4 kg were used at the same stages. The experiments were carried out by the regional advisory service and on experimental farms (for details see de Vos, 1964).

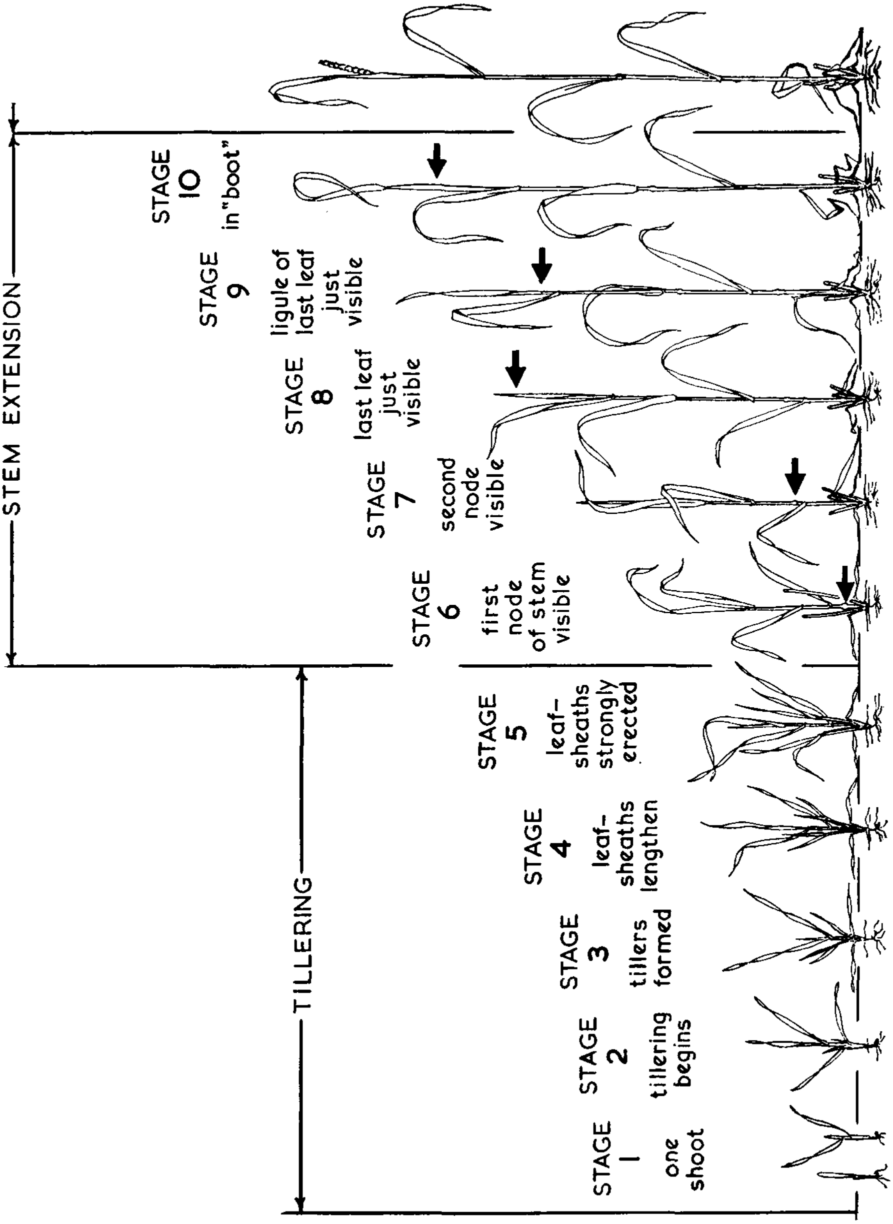

Fig. 1 Growth stages of wheat according to the Feekes-scale illustrated by Large (1954).

Results

Effect of CCC at different nitrogen levels

A typical example of the effect of CCC at different nitrogen levels is provided by experiment PAW 999 with spring wheat. This experiment was performed on a heavy clay soil, low in nitrogen and with a rather poor structure, so that even at the highest level of N fertilization (120 kg N/ha) the maximum yield did not appear to have been reached (Table 1). The CCC-treatment strongly reduced culm elongation, but the effect tended to decrease somewhat as the nitrogen rate increased, as is shown in Fig. 2 (see also Bruinsma et al., 1965).

In this experiment some lodging occurred on the control plots within 3 weeks of harvest where 90 and 120 kg N had been applied. Treatment with CCC prevented lodging completely. It was only at these nitrogen levels that the yield from CCC-

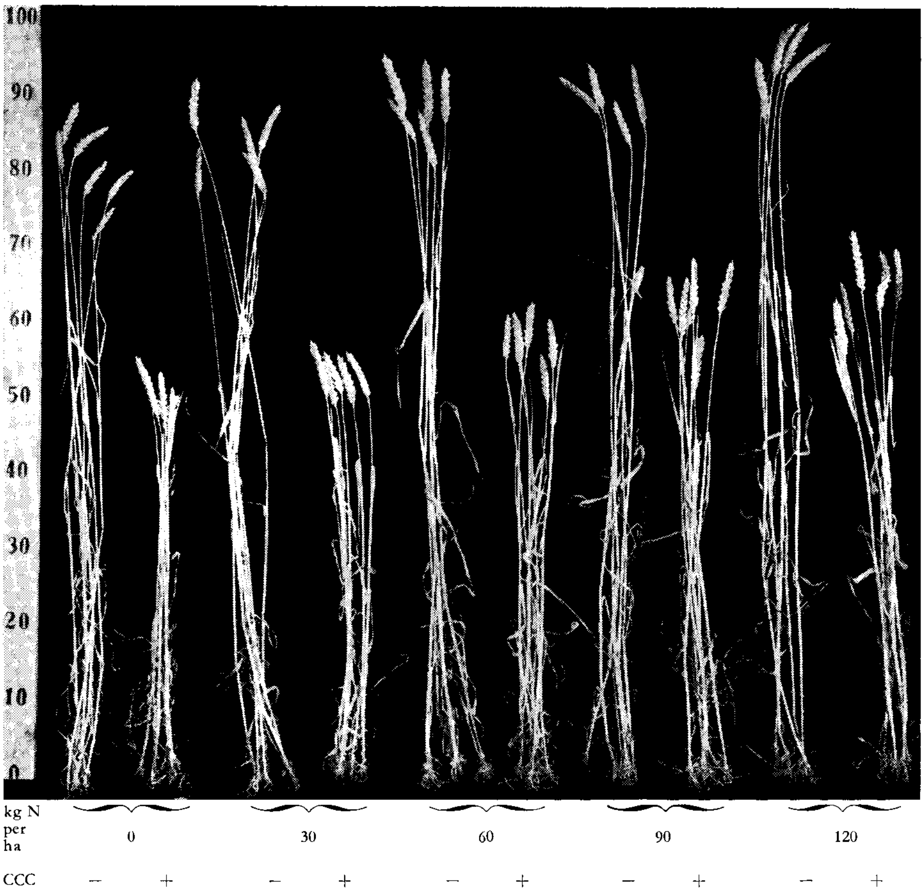

Fig. 2 Effect of nitrogen and CCC on culm length of spring wheat, var. Opal; 2.4 kg CCC applied in growth stage 6.

Table 1 Effect of nitrogen and CCC on yield, grain weight, grain number and culm length of Opal spring wheat (PAW 999); 2.4 kg CCC applied at stage 6

Nitrogen (kg/ha)	Yield (kg/are)		1000-grain weight (g)		Number of grains per are (× 10^6)		Culm length (cm)	
	—	CCC	—	CCC	—	CCC	—	CCC
0	25.2	23.0	42.3	40.5	0.59	0.57	77	46
30	31.4	31.9	42.2	40.8	0.74	0.78	77	48
60	40.3	40.1	43.8	42.1	0.92	0.95	86	52
90	41.4	45.6	44.2	43.1	0.94	1.06	84	56
120	46.8	51.2	44.2	42.9	1.06	1.19	89	58

treated plots surpassed that from control plots, so that the effect of CCC on yield in this experiment could be ascribed to increased resistance against lodging.
However, the systematically lower 1000-grain weight found in the CCC-treated plots, compensated for by increased grain numbers (Table 1), point to another effect of CCC occurring at all nitrogen levels. Because no determinations of ear numbers were made it was not possible to ascertain whether the CCC treatment increased ear number, the number of kernels per ear or both.
In general a similar response to CCC occurred in the nine experiments with winter wheat in the interprovincial series, results of which are summarized in Table 2. At the lower nitrogen level, which was the dressing estimated as optimum by the farmer concerned, CCC mostly increased yield to some extent but not significantly. In most experiments lodging occurred late if at all at the lower nitrogen rate.
At the higher nitrogen level yield was not increased where no CCC was applied. This demonstrates, on the one hand, the correct estimation of the nitrogen dose and, on the other hand, that the strength of the straw may still be a limiting factor in obtaining maximum yields from wheat crops. However, because the yield-increasing

Table 2 Yield and lodging of winter wheat at two levels of nitrogen and different CCC treatments; interprovincial series 1964

Variety and exp. field	Nitrogen (kg/ha)	Yield (kg/are)		Lodging index[1]		Nitrogen (kg/ha)	Yield (kg/are)			Lodging index[1]		
		—	early[2]	—	early		—	early[2]	late[2]	—	early	late
1 Cleo-NNH	60	60.1	62.6	5	7	100	60.7	64.6	64.4	4	7	7
2 Cleo-ZVl	70	65.2	67.5	4	8	100	62.6	67.4	69.3	3	6	8
3 Cleo-ZZH	60	62.9	64.8	8	10	120	60.2	63.4	62.3	7	10	10
4 Stella-OFl	80	64.3	68.5	9	10	120	65.7	70.1	69.9	6	9	9
5 Stella-Z	80	59.7	61.5	2	2	110	56.5	64.1	65.9	1	2	2
6 Stella-ZL	70	52.2	54.1	9	10	100	46.2	59.9	50.2	5	10	7
7 Ibis-Z'land	60	61.9	—	7	10	105	60.8	—	68.8	3	—	7
8 Felix-ZNH	30	60.2	61.8	6	8	60	59.9	59.8	57.5	5	7	7
9 Eno-OD	120	53.8	53.2	10	10	170	47.5	56.4	48.5	6	10	8

[1] Lodging index 10 = erect, 1 = completely lodged
[2] Early = CCC applied at stage 4–5, late = CCC applied at stage 8, both rates 3 kg CCC/ha

Table 3 Lodging indices during growth period as affected by nitrogen and CCC; interprovincial series 1964, No. 5, Stella Z

Date	Normal N		High N		
	CCC: none	stage 4–5	none	stage 4–5	stage 8
21/5	10	10	8	10	8
1/6	8	10	5	10	9
8/6	4	8	2	5	6
17/6	4	7	2	6	6
13/7	2	2	1	2	2
Yield (kg/are)	59.7	61.5	56.5	64.1	65.9

Table 4 Effect of nitrogen and CCC on yield, grain weight and culm length of Cleo winter wheat (PAW 998); 3 kg CCC applied at stage 5

Nitrogen (kg/ha)	Yield (kg/are)		1000-grain weight (g)		Number of grains per are (× 10⁶)		Culm length (cm)	
	—	CCC	—	CCC	—	CCC	—	CCC
0	64.5	74.8	46.3	46.8	1.39	1.60	99	73
30	55.0	69.7	42.0	45.8	1.31	1.52	93	79
60	51.8	67.6	41.2	44.9	1.26	1.50	91	80
90	47.9	64.5	41.0	44.1	1.17	1.46	93	81
120	51.5	65.7	42.0	43.9	1.23	1.50	95	78

effect of CCC treatment was not always significant, and in experiment 8 even absent, future research may be particularly directed towards the conditions under which lodging resistance is still a limiting factor.

In all cases except experiment 5 the CCC treatment, whether early or late, improved the resistance to lodging (Table 2), and even in experiment 5, where severe lodging occurred on all plots, lodging was postponed by the CCC spray (Table 3). Since early lodging is particularly harmful to yield this postponement reduced losses appreciably, as is shown by the yield data.

In two experiments with winter wheat, PAW 998 and IB 830, the nitrogen supply on the non-fertilized plots was already ample. Nitrogen dressing resulted in a yield decrease in PAW 998 from 30 kg N/ha on, with IB 830 from 80 kg N/ha on. It is not certain whether this negative nitrogen effect is due to too high a salt concentration in the soil or to ripening diseases interacting with the high nitrogen levels. In experiment PAW 998, on non-sprayed plots given 60, 90 and 120 kg N/ha, lodging occurred as early as the first week of June, i.e. just before anthesis. Two weeks after flowering severe lodging also occurred on the 30 N and even on the 0 N control plots. On the CCC-treated plots, however, lodging was completely prevented on plots given 0 and 30 kg N/ha, while some bending on plots given 60 kg and more showed that the improvement in straw sturdiness was insufficient to keep the culms fully erect. The first signs of this bending appeared only 3 weeks before harvest. In consequence, impressive yield differences of 10–15 kg/are were obtained between the untreated and the CCC-sprayed plots (Table 4). These, however, are by no means indicative of the responses generally to be expected in practice. CCC increased 1000-grain weight presumably because it prevented or at least delayed lodging. In addition it may be deduced from the data on total yield and 1000-grain weight that the yield increase due to CCC was largely brought about by an increase in grain number, which was 20 per cent on average.

The data obtained from experiment IB 830, presented in Table 5, show only small differences between the yields of the control and CCC-treated plots, since lodging did not occur before the second half of July. The yield decrease with increasing nitrogen levels appeared to be due entirely to a decrease in 1000-grain weight. The CCC treatment, however, increased grain number by 2–3 per cent on average.

Effect of time of application

The work of Tolbert (1960) indicates that wheat plants are able to take up CCC by the roots as well as by their aerial parts. Several modes of application may therefore be considered: seed treatment, soil application or spraying. Seed treatment and soil applications did not seem very promising, since with both methods the treatments have to be applied before the condition of the crop can be gauged. Spraying has a stronger effect than soil treatment, and furthermore the amount of CCC required to produce a given decrease in stem length may depend on soil factors (Jung and Sturm, 1964). In The Netherlands wheat is grown under widely varying soil conditions and a combined CCC and nitrogen fertilizer would complicate the recommendations on practical application. The 1964 experiments were restricted to application by spraying only.

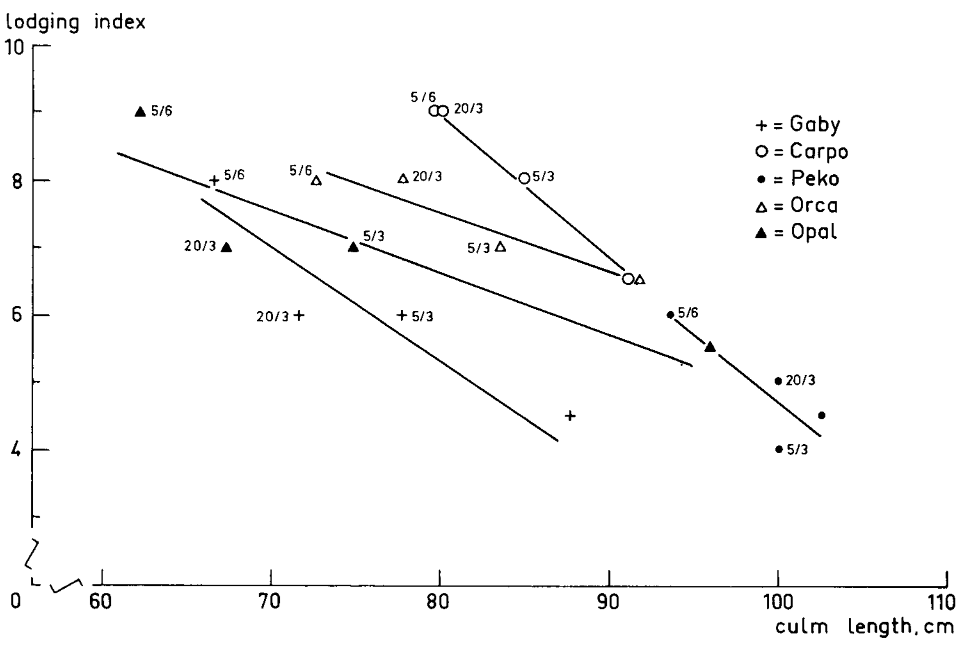

Fig. 3 Lodging index and culm length, as influenced by spraying with CCC for a number of spring wheats (control, 5 or 20 kg CCC in growth stage 3, 6 kg in growth stage 6); 200 kg N per ha

Table 5 Effect of nitrogen and CCC on yield, grain weight, grain number and culm length of Stella winter wheat (IB 830); 5 kg CCC applied at growth stage 3

Nitrogen (kg/ha)	*Yield (kg/are)*		*Lodging index*		*1000-grain weight (g)*		*Number of grains per are (× 10^6)*		*Culm length (cm)*	
	—	*CCC*	—	*CCC*	—	*CCC*	—	*CCC*	—	*CCC*
0	68.2	—	9.4	—	44.3	—	1.54	—	95.5	—
40	72.3	67.4	8.0	10	45.5	41.5	1.59	1.62	100.3	84.0
80	70.1	71.8	7.3	9.8	42.8	42.3	1.64	1.70	98.8	88.3
120	66.0	70.0	6.4	9.2	40.3	41.8	1.64	1.67	97.9	85.9
160	63.6	67.4	5.3	8.5	39.8	38.8	1.60	1.74	97.0	85.3
200	58.9	63.0	6.0	9.0	37.5	37.3	1.57	1.69	95.4	86.3
240	57.1	56.9	5.2	8.1	35.8	35.5	1.59	1.61	97.5	87.7

Table 6 Effect of CCC on internode length (cm) of Carpo spring wheat (exp. IB 827, 80 kg N per ha)

Internode number	*Control*	*CCC*		
		5 kg stage 3	*20 kg stage 3*	*5 kg stage 6*
5	44.1	38.4	36.1	33.8
4	22.1	20.0	18.3	17.0
3	13.4	11.5	10.5	9.4
2	9.5	7.6	6.0	5.7
1	3.6	2.9	2.1	3.2

The effect of time of application was studied in experiments IB 827, PAW 998 and PAW 999. In experiment IB 827 CCC was applied at rates of 5 kg and 20 kg at growth stage 3 and 5 kg at stage 6. On half of the plots the nitrogen rate was normal (80 kg N/ha), on the other half it was very high (200 kg N/ha) so as to increase the chance of lodging. Some results obtained with the three treatments at the high nitrogen level are represented in Fig. 3.

In all instances the later application yielded the best results in terms of culm shortening and improvement in lodging resistance. Even the excessive amount of 20 kg CCC applied at stage 3 produced less effect than did 5 kg applied at stage 6. The smaller effect of the earlier application may be also due to the limited leaf area present at stage 3. In effect, such a spraying may be regarded partly as a kind of soil dressing. Moreover, the greater interval between the date of spraying and the stem elongation period allowed of a larger measure of breakdown of CCC in the plants (Jung and Henjes, 1965) and possibly in the soil as well. Further, it may be seen from Fig. 3 that the relationship between the amount of stem shortening and lodging resistance depends on variety.

The data on internode length, given in Table 6, show that the first internode was shortened more by the earlier application. The second and higher internodes, however, were shortened to a greater extent by the later application, even 20 kg CCC at stage 3 being less effective than 5 kg at stage 6.

Table 7 Relative culm length (excl. ear) and yield of Cleo winter wheat (PAW 998) and Opal spring wheat (PAW 999) as influenced by time of spraying

Variety		*Control*	*Sprayed at growth stage*				
			4	*5*	*6*	*7*	*8.5*
Cleo	rel. culm length	100	87	87	84	80	77
	yield (kg/are)	62.8	69.3	69.5	67.2	66.4	61.8
			Sprayed at growth stage				
			3	*5*	*6*	*8*	*10*
Opal	rel. culm length	100	86	68	65	74	86
	yield (kg/are)	39.6	46.6	51.9	46.9	46.4	44.5

Table 8 Culm length (cm), excl. ear, as influenced by time of spraying; interprovincial experiments (high N level)

Variety and site	*Control*	*3 kg CCC/ha*	
		stage 4–5	*stage 8*
Cleo-NNH	99	86	75
Cleo-ZZH	106	102	91
Cleo-ZGe	84	77	78
Stella-OFl	111	95	94
Stella-WW	111	108	107
Flamingo-OGe	114	104	104
Ibis-YPo	100	91	78
Eno-OD	116	96	100
Felix-ZNH	109	101	92
Opal [1]-WD	106	86	78
Peko [1]-Ve	106	96	95

[1] Spring wheat given 2 kg CCC/ha

In two experiments, PAW 998 and PAW 999, the effect of time of application was studied in relation to culm length, lodging resistance and yield. CCC was applied at five different growth stages, from tillering up to the completion of stem elongation. Table 7 summarizes data from these experiments.

In winter wheat the later the application the more the culm was shortened, and the more the inhibition of internode elongation shifted to the higher internodes (see also Bruinsma et al., 1965). For spring wheat a similar trend occurred for applications up to stage 6, later applications having less effect on culm length. In the winter wheat experiment a sharp decrease in grain yield was observed from the latest spraying. The cause might be a phytotoxic effect of the spray, which resulted in white discolorations of the flag leaf.

In the interprovincial experiments, a comparison was made between spraying at stage 4–5 and at stage 8 (Table 8). The later application generally resulted in a more pronounced inhibition of stem elongation, but the variation was rather great, even

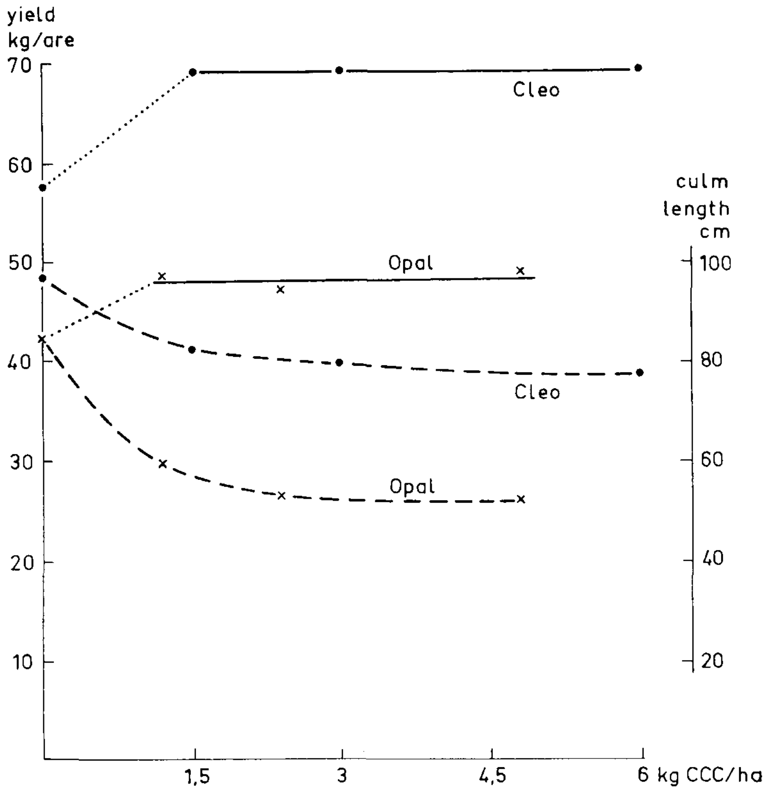

Fig. 4 Yield and culm length at various amounts of CCC for Cleo winter wheat and Opal spring wheat.

within the same variety. The extent of the effect is probably also influenced by variations in environmental conditions.

Effect of application rate

In the experiments PAW 998 and PAW 999 different amounts of CCC were compared in their effect on culm shortening and improvement in lodging resistance. It appeared that a considerable effect on culm height was obtained at the lowest application rate, while higher concentrations did not add much to the effect (Fig. 4). Lodging could be prevented by the lowest rates of application.

The effect on Opal spring wheat was much stronger than on Cleo winter wheat. This is partly due to varietal differences, spring wheat varieties generally reacting more strongly than those of winter wheat, Opal being one of the most sensitive varieties (Sturm and Jung, 1964; Bruinsma et al., 1965). Besides, the winter wheat was sprayed at an earlier growth stage (stage 4) while the growth stage 6 at which Opal was treated is a very sensitive one, as has been shown in the previous section.

In the interprovincial experiments, too, different amounts of CCC were applied, viz. 3 and 6 kg/ha for winter wheat and 2 and 4 kg for the spring wheat varieties.

Table 9 Yield and lodging index at two rates of CCC, applied in growth stage 4–5; interprovincial series 1964, high nitrogen level

Variety and site	*Yield (kg/are)*			*Lodging index*		
	control	*3 kg CCC*	*6 kg CCC*	*control*	*3 kg CCC*	*6 kg CCC*
Cleo-NHH	60.7	64.6	66.4	4	7	8
Cleo-ZVl	62.6	67.4	69.4	3	6	7
Stella-OFl	65.7	70.1	69.4	6	9	10
Stella-WW	58.5	58.8	61.0	5	6	8
Opal-OO	46.5	47.9	49.6	6	8	9

Table 9 summarizes some results from the high nitrogen levels. In several instances, the reduction in lodging seems to be slightly better at the higher rate of CCC and the yield also appears somewhat higher. The differences were small, however, and the higher amounts of CCC would have been far from economic. For practical purposes, therefore, the lower application rate is adequate.

Discussion

Modern wheat varieties usually have fairly short straw and have relatively good lodging resistance. Yield losses from lodging, however, can be expected every year in a number of fields where the nitrogen requirement of the crop has been overestimated or where the soil has released more nitrogen than the farmer expected. Estimating the nitrogen requirement accurately is always rather difficult, particularly where the wheat crop has been preceded by heavily fertilized crops such as seed potatoes and tulips, or after leys or green-manure crops.

In several of our experiments the nitrogen dressing was considerably increased so as to induce lodging and to study the effect of CCC under rather extreme conditions. It was shown that lodging could be prevented even at fertilizer rates as high as 100 or 120 kg N/ha above the nitrogen requirement of the crop. The interprovincial experiments, performed under a wider range of conditions, generally confirmed this result. Under a very high 'nitrogen pressure' lodging or bending could not always be completely prevented. It could, however, at least be postponed for a considerable time, and it has been shown that the yield losses become smaller the later the lodging occurs (Weibel and Pendleton, 1964).

It may be wondered whether CCC affects the yield in ways other than by increasing the lodging resistance. Divergent opinions are met with on this point. Sturm and Jung (1964) were unable to find any yield increases on CCC-treated plots if no lodging occurred on the control plots. In other instances, however, an increased yield could be found in the absence of lodging. Such an effect was reported by Humphries et al. (1965), who ascribe this to an increase in the number of ears. In some of the interprovincial experiments yield increases were observed when no lodging or only some slight bending had occurred on the control plots. Generally such bending is not taken into account in lodging assessments. However, for rye it has been shown that even slight deviation from the upright position can cause yield losses (van Burg, 1965).

It may be stated as a tentative conclusion that CCC treatment does not usually increase the grain yield of wheat crops if it does not prevent or delay lodging. However, the fact that positive effects of CCC have been obtained on some occasions stresses the importance of future research on this point.

A very important question is whether the application of CCC allows an increased nitrogen dressings. Some of the experimental results clearly show that the application of CCC, together with an increased input of nitrogen, results in a higher yield than could be reached by nitrogen alone applied at an early growth stage. The likelihood of achieving such an effect will depend mainly on soil fertility and particularly on the pattern of nitrogen mineralization in the soil. Besides, a high potential yield level and a large nitrogen response seem to be necessary conditions.

In some experiments the 1000-grain weight was lower on the CCC-treated plots. This agrees with the results of several authors (Bachthaler, 1964; Humphries et al., 1965; Lovato, 1965. Generally, CCC treatment increases grain number by increasing the number of ears, the number of grains per ear, or both.

This effect may at least partly account for the decreased 1000-grain weight. One of the effects of lodging is also a decrease in the 1000-grain weight. This would explain why in experiments in which severe lodging was prevented by CCC treatment, the 1000-grain weight was found to be higher on the treated plots.

Conflicting data are to be found in the literature as to the growth stage at which the CCC treatment exerts its strongest inhibitory effect on stem elongation. Jung and Sturm (1964) and Lovato (1965) reported greater effects from early application, viz. during tillering or at the beginning of stem elongation. Linser and Kühn (1963) obtained only small differences throughout the tillering and elongation periods. Sturm and Jung (1964) found a more pronounced effect from the later applications. All the data obtained in our own experiments indicate that the shortening effect on culm length increases with delay in applying CCC up to at least growth stage 7 or in some instances even growth stage 8. Later application is less effective, the lower two internodes already having reached their final length. All varieties tested showed a similar response.

The shortening of the lower internodes is often regarded as being more important for the improvement of culm sturdiness than is an overall reduction in culm height. In our experiments, however, no differences were found between sprayings at stage 4–5 and at stage 8 (see Table 3). Although the later treatment hardly reduced the length of the lowest internode, if at all, the improvement in lodging resistance was similar to that obtained by early spraying. This means that the farmer may postpone his decision on whether to spray or not until well after the onset of elongation.

References

Arnold, G. H., Belderok, B., Bruinsma, J., Burg, P. F. J. van, Dilz, K. en Vos, N. M. de, 1965. Over de toepassing van CCC (chloorcholinechloride) op tarwe. *Stikstof,* 4 (45/46) : 369–380.

Bachthaler, G., 1964. Feldversuche mit CCC. *Deut. Landwirtsch. Presse,* 87 (42) : 419—420; 87 : 430.

Bruinsma, J., Vos, N. M. de and Dilz, K., 1965. Effects of (2-chloroethyl)-trimethylammonium chloride (CCC) on growth and development of cereal plants. *Meded. Landbouwhogeschool Opzoekingssta., Gent,* 30 : 1990–2006.

Burg, P. F. J. van, 1966. De stikstofbemesting van granen. 11. De invloed van een licht overhangen van een gewas winterrogge op de opbrengst. *Stikstof,* 5 (49) : 40–42.

Cathey, H. M., 1964. Physiology of growth retarding chemicals. *Ann. Rev. Plant Physiol.,* 15 : 271–302.

Humphries, E. C., Welbank, P. J. and Witts, K. J., 1965. Effect of CCC (chlorocholine chloride) on growth and yield of spring wheat in the field. *Ann. Appl. Biol.*, 56 : 351–361.

Jonker, J. J., 1964. De stikstofbemesting van granen in de IJsselmeerpolders. *Stikstof*, 4 (42) : 206–212.

Jung, J. und Henjes, G., 1965. Analytische Untersuchungen an Weizenproben aus CCC-Versuchen. *Landwirtsch. Forsch.*, 17 : 267–270.

Jung, J. und Sturm, H., 1964. Wachstumsregulierende Wirkung von Chlorcholinchlorid (CCC). *Landwirtsch. Forsch.*, 17 : 1–9.

Large, E. C., 1954. Growth stages in cereals. *Plant Pathol.*, 3 : 128–129.

Linser, H. und Kühn, H., 1963. Höhe und Zeitpunkt der Düngung von Sommerweizen mit Chlorcholinchlorid zur Verkürzung der Halmlänge. *Z. Pflanzenernähr. Düngung Bodenk.*, 101 : 206–210.

Lovato, A., 1965. Effetto dei trattamenti con cloruro de chlorocolina (CCC) sul frumento. *Agrochimica*, 9 (3) : 249–262.

Mayr, H. H., Primost, E. und Rittmeyer, G., 1962. Untersuchungen über die Erhohung der Standfestigkeit von Getreide. I. Feldversuche mit Chlorcholinchlorid zu Winterweizen. *Bodenkultur*, 13 (1) : 27–45.

Mitchell, J. W., Wirwille, J. W. and Weil, L., 1949. Plant growth regulating properties of some nicotinium compounds. *Science*, 110 : 202–254.

Sturm, H. und Jung, J., 1964. Der Einfluss von Blattspritzungen mit Chlorcholinchlorid (CCC) auf Wachstum und Ertrag von Weizen. *Z. Acker Pflanzenbau*, 120 : 232–252.

Tolbert, N. E., 1960. (2-chloroethyl)-trimethylammonium chloride and related compounds as plant growth substances. II. Effect on growth of wheat. *Plant Physiol.*, 35 : 380–385.

Vos, N. M. de, 1964. De werking van het halmverkortend middel CCC bij winter- en zomertarwe. Gestencilde Verslagen Interprovinciale Proeven, No. 103.

Weibel, R. O. and Pendleton, J. W., 1964. Effect of artificial lodging on winter wheat grain yield and quality. *Agron. J.*, 56 : 487–488.