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CHLORMEQUAT (CCC) IN GROWING SPRING WHEAT IN FINLAND

Selostus: Klormekvatti (CCC) kevätvehnän laontorjunnassa

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TEITTINEN, P. 1975. **Chlormequat (CCC) in growing spring wheat in Finland.** Ann. Agric. Fenn. 14: 1—56.

An average yield increase of approximately 3 % (100 kg/ha) was achieved by spraying 2 or 2.5 kg of chlormequat per hectare on spring wheat shoots about thirty days after sowing. A higher increase in yield could be expected when the rainfall in May and June was heavy and when lodging was extensive. The yield increases were also more marked on sandy soil than on clay or humus soils, and they were generally greater at a high yield level than at a low level. Chlormequat treatment reduced the weight of grains in 71 % of the trials and the volume weight in 65 %. The falling number went up in 62 % of the trials, the protein content of the grains was lowered in 72 %, lodging was reduced in 86 %, the stem was shortened in 100 % and heading was delayed in 63 % of the trials. Chlormequat residues in the grain at the application level 1.5 kg/ha varied from 0.16 to 2.0 mg/kg. Late treatment and high dosage led to increased residues. Chlormequat applied to the crop as a spray stimulated root growth in the grains obtained from the crop. The stem shortening effect of chlormequat was most marked on the top internode and least on the bottom internode. An increase in the diameter of the stem base and the thickness of the stem wall was manifest. Different varietal responses to the treatment were apparent in the stem shortening effect. The mean reduction in lodging was greatest in Norröna and least in Apu.

The alteration of the time of treatment from the 3 leaf to the 6 leaf stage did not result in changes in the grain yield or its characteristics, apart from the grain weight.

Chlormequat promoted the yield increase resulting from nitrogen fertilization by reducing lodging due to nitrogen. The reduction in lodging and shortening of the stem achieved with the given rate of chlormequat was proportionately smaller with a high level of nitrogen fertilization than with a low level. As a result of chlormequat treatment the level of nitrogen fertilization, without giving rise to lodging, went up by about 50 kg of nitrogen per hectare.

1. INTRODUCTION

Spring wheat is grown in Finland above latitude 60. This is north of the ordinary wheat growing border and, thus, it is the most northerly wheat producing region in the world. Due to pronounced vegetative growth caused by the large number of daylight hours in this northern region, lodging becomes there a severe problem in wheat cultivation.

The occurrence of lodging varies from year to year depending on weather conditions. In variety experiments in the wheat growing area of Finland mean lodging in spring wheat was 23 % for the years 1955 to 1964. During the same period, mean lodging in rye was 40 %, in winter wheat 25 %, in barley 22 % and in oats 16 % (TEITTINEN 1966 a).

The effect of lodging on the yield of spring wheat has been studied in Finland by YLLÖ

(1966 a) and TEITTINEN (1973). Lodging led to a greatly reduced yield. The quality of the yield was also lowered: the grains were small and amylase activity accelerated. — Lodging slows down harvesting and increases the need for drying, which in turn reduces the profit derived from a crop.

To determine the effect of lodging a series of trials was conducted at the Satakunta Experiment Station from 1969 to 1972. Taking into account the yield and its quality, the mean loss resulting from severe lodging was 267 marks per hectare for spring wheat, 297 marks per hectare for barley and 321 marks per hectare for oats (TEITTINEN 1973).

On the basis of these results, it can be estimated that the mean financial loss suffered as a result of lodging in cereal growing areas of present size (c. 1 300 000 ha) is c. 75 million marks. In years of severe lodging, the loss may be much greater. Ways of reducing lodging are, therefore, of considerable financial significance.

Well-known ways of reducing lodging are variety selection, avoiding high densities in sowing (KÖYLIJÄRVI 1974), weed control and, most effective of all, limiting nitrogen fertilization (MUKULA and TEITTINEN 1973). However, the significance of the latter has been disregarded owing to the benefits that increased nitrogen fertilization brings to the plants for other reasons. In fact, it is the increased application of nitrogen that has made the prevention of lodging such a difficult problem nowadays (Fig. 1).

A new phase in the prevention of lodging in cereals, particularly in wheat, was initiated by the American, TOLBERT (1960). He observed that when (2-chloroethyl)trimethylammonium chloride (also referred to as chlorocholine chloride, hence the abbreviation CCC; according to the British Standards Institute, chlormequat) was applied to the growing wheat shoot, stem elongation was reduced. As Tolbert's studies became better known, the effects of chlormequat became the subject of copious investigations throughout the world. Numerous references to the results of these investigations have been published and collected into bibliographies (e.g. CYCOCEL Plant Growth Regulant 1967, CYCOCEL (CCC) 1968). Detailed descriptions of the history of the application of chlormequat as a plant growth regulant and of the findings

Fig. 1. Fertilization of 100 kg nitrogen per hectare (right) caused a heavy lodging in spring wheat in the rainy summer of 1974.

from experiments conducted on it have been given by e.g. JEPSON (1965), CALDICOTT (1967), HUMPHRIES (1968 a), LINSER (1968) and WÜNSCHE (1970). Extensive bibliography is included in these works.

Field trials pertaining to research to a practical end were initiated in Austria (MAYR et al. 1962). In Finland the effects of chlormequat on cereals has been studied in field trials since 1963, on the initiative of MUKULA (1967). This paper presents the findings of these field trials, conducted from 1963 to 1973. The trials were planned and for the most part carried out by the Agricultural Research Centre. The results of the first two years of the trial period have been published earlier (MUKULA 1965, MUKULA et al. 1966) and some interim data have been presented since then (TEITTINEN 1966 b, 1969, MUKULA and TEITTINEN 1967, TEITTINEN and MUKULA 1967, 1969).

The sales of chlormequat products in Finland in 1973 amounted to 197.8 tons containing 131.8 tons of active ingredient (MARKKULA 1974). The area of spring wheat sprayed with chlormequat is not known, but it can be estimated at about 55 000—60 000 hectares.

2. MATERIAL AND METHODS

The field trials for the present study were conducted in various parts of South and Central Finland, for the most part in the spring wheat growing area. The experiment localities with their degrees of latitude were as follows (Fig. 2):

Years of experiment	Locality	Latitude N
1965	Fiskari	60° 05′
1966—1969	Jomala	60° 08′
1963—1972	Tikkurila	60° 17′
1965—1966	Paimio	60° 29′
1964—1969	Mietoinen	60° 38′
1964—1966	Anjala	60° 43′
1968—1969	Leteensuo	61° 04′
1965—1967	Hauho	61° 09′
1964—1973	Peipohja	61° 17′
1964—1969	Pälkäne	61° 20′
1965—1967	Mikkeli	61° 40′
1968—1969	Laukaa	62° 30′
1964—1972	Ylistaro	62° 57′
1964—1972	Maaninka	63° 09′

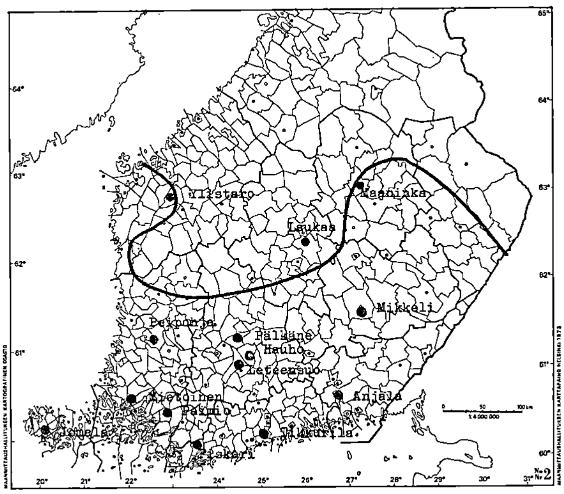

Fig. 2. The allocation of field trials. The map also shows the border south of which spring wheat comprised at least 1 % of the cultivated area in 1969.

Chlormequat was applied as a spray to the shoots in all except the seed treatment trials. With the exception of application time trials, the plants were sprayed at the four- to five-leaf stage, i.e. at growth stage 2—3 on the Feekes scale (LARGE 1954).

The following cultivars were grown in most experiments:

Apu, bred by the Institute of Plant Breeding of the Agricultural Research Centre, Finland; put on the market in 1949,

Diamant, bred by the Swedish Seed Association, Sweden; put on the market in 1928,

Norröna, bred by the State Experiment Farm Möystad, Norway; put on the market in 1952, Ruso, bred by the Plant Breeding Institute of Hankkija, Finland; put on the market in 1967,

Svenno, bred by W. Weibull AB, Sweden; put on the market in 1954.

Commercial chlormequat products were used in the trials. The active ingredient content in the products was 40, 60 or 75 %.

From 400 to 500 litres of spray solution were applied per hectare using a gas spray equipped a cyclone chamber nozzle. The rainfall (mm) for May and June at the trial localities was as follows (Kuukausikatsaus Suomen sääoloihin 1963—1972):

Experiment locality	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Fiskari			36							
Jomala[1]				42	97	79	45			
Tikkurila[2]	44	44	65	37	72	122	59	38	30	63
Paimio			48	45						
Mietoinen		65	25	51	98	82	45			
Anjala		58	102	48						
Leteensuo						96	59			
Hauho			25	65	89					
Peipohja		43	44	54	129	89	60	20	21	44
Pälkäne		77	31	69	91	92	73			
Mikkeli			84	47	112					
Laukaa[3]						114	53			
Ylistaro		44	47	51	102	122	53	70	80	109
Maaninka		110	86	64	158	112	54	47	55	110

1 = at Maarianhamina airport, 2 = at Helsinki airport in 1972, 3 = at Jyväskylä airport.

Quality analyses of the crop yield were performed according to conventional methods. The final viscosity of the starch at the time of harvest determined with a falling number test according to HAGBERG (1961). Analyses on residues were carried out partly at the Agricultural Research Center of the American Cyanamid Company, partly at the Laboratory of the State Institute for Agricultural Chemistry and partly at the Research Centre of the firm Kemira Oy by adapting the method of MOONEY and PASARELA (1967). Protein content in grains was calculated by multiplying N × 5.7.

The variance and regression analyses were performed according to SNEDECOR (1956).

The numbers in the tables include all the trials established that gave a correct result. The magnitude of the error variance for the trial was disregarded. Thus, the results were not weighted by the standard error of the trials (cf. YATES and COCHRAN 1970), but all the results presented have the same common weight.

3. RESULTS

3.1 Application rates for foliar treatment

TOLBERT (1960) added chlormequat to the soil, this being more effective than application as a foliar spray or seed soak. During the subsequent years, workers in Austria (MAYR et al. 1962, LINSER 1968) and in Germany (JUNG 1964, STURM and JUNG 1964, KÜHN et al. 1966) observed that stems were more readily shortened when chlormequat was sprayed onto the plant than when it was mixed into the soil. In Finland also the first field experiments (initiated in 1962—1963, before the aforementioned results were published) aimed at developing a method of using chlormequat as a foliar spray (MUKULA et al. 1966).

The quantities of chlormequat used experimentally at the beginning of 1960s were in general high; for instance MAYR et al. (1962) used 4—16 kg/ha, PINTHUS and HALEVY (1965) 10 kg/ha and van BURG and ARNOLD (1969) 8 kg/ha. However, it was very soon observed that smaller doses were sufficient when applied as a spray and not mixed into the soil (JUNG and STURM 1964, JEPSON 1965). Application rates of under 2 kg/ha were tried by SCHRÖDER and RHODE (1965), BACHTHALER (1966) and STURM (1965) in Germany and GEERING (1965) and MÜHLETHALER (1965) in Switzerland. As early as 1965 STURM recommended for spring wheat an application rate between 1.0 and 1.5 kg/ha.

The application rates in the first trial series of the present study were 2.5, 5 and 10 kg per hectare. It was observed that the lower application rate was almost as effective as the higher, and thus, in the second trial series application rates of 1, 2 and 3 kg per hectare were adopted. On the basis of the results of this trial series, the dosages were again readjusted, aiming at finding the smallest effective dosage. Rates of 0.7, 1.3 and 2 kg per hectare were used in this third trial series. At the same time the studies were extended to establish the effect of the dosage at different levels of nitrogen fertilization. In this trial series the weak-stemmed variety Norröna, widely grown in Finland at that time (in 1965 14.3 % and in 1970 11.4 % of total spring wheat; the third greatest area in both years), was used in most experiments. In previous experiments it had been observed that chlormequat had an especially beneficial effect on this variety.

On the basis of the results of preliminary trials in 1963, it was determined that the spray should be applied when half the plants were at five-leaf stage. In about one quarter of the experiments, development was examined by shoot count on the day when the spray was applied or on the following day. According to the counts, the spray was applied very close to the growth stage aimed at, although it was not always possible to apply it at the appointed time owing to rain, etc. The suitability of the timing could be checked by application time trials, the results of which are presented in chapter 3.2. On the basis of these results, correct timing of the dosage experiments could be ensured.

In the first trial series, the mean application time of the spray was the 31st day after sowing, in the second series the 29th day and in the third series the 32nd day. The mean height of the plants at spraying varied from 10 to 40 cm depending on the time of spraying, the variety of wheat and the rate of nitrogen fertilization. In the third trial series the mean height was 27 cm.

3.1.1. Grain yield

According to the results published by PESSI et al. (1970), treatment with chlormequat (3 kg/ha) produced increases in the yield of Svenno, maximum 58 %, in all cases except one. The yields of Apu and Ruso were reduced, by 22 % at the most, except where the fertilization rate had been raised. The experiments on Svenno were conducted in 1966 and 1967, and on Apu and Ruso in 1968. The mean yield increase in all trials was 14 %. Only the largest yield increases in Svenno were statistically significant. Otherwise the reliability of the results was low: the standard error of the mean was 10.1 % in the experiments conducted on Apu, and 9.5 % in those conducted on Ruso.

In the trials described by LAMPINEN (1972), the effect of chlormequat treatment on spring wheat fluctuated between a reduction in yield of 7 % and an increase of 9 %.

A trial carried out by JAAKKOLA (1967) indicated a mean reduction in yield of 13 %. According to him, this can be explained by the rapid ripening of the crop. The basic reason for this and the reduction in yield was probably the exceptionally dry early summer of 1965. The abnormal weather conditions under which Jaakkola conducted

Table 1. Effects of the different application rates of chlormequat on yield and on some characteristics of spring wheat. 1st trial series.

	Number of comparisons	Chlormequat kg/ha				P*)	
		0	2.5	5	10	1	2
Grain yield kg/ha	70	2790	2930	2920	2910	*<0.001*	*>0.500*
» » %	70	100	105	105	104		
Headed stems per m	28	67	66	64	65	*0.124*	*0.428*
Shoots per m²	5	373	408	392	385	*0.156*	*0.425*
Tillers per plant	5	1.14	1.17	1.19	1.16	*0.077*	*0.280*
Sterile shoots per 100 plants	5	3.9	4.6	4.4	4.4	*>0.500*	*>0.500*
Grains per head	2	16.0	17.8	17.8	20.0	*0.102*	*0.292*
» mg per head	2	490	532	556	603	*0.105*	*0.316*
1000-grain weight g	69	33.8	33.0	32.6	32.3	*<0.001*	*<0.001*
Scorching %	8	0	6	11	16	*<0.001*	*0.022*
Hectolitre weight kg	69	76.7	76.4	76.4	76.2	*<0.001*	*0.345*
Falling number	30	246	273	264	264	*<0.001*	*0.304*
Sprouted grains %	9	12.2	10.3	9.7	9.8	*0.015*	*>0.500*
Germination %	3	82	83	84	87	*0.102*	*0.109*
Protein %	11	13.2	12.4	12.5	12.4	*<0.001*	*0.491*
Residues mg/kg	4	0.25	1.24	1.57	1.25	*0.008*	*>0.500*
Lodging %	69	26	8	5	4	*<0.001*	*0.076*
Stem length cm	68	82	68	66	61	*<0.001*	*<0.001*
Straw yield kg/ha	31	4350	4110	3970	3830	*<0.001*	*<0.001*
Heading, day of	18	12/7	12/7	13/7	13/7	*0.002*	*0.410*
Growing period, in days	54	109	109	109	109	*0.233*	*0.284*
Moisture at ripening %	12	35.5	36.5	36.4	36.0	*0.163*	*>0.500*
» at harvesting %	9	30.0	30.0	29.2	29.9	*0.021*	*>0.500*
Green grains %	11	1.4	2.0	1.8	2.0	*0.050*	*>0.500*

*) Risk: 1 = between untreated and treated crops, 2 = between treated crops.

his trial diminishes the value of the yield results.

According to YLLÖ (1964), the effect of chlormequat on yield varied considerably in his trial.

Treatment with chlormequat in field experiments in Sweden has produced yield increases from 0 to 12 % (ENGSTRÖM 1965, FAJERSSON 1965), but also reduction from 3 to 10 % (FAJERSSON 1965, BENGTSSON and WÜNSCHE 1966, BENGTSSON 1971). Varying results have also been obtained in the trials conducted in Denmark (LARSEN 1973).

Increases of more than 50 % in the yield of spring wheat have been obtained by ADLER (1965) in Hungary, BACHTHALER (1966, 1967) in Germany, CALDICOTT (1966) in Great Britain, PRIMOST (1968) in Austria, ARKHIPOV et al. (1972) in Soviet Union and PHILPOTTS (1972) in Australia. Increases of 20 % or more have been obtained also by PINTHUS and HALEVY (1965) in Israel, LOVATO (1965) in Italy, STURM (1965) and JUNG et al. (1966) in Germany, de VOS et al. (1967) in the Netherlands, ALCOCK et al. (1967) and HUMPHRIES and BOND (1969) in Great Britain, SHRIVASTAVA et al. (1968) in India and IBRAHIM et al. (1972) in Egypt. Almost as great increases have been obtained also by GEERING (1965) in Switzerland and PETR and RYTINA (1967) in Czechoslovakia.

Besides the Finnish and Swedish experiments mentioned above some of the field experiments conducted by MÜHLETHALER (1965) in Switzerland, CALDICOTT (1966) and BARRETT et al. (1967) in Great Britain and MARTIN (1968) in Germany showed reductions in yield from 1 to 10 %.

In the first trial series of the present study 70 experiments were performed from 1963 to 1967. The mean yield without chlormequat was 2 790 kg/ha (Table 1). The yield was increased by 5 % when 2.5 kg chlormequat was applied per hectare. The yield was slightly

Table 2. Effects of the different application rates of chlormequat on yield and on some characteristics of spring wheat. 2nd trial series.

	Number of comparisons	Chlormequat kg/ha				P*)	
		0	1	2	3	1	2
Grain yield kg/ha	17	3160	3290	3350	3370	<0.001	0.435
» » %	17	100	104	106	107		
Shoots per m²	3	425	471	479	501	0.038	0.555
Tillers per plant	3	1.17	1.15	1.20	1.11	>0.500	0.276
1000-grain weight g	17	29.0	28.3	27.9	28.3	<0.001	0.250
Hectolitre weight kg	17	74.4	74.2	74.0	74.0	0.316	>0.500
Falling number	13	115	143	153	155	0.002	>0.500
Sprouted grains %	3	4.6	2.8	3.2	2.6	0.090	>0.500
Germination %	1	81	82	71	79	—	—
Protein %	2	14.4	13.6	13.6	13.8	0.089	>0.500
Lodging %	17	55	36	31	28	<0.001	0.221
Stem length cm	16	86	74	68	67	<0.001	<0.001
Straw yield kg/ha	4	3610	3130	3040	2700	0.006	0.171
Heading, day of	6	14/7	15/7	15/7	15/7	<0.001	0.061
Growing period, in days	12	99	100	100	100	<0.001	—
Moisture at ripening %	4	32.6	32.6	32.0	32.2	0.402	>0.500
Green grains %	3	0	0	0	0	—	—

*) Risk: 1 = between untreated and treated crops, 2 = between treated crops.

reduced when the dosage of chlormequat was increased. In separate trials the changes in yield varied from —22 to +33 %. The equation for the mean yields was (Fig. 3)

$$Y_1 = 2.9x^2 - 8.4x + 250.1 \lg(x + 1.13) + 2786.9$$

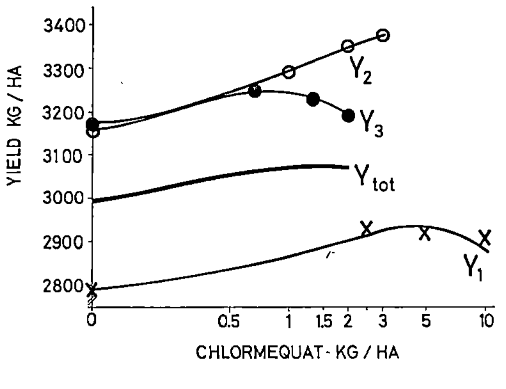

Fig. 3. The effect of the application rate of chlormequat on the yield of spring wheat.

$$Y_1 = 2.9x^2 - 8.4x + 250.1 \lg(x + 1.13) + 2786.9$$
$$Y_2 = -3460.0 (9.30x + 11.42)^{-1} + 3460.0$$
$$Y_3 = -25.0x^2 + 70.5 \lg(42.3x + 1.8) + 3154.0$$
$$Y_{tot} = -9.0x^2 + 96.5 \lg(10.5x + 1.5) + 2975.0$$

In the second trial series a total of 17 experiments were conducted, mainly in 1967, but also at one trial locality in 1971 and 1972. The mean yield without chlormequat was 3 160 kg/ha (Table 2). The mean increase in yield from 1 kg chlormequat was 4 %, from 2 kg 6 % and from 3 kg 7 %. The changes in yield between separate trials varied from —9 to +30 %. The equation for the mean yields in this series was (Fig. 3)

$$Y_2 = -3460.0 (9.30x + 11.42)^{-1} + 3460.0$$

In the third trial series 61 experiments were conducted from 1968 to 1972. The mean yield without chlormequat was 3 170 kg/ha (Table 3). The mean increase in yield with the smallest amount of chlormequat (0.7 kg/ha) was 3 %, with the next (1.3 kg/ha) 2 % and with the largest (2 kg/ha) 1 %. The changes in yield in separate trials varied from —30 to +31 %. The mean yields were expressed in the equation (Fig. 3)

$$Y_3 = -25.0x^2 + 70.5 \lg(42.3x + 1.8) + 3154.0$$

Considering all the yield results from application rate trials, the effect of chlormequat application rate on yield can be drawn according to the equation (Fig. 3)

$$Y_{tot} = -9.0x^2 + 96.5 \lg(10.5x + 1.5) + 2975.0$$

Table 3. Effects of the different application rates of chlormequat on yield and on some characteristics of spring wheat. 3rd trial series.

	Number of comparisons	Chlormequat kg/ha				P*)	
		0	0.7	1.3	2	1	2
Grain yield kg/ha	61	3170	3250	3230	3190	*0.004*	*0.068*
» » %	61	100	103	102	101		
Shoots per m²	39	536	534	527	531	*0.444*	*>0.500*
Tillers per plant	39	1.09	1.08	1.10	1.13	*0.334*	*0.095*
Grains per head	9	18.5	19.1	19.0	19.0	*0.145*	*>0.500*
» mg per head	9	548	570	561	550	*0.372*	*0.034*
1000-grain weight g	61	33.4	32.6	32.5	31.9	*<0.001*	*0.172*
Scorching %	1	0	0	0	1	—	—
Hectolitre weight kg	61	77.7	77.0	76.7	76.4	*<0.001*	*0.008*
Falling number	52	317	317	316	323	*>0.500*	*0.276*
Sprouted grains %	3	0	0.1	0	0	*>0.500*	*>0.500*
Germination %	15	72	72	70	70	*0.257*	*>0.500*
Protein %	34	14.1	13.7	13.6	13.7	*<0.001*	*>0.500*
Lodging %	61	30	13	10	9	*<0.001*	*0.114*
Stem length cm	61	82	71	69	66	*<0.001*	*<0.001*
Heading, day of	22	8/7	8/7	8/7	8/7	*<0.001*	*>0.500*
Growing period, in days	54	102	102	102	102	*0.003*	*0.210*
Moisture at ripening %	21	34.9	35.5	36.0	36.2	*0.025*	*0.340*
» at harvesting %	12	22.6	22.1	22.0	21.4	*0.055*	*0.345*
Green grains %	18	0.5	0.5	0.6	0.6	*>0.500*	*>0.500*

*) Risk: 1 = between untreated and treated crops, 2 = between treated crops.

Table 4. Effects of the application of chlormequat on yield and on some characteristics of spring wheat. All trial series

	Number of comparisons	Chlormequat kg/ha		P
		0	2 (2.5)	
Grain yield kg/ha	148	2990	3090	*<0.001*
» » %	148	100	103	
Shoots per m²	47	512	514	*>0.500*
Tillers per plant	47	1.09	1.13	*0.029*
Sterile shoots per 100 plants	5	3.9	4.6	*>0.500*
Grains per head	11	18.0	18.7	*0.125*
» mg per head	11	538	547	*>0.500*
1000-grain weight g	147	33.1	32.0	*<0.001*
Scorching %	5	0	9	*0.033*
Hectolitre weight kg	147	76.8	76.1	*<0.001*
Falling number	95	267	284	*<0.001*
Sprouted grains %	15	9.6	6.8	*<0.001*
Germination %	19	74	72	*0.123*
Protein %	47	13.9	13.4	*<0.001*
Lodging %	147	31	11	*<0.001*
Stem length cm	145	82	67	*<0.001*
Straw yield kg/ha	35	4270	3990	*<0.001*
Heading, day of	46	10/7	11/7	*<0.001*
Growing period, in days	120	104.7	105.0	*<0.001*
Moisture at ripening %	37	34.8	35.3	*0.354*
» at harvesting %	21	26.1	25.1	*0.075*
Green grains %	32	0.8	1.0	*0.080*

Significant differences in the yield of untreated crops were not obtained between the trial series ($P = 0.114$). On the other hand, the mean values for the increase in yield of crops treated with chlormequat differed significantly from each other ($P = 0.029$). To be more precise, the mean increase in yield of the third trial series differed from the others and was considerably smaller. The reason for this is that the third trial series consisted mainly of the Norröna cultivar, whose yield was not increased despite marked stem shortening (cf. chapter 3.4).

The results of the first trial series showed that not beneficial effect is obtained by raising the dosage of chlormequat above the smallest dosage (2.5 kg/ha) applied in these experiments. In the second trial series the mean yield increases were raised with a higher dosage of chlormequat. However, the significance of the differences in the mean values was very low ($P = 0.435$). Again, in the third trial series, when the application rates of chlormequat experimented were lowest, mean effect on the yield was of the same order.

A higher dosage increased the yield totally in only eight of the individual trials. The situation was different when it comes to lodging, as will be seen in chapter 3.1.5.

Since the differences in yield due to dosage had low significance, the examination of the changes in yield and their causes concentrates in the following on treatments with 0 and 2 or 2.5 kg chlormequat (Table 4). In this way the entire field experiment data can be utilized effectively in assessing the effects of chlormequat.

Trough closer study of the abundant data from the field experiments, the impacts of several factors on the effects of chlormequat could be evaluated.

There were significant annual variations in the yield of untreated trial crops ($P = 0.041$), as also in the mean values of the yield increases ($P = 0.028$; Table 5). Thus, weather conditions had a noticeable effect on the yield increases in plants treated with chlormequat.

There was a distinct, though only slight, positive correlation ($r = 0.239$, $P = 0.022$) between the moisture in the beginning of the growing period (rainfall May and June) and the increase in yield.

Variations in yield between different soil types were very significant (Table 5). The level of the yield was higher in sandy soils than in clay and humus soils. Likewise, the increases in yield due to chlormequat were significantly greater in sandy soils than in other soils. In humus soils the average yield was smaller for crops that had been sprayed with chlormequat.

Significant variations in yield were also observed between the trial localities, as were yield increases due to treatment with chlormequat (Table 5). It is supposed that the variations between sites are partly the result of the uneven distribution of soil types at the trial sites. It is also possible that the variations are due to dissimilar growth conditions at the trial sites, e.g. different nitrogen fertilization.

The spring wheat cultivars grown in most trials were Apu, Diamant, Norröna, Ruso or Svenno. The significance of yield differences between the varieties was rather high, as was that of the differences in yield increases due to chlormequat (Table 5). In Norröna the latter was practically zero, whereas in the other varieties it was moderate. In Ruso the treatment caused reduced yield. The effect of chlormequat on other characteristics of the wheat cultivars will be discussed in chapter 3.4.

On the whole, the higher the grain yield in untreated plots, the greater the grain yield increase obtained with chlormequat: the correlation coefficient between yield level and yield increase was $r = 0.374$ ($P < 0.001$).

3.1.2 Components of grain yield

The yield of a crop depends on the number of heads per unit area, the number of grains per head and the size of the grains. The effects

Table 5. Yields and yield increases obtained with an application rate of 2 (2.5) kg/ha chlormequat, classified according to years, soil types, trial sites and cultivars.

	Number of comparisons	Untreated yield kg/ha	Treated yield Increase kg/ha	%
Years:				
1963	1	2640	350	13
1964	13	2780	120	4
1965	24	2930	70	2
1966	29	2570	180	7
1967	18	3100	140	5
1968	22	2860	—70	—2
1969	23	3880	—50	—1
1970	4	3320	270	8
1971	7	2550	240	9
1972	7	3760	160	4
P		*0.041*	*0.028*	
Soil groups:				
Sandy soils	59	3370	160	5
Clay soils	69	2800	90	3
Humus and peat soils	20	2540	—80	—3
P		*<0.001*	*0.004*	
Trial sites:				
Fiskari	3	1760	120	7
Jomala	4	3660	80	2
Tikkurila	17	2890	90	3
Paimio	18	2800	100	4
Mietoinen	16	2720	—100	—4
Anjala	3	2240	130	6
Leteensuo	6	2720	—460	—17
Hauho	4	2790	270	10
Peipohja	22	2840	120	4
Pälkäne	16	3540	90	3
Mikkeli	5	2220	20	1
Ylistaro	19	2890	130	4
Maaninka	15	4040	250	6
P		*<0.001*	*<0.001*	
Cultivars:				
Apu	45	3190	180	6
Diamant	18	2630	160	6
Norröna	54	2960	10	0
Ruso	4	4200	—120	—3
Svenno	26	2810	110	4
Touko	1	1860	0	0
P		*0.009*	*0.021*	
Interactions				
years × soil groups	*P*	*<0.001*	*>0.500*	
» × trial sites	*P*	*<0.001*	*>0.500*	
» × cultivars	*P*	*<0.001*	*0.015*	
soil groups × trial sites	*P*	*<0.001*	*>0.500*	
» » × cultivars	*P*	*<0.001*	*>0.500*	
trial sites × cultivars	*P*	*<0.001*	*0.008*	

of the chlormequat treatment on all of these components of the yield has been studied.

Density and tillering

Apart from the data published earlier from the present study (Mukula et al. 1966), little mention is found in the literature regarding the effect of chlormequat on the survival of the seedlings of spring wheat after spraying. In diseased stands, Bockmann (1971) found that chlormequat treatment prevented the decrease caused by root rot diseases in a number of plants.

In many field trials chlormequat has increased the number of fertile tillers per plant (DILTZ et al. 1965, GEERING 1965, HUMPHRIES et al. 1965, BACHTHALER 1966, BARRETT et al. 1967, PRIMOST 1967, BOCKMANN 1971, LOWE and CARTER 1971, LOVETT and KIRBY 1971). According to HUMPHRIES (1968 a), chlormequat allows some tillers to survive that would otherwise have died. DILZ et al. (1965) found that the stems shortened due to chlormequat intercepted less light than the untreated ones. Therefore, the light penetrating the stand promoted the survival of the tillers. The same suggestion was also made by HUMPHRIES et al. (1965). Later HUMPHRIES et al. (1967) stated that chlormequat increased tiller survival only when heads were emerging at a period of increasing moisture deficit in the soil. They attributed the benefit of chlormequat to the larger root system which enabled the plant to obtain more water from the soil and so counteract the lethal effect to tillers of drought. HANUS (1967) and LINSER (1968) were of the same opinion. In some cases no increasing effect can be observed (BRUINSMA et al. 1965, YLLÖ 1969 b, IBRAHIM et al. 1972). In the trials conducted by PHILPOTTS (1972), chlormequat treatment had a distinct tendency to diminish density, but the significance of the differences was low. LUPTON and PINTHUS (1969) observed also an increase in the number of sterile shoots.

In some experiments during the present study, counts were made of the number of shoots emerged and/or of heads developed. The results indicated that the application of chlormequat did not produce any change in the density of the plants. Tillering was greater with chlormequat application than without it (Tables 1—4). However, the correlation between tillering and density was closer ($r = -0.239$, $P = 0.002$) than that between tillering and chlormequat application ($r = 0.079$, $P = 0.286$). In individual experiments tillering increased in 64 % of the cases (Table 26).

In this study the number of sterile shoots was determined on three varieties in 1964 and on two in 1965. The results indicated that the number of sterile shoots increased after the plants had been treated with chlormequat, but owing to the considerable variation, the significance of the differences between the treatments was low (Table 1).

Head size

Treatment with chlormequat had increased the number of grains per head in the field trials of many workers (MAYR et al. 1962, MAYR and PRIMOST 1963, ARNOLD et al. 1965, HUMPHRIES et al. 1965, LOVATO 1965, PINTHUS and HALEVY 1965, BACHTHALER 1966, PRIMOST 1967, LINSER 1968, HUMPHRIES 1968 b, HUMPHRIES and BOND 1969, BOCKMANN 1971, LOWE and CARTER 1971, 1972, LOVETT and KIRBY 1971, PHILPOTTS 1972). However, CALDICOTT and LINDLEY (1964) and YLLÖ (1969 b) found that the number of grains per head was not affected.

IBRAHIM et al. (1972) reported the weight of grains per head had increased, but HUMPHRIES et al. (1965) and YLLÖ (1969 b) found the reverse in their trials.

In some of the trials during this study the number of grains per head were counted and weighed. The results of two trials in the first series indicated a change in the number of heads and grains as well as in their weight after treatment with chlormequat (Table 1). However, the variation was so great that the statistical significance of the differences between the means remained low.

In the year 1966 a variety trial was conducted at the Satakunta Experiment Station. The head sizes of 17 varieties of spring wheat were measured in both untreated and treated plants. The rate of chlormequat was 2.5 kg/ha. The head sizes were as follows:

Chlormequat kg/ha	No. of heads investigated	No. of grains per head	Weight of grains per head, mg
0	975	19.2	592
2.5	918	22.4	658
P	*0.300*	*0.004*	>0.500

Both sample groups represents an area of equal size. Consequently, the difference in the number of heads means that the plants grew more sparsely in the plots treated with chlormequat. This was probably a coincidence because the variation in the number of heads had low significance. On the other hand, there was considerable correlation between the density of the plants and the number of grains per head ($r = -0.367$, $P = 0.063$). Thus, it was not possible to explain satisfactorily the direct influence of chlormequat on the size of the heads.

In other trials chlormequat treatment resulted in an increase in the number and total weight of grains per head (Table 3). The differences, however, had low statistical significance.

In the present study chlormequat treatment did not produce any change in head length (cf. chapter 3.1.5).

Grain weight

A decrease in grain weight due to chlormequat spraying has been reported by many workers (e.g. GEERING 1965, HUMPHRIES et al. 1965, LOVATO 1965, BACHTHALER 1966, BENGTSSON and WÜNSCHE 1966, BARRETT et al. 1967, JAAKKOLA 1967, PRIMOST 1967, IVANOVA 1968, MARTIN 1968, SYME 1968, van BURG and ARNOLD 1969, HUMPHRIES and BOND 1969, YLLÖ 1969 b, BENGTSSON 1971, LOVETT and KIRBY 1971, ARKHIPOV et al. 1972, PHILPOTTS 1972). In the trials conducted by PESSI et al. (1970) grain weight was lowered only when the development of the crop was weaker than is usual. In the other cases grain weight was increased. An increase was also reported by SCHULTZ (1971) in 1968, a wet year. It was suggested that a greater assimilation of water and nutrients produced the heavier grains. The weight increasing effect of chlormequat was also found in the experiments conducted by BARRETT et al. (1967), de VOS et al. (1967), MARTIN (1968), PRIMOST (1968) and HUMPHRIES and BOND (1969).

Grain weight was not affected in the trials carried out by MAYR et al. (1962), SCHRÖDER and RHODE (1965) and IBRAHIM et al. (1972).

In the present study, the weight of 1000 grains was determined in almost all trials. In 71 % of the trials weight was reduced (Table 26), which is revealed in the mean weight of 1000 grains from each trial series (Tables 1—3). The weight reduction after application of 2 (2.5) kg chlormequat per hectare amounted to an average of 1.1 g compared with untreated grains (Table 4). The limits of variation were —8.2 and +2.2 g. The equation for the mean changes in the thousand grain weight was (Fig. 4)

$$Y = 1.7 \cdot 1.56^{-x} + 31.40$$

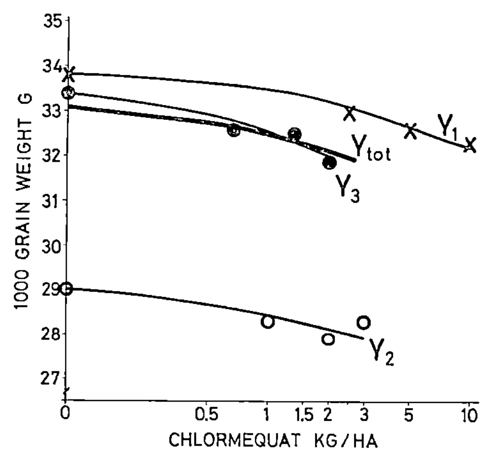

Fig. 4. The effect of the application rate of chlormequat on the 1000-grain weight of spring wheat.

$Y_1 = 15.0^{-1}x + 3.0 \cdot 1.15^{-x} + 30.80$
$Y_2 = 1.3 \cdot 1.8^{-x} + 27.70$
$Y_3 = 2.2 \cdot 1.66^{-x} + 31.20$
$Y_{tot} = 1.7 \cdot 1.56^{-x} + 31.40$

The yields from the trials in 1972 were classified in four categories according to grain size. A reduction in grain size was manifest, which no doubt also accounts for the reduction in weight (Table 6).

The reduced grain size, which was associated with a lower protein content as revealed in chapter 3.1.4, seems to indicate that the movement of assimilates to the grains was

Table 6. Variation in grain size caused by chlormequat application. Results from two trials conducted in 1972. Variety Norröna.

Chlormequat kg/ha	Size distribution % below 2.2 mm	2.2 – 2.5 mm	2.5 – 2.8 mm	over 2.8 mm	Mean size mm
0	10.8	25.9	45.1	18.2	2.56
0.7	10.9	26.8	44.5	17.8	2.56
1.3	11.5	28.4	43.2	16.9	2.55
2	12.2	29.5	42.7	15.6	2.54
P	*0.103*	*0.060*	*0.031*	*0.085*	*0.078*

disturbed at a very early stage. It is true that LOVE and CARTER (1972) in Australia did not notice any difference in the distribution of the assimilates between treated and untreated plants, but BIRECKA (1966), in Poland, observed that more carbohydrates were located in the head in plants treated with chlormequat than in untreated plants. One possible reason for this may be that chlormequat causes alterations in the structure of the cell wall. It has been observed that the cell wall is strengthened after treatment of crop with chlormequat (cf. chapter 3.1.5).

3.1.3 Additional factors affecting grain yield

The scorching of leaves after spraying may reduce yield. Chlormequat (2 or 2.5 kg/ha) caused scorching in five of the trials, that is, in 3 % of the total number of trials. According to visual estimations the mean scorching rate in these trials was 9 % of the leaf area of plants. There was no proof that scorching had a detrimental effect on yield, as can be seen from the following table.

Scorching %	Yield % from yield of untreated crop
1	99
7	97
7	121
13	109
18	100

The effect of chlormequat on susceptibility to disease in spring wheat is discussed in chapter 3.7. In the light of the observations, there is no indication that the alteration observed in the susceptibility of plants to disease after treatment with chlormequat had an effect on yield.

The effect of chlormequat on lodging is discussed in greater detail in chapter 3.1.5. Severe lodging generally reduces yield, sometimes considerably (MULDER 1954, SYME 1968, YLLÖ 1969 a, TEITTINEN 1973). The correlation between the increase in yield and the reduction in lodging was also evident in the trials to be discussed, even though it was only slight ($r = 0.209$, $P = 0.056$). In 22 % of the trials the yield was increased in the plots treated with chlormequat even when no lodging at all occurred in untreated plants or when the lodging was subordinate (maximum c. 10 %). Under similar conditions, the yield was reduced following chlormequat treatment in 13 % of the cases.

3.1.4 Quality of grain yield

Volume weight

The detrimental effect to be seen in the grain weight is also visible in the volume weight of the yield of a crop treated with chlormequat. FAJERSSON (1965), BENGTSSON and WÜNSCHE (1966) and BENGTSSON (1971) reported diminished hectolitre weight in spring wheat. Like the grain weight, the volume weight was increased in most trials made by PESSI et al.

(1970). It was only lowered when development of the crop was weakened.

In the present trial series, reduction in volume weight were manifest and became more marked when the application rate of chlormequat was increased (Tables 1—4). With 2 (2.5) kg chlormequat per hectare the hectolitre weight decreased in 65 % of the trials and fell below acceptable market limits (74 kg) in 9 % of the trials. In 45 % of the cases, the grain would have fetched a lower price on the market due to diminished hectolitre weight, the average reduction in price being 0.81 pennis per kilogramme according to the present official regulations on quality requirements in Finland (Decision of Ministry of Agriculture = Maatalousministeriön päätös, 3. 7. 1968). The mean hectolitre weight reduction from 2 (2.5) kg chlormequat per hectare was 0.7 kg. The mean reduction in price due to diminished weight would have been 0.27 pennis per kilogramme. The mean volume weight was like the curve described in Figure 5. The equation representing the curve was

$$Y = 0.476 \cdot 0.558^{(x-1.22)} + 75.88$$

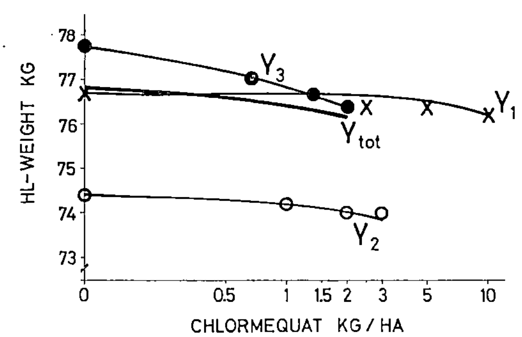

Fig. 5. The effect of the application rate of chlormequat on the hectolitre weight of spring wheat.

$Y_1 = -0.23 \cdot 1.25^{(2^{-1}x)} + 76.93$
$Y_2 = 0.8 \cdot 0.498^{(2^{-1}x)} + 73.60$
$Y_3 = 0.4 \cdot 0.485^{(x-2)} + 76.00$
$Y_{tot} = 0.476 \cdot 0.558^{(x-1.22)} + 75.88$

Amylase activity and germination

In the Nordic countries weather conditions in the autumn often are unfavourable to cereal cropping and cause changes in the starch consistency of grains. This decreases the baking qualities. The so called falling number method was, therefore, developed by the Swedes, Hagberg and Perten to measure the consistency of starch and, indirectly, the α-amylase activity in grains (Hagberg 1961). The higher the falling number, the better the consistency of starch from the baker's point of view. The falling number was measured in several Finnish and Swedish trials with chlormequat. Bengtsson (1971) found an increase in the falling number of spring wheat owing to chlormequat spraying in eight field trials conducted in Sweden in 1965 and 1966. In the trials carried out by Pessi et al. (1970), the falling number increased in Svenno, partly increased and partly decreased in Apu and regularly decreased in the Ruso cultivar.

The falling number has been determined in the trials of the present study since 1966. The falling number increased in 62 % of the trials (Table 26). The mean falling number of the yields from untreated plots was 267 seconds and in plants treated with 2 (2.5) kg chlormequat per hectare 284 seconds (Tables 1—4). In 5 % of the trials the falling number was below the limit of marketability (80) for the yields from untreated plots, but above it for plots sprayed with chlormequat. A higher price due to increased falling number would have been obtained in 27 % of the trials, the mean rise in price being 2.55 pennis per kilogramme according to the present official regulations on quality requirements. In those cases in which the yield from plants treated with chlormequat had a lower falling number than that of untreated plants, the falling number was usually especially high (average for untreated plants 321, for treated plants 300). In 5 % of the cases, the chlormequat treatment decreased the falling number to a level that would have affected the pricing of the yield. The average price reduction in these cases would have been 0.74 pennis per kilogramme. The development of falling number due to the increased chlormequat dosages could be expressed in the equation (Fig. 6)

$$Y = 26.4 \lg(x + 1.2) + 265.0$$

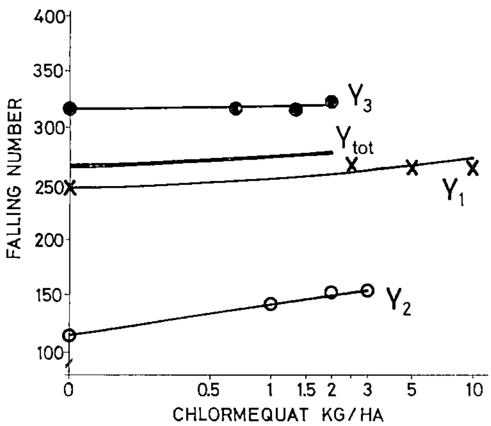

Fig. 6. The effect of the application rate of chlormequat on the falling number of spring wheat.

$Y_1 = 27.6 \lg (0.8x + 1.0) + 246.0$
$Y_2 = -165.9 (3.99x + 3.26)^{-1} + 165.9$
$Y_3 = 1.5x + 317.0$
$Y_{tot} = 26.4 \lg (x + 1.2) + 265.0$

In general, sprouting in the head is more abundant and the falling number is lower in yields from lodged crops than in yields from standing crops (Kivi 1961, Yllö 1969 a, Teittinen 1973). Thus, a decrease in lodging achieves an improvement in falling number. Chlormequat had, however, a direct effect on the falling number: even in the trials where untreated plants did not lodge chlormequat spraying increased the falling number by 15 ($P = 0.060$). The falling numbers were then: for yield from untreated crop 302 and for the yield from treated crop 317.

A rougher method for determining the damages in grain yield caused by bad weather is to count the proportion of sprouted grains in the yield. This count was made in 15 trials. The results indicated the same phenomenon as the falling number, i.e. that chlormequat treatment promoted the ability of plants to counteract the detrimental effects of unfavourable weather conditions (Tables 1—4).

The effect of chlormequat on falling number at various stages of ripening was investigated for three years with the Norröna and Touko varieties by harvesting an untreated and a treated plot three times a week for four to five weeks. The falling number of Norröna usually drops rapidly under unfavourable weather conditions, whereas Touko retains it relatively well (Teittinen and Kivi 1968). The falling number for the yield from crops treated with chlormequat was consistently higher than that for untreated crops. This difference was compounded with the progress of the harvesting period in the years of the trials (Fig. 7).

A few determinations were made in connection with this study on the germination or emergence of the crop harvested. The results indicated that chlormequat had no apparent effect on germination (Tables 1—4). Ibrahim et al. (1972) also reported from their experiments that though germination velocity was promoted, the final germination percentage was not affected.

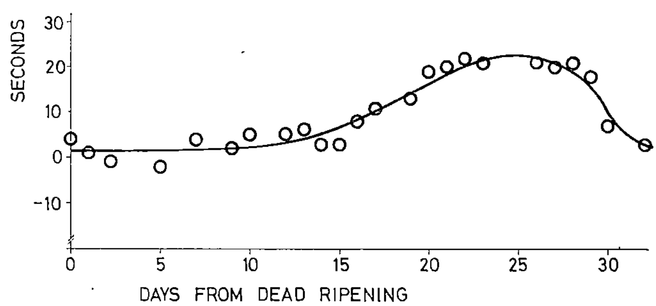

Fig. 7. The difference in the falling number between the yield of spring wheat with and without chlormequat during the harvesting periods in 1968—1970.

Protein content and baking qualities

According to the literature most of the studies conducted in various countries indicate that chlormequat did not affect protein content in grain (STURM and JUNG 1964, ENGSTRÖM 1965, FAJERSSON 1965, SCHRÖDER and RHODE 1965, MARTIN 1968, PRIMOST 1968, HUMPHRIES and BOND 1969, BENGTSSON 1971). There are, however, data on the protein-increasing properties of chlormequat and these are more numerous (FAJERSSON 1965, HUMPHRIES et al. 1965, BACHTHALER 1966, 1967, JAAKKOLA 1967, PRIMOST 1968, van BURG and ARNOLD 1969) than those on its protein-reducing capacity (NARANG et al. 1971, LAMPINEN 1972).

The amino acid composition of wheat protein has not been found to be affected (BAYZER and MAYR 1965, SADEGHIAN et al. 1968, LORENZ 1969). Milling and baking tests carried out in Great Britain did not indicate any undesirable effects of treatment with chlormequat on these qualities (CALDICOTT 1967). LOWE and CARTER (1971) found that chlormequat helped prevent weather damage to the grain; this inproved the baking quality. Closer studies on protein reduction and other phenomena that have a detrimental effect on baking qualities have been conducted by NARANG et al. (1971).

In the present study some investigations for baking qualities were carried out in the first experiments and published by MUKULA at al. (1966). The lowest application rate of chlormequat (2.5 kg/ha) improved baking qualities somewhat. This would seem to be an instance of the prevention of lodging having an indirect effect on the baking quality of wheat.

A protein analysis was made in eleven experiments in the first trial series of the present study. It was found that the protein content of the grains was reduced as a result of treatment with chlormequat (Table 1). In the second trial series protein analyses were only made in two of the trials. The results showed the same tendency as in the first series (Table 2). In the experiments of the third series the protein was analysed in thirty-four cases; the results corroborated those of the other analyses (Table 3). The protein content of the yield was reduced by 0.5 %-units when 2 (2.5) kg chlormequat were applied per hectare (Table 4). The reduction was manifest in 72 % of the trials (Table 26). The equation for the mean changes in protein content of grains was (Fig. 8)

$$Y = (0.2x + 0.9)\, 1.9^{-x} + 13.00$$

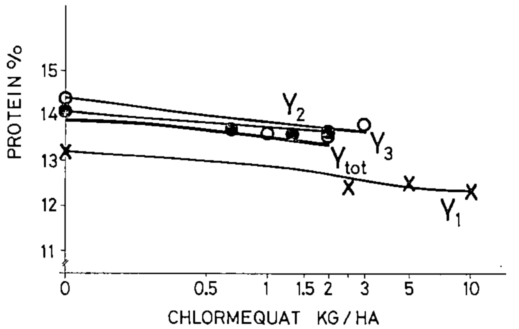

Fig. 8. The effect of the application rate of chlormequat on the protein content of the grains of spring wheat.
$Y_1 = 0.12x + 2.4 \cdot 1.2^{-x} + 10.80$
$Y_2 = 7.08\,(\sqrt{0.6x} + 2.76)^{-1} + 11.83$
$Y_3 = 10.5\,(10.0x + 12.2)^{-1} + 13.24$
$Y_{tot} = (0.2x + 0.9)\, 1.9^{-x} + 13.00$

Any explanation of the direct effect of chlormequat on protein content is inevitably ambiguous owing to the very close correlation between yield increase and protein content reduction ($r = -0.712$, $P = 0.002$) and between percentage of lodging and protein content ($r = 0.503$, $P = 0.006$). Lodging increased the protein content in the yields of untreated crops; hence, the reduction in lodging itself may have resulted in a reduction in the protein content (cf. YLLÖ 1969 a, TEITTINEN 1973). Protein determinations were made from six trials where the crop was not lodged. The mean protein content of the yield in these trials was 12.35 % for crops treated with chlormequat and 12.33 % for untreated crops. The correlation between protein content and lodging in the whole material (47 trials) was nearly the same in the untreated and treated crops: the correlation coefficient for the former was r = 0.503 ($P = 0.095$) and for the latter r = 0.332 ($P = 0.130$), the significance of the difference in two correlation coefficients being low ($P = 0.333$). All this seems to indicate that without lodging, the direct effect of chlormequat on the protein content of grain yield is only small.

It is obvious that the greater part of the increases in protein content found by several workers (HUMPHRIES et. al. 1965, JAAKKOLA 1967) are due to the decrease in yield and not to possible changes in uptake of nutrients caused by chlormequat spraying. In the present study, the protein content decreased by 0.71 %-unit in 27 trials where the yield was increased, but only by 0.05 %-unit in 18 trials where the yield was decreased. The significance of the difference was very high ($P < 0.001$).

3.1.5 Lodging of crops

The primary aim of chlormequat treatment is to prevent lodging of straw. Cereal straw has certain inherited characteristics that affect lodging: anatomical (thickness of cell wall and lignine content), morphological (length and thickness of stem, position of roots) and physiological (speed of growth). Environmental factors (density, spacing between rows, sowing time, availability of nutrients, incidence of eyespot disease) modify the anatomical, morphological and physiological characteistics thus affecting the tendency of straw to lodge. Chlormequat affects chiefly the anatomy and morphology of the stem. It considerably shortens the stem of spring wheat (e.g. TOLBERT 1960, MAYR et al. 1962, JUNG 1964, YLLÖ 1964, ADLER 1965, DILZ et al. 1965, ENGSTRÖM 1965, GEERING 1965, HUMPHRIES et al. 1965, LOVATO 1965, PINTHUS and HALEVY 1965, PETR and RYTINA 1967, IVANOVA 1968, SHRIVASTAVA et al. 1968, SCHULTZ 1971, IBRAHIM et al. 1972). It has been shown that chlormequat also makes the cell walls (PRIMOST et al. 1964, MAYR and BAYZER 1965, MARTIN 1968, PRIMOST and RITTMAYER 1968 a) and the base of the stem (MAYR and PRESOLY 1963, JUNG and RIEHLE 1966, KOCH 1968, PRIMOST and RITTMAYER 1968 a) grow thicker. Chlormequat also improves the elasticity of the stem (KOCH and LINSER 1969) and prevents the decrease in standing strength in the presence of eyespot disease (MAYR et al. 1964, BOCKMANN 1965, DIERCKS 1965, JUNG et al. 1966).

In the present study lodging was estimated visually in the field by using a scale of 0—100 (0 = no lodging, 100 = completely lodged). The length of straw was measured in the field before harvesting. Closer studies of the localisation of stem shortening and of stem thickness were made in the laboratory after harvesting. The straw yield was also weighed in some experiments.

Lodging

Reports from many countries show that lodging can be reduced or prevented by treating the crop with chlormequat (HUMPHRIES 1968 a).

Chlormequat treatment reduced lodging in the trials during the present study almost consistently (Tables 1—3). Lodging was reduced in 86 % of the trials (Table 26). The average reduction was two thirds in a crop treated with 2 (2.5) kg chlormequat per hectare in comparison with the untreated control (Table 4). Smaller rates of chlormequat (0.7 kg/ha) reduced lodging slightly in the Norröna cultivar (Table 3). The following equation expresses the effect of chlormequat on the lodging (Fig. 9),

$$Y = 27.6\,(x + 0.9)^{-1} + 0.7$$

Mean lodging varied considerably from year to year (Table 7). One of the worst years was 1967 when more than half of the untreated crops were lodged. Even in the best years, in untreated crops on average a good fifth of the

Table 7. Reduction in lodging obtained with an application rate 2 (2.5) kg/ha chlormequat, classified according to years, soil types, trial sites and cultivars.

		Number of comparisons	Lodging % Untreated	Treated	Reduction in lodging %
Years:					
1963		1	3	0	100
1964		12	22	6	64
1965		24	24	6	75
1966		29	27	8	70
1967		18	53	26	51
1968		22	32	4	88
1969		23	37	15	59
1970		4	22	17	23
1971		7	21	7	67
1972		7	31	22	29
P			<0.001	<0.001	
Soil groups:					
Sandy soils		59	44	10	77
Clay soils		68	22	7	68
Humus and peat soils		20	27	7	74
P			<0.001	0.002	
Trial sites:					
Fiskari		3	13	7	46
Jomala		4	6	1	83
Tikkurila		17	21	11	48
Paimio		18	16	2	88
Mietoinen		16	18	6	67
Anjala		2	46	28	39
Leteensuo		6	36	7	81
Hauho		4	77	32	58
Peipohja		22	21	6	71
Pälkäne		16	56	18	68
Mikkeli		5	18	0	100
Ylistaro		19	27	11	59
Maaninka		15	68	29	57
P			<0.001	<0.001	
Cultivars:					
Apu		45	43	17	60
Diamant		18	37	13	65
Norröna		54	30	7	77
Ruso		4	30	11	63
Svenno		26	9	3	67
P			<0.001	<0.001	
Interactions					
years × soil groups	*P*		<0.001	<0.001	
» × trial sites	*P*		>0.500	>0.500	
» × cultivars	*P*		0.258	0.004	
soil groups × trial sites	*P*		<0.001	<0.001	
» » × cultivars	*P*		<0.001	>0.500	
trial sites × cultivars	*P*		<0.001	0.007	

crop was lodged. There was also significant annual variation in lodging among crops treated with chlormequat. Apart from the years 1970 and 1972, which account for only eleven trials in all, lodging was reduced by at least one half as a result of chlormequat treatment. Statistical analyses of the whole experimental material revealed that chlormequat was relatively more effective when the lodging was heavy in untreated plots. The correlation coefficient between lodging in untreated crops and the reduction in lodging in crops treated with chlormequat was $r = 0.992$ ($P < 0.001$).

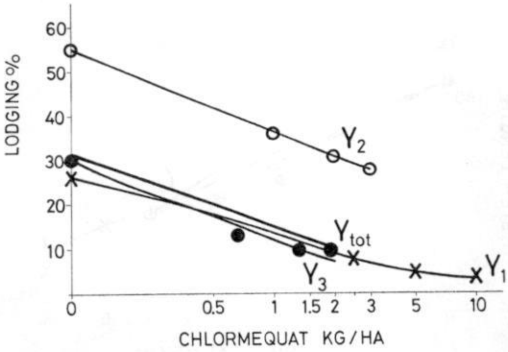

Fig. 9. The effect of the application rate of chlormequat on the lodging of spring wheat.

$Y_1 = 25.2\,(x + 1.0)^{-1} + 0.8$
$Y_2 = 24.5\,(x + 0.74)^{-1} + 21.9$
$Y_3 = 22.6\,(x + 0.8)^{-1.2} + 0.4$
$Y_{tot} = 27.6\,(x + 0.9)^{-1} + 0.7$

The correlation between the rainfall in the period of May and June and lodging was low ($r = 0.149$, $P = 0.305$). This is probably because the incidence of lodging at ripening did not occur until July or August.

In the figures classified by soil types, lodging was heaviest on sandy soil. Chlormequat reduced lodging somewhat more successfully in sandy soil than in the other types of soil (Table 7).

Examination of figures by trial districts indicated that lodging was heaviest in the typically sandy soil areas of Hauho, Maaninka and Pälkäne (Table 7). These were followed by the experimental location Anjala, with its clay soil, and then by Leteensuo, Ylistaro, Tikkurila and Peipohja. Lodging of crops treated with chlormequat differed considerably from each other in the various experimental areas. The most effective reductions in lodging occured at Mikkeli, Paimio, Jomala and Leteensuo, which represent all soil types. Reduction in lodging by chlormequat was smallest at Anjala, Fiskari and Tikkurila, where the mean reduction was less than one half.

Lodging according to cultivar varied significantly. Untreated Apu lodged the most and Svenno the least (Table 7). After treatment with chlormequat, the reduction in lodging was greatest in Norröna and smallest, but still remarkable, in Apu (Fig. 10). The differences were not great but statistically highly significant.

The mean values of cultivars are not fully comparable, since all varieties were not grown under the same conditions. Nevertheless, it seems fairly obvious that chlormequat was

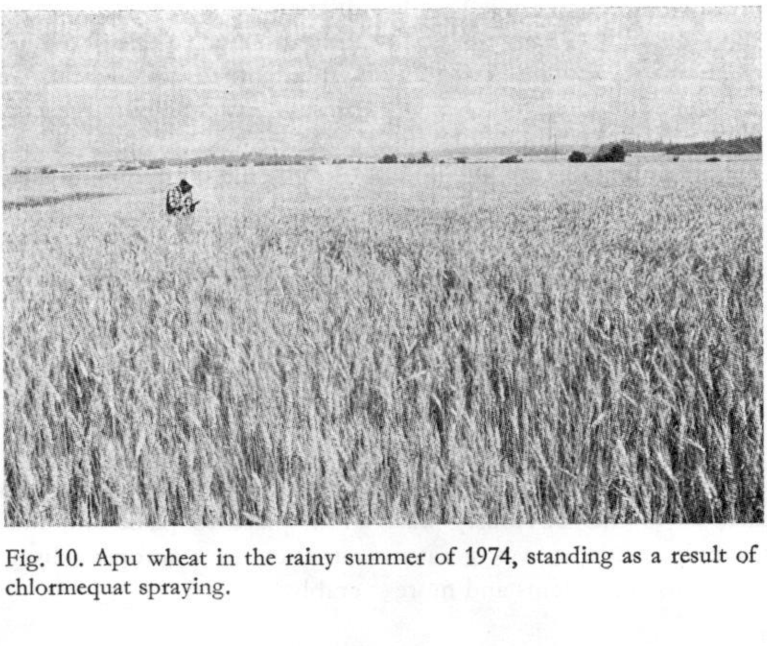

Fig. 10. Apu wheat in the rainy summer of 1974, standing as a result of chlormequat spraying.

able to reduce lodging to different degrees in different varieties. The examination by variety in chapter 3.4 corroborates this assumption.

Length of stem

HORN (1965) showed empirically that the shorter the cereal stem the less the lodging power directed to the base of stem. Several other workers (MULTAMÄKI 1962, KOCH and LINSER 1969, WÜNSCHE 1970) considered that lodging is highly dependent on the length of straw, and consequently, the most effective way of preventing lodging is to shorten the stem. The effect of chlormequat in preventing lodging apparently lies mainly in its ability to reduce the length of the stem.

In the trials under discussion the stem of spring wheat was shortened as a result of chlormequat treatment in all cases (Table 26). Apart from a few occasional exceptions, the higher the dosage of chlormequat the more the stem was shortened (Tables 1—3). However, shortening was not linear; the effect per dosage unit decreased with the increase in application rate (Fig. 11). The mean shortening in all trials with 2 (2.5) kg chlormequat per hectare was from 82 cm to 67 cm, that is, 18 % (Table 4). The following equation expresses the effect of chlormequat on length of stem,

$$Y = 14.41\,(x + 0.75)^{-1} + 62.8$$

The correlation between lodging and stem shortening was not close ($r = 0.128$, $P = 0.215$). The same applies to reduction in lodging and stem shortening ($r = 0.111$, $P = 0.193$). Accordingly, stem shortening would not necessarily be the main factor leading to a reduction in lodging.

There was also a clear dependence of stem shortening on the soil type. The stem grew taller on sandy soil than on other soils and the tall stem shortened more than the short one. The explanation to this obviously was that the water supply available was greater in sandy soil, leading to taller stems and more pronounced shortening. KÜHN and LINSER (1966), namely, found a close correlation between the water supply in soil and the length of stem. The pot trials carried out by EL-DAMATY et al. (1965) demonstrated that the stem shortening effect of chlormequat was greater on taller stems grown at a high soil moisture level.

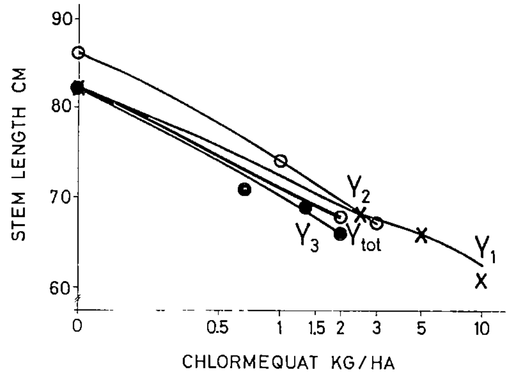

Fig. 11. The effect of the application rate of chlormequat on the length of the stem of spring wheat.
$Y_1 = 19.6\,(x + 1.0)^{-1} + 62.4$
$Y_2 = 33.36\,(x + 1.24)^{-1} + 59.1$
$Y_3 = 24.0\,(x + 1.0)^{-1} + 58.0$
$Y_{tot} = 14.41\,(x + 0.75)^{-1} + 62.8$

In the material under discussion, there were no significant differences in the stem length of the varieties between the various trial districts (Table 8), although there were indications that the stem was longer the farther north the wheat was grown. The present material is fairly extensive, but even so there are insufficient data to ascertain whether the shortening caused by chlormequat changes with latitude. There would seem, however, to be some justification for such a supposition (MUKULA 1967). According to PETR (1968), wheat, which grows well in the long days of the northern summer, reacts more strongly the longer the period of daylight during its growing period. However, in practice this phenomenon is not seen very clearly because the varietal distribution differs from place to place and the reaction of the varieties to photoperiodism differs considerably.

Table 8. Dwarfing of plants obtained with the application rate 2 (2.5) kg/ha chlormequat, classified according to years, soil types, trial sites and cultivars.

		Number of comparisons	Stem length cm Untreated	Stem length cm Treated	Reduction in length %
Years:					
1963		1	70	66	6
1964		13	82	68	17
1965		22	85	70	19
1966		29	79	65	18
1967		17	93	75	19
1968		22	84	67	20
1969		23	90	69	23
1970		4	68	59	13
1971		7	63	57	10
1972		7	76	67	12
P			*0.002*	*0.250*	
Soil types:					
Sandy soils		57	91	74	19
Clay soils		68	76	63	17
Humus and peat soils		20	82	69	16
P			*0.025*	*0.085*	
Trial sites:					
Fiskari		3	78	65	17
Jomala		4	77	64	17
Tikkurila		16	83	70	16
Paimio		18	84	66	21
Mietoinen		16	68	55	19
Anjala		3	64	59	8
Leteensuo		6	104	82	21
Hauho		4	92	79	14
Peipohja		22	82	62	24
Pälkäne		16	92	72	22
Mikkeli		5	94	71	24
Ylistaro		19	70	61	13
Maaninka		13	105	90	14
P			*<0.001*	*0.032*	
Cultivars:					
Apu		42	87	74	15
Diamant		18	87	71	18
Norröna		54	82	64	22
Ruso		4	93	73	22
Svenno		26	74	61	18
Touko		1	52	44	15
P			*0.005*	*<0.001*	
Interactions					
years × soil groups	*P*		*<0.001*	*<0.001*	
» × trial sites	*P*		*<0.001*	*<0.001*	
» × cultivars	*P*		*<0.001*	*<0.001*	
soil groups × trial sites	*P*		*<0.001*	*<0.001*	
» » × cultivars	*P*		*<0.001*	*<0.001*	
trial sites × cultivars	*P*		*<0.001*	*<0.001*	

In application rate experiments with chlormequat Norröna was shortened more than the other varieties (Table 8). There were distinct variations between the other cultivars in this respect, as will be shown in chapter 3.4.

Jung and Sturm (1965) found that shortening was relatively greatest in the lowest internode. Since the length of the lowest internode is a small fraction of the length of the upper internodes, it is not possible even for severe shortening of the former to induce shortening of the whole plant to the degree required to achieve a significant reduction in lodging.

In the present trial series, measurements were made from 20 application rate trials conducted in 1965—1968 and from 6 application time trials conducted during the same years at Peipohja. The application rate trials consisted of Apu (6 trials), Diamant (4 trials), Norröna (4 trials) and Svenno (6 trials). 30 culms from every plot were measured.

Measurements indicated that shortening was greatest in the upper internodes, but not in the head (Table 9). There is always the possibility of the lowest internodes having been shortened so much that they are indiscernible. This was the case in some Austrian trials (PRIMOST and RITTMEYER 1968 a). In the trials under discussion, however, there was no reduction in the number of internodes. The locality of the shortening depends on the time of the teatment: the later the treatment, the more strongly the shortening is focused on the upper internodes, a phenomenon observed also by JUNG (1967). This explains why shortening is not so marked when treatment is early as when it is late (de VOS et al. 1967).

Stem diameter

The thickening of the lowest internodes of the stem has been demonstrated by TOLBERT (1960), MAYR and PRESOLY (1963), PRIMOST et al. (1964), MAYR and BAYZER (1965), JUNG and RIEHLE (1966) and KOCH (1968).

In this study, the diameter of the stem and the thickness of the stem wall were measured in twenty trials with a micrometre half way up the two lowest internodes. A slight increase in the diameter of the stem and in wall thickness were found (Table 9). It may be presumed that these changes also affected the prevention of lodging.

Biomass of straw

Susceptibility to lodging does not depend alone on the dimensions of the stem, but also on the bulk of the stem and other factors described earlier. The biomass of straw is represented by the straw yield, which was weighed in some of the experiments. The straw yield was usually reduced as a result of chlormequat spraying but not in the same ratio as the shortening of the stem (Tables 1, 2 and 4). This partly explains why the correlation between lodging and shortening of the stem was not very close. The correlation between lodging and decrease in the straw yield was closer (r = 0.020, $P = 0.184$).

3.1.6 Development and ripening speed

Chlormequat treatment has been shown to retard plant development so that ripening will

Table 9. Effects of the application rate and timing of chlormequat on the dwarfing and thickening of the stem of spring wheat.

	Application rate of chlormequat		*P*	Application time of chlormequat[1])			*P*
	0	2 kg/ha		1	2	3	
Number of internodes	4.55	4.54	*>0.500*	4.52	4.50	4.56	*>0.500*
Bottom internode mm	29.7	28.6	*0.015*	23.2	26.5	28.2	*0.037*
Top internode mm	396.2	308.6	*<0.001*	303.9	293.0	284.2	*0.032*
Head mm	62.8	63.7	*0.010*	53.8	54.8	56.0	*0.355*
Diameter of stem at 1st internode mm	1.85	1.86	*0.025*	2.12	2.10	2.05	*0.381*
Diameter of stem at 2nd internode mm	2.01	2.05	*0.485*	2.38	2.33	2.27	*0.174*
Thickness of stem wall at 2nd internode mm	0.46	0.49	*0.440*				

[1]) Application times: 1 = 3—4 leaf stage, 2 = 4—5 leaf stage, 3 = 5—6 leaf stage.

be delayed in greenhouse studies (TOLBERT 1960, LINSER et al. 1961, MAYR et al. 1962, BRUINSMA et al. 1965, GEERING 1965, WÜNSCHE 1970), but not in open fields (ENGSTRÖM 1965, FAJERSSON 1965). Heading, however, has been delayed in field trials also (BRUINSMA et al. 1965, HUMPHRIES et al. 1965). Under adverse growth conditions ripening has been accelerated by chlormequat treatment (JAAKKOLA 1967, BENGTSSON 1971).

In the trials of the present study, chlormequat treatment delayed heading by an average of one day (Tables 1—4). The delay was slightly less with lower application rates than with higher.

Estimated visually, ripening was very little affected by the treatment (Tables 1—4). Since the colour and general appearance of plants were usually more or less modified by chlormequat treatment the visual estimations were somewhat inaccurate. Moisture determinations made on the day the grains ripened showed that the plants treated contained more moisture than those that were not treated. The difference, however, was very slight, only 0.5 %-units with 2 (2.5) kg/ha chlormequat. In addition, considerable variation occurred in the figures, and hence, the difference in the mean values of all the trials had low statistical significance. Moisture determinations on the day of harvesting (by combine) indicated that the yield of the plants treated was dryer than that of those that were not treated. This occurred in 90 % of the trials (Table 26).

Evenness in ripening was measured by the number of unripe green grains in the harvested yield. The average number of green grains increased slightly after application of 2 (2.5) kg chlormequat per hectare, i.e. 0.4 %-unit; however, the variation was too great to permit conclusions to be drawn whether the mean values did differ significantly from one another or not (Tables 1—4).

3.2 Application times for foliar treatment

Variation in effect have been observed by other workers when the spray has been applied at different times. STURM (1965) obtained the best results when the spray was applied between the 5 leaf stage and the beginning of tillering. According to LINSER (1968) the appropriate application time was between the four-leaf stage and the beginning of shooting, when the height of the plants varied from 10 cm to 25 cm. The best time was when the height was 20 cm. PRIMOST and RITTMEYER (1968 b) found that chlormequat was most effective at the start of stem elongation, de VOS et al. (1967) observed that late spraying shortened the stem most readily but did not improve standing ability.

The application time trials in this study were planned so that the chlormequat spray (2 kg/ha) was applied when the shoots were at the 3—4, 4—5 and 5—6 leaf stages. The average dates of spraying were the 10th, 17th and 25th June, respectively, i.e. an average of 26, 33 and 41 days after sowing. The mean length of the shoots at spraying was 18.0, 28.5 and 39.7 cm, respectively. The classified leaf stages of the shoots were as presented in the following table.

	Percentage of shoots with							
	1 leaf	2 leaves	3 leaves	4 leaves	5 leaves	6 leaves	7 leaves	8 leaves
1st spraying	0.2	9.0	55.1	35.2	0.5	—	—	—
2nd »	—	0.4	3.6	28.4	63.6	3.8	0.2	0.0
3rd »	—	—	1.1	3.5	60.7	27.7	6.4	0.6

The mean number of leaves per shoot was 3.4 at the first spraying, 4.7 at the second and 5.5 at the third.

The experiments were conducted from 1965 to 1968 and from 1971 to 1972. The trials were located in Tikkurila (four experiments), Leteensuo (one experiment), Peipohja (ten experiments) and Maaninka (one experiment). Apu was the cultivar tested in six of the experiments, Norröna in three and Svenno in seven.

In most trials the grain yield was not affected by the time of the spraying. The mean yield was slightly smaller with later spraying, but the variation was so great that statistical significance between the treatments remained low (Table 10). Only in two of the separate experiments did the variance analysis indicate significant differences between the teatments. In these experiments, delay in the time of the spraying produced a slight increase in yield. Of the yield parameters, the volume weight of the grains, the falling number and the protein content were not affected by the time of treatment. A distinct reduction in the 1000-grain weight was, however, apparent in the case of late spraying (Table 10).

Lodging and speed in ripening were not affected by the time of treatment either. On the other hand, the stem was more readily shortened when spraying was delayed and, therefore, the straw yield showed a tendency to decrease (Table 10).

The optimum time of application varied within rather large limits. From a practical viewpoint this is important, showing that the chlormequat spray may be applied at the same time as other sprays (herbicide, foliar fertilizer) whose effectiveness depends on exact timing.

Table 10. Effects of chlormequat spraying time on the yield and characteristics of spring wheat. Results from 16 trials.

	Spraying time			P
	3–4 leaf stage	4–5 leaf stage	5–6 leaf stage	
Grain yield kg/ha	3460	3440	3390	*0.395*
» » %	100	99	98	
Shoots per m²	601	534	581	*0.086*
Tillers per plant	1.02	1.14	1.03	*0.024*
1000-grain weight g	32.3	32.0	31.3	*0.002*
Hectolitre weight kg	75.7	75.5	75.7	*>0.500*
Falling number	224	231	225	*>0.500*
Sprouted grains %	12.8	15.2	16.5	*0.301*
Protein %	12.6	12.4	12.7	*0.401*
Lodging %	7	6	7	*>0.500*
Stem length cm	71	67	66	*<0.001*
Straw yield kg/ha	4140	4010	4000	*>0.500*
Heading, day of	14/7	14/7	14/7	*>0.500*
Growing period, in days	109	109	109	*>0.500*
Moisture at harvesting %	26.6	25.3	24.1	*0.159*
Green grains %	14.4	12.7	13.9	*>0.500*

3.3 Seed treatment

Tolbert (1960) studied the growth of seeds on blotting paper moistened with chlormequat. He found this absorption method to be an effective way of administering chlormequat. However, difffculties were encountered in adapting the technique to practical purposes. Jung and Sturm (1965) and Humphries (1969) were among the workers who tried unsuccessfully to solve this problem. Lowe (1971) demostrated that seed treatment increased the yield of irrigated wheat grown with a high level of nitrogen fertilizer (225 kg/ha N). However, the yield increases were still greater when the chlormequat was applied as a foliar spray. LOVATO (1965) also applied chlormequat as a seed dressing or as a spray, and found that both treatments increased resistance to lodging, and raised yields.

In Finland seed treatment trials were initiated by POHJANHEIMO (1968), who succeeded in preventing lodging with small amounts of chlormequat. His method consisted of a fifteen minute soak in a solution of 1, 2 or 4 % chlormequat.

In connection with the present study, trials on the treatment of seeds with chlormequat were conducted at Tikkurila and Peipohja from 1968 to 1972. In the first trial series chlormequat was absorbed into the grains by soaking them in chlormequat solution. In later trials, efforts were made to find a suitable method for dry or wet surface treatment.

Table 11. Effect of soaking seeds in chlormequat solution.

	Trials at Tikkurila				Trials at Peipohja			
	Chlormequat solution			*P*	Chlormequat solution			*P*
	0	1 %	2 %		0	1 %	2 %	
Grain yield kg/ha	2220	2340	2000	*0.048*	4600	5250	5480	*<0.001*
» » %	100	105	90		100	114	119	
Shoots per m²	336	343	346	*>0.500*	530	508	513	*>0.500*
Tillers per plant	0.94	0.85	0.95	*>0.500*	1.12	1.08	1.32	*0.004*
1000-grain weight g	32.9	32.6	32.0	*0.334*	31.0	32.8	33.9	*0.072*
Hectolitre weight kg	77.0	76.1	76.2	*0.233*	77.9	78.5	79.0	*0.414*
Falling number	374	353	385	*>0.500*	340	396	435	*0.240*
Lodging %	24	22	20	*>0.500*	82	38	18	*<0.001*
Stem length cm	84	87	82	*0.251*	102	104	104	*0.334*
Heading, day of					7/7	7/7	7/7	—
Growing period, in days					105	105	105	—

Table 12. Effect of seed soaking on spring wheat varieties at Peipohja in 1973. 0 = seeds soaked in water for 15 min.; chlormequat = seeds soaked in solution of 2 % chlormequat for 15 min.

Variety	Grain yield kg/ha		Lodging %		Stem length cm	
	0	chlormequat	0	chlormequat	0	chlormequat
Sv U65348	5090	4850	85	75	67	65
Jo 8045	4890	4470	85	80	67	66
Jo 3505	5080	4610	90	60	80	75
Apu	4580	4870	95	90	82	80
Jo 6861	4650	5140	90	85	80	74
Jo 8090	4980	5710	80	70	83	81
Jo 3499	5090	4930	85	60	81	76
Veka	5700	4940	95	95	85	81
Sv 69550	4860	5100	70	70	77	74
Jo 8078	5730	5900	85	80	79	72
Hja a 1416	4590	4940	90	65	74	69
Diamant	4380	4460	95	95	85	91
Jo 3522	5180	5460	90	85	75	72
Ruso	5620	5840	90	90	81	84
Svenno	5070	5360	95	90	80	75
Jo 3503	5020	5140	95	90	86	82
Tähti	5620	5380	90	90	91	88
Mean	5066	5124	89	81	80	77

Four experiments utilizing Pohjanheimo's method were conducted on Apu spring wheat in 1968, two at Tikkurila and two at Peipohja. At Tikkurila the treatment did not increase the yield, lodging was not reduced and the weight of grains was decreased. At Peipohja there were large increases in yield, lodging was reduced considerably and the 1000-grain weight was increased. In neither experiment did the treatment reduce the final height of the crop (Table 11).

In the summer of 1973, a trial was conducted at the Satakunta Experiment Station where several spring wheat cultivars were treated for fifteen minutes in a 2 % chlormequat solution. During the growing period it was observed that some varieties, e.g. Apu, were almost entirely lodged despite the treatment, whereas a number of other varieties treated in the same way lodged appreciably less than when untreated (Table 12). In this trial there was only one plot for each variety, and hence, it was not possible to calculate the statistical significance of the results.

In three dry dressing trials conducted on Apu spring wheat at Tikkurila and Peipohja in 1969 and 1970, the grains were treated with chlormequat powder mixed with white clay (*bolus alba*), which improved its fixative ability. No positive results were obtained for any of the characteristics from the treatment (Table 13). Chlormequat powder is hygroscopic, which makes it difficult to use dry. Hence, the method did not prove feasible.

Table 13. Effect of seed dressing with powdery chlormequat.
1 = powdery chlormequat 100 g/100 kg seeds;
2 = powdery chlormequat 200 g/100 kg seeds;
spray = chlormequat 1.5 kg/ha sprayed onto shoots.

	Untreated	Chlormequat treatment 1	2	spray	P
Grain yield kg/ha	2490	2360	2440	2380	*>0.500*
» » %	100	95	98	96	
Shoots per m²	437	434	432	432	*>0.500*
Tillers per plant	0.82	0.77	0.92	0.75	*0.195*
1000-grain weight g	30.3	30.1	29.8	29.5	*0.497*
Hectolitre weight kg	75.5	74.9	75.3	74.8	*>0.500*
Falling number	378	375	371	378	*>0.500*
Protein %	14.8	14.4	14.5	14.6	—
Lodging %	12	12	11	10	*0.416*
Stem length cm	71	70	71	67	*0.006*
Growing period, in days	87	87	87	87	—

Table 14. Effect of seed dressing with liquid chlormequat.
0 = untreated, 1 = fungicide, 2 = fungicide + chlormequat 100 g/100 kg seeds,
3 = fungicide + chlormequat 200 g/100 kg seeds, 4 = chlormequat 200 g/100 kg seeds,
5 = chlormequat 1.0 kg/ha sprayed onto shoots; 2 trials in 1st trial series, 7 in 2nd trial series.

	1st trial series 0	2	3	5	P	2nd trial series 0	1	3	4	5	P
Grain yield kg/ha	2510	2270	2320	2470	*>0.500*	2990	2900	2920	2950	3030	*0.127*
» » %	100	90	92	98		100	97	98	99	101	
Shoots per m²	412	424	423	451	*0.312*	466	457	490	453	486	*>0.500*
Tillers per plant	0.87	0.92	0.92	0.77	*0.251*	0.88	0.85	0.81	0.89	0.96	*0.285*
1000-grain weight g	30.5	28.8	29.3	29.4	*0.021*	32.0	31.6	31.8	32.5	31.6	*0.008*
Hectolitre weight kg	75.2	73.7	74.2	74.2	*>0.500*	76.4	76.4	76.3	76.4	76.3	*>0.500*
Falling number	372	362	349	372	*0.455*	258	251	268	276	329	*>0.500*
Protein %	14.8	14.8	14.5	14.6	*>0.500*	14.8	14.6	14.8	15.1	14.5	*>0.500*
Lodging %	15	15	15	12	*>0.500*	14	15	11	6	10	*>0.500*
Stem lenght cm	73	72	72	68	*0.054*	71	70	71	72	68	*0.042*
Growing period, in days	87	87	87	87	—	89	89	89	89	89	—
Moisture at harvesting %						18.4	19.0	20.4	19.8	18.6	*0.135*

In nine experiments conducted at Tikkurila and Peipohja from 1969 to 1972 on Apu wheat, chlormequat alone or in a mixture with a liquid seed disinfectant containing 2.3 % metoxy ethyl mercury hydroxide was tested. The methods were compared with the application of chlormequat as a foliar spray. A combination of fungicide and chlormequat usually resulted in reduced yield. The same was true of chlormequat applied alone. On the other hand, when chlormequat was sprayed onto the shoots it reduced stem length, inhibited lodging and increased yield in the manner described earlier (Table 14).

3.4 Response of wheat cultivars

The preliminary trials in 1963 and 1964 had already shown that the effects of chlormequat varied in different spring wheat cultivars (MUKULA et al. 1966). JUNG and STURM (1965) observed that short-stemmed varieties were shortened most by chlormequat treatment. PRIMOST (1967) demonstrated that the yield increase in Svenno spring wheat was smaller than that in other varieties. BENGTSSON and WÜNSCHE (1968) obtained yield reductions in Svenno. PESSI et al. (1970) found that chlormequat spraying led to reduced yield at Ruso.

In the application rate trials of the present study Apu, Diamant and Svenno gave a greater yield with chlormequat, whereas the yield of Norröna was unchanged and that of Ruso decreased (Table 5).

To establish the behaviour of the cultivars, trials were set up at some locations from 1965 to 1972; a large number of spring wheat cultivars were sprayed with chlormequat. The main characteristics of the crop and yield were investigated.

The results revealed significant differences in the response of the varieties to the treatments. Particularly stem shortening but also some other characteristics varied markedly (Table 15). The shortening effect was especially favourable with Vendel and Norröna varieties (Fig. 12). As to grain yield, Diamant and Apu profited most from the treatment.

The correlation between the unshortened length of stem and stem shortening was not statistically significant ($r = 0.345$, $P = 0.235$). Therefore, with this assortment of cultivars it could not have shown that the short-stemmed varieties shortened more than the taller ones.

In the harvesting time trials with Norröna and Touko varieties, discussed further in chapter 3.1.6, an abundant shedding of grain from the head was apparent in the late harvests

Table 15. Changes in the characteristics of spring wheat varieties sprayed with chlormequat.

Variety	No.of comparisons	Grain yield kg/ha	Lodging %	Stem length cm	Stem length %	Tgw g	Hlw kg	Falling number	Growing period, in days	Moisture %
Apu	27	+100	− 54	−14	18	−1.3	−0.8	+28	±0	−0.5
Diamant	28	+120	− 69	−17	20	−0.7	−0.5	−42	±0	−1.6
Erli	6	+110	− 86	−16	22	−1.6	−0.7	+81	+1	−1.6
Norröna	13	−140	− 86	−21	27	−1.2	−1.1	+52	±0	−1.3
Ring	5	−190	−100	−11	14	−2.0	−0.6	+36	±0	−1.2
Ruso	11	− 20	− 83	−13	18	−1.9	−1.1	+27	±0	−1.1
Snabbe	6	−120	−100	−14	17	−1.3	+0.1	−19	+0	−1.0
Svenno	21	− 70	− 75	−16	21	−2.6	−1.0	+18	±0	−0.7
Tähti	7	− 80	− 50	− 9	12	−0.5	−0.9	+34	±0	+0.6
Veka	4	± 0	− 45	−13	18	−1.1	−1.2	+12	±0	−0.4
Vendel	5	− 40	−100	−26	33	−3.8	−2.0	+11	±0	+1.5
Sv 62627	5	+270	− 80	−25	30	−2.6	−1.1	+ 7	±0	..
P		*0.025*	*<0.001*	*<0.001*						

Fig. 12. The Norröna cultivar was dwarfed with only little amount (0.7 kg/ha) of chlormequat (plot at the right).

of 1969. The effect of chlormequat on grain shedding was as follows:

		No. of grains shed per m²
Norröna,	untreated	1024
»	sprayed	275
Touko,	untreated	1306
»	sprayed	676

The effect of chlormequat on both varieties had considerable statistical significance ($P < 0.001$ and $P = 0.005$, respectively). Touko, which is especially susceptible to grain shedding, responded less markedly than Norröna.

3.5 Treatments at different levels of nitrogen

Increased nitrogen fertilization promotes the susceptibility of a crop to lodging (CALDICOTT 1966, MUKULA and TEITTINEN 1973). Many workers thought that chlormequat, by preventing lodging, would allow increased nitrogen fertilization and, conseqently, yields would be increased. Hence, the effect of chlormequat at high rates of nitrogen has been of particular interest in many countries.

BRUINSMA et al. (1965), HUMPHRIES et al. (1965), CALDICOTT (1967) and BENGTSSON and WÜNSCHE (1968) reported relatively less shortening of the stem with increased nitrogen fertilization. A larger yield increase from chlormequat with the addition of nitrogen fertilizer was noticed by MAYR et al. (1962), STURM and JUNG (1964), DILZ et al. (1965), FAJERSSON (1965), GEERING (1965), SCHRÖDER and RHODE (1965), BACHTHALER (1966) and de VOS et al. (1967). The reason for the

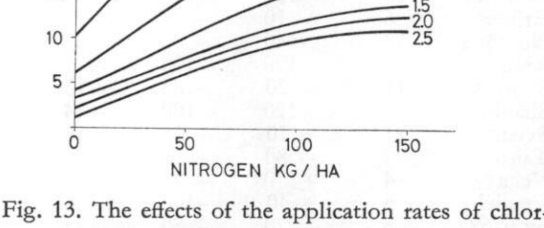

Fig. 13. The effects of the application rates of chlormequat on the lodging of spring wheat grown at the various levels of nitrogen fertilization.

Table 16. Effect of chlormequat spray on spring wheat grown at various nitrogen levels. 10 experiments with 2 nitrogen levels.

	1st N level (mean 45 N)		P	2nd N level (mean 120 N)		P
	0	chlor-mequat		0	chlor-mequat	
Grain yield kg/ha	2930	3030	*0.030*	3110	3250	*0.009*
» » %	100	103		100	105	
1000-grain weight g	34.0	33.6	*0.075*	33.8	33.1	*0.005*
Hectolitre weight kg	78.1	78.3	*>0.500*	77.5	77.6	*>0.500*
Falling number	220	297	*0.002*	205	279	*<0.001*
Sprouted grains %	2.6	1.8	*0.006*	4.4	2.4	*0.002*
Protein %	16.8	15.7	*<0.001*	16.9	15.8	*<0.001*
Lodging %	30	10	*<0.001*	43	17	*<0.001*
Stem length cm	78	65	*<0.001*	82	71	*<0.001*
Straw yield kg/ha	4310	4280	*0.011*	4810	4740	*0.033*
Heading, day of	9/7	10/7	*0.005*	9/7	10/7	*0.005*
Growing period, in days	107	107	—	109	109	—
Moisture at ripening %	38.3	41.1	*0.135*	42.5	42.0	*>0.500*
Moisture at harvesting %	28.6	28.0	*0.098*	28.5	30.2	*>0.500*
Green grains %	0.3	0.2	*>0.500*	0.4	0.6	*>0.500*

Table 17. Effect of chlormequat spray on spring wheat grown at various nitrogen levels. 37 experiments with 3 nitrogen levels.

	1st N level (mean 23 N)		P	2nd N level (mean 73 N)		P	3rd N level (mean 124 N)		P
	0	chlor-mequat		0	chlor-mequat		0	chlor-mequat	
Grain yield kg/ha	2860	2960	*0.021*	3140	3160	*0.375*	3250	3370	*0.004*
» » %	100	102		100	101		100	104	
Shoots per m²	533	533	*>0.500*	535	544	*>0.500*	541	539	*>0.500*
Tillers per plant	1.08	1.05	*>0.500*	1.07	1.16	*0.112*	1.10	1.16	*0.185*
1000-grain weight g	33.1	31.1	*<0.001*	33.1	31.4	*<0.001*	33.0	31.6	*<0.001*
Hectolitre weight kg	77.8	76.2	*<0.001*	77.1	75.7	*<0.001*	76.3	75.3	*<0.001*
Falling number	278	302	*<0.001*	283	292	*<0.001*	269	284	*<0.001*
Sprouted grains %	2.5	1.2	*>0.500*	2.7	1.9	*>0.500*	2.5	2.4	*>0.500*
Germination %	70	72	*>0.500*	73	69	*>0.500*	73	69	*>0.500*
Protein %	12.3	11.8	*<0.001*	13.8	13.4	*<0.001*	14.9	14.5	*<0.001*
Lodging %	19	4	*<0.001*	30	19	*<0.001*	38	12	*<0.001*
Stem length cm	81	62	*<0.001*	84	67	*<0.001*	86	71	*<0.001*
Straw yield kg/ha	2710	2460	*<0.001*	3570	3110	*<0.001*	3850	3550	*<0.001*
Heading, day of	7/7	8/7	*0.015*	8/7	8/7	—	8/7	8/7	—
Growing period, in days	105	105	—	106	106	—	106	107	—
Moisture at ripening %	33.7	35.4	*0.375*	35.6	35.9	*>0.500*	35.6	37.2	*0.118*
Moisture at harvesting %	21.8	21.0	*0.293*	23.4	20.9	*<0.001*	22.8	22.4	*0.003*
Green grains %	1.2	1.6	*>0.500*	1.2	2.0	*>0.500*	1.5	1.5	*>0.500*

larger yield increases was the retarding effect of chlormequat on increased lodging resulting from a higher rate of nitrogen fertilization.

In the present study, chlormequat dosage trials with two or three levels of nitrogen fertilization were carried out at various trial locations from 1964 to 1972. At the same time a series of nitrogen fertilization trials were set up at Peipohja using a constant chlormequat rate, 2 or 2.5 kg per hectare.

The results of these trials indicated that by increasing the nitrogen fertilization the grain yield and its protein content were raised (Tables 16—18). Likewise, the length of the stem and the straw yield were increased, which led to heavier lodging (Fig. 13). Some of the negative aspects of increased nitrogen fertilization were reduction in the weight of grains and in the volume weight of grains, a lower falling number, an increase in the proportion

Table 18. Effect of the chlormequat application rates on yield, lodging and stem length at various nitrogen levels.

Chlormequat kg/ha	1st nitrogen level		2nd nitrogen level		3rd nitrogen level	
			Grain yield kg/ha and %			
0	2930	100	3110	106		
2.5	3030	103	3250	111		
5	2980	102	3300	113		
10	2990	102	3360	115		
0	2150	100	2950	120	3120	145
2.5	2310	107	2670	124	3370	157
5	2270	106	2770	129	3400	158
10	2170	101	2630	122	3400	158
0	3020	100	3170	105	3100	103
0.7	3040	101	3170	105	3170	105
1.3	3240	107	3180	105	3180	105
2	3020	100	3110	103	3160	105
			Lodging %			
0	30		43			
2.5	10		17			
5	4		10			
10	3		9			
0			17		30	
2.5	1		2		5	
5	0		1		3	
10	0		1		2	
0	20		31		37	
0.7	6		11		17	
1.3	4		10		12	
2	4		8		12	
			Stem length cm			
0	78		82			
2.5	65		71			
5	62		68			
10	60		65			
0	79		83		89	
2.5	59		66		74	
5	54		66		72	
10	50		61		68	
0	80		82		82	
0.7	68		71		72	
1.3	64		68		69	
2	63		66		68	

of sprouted grains, delayed heading and ripening, and greater unevenness in ripening (green grains).

Differences in the effect of chlormequat at different levels of nitrogen fertilization were evident, although they were not all alike in the trial series with two or three levels of nitrogen. In both trial series chlormequat treatment resulted in a greater increase in grain yield with a high level of nitrogen fertilization than with a low level (Tables 16—18).

There is no doubt that the relative and absolute stem shortening due to chlormequat treatment was the less marked the higher the rate of nitrogen fertilization. In spite of that, the absolute decrease in lodging was greatest at the high nitrogen fertilization level, although it is true that the relative effect of chlormequat on lodging was also reduced with increased nitrogen. In practice, however, the most important factor is the absolute intensity of the lodging. Considered from this aspect, it can be said that chlormequat was very effective at a high level of nitrogen fertilization. In this respect, the goal set for chlormequat treatment was reached: a higher level of yield from increased nitrogen fertilization without damagingly severe lodging.

The increase in falling number due to chlormequat treatment in both trial series was smallest at a high level of nitrogen fertilization (Tables 16 and 17). However, at this level as well, there was a significant increase in the falling number; in the trials with two levels of nitrogen this meant that the mean falling number when chlormequat was applied remained above the limit of price reduction.

The reduction in the protein content of the yield from chlormequat was of the same order in both nitrogen levels in trial series with two levels of nitrogen (Table 16); in the trials with three levels of nitrogen the reduction was slightly more prominent at the higher levels than at the lower (Table 17). The difference was very slight, though. Therefore, it can be said that in this respect chlormequat treatment did not reduce the beneficial effect on the quality of the yield achieved with the addition of nitrogen fertilizer.

The results for the grain weight and volume weight of the yield differed from each other in both trial series. In the trials with two levels of nitrogen the effect of chlormequat was more harmful at the higher level of nitrogen fertilization than at the lower. In the trial series with three levels of nitrogen the reverse was true; at high levels of nitrogen there were less harmful effects from chlormequat than at lower levels. Owing to the greater number of experiments (37) conducted in this trial series and because the variations in the effect of chlormequat were smaller, it may be concluded that the harmful effects of chlormequat are generally slighter at a high level of nitrogen fertilization than at a low level.

3.6 Treatment with herbicide

Chemical weed control is one of the most common techniques employed in the growing of spring wheat. Therefore, the application of chlormequat in combination with a herbicide would be economical. The addition of the herbicides to chlormequat spray has neither altered the stem dwarfing characteristics of chlormequat nor the weed controlling effect of the herbicides (FROHNER 1965). The only exception has been dinoseb (JUNG et al. 1966). In experiments by ENGSTRÖM (1965), the addition of MCPA and dicamba to chlormequat spray reduced yield by 10 %.

In connection with the present study, the feasibility of combined spraying with chlormequat and the herbicide MCPA was investigated in field experiments conducted a Tikkurila and Peipohja in 1965—1967. In Finland, MCPA is the most common herbicide used for weed control in wheat. Mixing chlormequat with MCPA did not alter the effect of either chlormequat or MCPA (Table 19).

The optimum time for applying foliar herbicides is when the crop is at an early shoot stage (GRANSTRÖM 1962). In chapter 3.2 it was observed that a suitable application stage for chlormequat spray varies within comparatively broad limits. Thus, the timing of the chlormequat treatment can be fitted in with the optimum time for chemical weed control.

Table 19. Effect of chlormequat mixed with herbicide MCPA. Results from 3 trials.

	Chlormequat + MCPA separately	Chlormequat + MCPA together	*P*
Grain yield kg/ha	2370	2350	> *0.500*
» » %	100	99	
1000-grain weight g	29.3	29.2	> *0.500*
Hectolitre weight kg	76.9	76.7	> *0.500*
Falling number	322	318	> *0.500*
Lodging %	0	0	—
Stem length cm	45	45	> *0.500*
Growing period, in days	122	122	—
Weeds g/m²	13.4	9.9	> *0.500*

3.7 Impact on disease incidence

The effect of chlormequat on the susceptibility of cereals to diseases has been studied by several workers. In particular, the question has been raised whether chlormequat acts similarly on healthy plants and on those infected with root diseases, which often make the plants lodge. Attempts made by SLOPE and HUMPHRIES (1965) to diminish eyespot (*Cercosporella herpotrichoides* Fron.) infection in the field failed, perhaps because of a low natural incidence of the disease. DIERCKS (1965) succeeded in preventing winter wheat from lodging and reduced the incidence of eyespot with the chlormequat treatment. In BOCKMANN's (1965) field experiments with inoculated wheat, eyespot disease did not decrease the yield of crop treated with chlormequat even though the reduction in the yield of untreated wheat was considerable. POMMER (1967) tested chlormequat against a number of fungi and found that the eyespot fungus was the only one on which chlormequat had a fungistatic effect.

It is generally agreed that although chlormequat has an effect on the lodging of diseased crops and sometimes on the incidence of eyespot, it has no fungicidal action. The beneficial effects observed are due to the thickened stems or to the thickened cell walls of the stem (BOCKMANN 1964, MAYR et al. 1964, DIERCKS 1965, FROHNER 1965, JUNG et al. 1966, MEINX 1967, ZWATZ 1967, BECK 1968).

BECK (1968) considered that stem shortening made no difference to the ability of the plant to resist take-all disease (*Gaeumannomyces graminis* (Sacc.) v. Arx et Olivier).

JUNG et al. (1966) and MEINX (1967) studied the effect of chlormequat on powdery mildew (*Erysiphe graminis* de C.). They found that chlormequat increased the incidence of mildew. BECK (1968), and SANDFORD and STOVELL (1968), however, did not notice that chlormequat affected the occurrence of mildew, while KRISHENKO and GRUZDEV (1972) maintained that the treatment reduced the disease.

JUNG et al. (1966) found that chlormequat treatment increased infection by *Septoria nodorum* Berk. Similar results were obtained from trials by LANGERFELD (1971), when wheat was infected with *Septoria nodorum* and *Fusarium culmorum* (W. G. Sm.) Sacc. In the trials on wheat inoculated with *Septoria nodorum*, OBST (1968) also obtained results showing increased infection in the plots treated with chlormequat. VEZ and SPOORENBERG (1967) reported a greater incidence of fungal diseases in the plants sprayed with chlormequat.

Some workers (JUNG 1967, LINSER 1968, BOCKMANN 1968) have suggested that the increased susceptibility of wheat to the head diseases is caused by the shortened distance betweem the head and upper leaves. According to HUMPHRIES (1968 b) an alternative explanation is that heads of untreated and treated plants are in a susceptible condition at different times. Another explanation of the effect of chlormequat on diseases is the alteration in the microclimate in the crop (MEINX 1967, ZWATZ 1967, BOCKMANN 1968).

Certain wheat diseases occurred in the trials made during the present study. The frequency of occurrence of the following diseases was determined in various experimental treatments: wheat loose smut (*Ustilago tritici* Jens.), powdery mildew and take-all disease. Smut observations were carried out on plots of Apu wheat in the rate and time of application trials. No differences were found in the number of smutted heads with chlormequat treatment (Table 20). On the other hand, infection was appreciably higher in the plants grown from the yield of the crop treated with chlormequat than in the untreated ones. The increased susceptibility to infection was no doubt due to the different manner of head growth and the delayed development of the crop in the year of treatment.

Observations were made concerning powdery mildew in the trials of 1968, when the occurrence of this disease was very abundant (Table 21). In all trials spraying plants with chlormequat increased the frequency of mildew, while the spraying time had no effect.

The degree and severity of root and foot rot diseases were investigated in a crop sequence trial at Peipohja in 1973. The mean index of take-all (cf. NILSSON 1969) was greater and the number of healthy plants smaller in plots that had been treated with chlormequat (Table 22). However, the variations were so great that the statistical significance of the differences remained low.

Table 20. Effect of chlormequat on wheat loose smut.

Trial and treatment	No. of smutted heads per 50 m²
5 chlormequat dosage trials	
0	61
2.5 kg/ha chlormequat	60
5.0 » »	60
10.0 » »	57
P	*>0.500*
15 chlormequat-nitrogen fertilizer trials	
0	96
2.5 kg/ha chlormequat	100
P	*>0.500*
6 chlormequat timing trials	
1st spraying	154
2nd »	160
3rd »	161
P	*0.438*
4 seed soaking trials	
0	71
seeds soaked in 1 % solution	67
» » » 2 % »	67
P	*>0.500*
7 trials on after-effects of chlormequat	
seed from untreated plants	182
seed from plants treated with chlormequat spray	234
P	*0.108*

Table 21. Effect of cglormequat spraying on wheat mildew.

Trial and treatment	The portion of green plants covered by mildew %
Chlormequat dosage trial, Norröna	
0	41
0.7 kg/ha chlormequat	53
1.3 » »	57
2.0 » »	58
P	*0.011*
Clormequat timing trial, Norröna	
1st spraying	28
2nd »	30
3rd »	30
P	*>0.500*
Trials on harvesting time	
Norröna, 0	49
» , 2 kg/ha chlormequat	63
P	*<0.001*
Touko, 0	26
» , 2 kg/ha chlormequat	30
P	*0.323*
Apu 1972, 0	13
» » , 2 kg/ha chlormequat	22
P	*0.187*

Table 22. Effect of chlormequat spraying on the root and foot rot diseases. Results from a trial conducted at Peipohja.

	Chlormequat kg/ha	Healthy stems %	Take-all disease index thin roots %	Take-all disease index thick roots %	Plants with eyespot %
	0	13.5	27.0	3.2	2.7
	2	10.6	28.2	6.0	2.2
P		*>0.500*	*>0.500*	*>0.500*	*>0.500*

3.8 Residues in crop yield

The toxicity of chlormequat is low. According to Robert (1966), its acute oral LD_{50} value in mice was 450, in rats 433 to 660, in rabbits c. 75, in dogs c. 75 and in cats c. 10 mg/kg. No chronic or carcinogenic effects have been found.

The tolerances of chlormequat residues recommended by FAO/WHO are 3 mg/kg for wheat and 5 mg/kg for rye and oats (Pesticide Residues in Food 1973).

There are no regulations in Finland concerning chlormequat residue limits.

In the trials of Jung and Henjes (1964), and Youngner (1971) delayed spraying and higher dosage increased residues, although in general the residues were not very large. In addition to these factors Bier et al. (1970) reported that the nitrogen fertilizer rate and the method of spraying all affected the amount of residues. A higher rate of nitrogen fertilization increased the residues as did the application of chlormequat with a concentration sprayer. However in a trial conducted by Kühbauch and Ambergrr (1972) chlormequat residues decreased from 0.2 under 0.1 ppm when nitrogen fertilization was increased from 40 to 120 kg/ha N.

According to the studies of JUNG and EL-FOULY (1966), and of KÜHBAUCH and AMBERGER (1972) it is possible that the chlormequat residues will decrease during storage.

In the present study, analyses on residues were performed on the material of the first trial series at the Agricultural Research Center of American Cyanamid Company and on that of the later trial series in Finland at the State Institute for Agricultural Chemistry and in Kemira Oy's Research Centre.

Chlormequat residues found in the grains at a chlormequat application rate of 1.5 kg/ha or less varied from 0.16 to 2.0 mg/kg calculated as chlormequat chloride (Table 23). The results of the analyses indicate that the amount of residues in the grains depended to a large extent on the time of the treatment: the later the spray was applied, the larger the residues. On the other hand, the rate of application seems to have had little effect on the amount of residues. It also seems that variety and degree of stem shortening have some influence on residues while nitrogen fertilization has not.

Table 23. Chlormequat residues as chlormequat chloride (= 1.29 × chlormequat) in grains of spring wheat.

Trial site and year	Variety	No. of days between sowing and treatment	No. of days between treatment and harvest	Chlormequat kg/ha	Nitrogen kg/ha	Residues in grain mg/kg
Tikkurila 1964	Apu	5*)	98	2.5		0.16
		17	86	2.5		1.2
		24	79	2.5		1.6
		31	72	2.5		2.7
		38	65	2.5		3.2
Tikkurila 1964	Apu	36	67	2.5	0	2.0
		36	67	2.5	100	1.1
		36	67	5	0	1.9
		36	67	5	100	2.8
		36	67	10	0	2.1
		36	67	10	100	1.0
Tikkurila 1964	Diamant	36	77	2.5	0	0.76
		36	77	2.5	100	1.1
		36	77	5	0	1.1
		36	77	5	100	0.5
		36	77	10	0	1.1
		36	77	10	100	0.78
Tikkurila 1965	Svenno	42	78	1.5		0.3
		42	78	3		0.4
		57	63	1.5		2.0
		57	63	3		3.6
Peipohja 1971	Norröna	31	72	1.3	50	0.16
		31	72	1.3	150	0.18
Peipohja 1969	Norröna	39	64	2	50	1.5
		39	64	2	100	1.1
		39	64	2	150	0.92
Ylistaro 1971	Apu	35	84	2	50	0.62
		35	84	2	150	0.32
Maaninka 1968	Apu	20	90	2	100	0.9
		20	90	3	100	0.9

*) Spraying before emergence.

The significance of potential residues of chlormequat on the growing of wheat in practice were investigated at Tikkurila and Peipohja from 1966 to 1969, and also, indirectly, the following year by sowing seeds obtained from the plants treated with chlormequat and then studying the characteristics of the seedlings. In these tests, none of the plants from the yield of the sprayed crop showed the least signs of dwarfing or any other changes in characteristics testifying to the presence of chlormequat in the seeds (Table 24). However, some indications of possible slight chlormequat residues were found at the Satakunta Experiment Station in the seeds germinating from plants treated with chlormequat. The seeds germinated under laboratory conditions from the yield of the 1966 trials. The seeds were grown on blotting paper and their roots removed for measurement. The seedlings from the treated plants had longer and more numerous roots than those from the untreated plants (Table 25). It is true that the above phenomenon can possibly be explained on the basis of other changes in the grains resulting from treatment rather than from the chlormequat residues.

Table 24. Characteristics of plants grown from the yield of crop treated with chlormequat. Mean values of 10 comparisons.

Characteristics	Seed obtained from untreated plants	Seed obtained from treated plants	P
Grain yield kg/ha	3920	3920	*>0.500*
1000-grain weight g	29.7	29.8	*>0.500*
Hectolitre weight kg	74.2	74.4	*>0.500*
Falling number	137	144	*>0.500*
Sprouted grains %	5.6	4.6	*0.114*
Lodging %	68	68	*>0.500*
Stem length cm	102	102	*>0.500*
Growing period, in days	108	108	*>0.500*
Green grains %	0.2	0.1	*>0.500*

Table 25. Growth of roots in seedlings germinated from the yield of crop treated with chlormequat.

Variety	Period of germination in days	Germination % 0	Germination % chlormequat	P	Length of roots mm 0	Length of roots mm chlormequat	P
Apu	4	90	86	*0.252*	31.0	35.4	*<0.001*
	7	92	94	*>0.500*	83.4	84.7	*>0.500*
	10	89	88	*>0.500*	107.7	115.7	*0.002*
Svenno	4	83	86	*0.036*	29.7	29.7	*>0.500*
	7	86	81	*0.368*	72.3	75.7	*0.081*
	10	82	84	*>0.500*	117.6	130.6	*<0.001*
Mean value of 9 varieties	10	91	91	*>0.500*	100.3	106.6	*<0.001*
		Number of roots 0	Number of roots chlormequat				
Apu	10	5.02	5.20	*0.179*	79.6	90.5	*<0.001*
Svenno	10	3.66	3.82	*0.123*	77.7	79.5	*>0.500*

4. DISCUSSION

4.1 Suitability of results in practice

Abundant investigations have been carried out on the use of chlormequat for wheat in different parts of the world; the remarkable fact is that the results they have produced have been incompatible. In several of the investigations the effect of chlormequat on the yield has been positive. Nevertheless, there have been instances where the application of chlormequat was not found to have any effect at all or where the effect has even been detrimental as regards the yield and its quality.

A considerable diversity in the results is also obvious in the Finnish experiments reported in the present study. However, in general, the trend is towards increased yield and reduced lodging and, hence, improved yield quality and lower harvesting costs (Table 26).

In some aspects the present results agree well with those of investigations carried out elsewhere: of these the most important are the dwarfing effect of chlormequat, which is manifest almost without exception in all investigations dealing with the treatment of spring wheat with chlormequat, the diminished grain size, the greater effectiveness on sandy than on clay soil, the delayed development, the differences in varietal response and the rather ample timing limits of the spraying. It must be said, however, that there are also exceptions to these results in the trial series reported.

The results of greenhouse experiments often differ from those conducted in open fields as to both crop formation and other characteristics. WÜNSCHE (1970) has gathered abundant data on the effect of chlormequat on the grain yield of wheat. Most of the field trials displayed yield increases, whereas the majority of the pot trials in greenhouses showed yield reductions. A possible explanation for this difference may be that the wave length of light in a greenhouse is not the same as that in the open field. The shortest wave length that can penetrate the ordinary greenhouse glass is 300

Table 26. The distribution of changes in the characteristics of the yield and plants treated with 2 (2.5) kg chlormequat per hectare.

	Characteristic in % of the comparisons increased	unchanged	reduced	*P*
Grain yield	63	4	33	*0.002*
Density	47	6	47	*>0.500*
Tillering	64	0	36	*0.175*
Grains per head	64	0	36	*>0.500*
Weight of grains per head	55	0	45	*>0.500*
1000-grain weight	23	6	71	*<0.001*
Hectolitre weight	31	4	65	*<0.001*
Falling number	62	7	31	*0.008*
Sprouted grains	6	27	67	*0.031*
Germination	42	5	53	*>0.500*
Protein	21	7	72	*0.005*
Lodging	0	14	86	*<0.001*
Stem length	0	0	100	*<0.001*
Straw yield	17	3	80	*<0.001*
Heading	63	35	2	*<0.001*
Growing period	24	67	9	*0.018*
Moisture at ripening	65	0	35	*<0.001*
Moisture at harvesting	10	0	90	*<0.001*
Green grains	50	22	28	*>0.500*

nanometres (TRICKETT and GOULDEN 1958). KAUKOVIRTA (1968, 1970) conducted experiments on chrysanthemums and beans which revealed that the strong growth-retarding effect of chlormequat in daylight disappeared in UV light (maximum wave length 365.5 nm). PETR (1972) also showed that the retarding effect of chlormequat on spring wheat was greater at wave lengths of 500 to 700 nm than of 400 to 500 nm. Since the formation of endogenic gibberellin is more abundant in long-wave than in short-wave light, Petr concluded that the effectiveness of chlormequat is due to its ability to prevent gibberellin synthesis. Although there is as yet no definitive explanation for the mode of action of chlormequat, it is justifiable to presume that variations in the quality of light at least partially account for the variations in the effect of chlormequat observed in the different experiments. This may also explain the different responses of wheat cultivars, since the gibberellin synthesis differs with variety (CLELAND 1969).

The fact is that only results obtained from field experiments are adaptable to wheat growing in practice. The results presented here are obtained in field experiments and are, therefore, valuable from the practical viewpoint. It must be kept in mind that the aim of the present study is to provide recommendations concerning the use of chlormequat on spring wheat in practice.

4.2 Application rates under different conditions

In the investigations of the present study, the effects of chlormequat were examined for the most part at an application rate of 2 or 2.5 kg per hectare. This does not mean, however, that the most suitable chlormequat rate is necessarily 2 or 2.5 kg per hectare. The second and particularly the third dosage trial series indicated that smaller application rates had a similar effect on the yield and its characteristics in general.

The results showed that the application of chlormequat has a direct effect on the economy of wheat growing. This effect is due to the changes in grain yield, in hectolitre weight, in the falling number and in the moisture content of grains, and also the changes in lodging. The other changes caused by chlormequat application have no economic significance to the wheat producer, according to the basis on which the price is determined for wheat grown in Finland.

The most pofitable application rate was calculated on the basis of the curves drawn from the results of the field experiments of this study.

Earlier (in chapter 3.1.1) it was found that the grain yield of wheat increased as a result of chlormequat treatment according to the following equation:

$$Y = -9.0x^2 + 96.5 \lg(10.5x + 1.5) + 2975.0$$

The hectolitre weight decreased with the chlormequat treatment on an average according to the equation (chapter 3.1.4)

$$Y = 0.476 \cdot 0.558^{(x - 1.22)} + 75.88$$

The application of chlormequat increased the falling number of grain according to the equation (chapter 3.1.4)

$$Y = 26.4 \lg(x + 1.2) + 265.0$$

The moisture of grain yield at harvesting decreased; the decrease followed the equation

$$Y = -0.35x + 25.8$$

The mean lodging of plants was expressed in the equation (chapter 3.1.5)

$$Y = 27.6\,(x + 0.9)^{-1} + 0.7$$

In estimating the most economical application rate for chlormequat, the production and cost factors mentioned above were evaluated in Finnish marks on the following basis.

The price of wheat was 67.05 pennis per kilogram (wholesale cost price set by the State Granary in the summer of 1974), the effects of hectolitre weight and falling number on the wheat price were calculated according to the decision of the Ministry of Agriculture and Forestry (Maatalousministeriön päätös 1968, Maa- ja metsätalousministeriön päätös 1974).

The effect of grain moisture was presented as a drying cost in relation to water evaporated according to the equation

$$c = 1.1 + (a - 14)\ 0.28,$$

where c = drying cost in pennis per kilogram and a = the percentage moisture of grain when drying started. The equation originally presented by Uotila and Nissi (1973) was modified by the author because of higher energy prices.

The effect of lodging in increasing expense was evaluated as follows. 10 % or less lodging corresponds to a harvesting cost of 150 mk/ha, and every percent lodging over 10 % increases the cost by 0.5 per cent.

The price of chlormequat was considered as 19,00 mk/kg.

Thus, the following equations describe the revenues and expenses in mk/ha,

for yield: $Y = 0.6705$ (yield kg/ha),
for hectolitreweight: $Y = [-0.2 \cdot 0.558^{(x-1.22)} + 0.89]$. (yield kg/ha),
for falling number: $Y = 0.0141$ (yield kg/ha),
for drying cost: $Y = (-0.00098x + 0.044)$ (yield kg/ha),
for harvesting cost: $Y = 20.7(x + 0.9)^{-1} + 143.025$
and for spray cost: $Y = 19.00x$.

In the equations, x = kg/ha chlormequat.

The following equation was obtained to express the change in the returns of chlormequat treatment (Fig. 14):

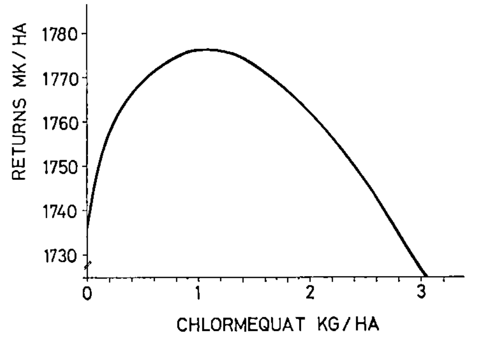

Fig. 14. The dependence of returns in growing spring wheat on chlormequat treatment.

$$Y = -9.0x^2 + 48.3\ \lg(10.8x + 1.1) + 1733.0$$

In the equation, the value of Y_{max}, 1777 mk/ha, was obtained at the level of 1.05 kg per hectare of chlormequat. This value is valid only when all the factors applied in the calculations are unchanged. If the unit prices of the factors vary, the maximum point of the equation may change. — The grain yield was highest at the level of chlormequat rate 1.5 kg/ha (Fig. 3).

Both the results well agree with the experimental results gained in decreasing lodging. A satisfactory reduction in lodging (up to 10—12 %) was obtained on an average with 2 kg chlormequat per hectare. An application rate of 1 kg chlormequat per hectare was sufficiently effective if the level of nitrogen fertilizer was c. 50 kg per hectare. If nitrogen was increased by c. 50 kg per hectare, lodging was still tolerable (12 %) at the rate of 1.5 kg chlormequat per hectare (Fig. 13).

Considering the economically most beneficial result and the effects on yield and lodging the application rate of 1—1.5 kg/ha can be recommended.

The mean effects estimated from equations on the yield and its characteristics with an application rate of 1.5 kg chlormequat per hectare were as shown in following table.

Characteristics	Level	Change compared with untreated plants
Grain yield kg/ha	3075	+83
1000 grain weight g	32.3	−0.8
Hectolitre weight kg	76.3	−0.5
Falling number	276	+9
Protein %	13.4	−0.5
Lodging %	12	−19
Stem length cm	69	−13
Moisture at harvesting %	25.3	−0.5

The results of the dosage trials indicate that chlormequat treatment is most beneficial on sandy soil, where yield increase, lodging reduction and stem shortening are all more marked than on other soil types. The higher yield attained on sandy soil than on clay soil proves that it was not possible in these experiments, any more than it would be using conventional methods in practice, to make fully effective use of the yield producing capacity of the Finnish clay soils. This is due to loss of moisture in the spring (cf. POHJANHEIMO and HEINONEN 1960). Chlormequat treatment would be more beneficial on clay soils if the initial development of the roots could be accelerated, thus enabling the roots to utilize the abundant ground water reserves in the soil. This may be achieved by early sowing, by tilling the soil in such a way as to prevent exess evaporation of water and by irrigation.

A significant correlation between the yield of the untreated crop and the yield increasing effect of chlormequat was evident ($r = 0.374$, $P < 0.001$). The effect of chlormequat at a low level of yield was slight and the value of its application uncertain. However, spraying with chlormequat at a rate of 1 kg per hectare is justified to ensure that those varieties in which lodging is common will stand. At the lowest yield levels the treatment may reduce the yield. However, situations leading to reduced yields can normally be avoided, under Finnish conditions, by making the best use of technical developments in the soil treatment, incorporating row fertilization and irrigation, thus ensuring the success of the crop.

4.3 Reasons for changes in yield

The increase in grain yield in 63 % of the experiments was evidently due to the increase in the number of heads and grains per individual plant. However, the statistical significance of these results was low, owing to the investigation techniques employed.

The density of plants was determined from a sample of 5 × 1 row metres in each plot. The number of heads were counted for only one row metre in the sample. The variation in density was great, and because tillering and head size also depend on density, as has been revealed in this study, this variation concealed the effect of chlormequat in the significance tests. Tillering and the number of grains per head were both increased in 64 % of the experiments and reduced in 36 %. In cases of yield increase, the yield components mentioned earlier also had to offset the reduced yield due to diminished grain size.

Increased tillering might be caused by the fact that the plants treated remained shorter. In that case, increased light at the stem base would trigger tiller formation, assuming that moisture and nutrients are available. This supposition is supported by the observations of DILZ et al. (1965) on increased light in crops treated with chlormequat. HUMPHRIES et al. (1965) presumed that the greater light transmittance of plants treated resulted in better survival of the adventive tillers and, hence, in increased tillering and yield. However, they presented another explanation in a later publication (HUMPHRIES et al. 1967).

Without going into further details on the physiological basis for the increased number of side tillers and grains, it may be considered that the requirements for the development of ever more numerous grain embryos into fully-grown grains are the availability of sufficient quantities of nutrients and water. If these are lacking, the yield is reduced. On the other hand, the results of some investigations do in fact indicate yield increases under dry conditions alone. It is the opinion of WÜNSCHE (1970), that in those cases chlormequat promotes the economy of the plant's use of water.

4.4 Residue analyses

The results of the residue analyses of the grains from the first experiments show high values even with moderate dosage and early spraying. All those determinations were performed at the Agricultural Research Center of the American Cyanamid Company. Subsequent determinations were conducted at the State Institute for Agricultural Chemistry and at the Research Centre of Kemira Oy. The method used was based on the same colorimetric method employed in America, but with improved reliability and accuracy. In the latter determinations, the residue figures were large only when the spray was applied late and the development of the plant was already approaching the heading stage. In the light of these results, the spray must not be applied later than forty days after sowing. This limitation in timing chlormequat application seems to be sufficient to keep the residues under the limit of 3 mg/kg in practice.

4.5 Effect on the growth of roots

The chlormequat residues in the grains leading to more vigorous root growth is a phenomenon that may be significant in improving the drought tolerance of the crop. The abundance of assimilates as a result of the slow down in growth of the aerial shoot seems to accelerate the root growth and, hence, enables them to make better use of water supplies in the soil. This is one of the prerequisites for a large yield. The same phenomenon occurs with early sowing (HEINONEN 1970). It has been considered that the explanation lies in the relationship between light and temperature.

Not only chlormequat residues from previous treatment but also a small amount of chlormequat supplied directly to the grains stimulate root growth (WÜNSCHE 1970). The proper time for providing the seed with a suitable amount of chlormequat is just before the crop is harvested. In this case, however, the treated crop should be confined to use as seed — a restriction difficult to supervise. Therefore, a study should be made of the feasibility of developing a useful method whereby chlormequat could be supplied to the grains later, just before sowing. Advantages of seed treatment would possibly be an improved drought tolerance and a lower residue in the following crop yield. The trials conducted at Peipohja and reported in chapter 3.3 indicate that the results from seed treatment might in some cases be more profitable than those from spraying.

4.6 Effect on the cultivars

The wheat cultivars employed in the trials exhibited variations in lodging susceptibility. In the spring wheat variety trials performed in Finland from 1959 to 1966, the lodging in Apu was 27 %, Norröna 27 %, Diamant 28 % and Svenno 10 % (Teittinen and Kivi 1967). Also in the trial series described in this study lodging was slight in Svenno, but distinctly heavier in Apu than in the other varieties (Table 7). Although the reduction in lodging was lower in Apu than in the other varieties, the use of chlormequat on Apu may still be worthwile, taking into account the increase in yield. Lodging in Norröna can be almost completely eliminated with chlormequat and thus, it is usually advisable for this cultivar be given chlormequat even though there is no increase in yield. Chlormequat is also of benefit to Diamant, but the stem of Svenno is strong enough without chlormequat treatment. Lodging in Ruso was obviously heavier than normal in the present experiments. Lodging preventive measures are not usually necessary with Ruso and since chlormequat caused a reduction in yield in this cultivar, chlormequat cannot be recommended for it.

The continuous use of chlormequat can cause an increase in the frequency of loose smut in Apu cultivar, which is susceptible to this disease. Smut could be controlled by disinfecting the seed. The effect of chlormequat on new cultivars should be tested in good time while they are still at the breeding stage. In this way information would be available when they are ready to be put on the market. Since the mode of action of chlormequat is not known, its effects on new varieties cannot be estimated by analysing their biochemical properties.

4.7 Nitrogen fertilization and control of weeds

When the stem has been sufficiently strengthened as a result of treatment with chlormequat the level of nitrogen fertilization can be raised, since heavier lodging is not then expected. Increasing the former conventional nitrogen rates of 50—70 kg/ha by a maximum of c. 50 kg/ha may still secure a satisfactory standing ability in the crop. This nitrogen rate would also be economically profitable.

The most economical way of applying chlormequat is in combination with herbicide spraying. Obviously there may be little variations in the optimum timing as well as in the length of the suitable time for both treatments. The optimum for herbicide treatment is about one week before that of chlormequat. Combined spraying can be performed earlier or postponed by a few days depending on which measure is regarded as more important.

5. SUMMARY

Altogether 280 field trials were conducted from 1963 to 1973 at the Institute of Plant Husbandry and Satakunta Experiment Station of the Agricultural Research Centre as well as at some other experimental sites throughout the Finnish wheat growing area, in order to delineate the effects of chlormequat (= (2-chlorethyl)trimethylammonium chloride or CCC) on the yield and lodging of spring wheat. The results indicated the following:

1. A mean increase in yield of 3 % (100 kg/ha) was obtained by foliar spraying of spring wheat with 2 or 2.5 kg chlormequat per hectare about 30 days after sowing (Tables 1—4). The yield increase was approximately 80 kg/ha with the application rate 1—1.5 kg/ha chlormequat (Fig. 3). The increase was evident in 63 % of the trials and it was obviously caused by the greater number and size of the heads (Table 1, 3 and 4). The yield increase was greatest when rainfall was abundant in May and June ($r = 0.239$, $P = 0.022$) and when lodging in the untreated crop was severe ($r = 0.209$, $P = 0.056$). In addition, the yield increases were more marked on sandy soil than on clay or humus soils (Table 5), and, in general, when the level of the yield was high rather than low ($r = 0.374$, $P < 0.001$).
2. A reduction in the size of grains (Table 6) and, hence, in the weight of one thousand grains was seen in 71 % of trials (Table 26). It was 1.1 g at the application rate 2 or 2.5 kg/ha chlormequat and 0.8 g at the application rate 1—1.5 kg/ha (Fig. 4).
3. The hectolitre weight was reduced as a result of the treatment in 65 % of trials (Table 26) by an average of 0.7 kg at the application level 2 (2.5) kg/ha chlormequat and 0.5 kg at the level 1.5 kg/ha (Tables 1—4, Fig. 5). According to the official quality regulations, a dosage of 2 to 2.5 kg per hectare would have meant an average reduction in price for grain yield of 0.27 pennis per kilogramme. As a result of the treatment the hectolitre weight went below the acceptable limits of marketability (74 kg) in 9 % of the trials.
4. In 62 % of trials there was a mean increase of 17 in the falling number of the yield (Tables 1—4, Fig. 6). With an application rate of from 2 to 2.5 kg per hectare there would have been an increase in the price of the grain yield as a result of the higher falling number in 27 % of the trials, the mean increase being 2.55 pennis per kilogramme. In 5 % of the trials the treatment raised the falling number above the limits of marketability (80). The differences in falling numbers between the untreated and treated crops increased as the harvesting season advanced (Fig. 7).
5. The treatment had no effect on the germination of the yield (Tables 1—4).
6. As a result of the treatment there was a mean reduction in the protein content of the yield of 0.5 %-units at the application level 2 (2.5) kg/ha and 0.4—0.5 %-units at the level 1—1.5 kg/ha chlormequat (Tables 1—4, Fig. 8). The protein content decreased in 72 % of the trials (Table 26).
7. There was a reduction in lodging in 86 % of trials (Table 26). The average reduction was from 31 % to 11 % at the application level 2 to 2.5 kg/ha chlormequat and to 12 % at the level 1.5 kg/ha (Tables 1—4, Fig. 9). The reduction was larger in sandy soil than in other soil types (Table 7). Susceptibility to lodging was diminished by shorter stem length, thickened stem wall (Table 9) and smaller straw yield (Table 4).

8. With a chlormequat rate from 2 to 2.5 kg per hectare, the mean stem shortening was from 82 cm to 67 cm, that is, 18 % (Tables 1—4). Stem shortening occurred in all the trials (Table 26), but it was most marked on sandy soils (Table 8). Lower chlormequat rates also caused considerable stem shortening (Fig. 11).
9. The greatest shortening was located in the upper internodes. In the cases investigated the mean shortening of the top internode was 22 % and of the bottom one 4 %. The diameter of the stem in the middle of the second to bottom internode had increased by an average of 2 % and the thickness of the stem wall by an average of 7 % (Table 9).
10. Delayed heading after the treatment occurred in 63 % of the trials (Table 26). Heading was delayed by an average of one day. Moisture determinations carried out on the grains at ripening indicated that the treated crop was more moist by 0.5 %-units than the untreated (Tables 1—4). Moisture determinations conducted at harvesting (by combine) indicated that the grains from the treated crop were drier than those from the untreated in 90 % of trials (Table 26). The mean difference was 1 %-unit (Tables 1—4). There were no significant differences in the evenness of ripening between the untreated and treated crops (Tables 1—4).
11. No changes in yield or its characteristics were apparent when the timing of treatment was altered from the 3 leaf stage to the 6 leaf stage. The spray was applied an average of twenty-six to forty-one days after sowing, when the mean length of the shoots varied from 18 to 40 cm, respectively. However, the 1000-grain weight was reduced when the time of spraying was postponed. The effect of chlormequat on stem length was stronger with later application (Table 10).
12. Soaking seeds in a chlormequat solution produced a strong yield-increasing and lodging-reducing effect in some of the trials (Tables 11 and 12). No positive results were obtained, however, from the treatment of seeds with chlormequat as a dry or wet surface dressing (Tables 13 and 14).
13. There were distinct varietal differences as to stem shortening. The cultivars that were most readily dwarfed in the application rate trials were Norröna and Ruso, both 22 %, and least readily Apu, 15 % (Table 8). Varietal differences were also manifest in lodging reduction. These, however, did not correspond to the stem shortening. Lodging was reduced most succesfully in Norröna, 77 %, and least succesfully in Apu, 60 % (Table 7). Chlormequat increased the yield of Apu, but diminished that of Ruso, while the yield of Norröna remained unchanged (Table 5). Also in the special variety tests Norröna shortened markedly, 27 %, and its lodging diminished 86 %. In these tests chlormequat had an advantageous effect on Apu also (Table 15).
14. Chlormequat augmented the yield increase resulting from nitrogen fertilization by reducing the lodging caused by nitrogen. The reduction in lodging and stem length obtained with a given chlormequat rate was proportionally smaller with a high level of nitrogen fertilization than with a low level (Tables 16—18). The nitrogen fertilization level causing harmful lodging went up by approximately 50 kg/ha N (Fig. 13).
15. Combined spraying with chlormequat and MCPA did not reduce the effects of either chemical (Table 19).
16. Chlormequat had no effect on the amount of loose smut in the treatment

year. The following year, however, an increase in the occurrence of this disease was manifest (Table 20). Chlormequat increased both powdery mildew and take-all disease (Tables 21 and 22).

17. Chlormequat residues were low (from 0.16 to 2.0 mg/kg with a chlormequat application rate of 1.5 kg/ha) and depended mainly on the timing of the treatment, but also on the application rates. Late treatment and higher application rates increased the residues (Table 23). No signs were manifest of the effect of chlormequat in the crop sown with seeds from treated plants (Table 24). However, laboratory experiments demonstrated that more abundant and longer roots developed in such seeds than in those from untreated plants (Table 25).
18. The following recommendations were made on the basis of the findings: Under growth conditions favourable to spring wheat (abundant spring moisture, sandy soil, strong fertilization), cv. Ruso excepted, the most beneficial application rate for chlormequat is 1.5 kg per hectare. Under less favourable conditions, varieties more susceptible to lodging may be treated with 1 kg chlormequat per hectare. Cv. Apu should always be treated. Chlormequat can be applied as a spray in combination with herbicides. The proper time for combined spraying is when the shoots are at the 4—5 leaf stage, but not later than forty days after sowing.

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SELOSTUS

Klormekvatti (CCC) kevätvehnän laontorjunnassa

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Maatalouden tutkimuskeskus

Maatalouden tutkimuskeskuksen kasvinviljelylaitoksella ja Satakunnan koeasemalla sekä eräillä muilla Etelä-Suomen koepaikoilla (kuva 2) suoritettiin v. 1963—1973 sarja kenttäkokeita, joissa tutkittiin klormekvatin (= (2-kloorietyyli)trimetyyliammoniumkloridi eli CCC) vaikutuksia kevätvehnän satoon ja lakoutumiseen. Tulokset osoittivat seuraavaa.

1. Ruiskuttamalla kevätvehnän oraat n. 30 vrk kylvöstä käyttäen 2 tai 2.5 kg/ha klormekvattia saatiin keskimäärin 3 % (100 kg/ha) sadonlisäystä (taul. 1—4). Sadonlisäys oli lähes samansuuruinen myös pienemmillä kokeilluilla klormekvatin käyttömäärillä (kuva 3). Sadonlisäyksen, jota saatiin 63 %:ssa kokeista (taul. 26), ilmeisesti aiheutti sekä tähkien lukumäärän että tähkien koon kasvaminen (taul. 1, 3 ja 4).

Sadonlisäyksiä saatiin todennäköisimmin silloin, kun touko—kesäkuun sademäärä oli runsas (r = 0.239, $P = 0.022$) ja kun lakoutuminen oli yleistä (r = 0.209, $P = 0.056$). Edelleen sadonlisäykset olivat suuremmat hietamailla kuin savi- ja multamailla (taul. 5) ja yleensä suuremmat korkealla kuin alhaisella satotasolla (r = 0.374, $P < 0.001$).

2. Jyvien koko pieneni (taul. 6) ja niiden paino väheni 71 %:ssa kokeista (taul. 26). Tuhannen jyvän paino aleni klormekvatin käyttömäärän ollessa 2 (2.5) kg/ha keskimäärin 1.1 g (kuva 4).

3. Hehtolitranpaino aleni käsittelyn seurauksena 65 %:ssa kokeista (taul. 26) keskimäärin 0.7 kg (taul. 1—4, kuva 5). Tämä olisi merkinnyt voimassa olevan laatuvaatimuspäätöksen mukaan keskimäärin 0.27 p/kg hinnanalennusta leipäviljalle. Käsittelyn seurauksena hehtolitranpaino laski kauppakelpoisuusrajan (74 kg) alapuolelle 9 %:ssa kokeista.

4. Sadon sakoluku lisääntyi 62 %:ssa kokeista (taul. 26) keskimäärin 17 (taul. 1—4, kuva 6). Sato olisi saanut hinnanlisää sakoluvun kohoamisen johdosta 27 %:ssa kokeista ja keskimääräinen hinnanlisä olisi ollut 2.55 p/kg. 5 %:ssa kokeista käsittely aiheutti sakoluvun kohoamisen kauppakelpoisuusrajan (80) yläpuolelle. Käsittelemättömän ja käsitellyn kasvuston sakoluvun ero suureni tutkituissa tapauksissa korjuukauden edistyessä (kuva 7).

5. Käsittely ei vaikuttanut sadon itävyyteen (taul. 1—4).

6. Sadon proteiinipitoisuus väheni käsittelyn seurauksena 72 %:ssa kokeista (taul. 26) keskimäärin 0.5 %-yksikköä (taul. 1—4, kuva 8).

7. Lakoutuminen väheni 86 %:ssa kokeista (taul. 26). Klormekvatin käyttömäärällä 2 (2.5) kg/ha lakoutuminen oli keskimäärin 11 %, kun se ilman klormekvattikäsittelyä oli 31 % (taul. 1—4, kuva 9). Lakoutumisalttiutta vähensivät lyhentynyt korren pituus, paksuntunut korren seinämä (taul. 9) sekä pienentynyt olkisadon määrä (taul. 4). Lakoutuminen väheni voimakkaimmin hietamaalla (taul. 7).

8. Korsi lyheni keskimäärin 82 cm:stä 67 cm:iin eli 18 % (taul. 1—4). Korren lyhenemistä tapahtui kaikissa kokeissa (taul. 26), mutta se oli voimakkainta hietamaalla (taul. 8). Pienimmätkin kokeillut klormekvattimäärät lyhensivät kortta huomattavasti (kuva 11).

9. Voimakkain korren lyheneminen paikallistui ylimpiin solmuväleihin. Tutkituissa tapauksissa ylimmän solmuvälin lyheneminen oli keskimäärin 22 % ja alimman 4 %. Korren läpimitta lisääntyi toiseksi alimman solmuvälin keskikohdalla keskimäärin 2 % ja korren seinämän vahvuus keskimäärin 7 % (taul. 9).

10. Käsittely viivästytti tähkälle tuloa 63 %:ssa kokeista (taul. 26). Viivästymisen pituus oli keskimäärin yksi päivä. Tuleentuessa tehdyt jyvien kosteusmääritykset osoittivat käsitellyn kasvuston olleen 0.5 %-yksikköä kosteampaa kuin käsittelemättömän (taul. 1—4). Leikkuupuintihetkellä suoritetut kosteusmääritykset osoittivat käsitellyn kasvuston jyvien olleen keskimäärin 1 %-yksikköä kuivempia kuin käsittelemättömän. Tämänsuuntainen ero esiintyi 90 %:ssa kokeista (taul. 26). Tuleentumisen tasaisuudessa ei ollut luotettavia eroja käsittelemättömän ja käsitellyn kasvuston välillä (taul. 1—4).

11. Sato ja sen ominaisuudet eivät muuttuneet ruiskutusajankohdan siirtyessä 3-lehtiasteelta 6-lehtiasteelle, jolloin ruiskutus tapahtui keskimäärin 26—41 vrk kylvöstä ja oraan pituus vaihteli keskimäärin 18—40 cm. Kuitenkin sadon tuhannen jyvän paino pieneni ja

klormekvatin vaikutus korren pituuteen voimistui ruiskutusajan siirtyessä myöhemmäksi (taul. 10).

12. Siementen liotus klormekvattiliuoksessa lisäsi eräissä kokeissa voimakkaasti satoa ja vähensi suuresti lakoutumista (taul. 11 ja 12). Sen sijaan siementen käsittelystä klormekvatilla kuiva- tai nestepeittauksen tapaan ei saatu positiivisia tuloksia (taul. 13 ja 14).

13. Lajike-erot korren lyhenemisessä olivat selvät. Käyttämääräkokeissa olleista lajikkeista lyhenivät eniten Norröna ja Ruso, kumpikin 22 %, ja vähiten Apu, 15 % (taul. 8). Myös lakoutumisen vähenemisessä esiintyi lajike-eroja, jotka eivät kuitenkaan käyneet yksiin korren lyhenemisen kanssa. Eniten väheni Norrönan lakoutuminen, 77 %, ja vähiten Avun, 60 % (taul. 7).

Klormekvatti lisäsi Avun, mutta vähensi Ruson jyväsatoa. Norrönan jyväsatoon vaikutus oli vähäinen (taul. 5). Suoritetuissa lajiketestauksissa Norröna lyheni keskimäärin 27 % ja sen lakoutuminen väheni 86 %. Näissä kokeissa klormekvatti vaikutti edullisesti myös Apuun (taul. 15).

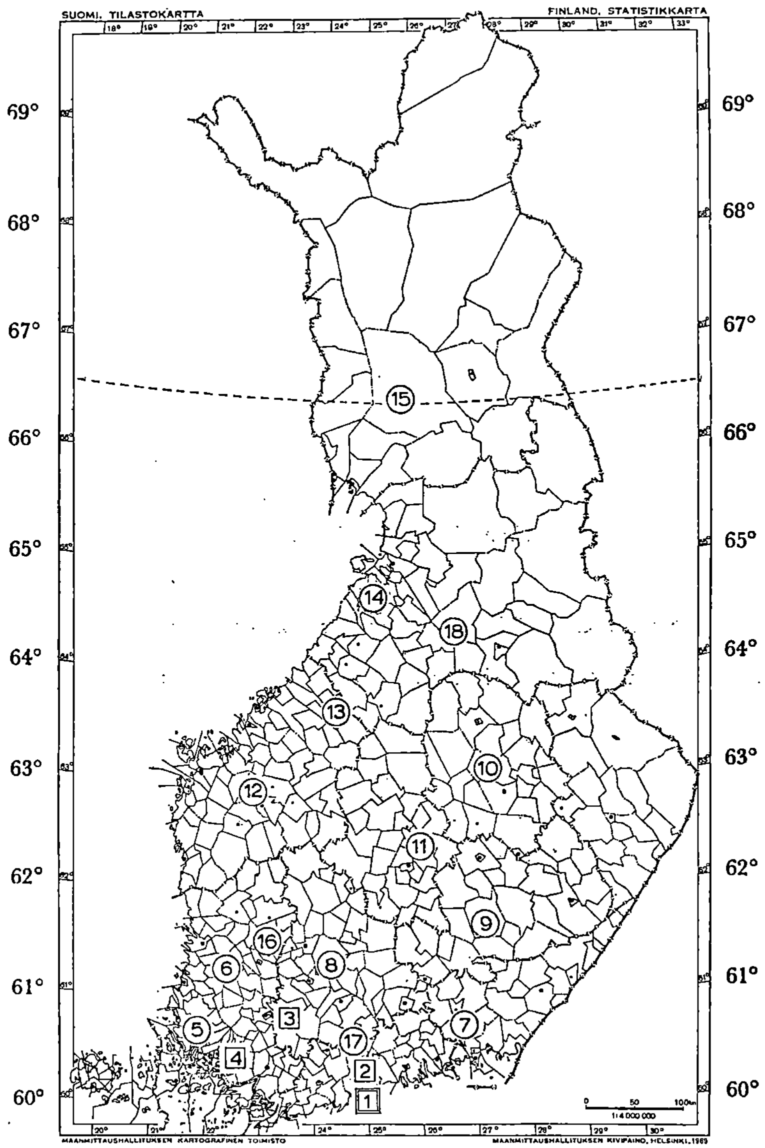
14. Klormekvatti lisäsi typpilannoituksen avulla saatua sadonlisäystä vähentämällä typen aiheuttamaa lakoutumista. Saman klormekvattimäärän aikaansaama lakoutumisen väheneminen ja korren lyheneminen oli suhteellisesti pienempi korkealla typpilannoitustasolla kuin alhaisella (taul. 16—18). Haitallista lakoutumista aiheuttava typpilannoitustaso kohosi n. 50 kg/ha N (kuva 13).

15. Klormekvattiruiskutuksen suorittaminen samanaikaisesti MCPA-ruiskutuksen kanssa ei vähentänyt klormekvatin eikä herbisidin tehoa (taul. 19).

16. Klormekvatti ei vaikuttanut käsittelyvuonna esiintyneen lentonoen määrään, mutta lisäsi lentonoen runsautta käsittelyä seuraavana vuonna (taul. 20). Kasvien härmäisyyttä klormekvatti lisäsi (taul. 21). Sillä oli myös mustatyvisyyttä lisäävä vaikutus (taul. 22).

17. Klormekvattijäämät jyvissä olivat vähäisiä, 1.5 kg/ha klormekvattimäärällä 0.16—2.0 mg/kg. Ne riippuivat eniten käsittelyajasta, mutta myös käyttömäärästä. Myöhäinen käsittely ja käyttömäärän suurentaminen lisäsivät jäämiä (taul. 23). Käsitellystä kasvustosta saadulla siemenellä kylvetyssä kasvustossa ei todettu merkkejä klormekvatin vaikutuksesta (taul. 24). Kuitenkin laboratoriokokeissa tällaiseen siemeneen kehittyi runsaammin ja pitempiä juuria kuin käsittelemättömän kasvuston sadosta saatuun (taul. 25).

18. Tulosten perusteella voidaan antaa seuraavat suositukset: Kasvuolojen ollessa suotuisat (runsas kevätkosteus, hietamaa, voimakas lannoitus) kevätvehnälle kannattaa Rusoa lukuun ottamatta käyttää klormekvattia 1.5 kg/ha. Tällöin on odotettavissa, että sato lisääntyy n. 3 % (80 kg/ha), sadon tuhannen jyvän paino alenee n. 0.8 g, hehtolitranpaino alenee n. 0.5 kg, sakoluku suurenee n. 9, proteiinipitoisuus pienenee n. 0.3 %-yksikköä, lakoutuminen vähenee n. 12 %:iin, korsi lyhenee n. 16 % (13 cm) ja sato on n. 0.5 %-yksikköä kuivempaa kuin käsittelemättömän kasvuston. Heikoimmissakin kasvuoloissa lakoutumisalttiille lajikkeille voidaan antaa klormekvattia 1 kg/ha. Lajike Apu on syytä käsitellä aina. Klormekvatti annetaan ruiskuttaen yhdessä herbisidien kanssa oraiden ollessa 4/5-lehtiasteella, ei kuitenkaan myöhemmin kuin 40 vuorokauden kuluttua kylvöstä.



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