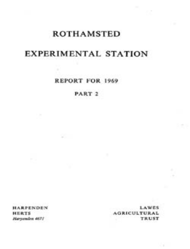
Rothamsted Experimental Station Report for 1969 Part 2



Chemical Control of Plant Growth

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Chemical Control of Plant Growth

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That the form of plants, and the relative proportions of their different parts, can change greatly is evident from the differences between plants of one variety when grown in different environments. The sequence of environmental changes that gives the greatest yield of either total dry matter or the economically important parts of the plant can be discovered experimentally, but the scope for increasing yield of field crops by changing the environment is small. There is more scope in changing the morphology and development of the plant to suit the environment, and the larger potential yield of new than of old varieties of some crop plants reflect the success of the plant breeder in doing this. However, plant breeding is a slow process, and with the knowledge that the effects of the environment are mediated by the changes in the content and distribution of endogenous growth substances (chemicals produced within the plant that affect such processes as cell division and extension), there comes the possibility of altering the growth and morphology of existing varieties in ways that will increase yield.

This paper discusses this possibility and describes how growth regulators affect plant form; a growth regulator is defined as either a naturally occurring or a synthetic chemical that, when applied to plants in small amounts, changes their form by altering the relative proportions of its component parts (Humphries, 1967).

Hormone weedkillers are growth regulators, but I shall not consider them though they represent by far the largest use yet of growth regulators in agriculture. I shall deal only with chemicals applied to change the form and growth of crop plants directly. Research on such chemicals was stimulated by the discovery of gibberellic acid, gibberellin A_3, first identified as a metabolic product of the fungus *Fusarium moniliforme*. This greatly increased the growth of some plants, especially of their stems, but sometimes also of leaves, and increased total dry weight. Regrettably the early promise that gibberellic acid could be used to increase crop yield has not been realised, although only few tests have been made on field crops because it is expensive. However, a claim that cheaper unrefined preparations increase yields of sugar cane (Tanimoto & Nickell, 1966) implies the need for further tests.

The chemicals whose effects and interactions I shall consider are:

Gibberellic Acid, a naturally occurring growth regulator that increases both cell division and cell growth.

CCC (2-chloroethyl-trimethylammonium chloride), a synthetic chemical that inhibits gibberellin synthesis, slows cell division, lessens apical

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dominance, causing more branches to develop, and strengthens stems of cereals.

B9 (N-dimethylaminosuccinamic acid), a synthetic chemical that stunts plant growth, probably by interfering with auxin synthesis (e.g. Cooper *et al.*, 1968).

Morphactins, which are synthetic derivatives of fluorene carboxylic acid, and chemically related to the gibberellins, but with very different properties. The morphactins stunt plant growth at smaller concentrations than CCC or B9.

Ethrel (2-chloroethylphosphonic acid), a chemical that causes growth changes by liberating ethylene in the plant.

Effects of growth regulators on potatoes

The yield of potatoes could be increased if a greater proportion of the total dry weight could be made to pass into the tubers, or if the dry weight could be increased by increasing the leaf area or by prolonging the life of the haulm. Gibberellic acid usually increases stem extension, but not of potato plants except when nitrogen is deficient (Humphries & French, 1960) or when potato seed pieces are soaked in concentrated solutions (Dyson & Humphries, 1966). It increased the areas of some leaves and increased the yield of dry matter, (Humphries & French, 1960, 1961, 1963) and sometimes tuber yield (Humphries & French, 1963). Treated leaves had larger cells and more cells per leaf (Humphries & French, 1963). Apparently gibberellic acid affected only growing leaves or those that had reached a minimum size in the apical primordium, but by enough to increase dry matter. It also increased tuber number but made them smaller and shortened the dormant period (Humphries, 1958; and Humphries & French, 1960). Gibberellic acid increases the activity of hydrolysing enzymes and this may be why treated potato leaves have less total nitrogen and protein per unit area than untreated (Humphries & French, 1961). As gibberellic acid also makes the root system smaller, the paler colour of the leaves could imply that the roots were not absorbing enough nitrogen, but spraying the leaves of treated plants with urea did not affect their appearance (Humphries & French, 1963).

The ability of gibberellic acid to break tuber dormancy could be an advantage if the precocious growth were subsequently checked by applying inhibitors. Krug (1963) found a balanced combination of the inhibitor CCC and gibberellic acid produced compact plants in the dim light of winter, but Dyson (1965) found that applying CCC to soil containing seed pieces soaked in 50 mg/l gibberellic acid did not counteract the effect of GA. Effects depend on the concentration of the growth substances and when they are applied. For instance, Dyson and Humphries (1966) found that CCC or B9 had different effects on Majestic potato plants treated with gibberellic acid when applied at different times. When growth of lower lateral branches was retarded, upper laterals often grew more than in untreated plants. However, Bruinsma and Swart (1966) controlled the growth of potato plants from tuber buds by giving gibberellic acid and B9 simultaneously.

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The effects of applying gibberellic acid at different concentrations and times and its interaction with growth inhibitors, are still far from fully known, but none has yet proved to be useful. However, it might be better to treat a plant with a gibberellin that occurs naturally in it. Gibberellic acid itself is not a common constituent of most plants but Gibberellin A_5 is; Wheeler and Humphries (1963) found when potato plants were sprayed with gibberellic acid it was converted to another gibberellin, possibly A_5.

Stimulating the growth of one plant part at the expense of another may lead to compensating effects later when the stimulation stops. This happens with gibberellic acid and is one reason why it is not useful. An effective stimulator should accelerate the growth of all plant parts equally, so that its effects would resemble those of increasing temperature on plant growth. This could be achieved if the substance increased cell division in all parts of the plant so that their relative growth rates were maintained. This seemed possible with the discovery of the phytokinins, but although they stimulate cell division and growth in isolated plant parts they have little effect when applied to intact plants (e.g. Humphries, 1958), perhaps because they do not penetrate or move easily in the intact plant. Small amounts of some herbicides (especially triazole compounds) seem to have the desired properties of a growth stimulator and need further study.

Increasing leaf growth, especially at first, increases yield but when crops become dense part of their leaf area is inefficient and uses dry matter that might otherwise have been diverted to increase the economic part of the plant (e.g. see Humphries & Wheeler, 1963). As already mentioned the relative distribution of dry matter in different parts of a plant is determined by the environment working through endogenous growth substances, but the distribution is altered by applying growth regulators. CCC and B9 slow growth of stems and leaves and divert assimilates to other parts. Such diversion could be valuable in the potato. Humphries and Dyson (1967a) showed that a potato crop can have more leaf area than is necessary for maximum tuber yield; some leaves contribute little to useful dry matter production, for Majestic potato plants sprayed with B9 (5 g/l) at tuber initiation and two weeks later had 20% less leaf area than unsprayed plants at the time of maximum leaf area index, but yielded the same weight of tubers. B9 speeded tuber growth and increased the number of tubers. This result suggests potential uses of growth regulators in potato culture, and in preliminary tests, Humphries, French and Williams (1967) found that different potato varieties may respond differently and that yield increased more in early than in main crop varieties. Whereas CCC increased tuber yields of Arran Pilot by 37% and B9 of Craigs Alliance by 28%, neither chemical increased the yield of Maris Peer or Pentland Dell by more than 5% (Table 1). Whether such effects can be obtained consistently remains to be seen. Bodlaender and Algra (1966) found that B9 also increased yield of the variety Alpha. Shibles and Weber (1966) concluded that converting as little as 8% of the top vegetative dry matter of the soybean plant to beans would increase yields by about 15%.

CCC hastens tuber growth (Dyson, 1965) and this earlier development of tubers increases sinks for carbohydrate and increases net photosynthesis of the leaves (Dyson & Humphries, 1966; Gifford & Moorby, 1967). The

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TABLE 1

Effect of the growth regulators CCC and B9 on % change in (a) total fresh weight of tubers, and (b) tuber number of some potato varieties

	(a) Fresh weight		(b) Tuber number	
	CCC	B9	CCC	B9
Ulster Prince	5	−7	4	5
Arran Pilot	37	12	−12	11
Craigs Alliance	5	28	1	15
Maris Peer	4	3	6	13
Pentland Dell	7	6	−9	41

factors determining the number of tubers that a potato variety produces are not fully understood but it is certain that the potential number is greater than the actual number. For instance, Nösberger and Humphries (1965) found that removing tubers caused more to form. In the variety Epicure, 98 tubers formed on a plant when they were continually cut off, but only 45 formed when they were undisturbed. This result suggests that tuber number can be altered by appropriate treatments and this might have practical benefits. For instance the potato-seed grower requires the maximum number of tubers in the seed-size range, and the canner small evenly-shaped tubers. These requirements are met, to some extent, by suitable varieties or cultural practices, but growth regulators can also change tuber size and number. Thus, B9 increased mean tuber number in Majestic by nearly 30% (Humphries & Dyson, 1967b). In this experiment, seed tubers of different sizes were planted and, as expected, the smaller seed produced plants with fewest tubers, but B9 also affected tuber number, so the number of tubers per plant in this experiment ranged widely. B9 increased tuber number in some other varieties but CCC did not, and sometimes decreased the number. The effect of a growth regulator depends on whether it is applied before or at the time of tuber initiation.

Preliminary results with potatoes grown in pots show that Morphactin slows haulm growth, and this has beneficial effects on stolon and tuber development. Sprays of 1 or 10 mg/l completely stopped growth of new leaves and stimulated growth of axillary shoots, especially at the base of the main stem, and increased the leafy stolons i.e. branches originating beneath the soil and emerging to bear leaves. In the field, with greater depth of soil and more competition for light, these branches might have remained in the soil and produced tubers. Increase in growth activity at the base was also reflected by greater weight and length of stolons. Morphactin also increased the number of small tubers (Humphries & Pethiyagoda, 1969).

Effect of CCC on white mustard (*Sinapis alba*)

CCC increases leafiness in some plants—for example length and dry weight of the main stem of white mustard decreases with increasing amounts of CCC, whereas leaf weight may increase. The net effect of moderate amounts of CCC is a greater total leaf area (Humphries, 1963a), a good example of how a growth regular may be used to increase the useful part of the plant (leaf) and decrease the less desirable part. CCC and B9 also

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delay the decrease with age in total-N and protein-N of bean leaves, probably because the shoot grows more slowly and demands less nitrogen (Humphries, 1968a).

Effect of CCC and gibberellic acid on sugar beet

CCC hastened leaf production by sugar beet and gibberellic acid slowed it. Both changed the shape of the crown of the plant, CCC flattening it and gibberellic acid elongating it, and this change was associated with the rate leaves were produced (Humphries & French, 1965). More leaves on the sugar-beet plants did not affect the dry matter produced because they were smaller; nor did the fewer leaves of plants treated with gibberellic acid, because they were larger and persisted longer than on untreated plants. The result showed that dry weight can depend more on size and longevity of leaves than on total number of leaves.

Although CCC hastened leaf production of sugar beet, it had no such effect on potatoes or cereals. When CCC was applied to sugar-beet seedlings with only two leaves, its effect persisted for the rest of the season, as do the effects of environment in which sugar-beet seedlings are raised, (Humphries, 1966; French & Humphries, 1969; Humphries & French, 1969a, 1969b). Suitable growth regulators might change the relative proportions of plant parts in the same way as environment does. If this is done at an early stage it may be possible to increase yield in other plants with organs that store carbohydrate (Humphries, 1969). For example, CCC applied to sweet potato (*Ipomoea batatus*) grown in pots increased the weight of tubers. Possibly some growth substances may also increase net photosynthesis in leaves, for there is evidence that the leaves of sugar beet do not always photosynthesise to full capacity.

CCC and cereals

Up to now the growth regulator most studied on cereals is CCC. Soon after it was described by Tolbert in 1960 it was used to prevent lodging of cereals and many papers show its practical value (see Humphries, 1968b). Although its main effect is to shorten and strengthen the stems, and so lessen losses caused by lodging, it has other effects that increase yield.

In the first experiments with CCC on wheat on Rothamsted farm in 1964, the untreated crops did not lodge, but CCC increased grain yield by 2 cwt/acre, mainly by increasing the number of ears; a decrease in grain size by CCC was offset by more grains/ear (Humphries, Welbank & Witts, 1965a). Leaf area index of sprayed plants was 70–80% of unsprayed. With less leaf more light penetrated the canopy of crops sprayed with CCC than of unsprayed crops, and at first this was thought to be the reason why more shoots survived, but later experiments did not support this explanation.

In the following years, experiments were done mainly to see how CCC affected lodging and yield of crops given different amounts of nitrogen fertiliser, spaced at different row widths or irrigated. Some experiments also

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studied the effects of CCC on leaf area, the number of ear-bearing shoots, grains per ear and grain size.

Spacing experiments. In 1965, spring wheat, Opal, was sown in rows 4 in. or 8 in. apart at usual and twice usual seed rates, with 0·5 or 1·0 cwt nitrogen/acre. Yield was slightly increased by CCC at 4 in. spacing, but not at 8 in.; however, the interaction was not significant (Humphries & Bond, 1969a). Yield was less with the larger seed rate, although it increased leaf area duration after anthesis.

Similar results were obtained in 1968, when CCC was tested on both winter wheat (Cappelle) and spring wheat (Kolibri) grown at different spacings. Nitrogen fertiliser was applied at 0·8, 1·6 or 2·4 cwt N/acre. The winter wheat did not lodge and mean yield of grain was 28·8 cwt/acre; closer spacing increased it by 0·9 cwt/acre and spraying with CCC increased it by 1·9 cwt/acre, but there was no indication that CCC had a greater effect with closer spacing.

The mean yield from Kolibri was 31·8 cwt/acre and closer spacing increased grain yield by 1·3 cwt/acre, spraying with CCC increased it by 4·7 cwt/acre but, as before, there was no interaction between CCC and row width. Thus, although the shortened shoots of CCC plants allow more light to penetrate to the base of the plants (Humphries, Welbank & Witts, 1965b), this seems to have little effect on yield (Humphries & Bond, 1969b).

Irrigation experiments. In 1964 and 1965, CCC-treated plants pulled by hand from the soil had more attached roots than untreated plants. Hanus (1967) found that CCC usually increased the amount of wheat roots at all soil depths. Others have reported similarly and it can be accepted that CCC usually makes root systems larger, especially of spring wheat, whose stems are shortened more by CCC than are stems of winter varieties. The enlarged root suggested that CCC may increase yield by enabling shoots to avoid water stress during the period near ear emergence, so that more survive to produce ears. CCC increases tillering of wheat growing in pots (Humphries, 1963b, Tolbert, 1960); but in a field crop, where competition causes many tillers to die before maturing, CCC presumably increases the number of fertile tillers by allowing some tillers to survive that otherwise would have died. Humphries, Welbank and Witts (1965b) showed that the shoot number of an untreated crop declined from about 700/m^2 in mid-May to 450/m^2 at the end of June. The survival of an additional 20 ears/m^2 would increase grain yielded about 2 cwt/acre (Humphries, 1968c). The dependence of yield on the number of ear-bearing shoots per acre is illustrated by results obtained in 1966 from the Woburn Irrigation Experiment (see Fig. 1, which shows the partial regression of yield on shoot number at constant ear weight). Yields ranged from about 25 cwt/acre with 300 shoots/m^2 to about 50 cwt with more than 500 shoots/m^2.

Soil moisture deficits at Rothamsted for the 3 weeks after ear emergence, calculated by Penman's method, were more than 2 in. in 1964 and 1966, when CCC increased yield, but less than 1 in. in 1965 when CCC had no effect on yield of a normally spaced crop. The conclusion that the enlarged root system of CCC plants is important in drought was

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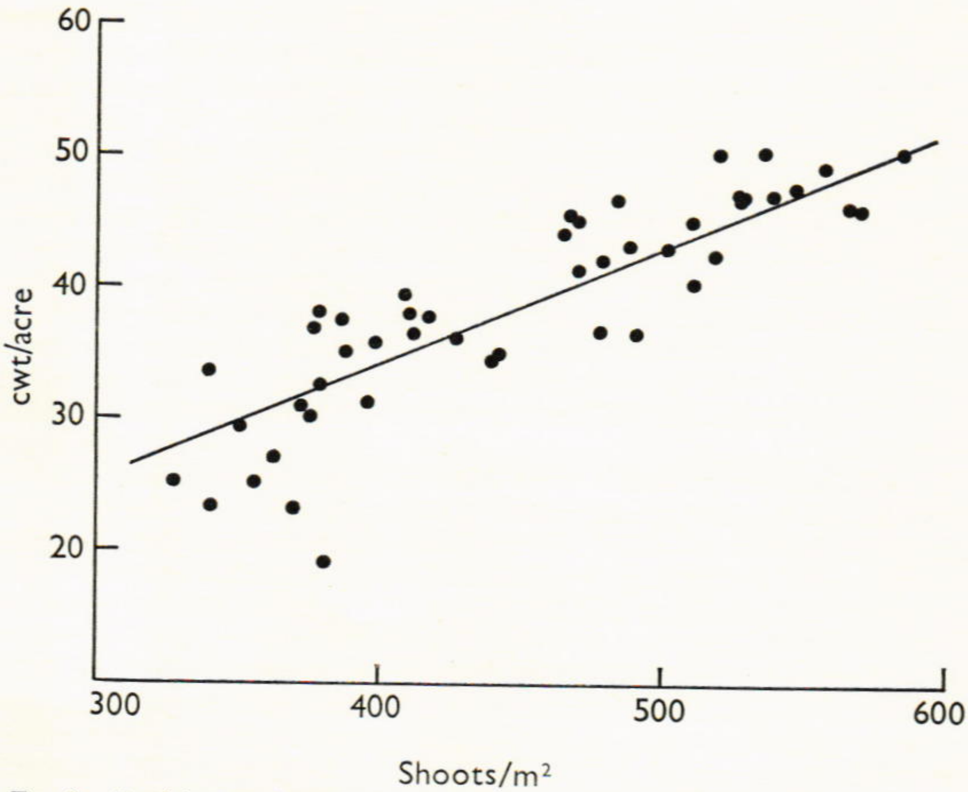

FIG. 1. Partial regression of yield on shoot number. Woburn Irrigation Experiment, 1966.

further tested in 1966 on the Irrigation Experiment at Woburn Experimental Farm by spraying half of each irrigated and unirrigated plot of spring wheat with 2½ lb/acre CCC at 5-leaf stage. The experiment also tested N at 0·4, 0·8, 1·2 or 1·6 cwt/acre in all combinations with CCC and irrigation.

Both irrigation and CCC increased grain yield, but CCC had no effect on irrigated plots and the effect of irrigation was less on plots sprayed with CCC. On plots receiving 1·2 or 1·6 cwt N/acre, CCC increased grain yield by 6 cwt/acre, and irrigation by 10 cwt/acre, mainly by increasing ear number (Humphries, Welbank & Williams, 1967; Humphries, 1968c). In an identical experiment in 1967, irrigation increased yield but CCC did not, possibly because the dry spell in June and July was longer than in 1966. Root sampling showed that CCC without irrigation increased total root weight by 14%, and in the subsoil (25–60 cm) by 37%, but very little with irrigation (Humphries & Bond, 1969b). Thus, CCC increased the root system most in the subsoil, where water would not be lacking during a brief dry spell but might during a longer one.

Interaction of CCC with nitrogen supply. Several experiments were made to test the possibility that shortening the straw of a wheat crop with CCC may allow larger N dressings to be given and the yield increased more without risk of lodging (Humphries & Bond, 1969b). In 1966 at Rothamsted, Kloka

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wheat was given 0, 0·8, 1·6 or 2·4 cwt N/acre. Plots without CCC did not lodge, even with 2·4 cwt N, but CCC increased grain yield by an average of 2 cwt/acre as in 1964. Tests on grain from this experiment (Evers & Kent, 1968) show that CCC did not affect protein content. In 1967, when both winter (Cappelle) and spring wheat (Kloka) were given the same amounts of nitrogen as in 1966, CCC increased yield of Cappelle without N by 12 cwt/acre but by only 0·6 cwt/acre when N was given. The increase in yield with CCC came mostly from more ears and more grains per ear, offset to a small extent by smaller grains. More grains per ear is a usual effect of CCC but the cause is still in doubt and requires further investigation. That the slower development of CCC-treated plants allows more grains to form seems the most probable explanation. CCC did not affect grain yield of Kloka in 1967 and the maximum yield was obtained with 0·8 cwt N.

In 1968, more experiments were done with large N amounts, both on Cappelle and the new spring variety Kolibri; for the first time we could assess the benefits of CCC in conditions favouring lodging. Lodging occurred on all untreated plots of Kolibri, in amounts that increased with increasing N. Spraying with CCC increased the mean yield of grain by 4·7 cwt. Early lodging on untreated plots caused slower development of grains than on treated plots, so by delaying and decreasing lodging CCC increased grain size. It makes grains smaller in unlodged crops. There were also more grains per ear on CCC-treated plots, so more, larger grains account for the increased yield. Cappelle did not lodge and CCC increased yield only with 1·6 cwt N, by increasing the number of ears.

TABLE 2

Summary of results of CCC experiments 1964–69; Rothamsted and Woburn

				Yield cwt/acre			
Year		Variety		Nil	CCC	S.E.	Mean of
1964	R	Phoebus*	SW	39·7	41·9	1·21	3 N amounts and 2 CCC amounts
1965	R	Opal*	SW	32·5	33·1	0·89	1 cwt N/acre
1966	R	Kloka*	SW	31·8	33·8	0·71	4 N amounts
1966	W	Kloka*	SW	37·5	43·5	0·86	2 N amounts
1967	R	Kloka†	SW	45·8	45·8	0·65	4 N amounts
1967	R	Cappelle†	WW	56·1	60·8	1·32	4 N amounts
1967	R	Champlein*	WW	54·9	59·0	1·00	3 spraying dates
1967	W	Kloka*	SW	44·7	44·9	0·84	4 N amounts
1968	R	Kolibri‡	SW	32·1	39·2	0·45	3 N amounts
1968	R	Cappelle†	WW	27·8	29·7	0·50	3 N amounts
1968	R	Champlein‡	WW	37·4	40·6	0·53	2 N amounts and autumn and spring spray of CCC
			Mean	40·0	42·9		

R = Rothamsted
W = Woburn
SW = Spring Wheat
WW = Winter Wheat

* not lodged
† slightly lodged
‡ severely lodged

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Table 2 summarises the results of experiments on wheat at Rothamsted and Woburn between 1964 and 1968. In ten out of eleven experiments CCC increased yields. In some experiments yield was increased when no lodging occurred on untreated plots, in others the yield was increased because lodging was delayed or prevented. The mean increase in yield by CCC in all experiments was 7%. There was no evidence that yields increased by giving more than the usual amount of nitrogen when CCC was applied to prevent lodging. I have done no experiments in which CCC was mixed and applied with herbicide spray, but this has been shown to be a practical procedure, and the extra cost of CCC is then only that of the chemical. The Rothamsted results suggest that the use of CCC would have been profitable in most years.

Effect on wheat diseases. In spite of modern stiff-strawed varieties, lodging often limits grain yield. The likelihood of lodging is increased when the eyespot fungus, *Cercosporella herpotrichoides*, invades and weakens the base of straws. CCC increases the resistance of infected crops to lodging, but opinions differ on how it acts. Some claim it decreases the incidence of the disease, others that it acts merely by strengthening the straws, so experiments were done at Rothamsted to try and resolve the conflict. In an experiment with the susceptible variety Squarehead's Master grown in pots (Slope & Humphries, 1966) CCC applied to the soil lessened the number of lesions by the fungus but field experiments done in three years have not confirmed this effect. In 1966, CCC did not alter the number of eyespot lesions on Rothwell Perdix but it prevented lodging. In 1967 Champlein winter wheat was sprayed with CCC at the 3-leaf stage, the 5-leaf stage and the 6-leaf stage. CCC had no effect on severity of lesions but although only 4% of the unsprayed crop lodged, it increased yield by 4 cwt/acre. Even when the crop of Champlein was treated with CCC in autumn, when eyespot is most likely to spread, there were as many lesions as on spring treated or untreated plants, (Slope, Humphries & Etheridge, 1969). Thus, CCC did not affect the incidence of eyespot or the severity of its lesions. It decreases lodging of infected crops as of uninfected crops by shortening the straw. CCC is said to increase the incidence of ear diseases such as *Septoria culmorum* and *Fusarium* in some climates, but this has not been critically studied.

Semi-dwarf wheats. Dwarf wheat varieties that are less likely than taller ones to lodge may make the use of CCC unnecessary. However, CCC could benefit the yield of dwarf cereals by increasing the root system and increasing grains per ear, just as it does in current varieties. In a trial done in 1966 with several dwarf wheats grown in pots, CCC at a dilution of 1 in 200 (equivalent to 2 lb/acre) shortened the straws of all but one of the varieties and none as much as of Opal or Kloka (Table 3). However, effects in field crops have yet to be tested.

Effects on barley and oats. A treatment that shortens straw would be useful with barley which is more susceptible than wheat to lodging, but many experiments at Rothamsted and elsewhere show that CCC has little effect

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TABLE 3

Effect of CCC on straw length of some semi-dwarf wheat varieties (cm)

	CCC	Untreated	Straw length % of untreated
843–6	49·7	59·4	83
843–7	47·4	50·4	94
Gaines	43·4	46·5	93
Chilean 13573	30·2	28·0	106
Mexico 120	24·6	28·0	86
NBJ 115	43·6	51·4	85
PC 81 EEE	44·7	50·9	88
Cappelle	61·2	64·0	95
Opal	44·3	60·2	74
Kloka	44·6	57·5	77

on barley. In tests with six varieties grown in pots, CCC shortened the shoots of the old long-strawed variety Plumage Archer but not of Proctor, Maris Badger, Europa, Cambrinus or Impala (Humphries, Welbank & Witts, 1965a). Whether the lack of effect is because CCC does not penetrate into the plant readily, is not translocated, or is metabolised once inside the plant, was not determined. When dimethylsulphoxide, which aids penetration of chemicals into plant and animal tissues, was added to CCC spray, the mixture shortened barley plants grown in pots in the glasshouse more than CCC spray alone, suggesting that more CCC entered the plant. However, when the ears were ripe, the plants treated with CCC alone or together with dimethylsulphoxide were nearly as tall as untreated plants. The same result was obtained in the field; soon after spraying, plants were shorter but afterwards grew faster than untreated plants (Humphries & Williams, 1968). The peduncle and highest internode at maturity were longer on sprayed than unsprayed shoots, but the lower internodes, which were elongating when sprayed, were shorter (Humphries, 1968d). Why barley plants treated with CCC eventually grew faster than untreated plants is not known, but the effect suggests that CCC may increase the gibberellin content of barley. Apparently if enough CCC can be maintained in the barley plant the shortening achieved is comparable with that in wheat. Thus, Larter (1967) who sprayed successively at the 3-leaf, 5-leaf and flag-leaf stages reported that stems were shortened by 25% and lodging was prevented. Successive sprayings are neither practical nor desirable because of the risk of increasing harmful residues in the grain. Stoy (1968) showed that tetraploid rye responds to CCC much more than diploid strains. So genotype is probably concerned with response of cereals to CCC, but perhaps this is only a part of the problem because I have shown that strains of wheat that are unresponsive in the hot climates of Egypt and Kenya show the expected shortening when tested here.

To shorten oat straw would be very valuable, for oats are very susceptible to lodging, but unfortunately CCC is not a general help because it affects only some varieties (Humphries, 1968b). When tested on the responsive variety Maris Quest in 1968, given 0·5, 1·0 or 1·5 cwt N/acre, the effect of 2½ or 5 lb/acre CCC was to shorten straws by 11% or 15% respectively; the effect decreased with increasing N supply. Slight lodging in July on plots given 0·5 cwt N/acre was decreased by spraying with CCC, but plots with more N were severely lodged whether sprayed with CCC or not. On plots with 0·5 cwt N/acre, spraying with CCC at 2½ lb or 5 lb/acre increased grain yields 2 cwt and 9 cwt/acre respectively, mainly by increasing grains per panicle. With more N, CCC did not affect yield (Humphries & Bond, 1969a).

A new growth regulator 'Ethrel' (2-chloroethylphosphonic acid) was tested on barley and oats in 1969. Plots of each crop sprayed with 1 lb or 2 lb/acre of active ingredient at 5–6 leaf stage lodged sooner than unsprayed plants but yields were not affected.

Effect of growth regulators on field beans

The first growth regulator experiments on field crops at Rothamsted were done by Moffatt and Hill (1960) between 1955 and 1957. They tested the effect of 4-chloro-phenoxyacetic acid and α-(2,4,5-trichlorophenoxy) propionic acid at 5 ppm on set of pods of spring-sown tick beans (*Vicia faba* var. *minor*). Two applications of the propionic acid decreased yield in 1955 and four applications of the phenoxy acid increased it in 1956. In 1957, it increased flower set on dunged plots and decreased it on irrigated plots.

In trials on field beans (McEwen, 1969), CCC did not shorten the stems and lessened yield by 1·9 cwt; B9 greatly affected growth and shortened stems by as much as 30%, depending on time and amount applied. A single application in early June was most effective. However, B9 affected yields inconsistently; without fertiliser nitrogen it increased yield by about 2·5 cwt in 1966 and 1968 but decreased it by 2·1 cwt in 1967. The main effects of B9 were to increase the number of stems and pods per acre and lessen 1000 bean weight. Plants given B9 in 1968 produced half a million more beans per acre than untreated plants.

Conclusion

Applying chemicals to crops to alter their character and make them better able to withstand adverse conditions, or to alter their growth to produce more of the useful parts, is a new departure in agriculture but the success of CCC on cereals shows promise of future practical benefits. The search for growth-regulating chemicals has been intensified and there are now several promising compounds that warrant thorough testing. Experience with CCC and other growth regulators shows that when a chemical is selected for a particular property, such as stem shortening, it is soon found to have other apparently unrelated effects. For instance, CCC usually also increases the number of grains, stem diameter and the root system in wheat. Such multiple effects make it important that each growth regulator be tested on many species in different conditions.

It would be an advantage if a regulator also controlled pests and diseases, but the claim that CCC lessened eyespot disease of wheat has not been sustained, and it is now certain that it decreases lodging because it strengthens infected straws.

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There are other ways in which chemical regulators may aid crop production in the future. We still know little about the causes of flowering. The productivity of some crops, e.g. cereals, depends on time and amount of flowering, and perhaps suitable chemicals will be found to hasten flowering and seed set and shorten the crop cycle.

Little attention has yet been given to shortening the time a crop occupies the ground. Chemical regulators may eventually enable us to grow more crop in a shorter time. Yields of some crops in this country are limited by the length of the growing season. Potato plants for instance are easily frosted and a treatment to increase resistance to cold could increase yield by allowing earlier sowing. Both CCC and B9 are said to increase frost resistance of plants, including potatoes, but so far there is little reliable evidence.

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