EFFECTS OF FOUR PLANT GROWTH REGULATORS
ON TRIUMPH 64 WINTER WHEAT

By

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CHAPTER I

INTRODUCTION

With the population of the world growing at an ever increasing pace, countries that now have ample foodstuffs may someday have a food shortage unless scientists can discover methods of increasing production of food crops. With this thought in mind, today's plant breeders are seeking both new crops and ways to improve present ones. Improvement in yielding potential and nutritional value are prime objectives in breeding programs concerned with basic food crops.

Wheat is one of the world's most important food crops, and it takes six to ten years or even longer to develop a new improved variety. Years of observation, selection, and testing must precede the release of a new wheat variety. As a result, today's initial breeding work must fill the farmer's needs ten years hence.

Another approach to increased production may be the use of chemicals to increase the yield of present varieties. In the past decade a new family of chemicals, the plant growth regulators, has arisen. These chemicals, some of which cause striking changes in normal development patterns, work within the biochemical system of the plant.

If a growth regulator could be found that would increase yield of wheat easily and inexpensively, the potential benefits to man would be of great importance. Once identified the use of such a chemical could immediately increase production of wheat to new levels.

Increased yields of wheat by the use of growth regulating chemicals have been reported in certain areas of the world, but limited information is available for the Southern Great Plains, an important wheat-growing area. Consequently, it would appear to be of considerable importance to study the effects of a group of these chemicals on the performance of wheat adapted to this region.

The objective of this study was to determine the effects of several of these growth regulators when applied to a wheat variety of commercial importance in Oklahoma. Of primary consideration were the effects of these growth regulators on yield and yield components, but plant height, straw strength, maturity, and grain protein content were also studied to gain an overall picture of the effect of these chemicals.

CHAPTER II

LITERATURE REVIEW

The term "growth regulator" can be applied to various biological chemicals, such as the natural gibberellins and auxins, as well as to a number of synthetic formulations. Striking and sometimes contradictory results have been noted by various researchers involved in studies with a specific growth regulator on a particular crop. Although a number of species, especially the fruits, have been tested to some extent, many recent studies have dealt with wheat or barley. The majority of such studies on wheat or barley have utilized the chemical 2-chloroethyltrimethylammonium chloride (Cycocel or simply CCC). Other chemicals such as Mendok (sodium α, β dichloroisobutyrate), Ethrel (2-chloroethylphosphonic acid), and RH-531 (an experimental growth regulator from Rohm and Haas) have been used to a lesser extent. Kuraishi and Muir (21, 22) studied the effect of the gibberellins as compared to CCC, and reported that in certain instances the natural hormones produce results opposite to those invoked by the synthetic growth regulators.

In general, the areas affected by growth regulators in the wheat plant are: stem height, leaf surface area, kernel weight, kernels per spike, spikes per plant, total grain yield and grain protein content. Several chemicals have in some cases given different results regarding one of these specific areas even when applied to the same crop species.

Effects of Growth Regulators on Cereal Stem Elongation and Lodging

Tolbert (38, 39) pioneered the work with the growth retarding properties of CCC and reported that the major growth difference in CCC-treated wheat was due to the development of plants with shorter and thicker stems compared to untreated plants. He tested the three derivatives of choline (2-chloroethyltrimethylammonium chloride, 2-bromethyl-trimethylammonium bromide, and 2, 3-propylenetrimethylammonium chloride or bromide) and found their growth effects similar and active over the same range of concentrations. 'Thatcher' spring wheat showed a shorter stem length due to CCC, a result which produced plants with no tendency toward lodging. After Tolbert made the initial discoveries involving CCC, more studies followed which examined the lodging problem in particular (32, 40).

Lockhart (27, 28), in studies concerning the physiological mechanism of action of stem growth inhibitors, commented on the ability of CCC to influence stem elongation while permitting essentially normal plant development. In these studies different effects on stem elongation of treated and untreated plants were noted between the two cereals wheat and barley. Linser and Kühn (26) found that wheat treated with CCC was usually shorter, spring wheats more so than winter wheats. They also reported that barley was shorter when young, but later-treated plants became taller than untreated ones.

Using CCC treatments on 'Phoebus' spring wheat, Humphries *et al.* (18) found that treated plants at maturity were only 60% the height of untreated plants (shoots were all shorter by about 12.5 cm with a single dose and about 13.6 cm with a double dose); however, the shortening was less as the nitrogen fertilizer rate increased. This suggested a nullifying effect of CCC in proportion to nitrogen fertilizer applied to the soil.

Caraus et al. (9) observed a 12.1 to 22.4% reduction in stem height of 'Bezostaia 1' winter wheat, although the effect on the oat variety 'Cenad 88' was insignificant. Similarly, Adler et al. (2) observed the same shortening and thickening of stems in Bezostaia grown on three soil types in the Banat region of Romania in 1966. Similar results were later reported by Koch and Linser (20). Martin (29) observed a shortening of stem length of about 29% in CCC-treated wheat and indicated that in his study, CCC-treated spring wheat had a better lodging resistance than winter wheat. According to deVos et al. (12), lodging resistance was greater in wheat treated later in its growth cycle than in that treated earlier.

In barley, Humphries et al. (18) found that some of the newer varieties were not shortened much by CCC, but the older variety 'Plumage Archer' was shortened by 20%. Larter (23) used CCC at three rates of application and showed a retardation of maturity as well as a reduction in plant height in barley. Maximum height reduction was about 25% of the control with his heaviest rate of application. Larter found that the greater the amount of soil moisture present, the shorter the CCC-treated plants were in relation to the controls. Barrett et al. (7) found that CCC treatment reduced growth and partially controlled lodging in 'Dea' winter barley, though 'Rika' and other spring varieties were little affected.

Lhoste (25) stated that CCC was the most promising growth regulating chemical in agriculture and reported that the best time of application on spring wheat was from the five-leaf stage up to the boot stage.

On the other hand, deVos et al. (12) stated that the practical application of CCC is possible over a fairly wide range of growth stages. According to Cyanamid International Inc. (11), however, CCC must be applied at the time of first stem elongation in order to avoid residues of the compound in the wheat grain. Differences in response to treatment application stages from variety to variety in wheat was reported by Sturm and Jung (37).

Exactly how CCC works is not known, but according to Caraus et al. (9) the effect depends on the crop treated, solution concentration, number of treatments and the interaction with soil fertilization. The information provided by the Cyanamid Company (11) indicates that the effect of CCC applied to the soil is significantly influenced by sorptive capacity, pH, temperature, and moisture content of the soil. Humphries and Bond (17) stated that nitrogen fertilization was inversely related to the shortening effect of CCC. Therefore, they advised increasing the CCC concentration when nitrogen fertilizer application was increased. According to Pinthus and Rudich (33) the beneficial effect of CCC in the absence of lodging may be due to its delaying effect on senescence.

Other growth regulants have been studied regarding their effects on stem elongation in wheat and barley, but to a much lesser extent than CCC. According to Ram and Rustagi (35), treatment with Mendok resulted in wheat plants with shorter, stiffer straw and less susceptibility to lodging. They noted that Mendok appeared to affect stem elongation and lodging resistance much in the same way as CCC. Plant height was reduced by all treatments applied. The shortening of the stem was a result of shorter internodes and was not due to a reduction in number of nodes.

The stems also were thickened slightly, which was a beneficial result because of lodging potentiality.

Ethrel, another growth regulator, has been studied only slightly. Karchi (19) compared CCC and Ethrel in regard to stem height reduction and yield. The effects of Ethrel sprayed on spring wheat resembled the effects produced by CCC on the length of the culm internodes and resistance to lodging. Information provided by Amchem Inc. (3) indicated that tests in Europe have shown that the reduced lodging tendency from Ethrel treatment may be associated with straw stiffness since straw height was not always reduced. The most consistent straw shortening effect occurred when Ethrel was applied at the later growth stages, although there was a trend toward lower yields with treatment rates above 1.12 kg active ingredient/ha.

Effects of Growth Regulators on Cereal Yield and Yield Components

Besides reducing lodging by shortening and thickening the stems in wheat and barley, certain growth regulators have sometimes increased yield when lodging was not a factor in the experiment. Humphries and Bond (17), working in England, found that CCC increased yields in spring and winter wheat varieties planted at close spacing. The yield increase was a result of increased spike number and kernels per spike. Using the winter wheat variety 'Capelle' in another portion of this experiment, they found that yield increased by 10% with closely-spaced CCC-treated plants when compared to closely-spaced untreated plants. In the CCC-treated spring wheat variety 'Kolibri' yield was increased due to a reduction of lodging. Other spring wheat varieties such as 'Kloka' and 'Opal' were involved in the experiments and produced similar results.

Humphries and Bond (17) observed that the leaf area per shoot of CCC-treated plants averaged about 25% less than the control in their experiments. They also noted that leaf area was reduced more in spring wheats than in winter wheats by CCC treatment. In these experiments severe lodging occurred one year in four, and when lodging was a factor, CCC treatment increased grain yield by as much as 30%. Working with Phoebus spring wheat, Humphries et al. (18) found that grain yield was increased by about 5% with CCC treatment when lodging was not a factor. There was an increase in the number of spikes and number of grains per spike, but a decrease in weight per kernel. In similar studies with CCC treatments, Primost (34) found that thousand grain weight was decreased by about 13%, and Linser and Kühn (26) found that grain number per spike was increased in 'Wika' winter wheat.

Farah (13) studied various factors regarding yield in the spring wheat Kloka when treated with CCC. His experiment, conducted in the greenhouse, involved three moisture levels. Under CCC treatment the number of spikes, number of grains per spike, and the leaf surface area decreased as water stress increased. Although kernel weight of CCC-treated plants increased as water stress increased, the kernel weight of treated plants was less than that of the control. Farah suggested that the reduced yield of grain in the wet regime might be due to inter- and intra-spike competition for available nutrients during and after heading, especially when CCC produces many spike-bearing tillers in a favorable moisture condition.

Tolbert (39), in an experiment conducted in the greenhouse with Thatcher and 'Russell' wheat varieties, noted a slight increase in yield in CCC-treated wheat plants even when height was reduced. He reported that this was due to a higher average kernel weight, since the total number of kernels per spike and the total number of spikes per plant did not vary. There was no difference in wet or dry weights of tops of treated or untreated plants. Thus, Tolbert suggested that perhaps the overall growth rate was not so much affected as the developmental pattern itself.

In the variety Bezostaia 1, Caraus et al. (9) observed a 5.9 to 19.0% grain production increase with CCC treatment. However, Paccucci (31) noted that CCC-treated 'Capelli' wheat did not change in grain yield, straw yield, or kernel characteristics. Pinthus and Rudich (33) on the other hand, using CCC-treated wheat, noted no reductions in yield in 14 field trials, while in 12 of the trials grain yield was increased by 5 to 16%. This increase was attributed to a greater number of spikes per plant. Treatment by CCC had no effect on kernel weight as observed by Lhoste (25), although leaf surface area was increased.

Michniewicz et al. (30) reported cases in which an increase in yield due to CCC was lodging-independent. They stressed that CCC treatment in relation to stage of plant growth and time of maturation was very important and greatly affected yield. Adler et al. (2) observed yield increases of 10 to 30% in CCC-treated Bezostaia and 'Bulgaria 301' wheat varieties as a result of a more vigorous root system which caused an increase in spike number and grain number in spikes. In another experiment Adler (1) found increased yield in all cases of different applications of CCC to Bezostaia 1 and Bulgaria 301. All applications increased number of kernels per spike. Similar results were observed by Zadontsev et al. (41) with a Russian winter wheat variety.

Martin (29) found that CCC increased the yield of winter wheat as long as the nitrogen fertilizer application rate was not more than 100 kg/ha. Spring wheat showed an increase of yield due to CCC only in those years in which lodging occurred. There was a decrease in kernel weight due to CCC, and this was greater in spring than in winter wheat. deVos et al. (12) also noted an increase in yield when nitrogen and CCC were used together at different rates on both spring and winter wheat. A higher yield level was reached with CCC plus nitrogen than with nitrogen alone.

Working with the winter barley variety Dea in Britain in 1964-65, Barrett et al. (7) noticed an increase in yield in CCC-treated plants due to reduced lodging. The kernel weight was reduced, while the number of tillers was increased. Larter (23) in Canada conducted a two-year experiment in the field using CCC on barley varieties. Grain yields, kernel weights, tillers per plant, protein percentage, and total betamylase activity of grain from treated plants were not influenced by any of the treatments used. Goodin et al. (15) reported no significant effects of CCC on the kernel weight in barley.

Ram and Rustagi (35), in their work with Mendok on the wheat variety 'N.P. 718', observed an increase in yield along with certain effects on stem elongation and lodging. There was a significant increase in grain yield (94%) when plants were sprayed two or three times at 250 ppm. Grain yield remained almost constant with other rates, except in plants given a heavy dosage (1000 ppm) of Mendok. There was a 72.3% increase of grain yield at this heavy rate of application. Because the number of spikelets was the same in control plants and those treated at 1000 ppm, Ram and Rustagi attributed the increase in grain yield to an increased number of spikes and an increase in floret number followed by a better grain set.

A number of small-scale field trials were conducted with Ethrel-treated winter wheat in 1967 and 1968 in several European countries as well as in the United States (3). Ethrel acted in much the same way as CCC and Mendok in shortening the stem, and preventing lodging, and to some extent increasing yield. Different varieties of wheat were employed in the experiments, among which were 'Starke' in Denmark, 'Cama' in Belgium, Capelle in England, and 'Manella' in the Netherlands. Generally, results showed that Ethrel applied at relatively low rates was effective in increasing yield, though the results varied with variety and the time of application in relation to stage of growth. It appeared that with later dates of application, smaller amounts of Ethrel were needed to produce the same effect.

Studies with Ethrel involving spring wheat have been conducted both in Europe and the United States. The greatest yield increases in spring wheat varieties (Opal, 'Durum', 'Ring', 'Sheridan', and 'Jufy') occurred when applications were made at the time stem elongation was initiated. Yield increases ranged from 5 to 30% with Ethrel treatment at rates of 1/4 to 2 kg/ha. Ethrel applied during the tillering stage increased the number of tillers, which might have accounted for some of the yield increases.

The effect of Ethrel on barley varieties has been studied in Europe, Great Britain, and the United States (3). Applied during the tillering stage, Ethrel increased tiller number but resulted in no increase in yield. Generally, Ethrel did not increase yield in barley varieties, although when applied in early stages of growth an application of 1/2 to 1 1/4 kg/ha gave small increases. When applied at mid-boot stage, yields were actually reduced.

Favorable comments have been made as to the practical use and economic value of growth regulators (5, 6). However, Rixhorn and Crohain (36) mentioned the necessity for revision of many cultural techniques when using CCC. According to their study, CCC was not only superfluous but usually detrimental when applied to weakened or poorly developed plants. Ram and Rustagi (35) indicated that the potential market for growth regulators is large enough to equal that of fertilizers, pesticides, herbicides, or other major agricultural chemicals; however, the potentialities for large scale use of a growth regulator such as CCC are still undergoing study. Barrett *et al*. (7) noted that in studies conducted in Great Britain with wheat and barley, lodging in barley was not effectively controlled in most varieties, and wheat in most areas did not lodge seriously; therefore, he questions the economic value of CCC in particular in treating British cereal crops.

CHAPTER III

METHODS AND MATERIALS

This study was conducted during the 1969-1970 crop season at the Agronomy Research Station, Stillwater, Oklahoma. The wheat variety chosen as the subject for this study was 'Triumph 64', a widely grown variety in Oklahoma. Its popularity is due to its early maturity, wide adaptation and moderately good standing ability. The variety has good test weight with acceptable milling and baking characteristics. Foundation seed of Triumph 64 was used to insure genetic uniformity.

The field received a preplant application of 45-90-45 kg/ha of N, P_2O_5, and K_2O, respectively. An additional application of 45 kg/ha of N was made early in the spring of 1970.

The experiment was arranged in a split-split plot design with chemicals as main plots, dates of application as subplots and rates of chemicals as subsubplots. Main plots were placed in a randomized block design while subplots and subsubplots were completely randomized within blocks. Four replications of each treatment combination were included in this study. Each plot was 3 m in length and consisted of two rows 30 cm apart. At maturity a 2.5 m X 60 cm area of each plot was harvested for yield determination.

Four growth regulators were included in the experiment: Mendok (FW 450), RH-531, Ethrel, and Cycocel (CCC). Both Mendok and RH-531 are produced by Rohm and Haas Company, while Cycocel is produced by

American Cyanamid Company, and Ethrel is a product of Amchem Products Inc. All the above chemicals have been reported by their manufacturers to increase grain yield and reduce straw height in cereal crops.

Each chemical was applied at four different stages of growth of the wheat plant, and four different application rates were used (Table I). On each application date, three application rates plus a check treatment were applied to the plots as a foliar spray. A gasoline-powered paint sprayer/compressor was used to apply the chemicals on the first three application dates, but on the last application at heading time, the plants were so tall that it was impossible to use the bulky compressor. Instead, cans of aerosol propellant were used. However, all other factors remained the same.

In preparation for the application, each rate of chemical was measured and placed in a one-liter bottle of water. This amount was then divided into four 250 ml bottles which were attached directly to the sprayer apparatus by a short length of rubber tube. All four rates of each chemical were applied in each replication before advancing to the next replication.

In each instance, a drop of Tween-Twenty per 250 ml bottle was added to act as a surfactant to insure maximum penetration of the chemical, with minimum runoff. Also, to minimize wind-action, a fiberboard windbreak was constructed and used in each phase of the application procedure.

Application of these growth regulators was made at four different stages throughout the growing season. The first treatments were applied on December 1 and also on December 14 while the plants were in the tillering stage. Two separate dates of application were deemed

TABLE I

CHEMICALS, RATES AND DATES OF APPLICATION

CHEMICAL TREATMENTS	
Chemicals	Formulations
Mendok	Sodium α, β dichloroisobutyrate
RH-531	(not released)
Ethrel	2-chloroethylphosphonic acid
Cycocel	(2-chloroethyl) trimethylammonium chloride

DATES OF APPLICATION WITHIN CHEMICALS		
	Growth Stage	Date
Date I	Tillering formation	December 1 & 14
Date II	Stem elongation	April 9
Date III	Boot stage	April 21
Date IV	Flowering stage	April 28

APPLICATION RATES WITHIN APPLICATION DATES (ACTIVE INGREDIENT, Kg/Ha)

Chemical	Rate			
	1	2	3	4
Mendok	0.00	0.28	1.12	4.48
RH-531	0.00	0.28	0.56	1.12
Ethrel	0.00	1.12	2.24	4.48
Cycocel	0.00	1.12	2.24	4.48

necessary to insure complete uptake of the chemical during this time of reduced leaf area. The second application was on April 9 in the stem elongation stage of growth, while the third spraying was on April 21, the boot stage. The fourth and final application was made on April 28 during the flowering stage. These growth stages were selected as application dates because of recommendations made by the manufacturers to get best results. Growth regulator applications were made in growth stages 3, 8, 10 and 10.5 as depicted in Figure 1.

Each chemical was applied in four different rates on each date. There was a zero rate or check, and a light, intermediate and heavy rate (Table I). These rates were applied as kg/ha of active ingredient of each chemical. These rates were chosen to span the range of rates that had been determined to be most effective on wheat, as reported by other investigators working with these chemicals.

Notes and comments on several observable characters (color, lodging, maturity, etc.) were recorded from the beginning of the experiment.

Tiller Number

Tillers with seed-bearing spikes in a 30 cm section of each row were counted. Counts were made in all plots of all replications. Tiller number was expressed as tillers per plot.

Plant Height

Height notes were recorded approximately June 1. Several measurements were taken within each plot and the average determined. Height was measured in centimeters from the soil line to the tip of the spike excluding the awns.

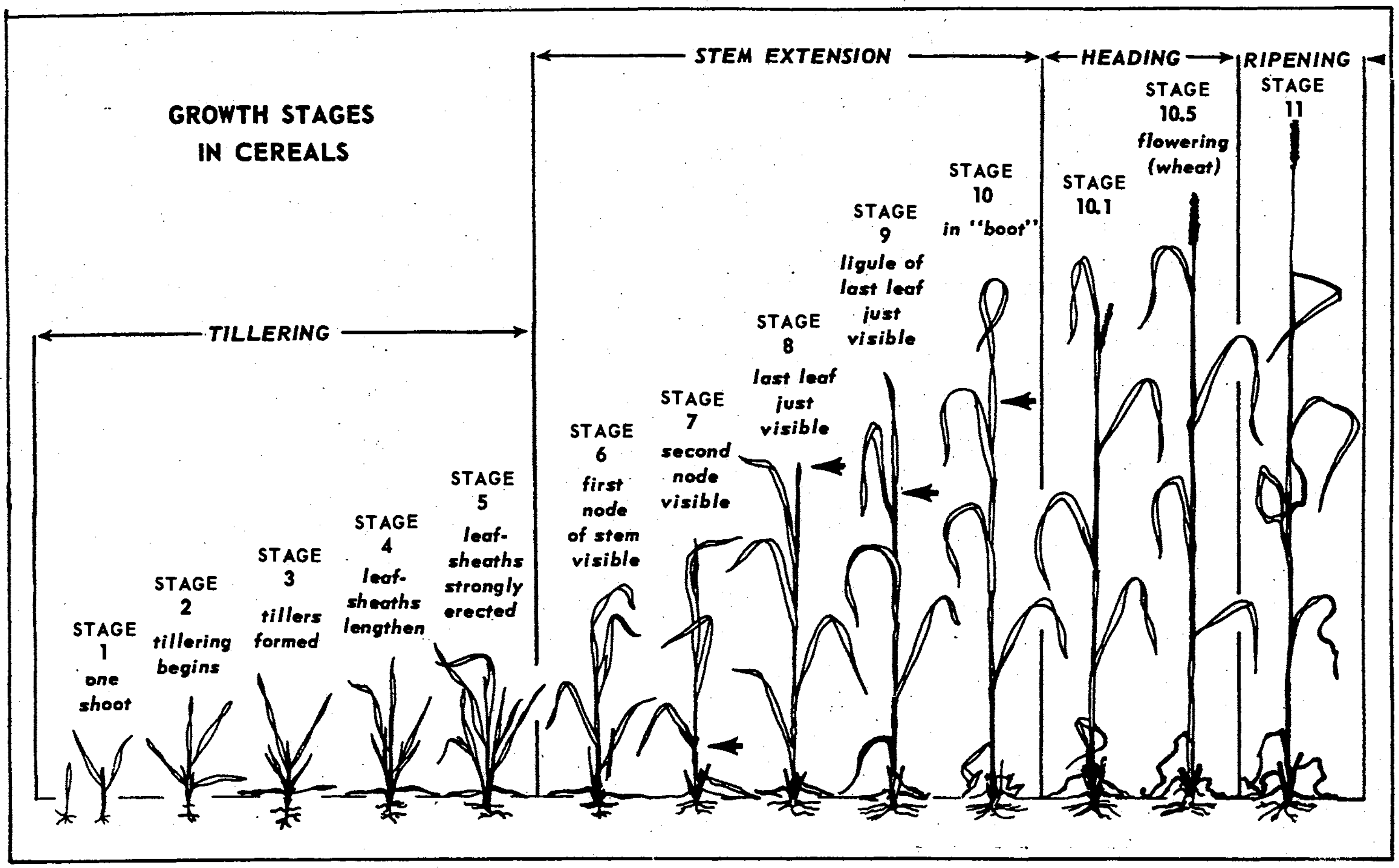

Figure 1. Growth Stages in Cereals (after Feekes-Large) (14).

Kernel Weight

Random samples of 200 seeds from each plot were counted and weighed to determine average kernel weight. Weights were recorded in milligrams for decimal accuracy during computer analysis of data. Kernel weights were expressed as milligrams per kernel.

Kernels/Spike

Kernel weights were used with tiller number and total grain yield to mathematically determine the third yield component, kernels per spike. This character was expressed as the average number of kernels per spike.

Grain Yield

A 2.5 m X 60 cm area of each plot was harvested at maturity and used for yield determination. Grain weight was recorded in grams as it came from the threshing machine and was expressed as grams per plot.

Maturity

Heading date was used as a measure of maturity. When 75% of the heads were out of the boot, the plot was deemed headed.

Kernel Protein Content

Protein was assayed approximately two months after harvest in the cereal chemistry laboratory, Oklahoma State University, Stillwater, Oklahoma. Analysis of 10 g ground wheat sample from each plot was performed by standard Kjeldahl methods, according to AACC cereal laboratory procedures (4).

Statistical Analysis

A statistical analysis of variance was made by the Computer Center, Oklahoma State University, on the data collected in this study. Significance of variability was determined for yield, yield components (grains per spike, weight per grain, and tillers per unit area), height, and percent grain protein. Also, an analysis of variance was made for tiller counts made in each row of the plots to determine the importance of intraplot variability for this character. A combined analysis of variance along with an analysis of variance for each chemical was used to assess treatment effects. Analysis of chemical X date interactions was made to check the accuracy of using combined subplot error.

CHAPTER IV

RESULTS AND DISCUSSION

General Growing Conditions

The 1970 growing season at the Agronomy Farm, Stillwater, was favorable for wheat production. There was soil moisture in the fall, although some drought stress occurred in the spring. There were no disease or insect problems. No winter-killing was detected in the check plots and no lodging occurred. The average yield of the Triumph 64 check plots in this study was 417.5 g which was slightly below the 1970 Stillwater station wheat performance test average of 481 g/plot.

Analysis of Variance

Data collected from this study were analyzed for six characters: grain yield, tiller number, kernel weight, kernels per spike, plant height and percent grain protein. The components of yield (tiller number, kernel weight, and kernels per spike) were statistically analyzed to determine the effect of growth regulating chemicals on these traits and the effect of these traits on changes in yield. The source of variation and the mean squares for these six characters are shown in Tables II through V. The standard notation for significance is used in these and all subsequent analyses; *i.e.*, * denotes significance at the .05 level of probability while ** denotes significance at the .01 level.

As shown by these tables, Mendok treatment resulted in significant

TABLE II

MEAN SQUARES FROM ANALYSES OF VARIANCE OF DATA FROM MENDOK TREATMENT

Source of Variation	d.f.	Grain Yield	Tiller Number	Kernel Weight	Kernels per Spike	Plant Height	Percent Grain Protein
Total	63						
Reps	3	1594.54	814.67	12.72	1.07	1.73	2.65
Date	3	57904.21**	98278.67*	49.81**	32.09**	75.94**	56.63**
Error (a)	9	4359.22	14716.00	5.20	2.79	0.88	0.24
Rate	3	35407.63**	40220.00	39.91**	31.84**	64.40**	49.20**
Date X Rate	9	35764.69**	127607.56**	18.11**	27.43**	28.38**	51.09**[1]
Error (b)	36	1909.43	21078.89	1.76	4.92	1.00	0.14

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

[1]Date I, heavy rate was entered at 0% grain protein, because plots of this date X rate treatment combination were so severely damaged that not enough grain was produced for analysis.

TABLE III

MEAN SQUARES FROM ANALYSES OF VARIANCE OF DATA FROM RH-531 TREATMENT

Source of Variation	d.f.	Grain Yield	Tiller Number	Kernel Weight	Kernels per Spike	Plant Height	Percent Grain Protein
Total	63						
Reps	3	9952.40	13068.00	4.04	12.42	0.52	3.87
Date	3	10398.52*	1553.33	8.05*	8.92	33.93**	2.15*
Error (a)	9	1874.91	11765.78	1.57	3.63	0.81	0.41
Rate	3	5303.85	9870.67	0.76	3.53	12.39**	1.04**
Date X Rate	9	3988.42	13699.11*	2.06*	7.45*	2.46**	0.52*
Error (b)	36	2041.03	5102.89	0.88	3.00	0.71	0.23

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

TABLE IV

MEAN SQUARES FROM ANALYSES OF VARIANCE OF DATA FROM ETHREL TREATMENT

Source of Variation	d.f.	Grain Yield	Tiller Number	Kernel Weight	Kernels per Spike	Plant Height	Percent Grain Protein
Total	63						
Reps	3	3083.85	19058.67	0.98	7.39	7.42	9.26
Date	3	4054.27*	1128.00	9.47*	1.23	51.44**	0.98
Error (a)	9	915.11	12542.22	1.40	3.83	1.53	0.43
Rate	3	3568.06*	14440.00	1.69	9.13**	20.08**	0.41
Date X Rate	9	1048.54	27543.11*	0.94	3.64*	5.36**	0.23
Error (b)	36	832.76	8879.78	1.22	1.57	0.92	0.31

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

TABLE V

MEAN SQUARES FROM ANALYSES OF VARIANCE OF DATA FROM CYCOCEL TREATMENT

Source of Variation	d.f.	Grain Yield	Tiller Number	Kernel Weight	Kernels per Spike	Plant Height	Percent Grain Protein
Total	63						
Reps	3	2915.54	8668.00	5.05	1.47	11.97	5.49
Date	3	1771.29	39972.00*	1.67	1.91	6.85*	0.46
Error (a)	9	1881.25	8586.22	3.41	1.45	1.57	0.79
Rate	3	300.13	3108.00	1.29	2.94	4.56**	0.14
Date X Rate	9	1561.39	14841.33	1.32	0.81	3.49**	0.86**
Error (b)	36	1386.31	16428.89	0.93	3.30	0.60	0.14

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

differences due to date of application for all six of the characters analyzed, while differences among dates for RH-531 were significant only for grain yield, kernel weight, and plant height. Ethrel treatment resulted in significant differences among application dates for grain yield, kernel weight, and plant height also, but Cycocel treatment showed significant differences among dates for tiller number and plant height only. Mean squares for rates of application shown in these tables are from pooled data.

Individual rate within date analysis for each chemical was conducted. Those rate within date treatment combinations which resulted in statistically significant differences were analyzed further. Comparisons of the means of all plots within dates which showed significant differences among rates of application are presented in Tables VI through XI and are discussed by each character measured.

Grain Yield

Grain yield was not significantly increased over the check by any chemical on any application date or by any application rate combination treatment. However, significant decreases of grain yield were observed in several instances. Of the 16 chemical by date of application treatment combinations, four resulted in significant decreases in yield. Data for these combinations are shown in Table VI. Decreases in grain yield ranged from about 10% in one treatment combination to near 93% in another.

Mendok treatment at the higher application rates resulted in highly significant yield decreases when applied on Date I. RH-531 showed a significant yield reduction on Date II at the heavy and

TABLE VI

COMPARISONS OF MEANS SHOWING SIGNIFICANT DIFFERENCES FOR YIELD OF TREATMENTS WITHIN CHEMICALS

Growth Regulator	Date of Application	Rate of Application	Mean Yield (gms/plot)
Mendok	I	1	431.00
		2	407.50
		3	330.50**
		4	028.50**
RH-531	II	1	433.50
		2	407.75
		4	315.75*
		3	311.50*
Ethrel	I	1	436.00
		2	433.50
		4	399.00*
		3	392.75*
Ethrel	II	1	477.25
		2	446.00
		3	415.25*
		4	410.50*

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

intermediate rates. Yield reductions due to Ethrel treatment were noted on application Dates I and II. On Date I the two heavier application rates reduced yields significantly. One Date II, however, all three application rates of Ethrel significantly reduced yields. None of the Cycocel-treated plots differed significantly from the check plot in grain yield.

Yield Components

Kernels per Spike

Although there was no effect on yield, Ethrel treatment produced significantly more kernels per spike (.01 level) than the check of Date IV with the lightest application rate of 0.56 kg/ha (Table VII).

The heavy Mendok treatment rate resulted in a significant drop in the number of kernels per spike on Date I. These Mendok-treated plants averaged approximately 4 kernels per spike as compared to 15 for the check. Two other growth regulators also resulted in significant reductions in kernels per spike. Date II application of RH-531 at the two heavier rates produced fewer kernels per spike than the check, and Ethrel on Date III at the two heavier rates produced similar results.

Tiller Number

Mendok applied on Date III at the intermediate rate (1.12 kg/ha), although not affecting yield, resulted in a significant increase in tiller number (Table VIII). There was a significant decrease in tiller number caused by the lightest rate (0.28 kg/ha) of Mendok on the same date. Mendok applied at the heavy rate on Date I also significantly lowered the tiller number. Analysis of data showed significant

TABLE VII

COMPARISON OF MEANS SHOWING SIGNIFICANT DIFFERENCES FOR KERNELS/SPIKE OF TREATMENTS WITHIN CHEMICALS

Growth Regulator	Date of Application	Rate of Application	Kernels per Spike
Mendok	I	1	14.9043
		2	13.8799
		3	13.4142
		4	03.9522**
RH-531	II	2	15.2750
		1	14.3684
		3	11.4789*
		4	11.1937*
Ethrel	III	1	15.4097
		2	14.3926
		3	13.1608*
		4	12.3726*
Ethrel	IV	2	15.0718**
		4	13.1294
		1	12.4407
		3	12.2597

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

TABLE VIII

COMPARISON OF MEANS SHOWING SIGNIFICANT DIFFERENCES FOR TILLER NUMBER OF TREATMENTS WITHIN CHEMICALS

Growth Regulator	Date of Application	Rate of Application	Tillers per Plot
Mendok	I	2	1172
		1	1120
		3	1066
		4	0526**
Mendok	III	3	1198*
		4	1098
		1	1076
		2	1002*
RH-531	II	1	1124
		3	1020*
		4	1016*
		2	1006*
Ethrel	III	4	1270**
		3	1160*
		2	1084*
		1	1002

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

decreases in tiller number for RH-531. The RH-531-treated plots were significantly reduced in tiller number by all applications made in the stem elongation stage (Date II). Tiller number was significantly increased with Ethrel with each successive rate applied on Date III, but these increases had no apparent influence on yield. Cycocel treatment had no effect on tiller number.

Kernel Weight

On Date II, the heavy rate of Ethrel resulted in a significant increase in kernel weight, although the intermediate application rate resulted in significantly lighter kernel weights (Table IX). Cycocel treatment on Date III at the intermediate treatment rate resulted in significantly heavier kernels. Mendok treatment on Date I produced significantly lower kernel weights at the intermediate and heavy rates of application. Mendok treatment applied on Date II at the heavy application rate also significantly reduced kernel weights. On RH-531-treated plants, kernels were significantly lighter when treated at the heaviest rate on Date I.

Discussion of Yield and Yield Components

Comparison by chemical of grain yield and yield components with the average check are shown in Figures 2 through 5. These figures give a general indication of treatment effects averaged over each application date. In Mendok-treated plots (Figure 2) kernel weight is more closely associated with yield changes while tiller number is not. While tiller number is closer than kernels per spike in the RH-531-treated plots, (Figure 3) kernel weight is again most closely

TABLE IX

COMPARISON OF MEANS SHOWING SIGNIFICANT DIFFERENCES FOR KERNEL WEIGHT OF TREATMENTS WITHIN CHEMICALS

Growth Regulator	Date of Application	Rate of Application	Kernel Weight (mgs)
Mendok	I	1	25.9500
		2	26.6750
		3	23.3750*
		4	16.1125**
Mendok	II	2	27.1500
		3	26.8750
		1	26.4750
		4	24.3625*
RH-531	I	2	26.9625
		1	26.3625
		3	26.1875
		4	25.0500*
Ethrel	II	4	29.7000*
		1	28.9750
		2	28.6250
		3	27.8125*
Cycocel	III	3	28.7750*
		1	27.5500
		4	27.4500
		2	27.2750

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

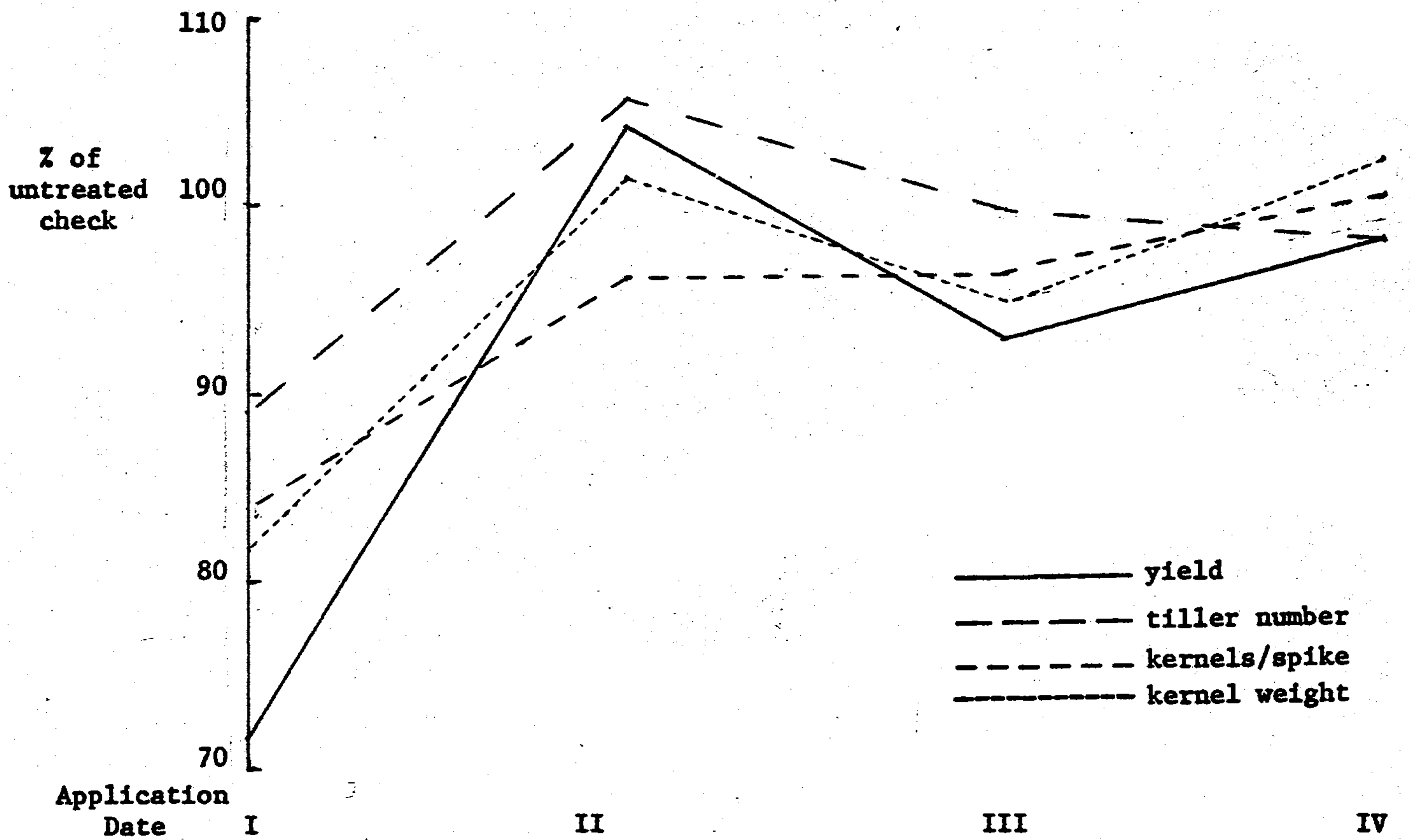

Figure 2. Comparison of yield and yield components of Mendok treatment to average untreated check (percentage). Application rates are averaged by date application.

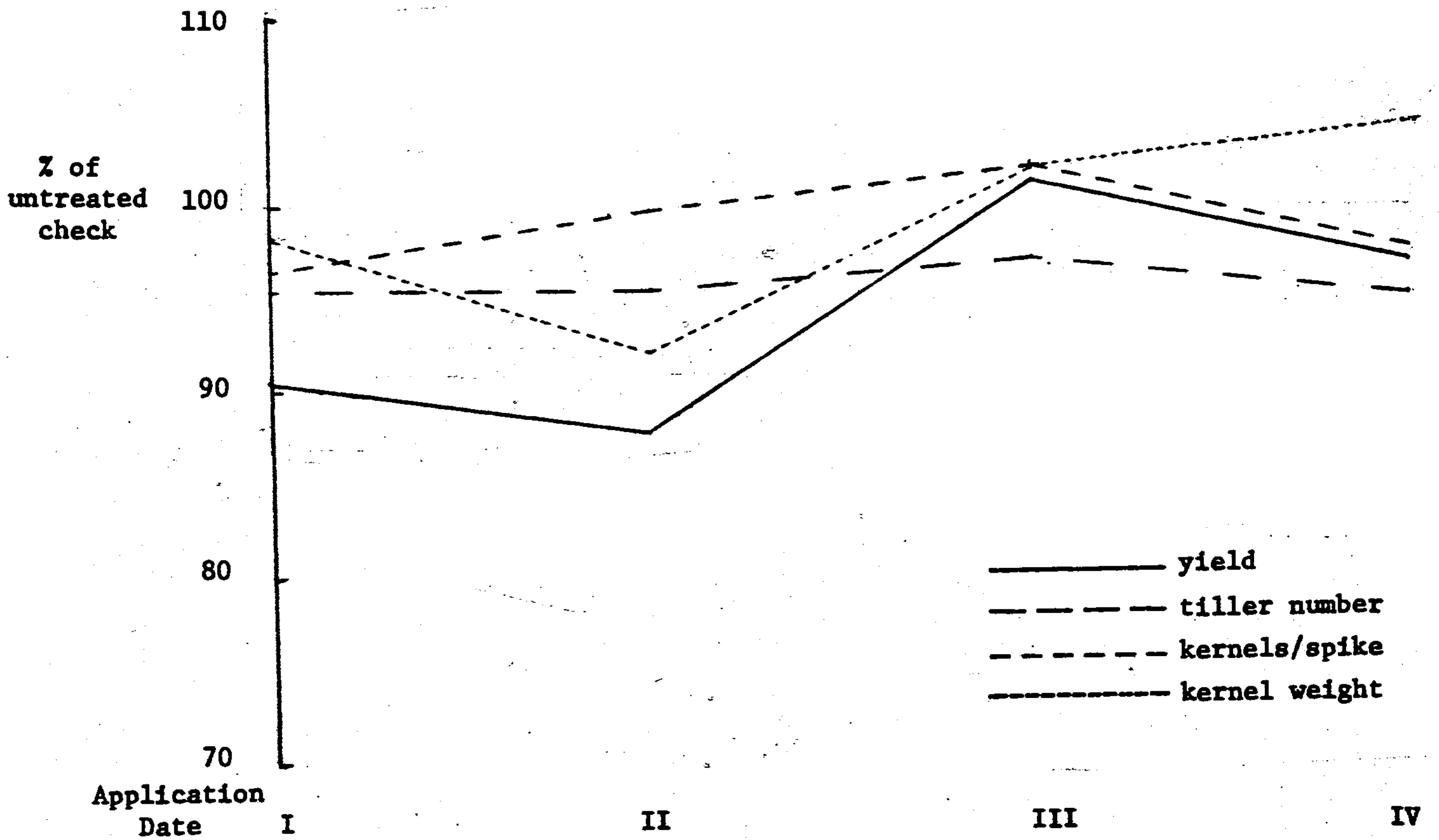

Figure 3. Comparison of yield and yield components of RH-531 treatment to average untreated check (percentage). Application rates are averaged by date of application.

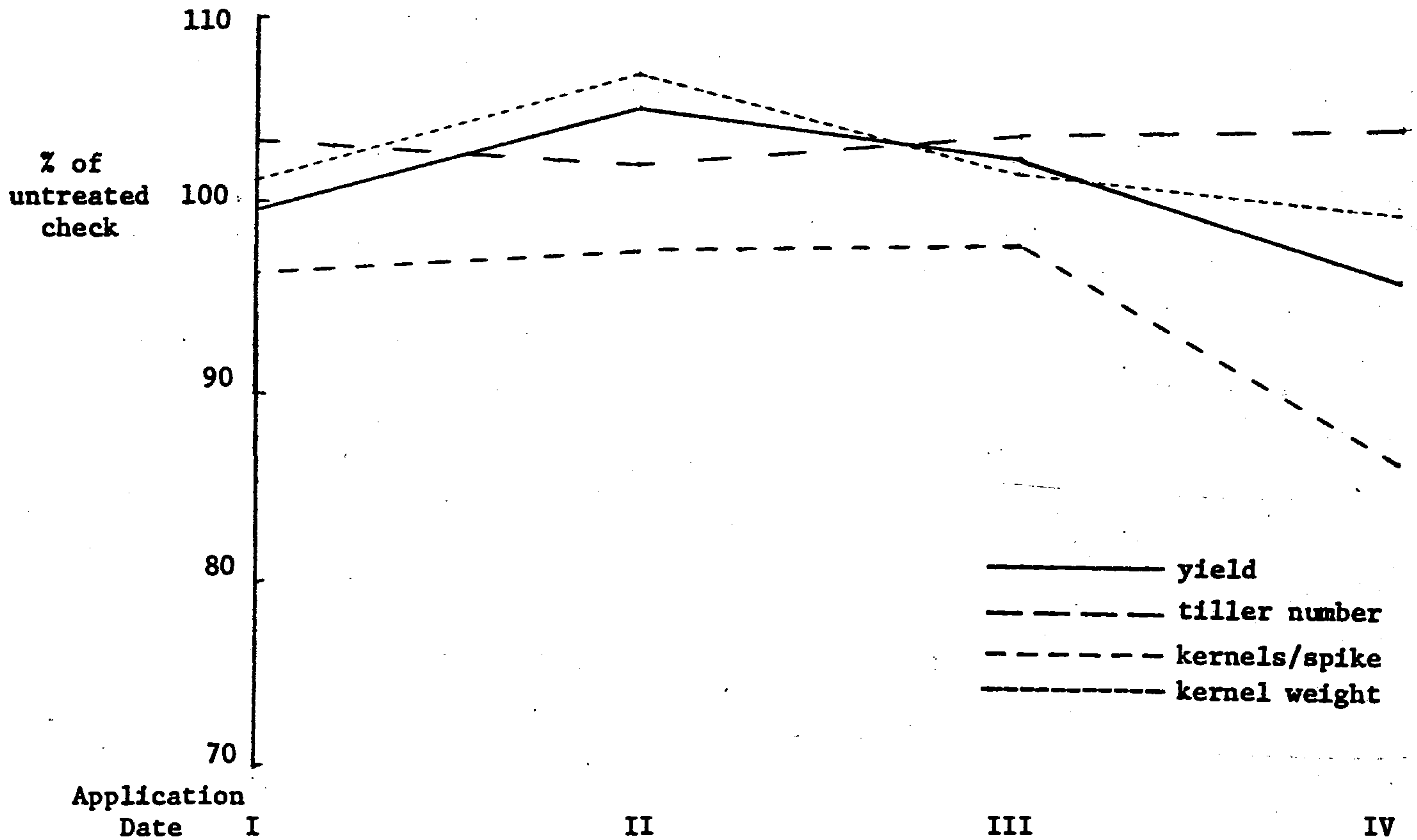

Figure 4. Comparison of yield and yield components of Ethrel treatment to average untreated check (percentage). Application rates are averaged by date of application.

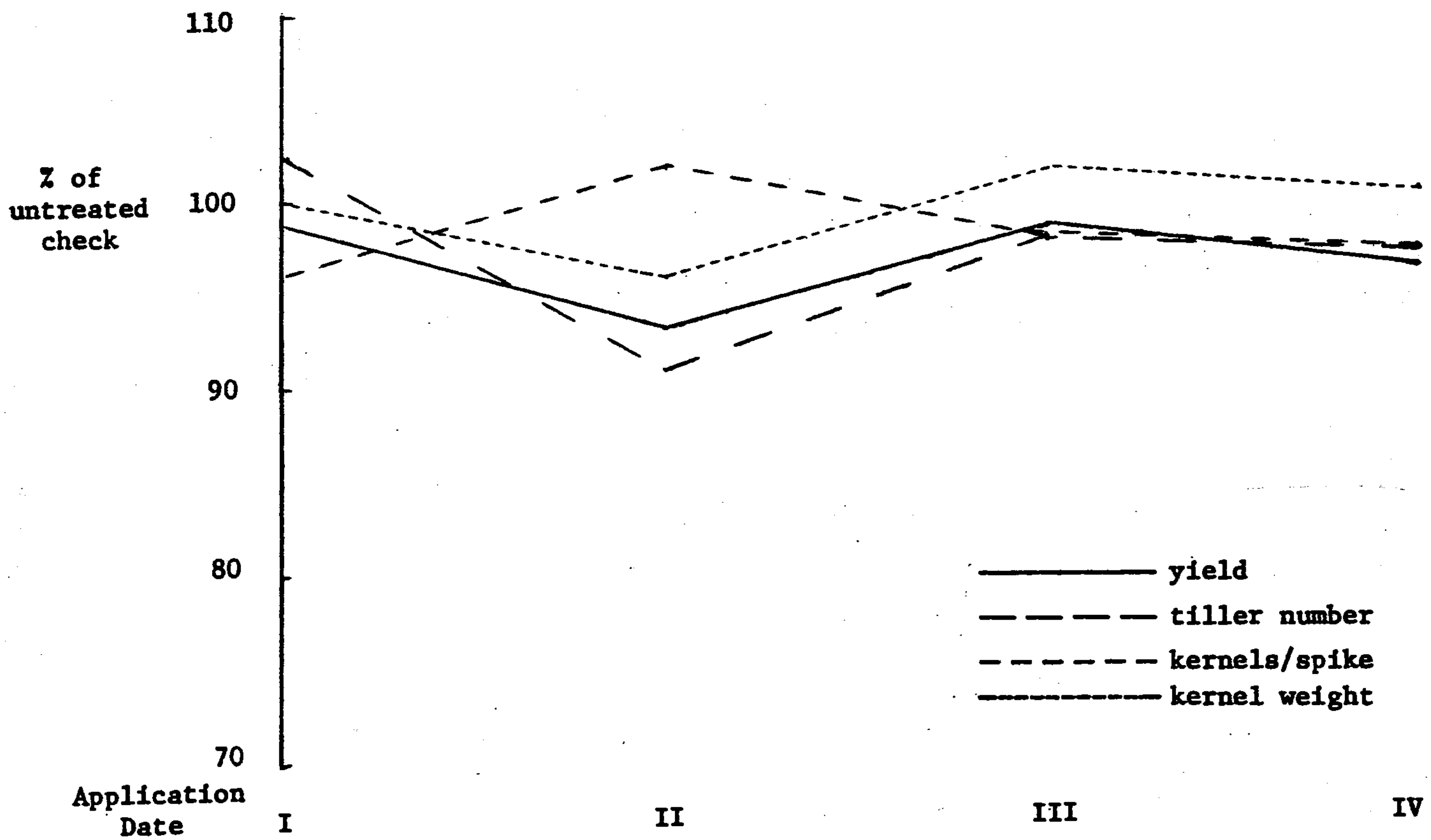

Figure 5. Comparison of yield and yield components of Cycocel treatment to average untreated check (percentage). Application rates are averaged by date of application.

associated with changes in yield than kernels per spike. Kernel weight appears to be more closely related to yield than tiller number. Cycocel treatments (Figure 5) were similar to those of Ethrel.

Comparison of the different chemicals on Date I reveals a drastic reduction in yield and yield components due to Mendok treatment. There is also a reduction in yield and yield components due to RH-531 treatment. Cycocel and Ethrel treatments were essentially no different from the check. On Date II Mendok treatment resulted in yield, kernel weight, and tiller number slightly above the control while kernels per spike were lower. The same was true for Ethrel on Date II. Yield, tiller number and kernel weight were below the control with Cycocel treatment, while kernels per spike were slightly above. With RH-531 treatment both yield and yield components were lower than the control. Treatments made on Date III with all chemicals were little different from the control. On Date IV Mendok and Cycocel treatments were no different from the control although Ethrel treatment brought a sharp reduction in kernels per spike compared to the control. RH-531 treatment resulted in kernel weight above the controls on Date IV.

Plant Height

All four chemicals significantly decreased height on at least one date of application (Table X). The average height of the untreated checks was 96.38 cm while the treated plots ranged from 62.87 to 99.06 cm.

When Mendok was applied on Date I, there was a significant difference in height due to rates of application. Both the intermediate (1.12 kg/ha) and the heavy (4.48 kg/ha) rate resulted in significantly

TABLE X

COMPARISON OF MEANS SHOWING SIGNIFICANT DIFFERENCES FOR HEIGHT OF TREATMENTS WITHIN CHEMICALS

Growth Regulator	Date of Application	Rate of Application	Height (cm)
Mendok	I	2	95.25
		1	93.35
		3	89.54*
		4	62.87**
Mendok	II	1	95.89
		2	95.89
		3	93.98
		4	89.54*
Mendok	III	1	95.89
		2	94.61*
		3	94.61*
		4	92.08*
RH-531	II	1	94.61
		2	88.90*
		3	87.00*
		4	81.92**

TABLE X (Continued)

Growth Regulator	Date of Application	Rate of Application	Height (cm)
RH-531	III	1	96.52
		2	92.71*
		3	91.44*
		4	90.81*
Ethrel	II	1	96.52
		2	92.08*
		3	91.44*
		4	88.27**
Ethrel	III	1	95.89
		2	84.46*
		3	83.19*
		4	80.65**
Cycocel	II	2	97.16
		1	96.52
		3	95.89
		4	88.90**

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

shorter plants. The heavy application on Date I resulted in the greatest reduction in height of any treatment conducted.

All chemicals affected height when applied on Date II. On this date Mendok treatment caused significant shortening of the plants only at the heavy application rate (4.48 kg/ha). RH-531 treatment, however, reduced height at all rates. Ethrel showed the same results as RH-531 while the results due to Cycocel were similar to those of Mendok.

Although the application of Cycocel during the boot stage (Date III) caused no shortening, the other three chemicals did have a shortening effect when applied on this date (Table X). There were no significant differences in height for any chemical treatment when applied on Date IV (flowering stage).

The purpose of height measurements was to determine possible relationships between height and lodging and its effect on grain yield. Due to an almost perfect growing season without excessively high wind or hard driving rain, it was impossible to determine whether any of the chemical treatments reduced the tendency of the plants to lodge. However, Ram and Rustagi (35) reported decreased lodging of Mendok-treated wheat as the prime cause of increased yield in their 1968 study. Other workers have reported the same results with Cycocel.

Grain Protein

The mean percentage of protein for all untreated check plots in this study was 14.44 percent. Mendok applied on Date IV (heading time) resulted in a significant increase in grain protein with the light and intermediate application rates. RH-531 treatment on Date II also resulted in significant protein increases. The heavy rate of application

TABLE XI

COMPARISON OF MEANS SHOWING SIGNIFICANT DIFFERENCES FOR PERCENT GRAIN PROTEIN OF TREATMENTS WITHIN CHEMICALS

Growth Regulator	Date of Application	Rate of Application	% Grain Protein
Mendok	I	3	14.2750
		2	14.2500
		1	14.1250
		4	00.0000**[1]
Mendok	IV	3	14.6250*
		2	14.5500*
		4	14.2500
		1	14.1750
RH-531	II	4	16.2000**
		3	15.5750*
		2	14.9000
		1	14.7250

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

[1]No protein analysis was made due to lack of grain.

of the chemical X date combination treatment resulted in highest percent protein in the test. This was 16.2% as compared to 14.7% for the check.

One treatment combination in this study (heavy Mendok application in the tillering stage of growth)(Date I) resulted in so few kernels that grain protein content could not be measured. In the analysis of data, therefore, since protein was entered as 0.0%, a striking significant difference is noted for that date and rate.

These three chemical X date treatment combinations were the only ones in which significant differences occurred. Although Chrominski (10), a Polish worker, found that Cycocel significantly lowered protein in wheat, the results presented here disagreed with his findings.

General Discussion

In most instances in this study, decreases in yield could be accounted for by decreases in at least two of the three yield components. As for the infrequent times that one of the yield components was increased by chemical treatment, not once was a significant increase in total grain yield noted.

Agronomic characters aside from the ones discussed above were also noted to be affected by these growth regulators. Blaim (8) has reported a continuing decrease in the content of pectic substances in CCC-treated wheat as the wheat grew; this fact he attributed to the negative effect of choline on metabolism of the mono-carbon fragments.

Other effects were noted in the field. Mendok caused a dark color to appear in the foliage when applied in the fall. This color effect was lost, however, when spring growth was initiated. In contrast, RH-531 caused a dark green color that persisted throughout the growing season and lated until senescence just before harvest. At that time, and lasting until harvested, a slight purple tinge was noticeable in the upper internodes of the wheat plants.

RH-531 also produced another characteristic that became evident when the treated plants were threshed. All plots that received the heavy dosage of this chemical were very difficult to thresh; i.e., the lemma, palea, and glume were very tough and were firmly attached to an unusually sturdy rachis. Whether or not this could be beneficial is a question that is difficult to answer. Although it might provide some insurance from shattering, it would also be difficult for a combine to remove the grain at harvest. Further work on this aspect would be interesting to observe.

No differences in maturity were observed between check plots and treated ones. All plots were 75% headed by April 24, 1970.

No intraplot differences in tiller number was detected by the analysis of variance performed on the tiller counts made in each row of the plots.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this experiment was to study the effect of four plant growth regulators on an adapted variety of hard red winter wheat. The effects on yield, yield components, plant height, and protein content percentage were measured and analyzed.

The yield of a wheat variety is determined by the product of its three yield factors: if x = average number of spikes per unit area, y = average number of kernels per spike, and z = average kernel weight, then xyz = yield. Provided there is no corresponding decrease in the other two components, an increase in any one of them would result in an increase in total grain yield.

No chemical used in this study on any date at any rate increased grain yield, although in several treatment combinations one of the yield components was increased. However, in these cases the other two components always decreased. This is often the case, even in wheat grown without chemical application. As one component of yield is increased, the others tend to decline.

This study clearly displays that height of the wheat plant can be decreased by application of these growth regulating chemicals. Although it was not demonstrated here, other workers (Koch and Linser) (20), reported a high correlation between shortened stems and thicker, more flexible stems which greatly aid in reduction of lodging. Rain, hail, and windstorms occurring after the wheat has headed, but before it ripens are common causes of lodging. Breakage of the culm at this stage can cause yield reductions of from 20 to 30% and will also lower test weight and protein content (24).

Although Haunold, et al. (16) found that grain protein was negatively correlated with yield, it was evident in only one of the two cases of increased protein in this study. A significant grain protein content increase was shown when RH-531 was applied in heavy and medium concentrations in the stem elongation growth stage while statistically significant yield reductions were recorded for the same rate and date. However, Mendok treatment increased grain protein when applied at heading time, with no apparent yield loss. Other studies are needed in this area to further investigate the possibilities of increasing protein content by chemicals.

Though the potentialities of growth regulators are promising, considerations such as their limited effect on yield increases have to be weighed against reduced lodging. Whether or not it would be economically advisable for growth regulators to be used on a commercial scale would rest within results obtained after long and careful study on the main commercial crop in a particular area.

In conclusion, within the limits of this study, growth regulating chemicals do not seem to be a practical method of increasing yield in this region of wheat production. All indications are that instead of increasing yields, either there is a decrease or no effect at all. Perhaps if lodging had been a factor in this study, the results would have been different. Other workers using growth regulators have usually noted a yield increase due simply to reduced lodging. In areas of high rainfall with high nitrogen fertilizer rates, this type of procedure might merit further consideration.

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