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Fall Applications of MCPA to Improve Tiller Synchrony and Reduce Lodging in Winter Wheat

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Abstract. Poor developmental spike synchrony in wheat (*Triticum aestivum* L.) can reduce the effectiveness of chemical treatments keyed on reproductive events. The broadleaf herbicide (2-methyl-4-chlorophenoxy) acetic acid (MCPA) can be used to retard the development of wheat tillers if applied to winter wheat in the fall prior to the initiation of tiller primordia. Fall applications of 0.5 kg ha^{-1} MCPA were sufficient to reduce the tillering rate by 20–30% while providing a slight, but statistically nonsignificant, increase in yield. Significant increases in kernels spike^{-1} were observed in the MCPA treatments. The effect of MCPA on kernels spike^{-1} could be modulated by nitrogen fertility and planting density. A linear relationship between spike number m^{-2} and planting density could be observed with MCPA treatments. Reductions in total number of spikes m^{-2}, but an increase in kernels spike^{-1}, resulted in significant improvements in tiller synchrony. Improved tiller synchrony is important in optimizing chemical treatments where applications are based on the developmental stages of the spike. Significant reductions in plant height and subsequent reductions in lodging under high nitrogen fertility and high plant populations were observed with MCPA treatments.

The effectiveness of many agricultural chemicals can be reduced by a lack of developmental uniformity of the target crop, and application of many postemergence chemicals is based on the stage of development of the reproductive structure of the crop. Chemical hybridizing agents are particularly sensitive to the degree of developmental synchrony in plants, and poor reproductive synchrony can significantly reduce their effectiveness. Much of the poor synchrony in wheat (*Triticum aestivum* L.) is the result of excess tillering. If a developmental inhibitor could be used to retard later tillers, the number of tillers per plant would be limited and the total number of tillers per unit area would reflect the planted population. Thus, the remaining, earlier developing tillers, would be more synchronous. Terpal (mepiquat chloride:ethephon/2:1) has been used in barley (*Hordeum distichum*) to retard main spike development (Woodward and Marshall 1987). Phenoxyacetic acid herbicides have been shown to inhibit barley tiller primordia (Derscheid 1952) and cause spike malformations in barley (*Hordeum valgare* L.), oats (*Avena sativa*), and wheat (Coupland 1951, Friesen 1950, Friesen and Harris 1951).

The objective of these experiments was to determine if the phenoxyacetic acid herbicide, (2-methyl-4-chlorophenoxy) acetic acid (MCPA), could be used as a developmental inhibitor of later tillers. If the yield potential could be maintained while reducing the total number of spikes per unit area, development would be more synchronous if the same number of kernels are developed on fewer spikes.

Materials and Methods

Cultural Practices and Experimental Design: 1985–1986

A Muscatine silty clay loam soil (fine-silty, mixed, mesic Aquic Argudolls) was prepared for planting. Fertilizer (4-100-100 kg ha^{-1}, N-P-K) was incorporated along with an insecticide [DiSyston, (O,O-diethyl S-[2-(ethylthio)ethyl]phosphoro-dithioate] (6.6 kg ha^{-1}) just prior to drilling to control aphids. Certified wheat (cv. Caldwell) seed was sized using steel mesh screens before planting to eliminate the larger 10% and smaller 30% of the seed. The seed was also applied to a gravity table and the 10–20% less dense seed was discarded. The remaining seed was drilled at a depth of 2–4 cm on September 16, 1985 to a population of 2 million viable seeds ha^{-1}. Each plot consisted of six 20-cm rows 2.5 m in length. Additional nitrogen fertilizer (60 kg ha^{-1}, N) was applied as NH_4NO_3 at spring greenup. Split applications of Bayleton [1-(4-chlorophenoxy)-3-3-dimethyl-1-(H-1,2,4-triazol-1-yl)-2-butanone] (35 ml ha^{-1} at each application) were made at Zodoks' stages 37 and 45 (Zodoks et al. 1974). MCPA-amine (50% ai) was formulated in water and sprayed in a volume of 210 liter ha^{-1}. The experiment was a split plot with application dates (Zodoks' stages 12, 18, 31, and 43) as the main plots and rates of MCPA (0, 0.5, 1.0, 1.5, and 2.0 kg ha^{-1}) as the subplots. All treatment combinations were replicated six times. Phytotoxicity ratings were determined 1 week after chemical application. Prior to harvest, the outside rows of each plot were removed with a binder and the ends of the plots trimmed to 2.1 m in length. Plant height (top of culm) was determined at maturity after the border rows were removed. The number of productive spikes in 1 m length of each remaining outside row (rows 2 and 5) was determined at maturity. Total grain weight was determined at maturity after drying to a uniform moisture in an 80°C forced air oven.

Cultural Practices and Experimental Design: 1986–1987

Cultural practices in the 1986–1987 cropping season were the same as in the 1985–1986 season, except the wheat was drilled in 11 15-cm rows on September 24, 1986. MCPA-amine (50% ai) was formulated in water and sprayed in water at 120 liter ha^{-1} using a commercial sprayer at Zodoks' stage 12. The experiment was a strip, split plot with MCPA treatments (0 and 0.5 kg ha^{-1}) as the main strip, planted population (1, 2, and 3 million viable kernels ha^{-1}) as the subplot and nitrogen rates (30, 60, 90, and 120 kg-N ha^{-1}), as NH_4NO_3, applied at Zodoks' stage 29 as the sub-subplots. All treatment combinations were replicated six times. At maturity, the two outside rows on both sides of the plots were removed and the length of the plots trimmed to 2.1 m. The number of viable tillers in 1 m length of each remaining outside row (rows 3 and 9) was determined at maturity. The number of these tillers that leaned greater than 45° from vertical was used to calculate the lodging percentage. Total biomass, grain weight, and 1000 kernel weight of the entire plot were also determined at maturity.

Results and Discussion

In 1985–1986 experiments, fall applications of MCPA had significant effects on the number of spikes m^{-2} (Table 1). All rates applied at Zodoks' stages 12–14 were effective in reducing the number of productive spikes m^{-2}, with an average reduction in spikes m^{-2} of 29% across all rates. An average reduction of 20% in the number of spikes m^{-2} was observed when MCPA was applied at Zodoks' growth stage 17–20. No effect on spike number was observed when spring applications of MCPA were made (Zodoks' 31–45). Plant height was also significantly reduced by fall MCPA applications. Average plant height reduction across all rates of MCPA applied at Zodoks' 12–14 and Zodoks' 17–20 were 12% and 11%, respectively. Grain yields were only significantly reduced (2.4% and 4.2%) by the highest rate of MCPA applied at Zodoks' 12–20 (Table 1).

Table 1. The effect of MCPA on grain yield, plant height, and spike density of wheat (cv. Caldwell), 1985–1986.

Application stage (Zodoks')	MCPA rate (kg ha^{-1})	Grain yield (t ha^{-1})	Plant height (cm)	Spike density (spike m^{-2})
12–14	0.0	5.0	83	781
12–14	0.5	5.1	77*	612***
12–14	1.0	5.0	71***	556***
12–14	1.5	5.0	72***	525***
12–14	2.0	4.9*	7.0***	562***
17–20	0.0	5.1	83	743
17–20	0.5	5.0	77*	565**
17–20	1.0	5.0	76**	625*
17–20	1.5	5.0	72***	600**
17–20	2.0	4.9*	69***	600**
31–33	0.0	5.1	83	743
31–33	0.5	5.1	82	750
31–33	1.0	5.1	82	743
31–33	1.5	5.0	82	750
31–33	2.0	5.0	82	756
43–45	0.0	5.1	84	751
43–45	0.5	5.1	81	737
43–45	1.0	5.0	78*	753
43–45	1.5	5.0	78*	743
43–45	2.0	5.1	80	743

* Significant LSD (0.05); **LSD (0.01); ***LSD (0.001).

Table 2. The effect of MCPA on wheat (cv. Caldwell) yield components, 1986–1987.

Yield component	Control	MCPA	$p > F$
Spike density (spikes m^{-2})	853	690	<0.001
Biomass (t ha^{-1})	13.18	12.66	<0.01
Grain yield (t ha^{-1})	4.8	4.9	NS
Harvest index	0.36	0.39	<0.01
Kernel weight (mg $kernel^{-1}$)	28.72	28.87	NS
Kernels m^{-2}	44180	46258	<0.01
Kernels $spike^{-1}$	54.8	64.9	<0.001

A comparison of the overall effect of 0.5 kg ha^{-1} MCPA treatment at Zodoks' stage 12 to soft red winter wheat (cv. Caldwell). The means are those summed across three populations, four nitrogen fertilities, and six replicates. The probability of a greater F value as a result of analysis of variance for each yield component is given.

These data suggest significant tiller synchrony was attained with fall applications of MCPA. Since the number of productive spikes m^{-2} was reduced

Table 3. The effect of MCPA on wheat (cv. Caldwell) yield parameters at various plant populations, 1986–1987.

	Planted population (million ha^{-1})	Grain yield (t ha^{-1})	Biomas (t ha^{-1})	Harvest index	Spike density (spike m^{-2})	Kernel density (kernels spike^{-1})
Control	1	4.9	13.4	0.36	848	56.6
	2	4.8	13.2	0.36	853	54.3
	3	4.6	13.0	0.35	858	53.6
MCPA	1	5.0	13.2	0.38	647	72.1
(0.5 kg ha^{-1})	2	4.8	12.2	0.40	700	60.5
	3	4.9	12.5	0.39	735[a]	62.3
LSD (0.05)		0.38	1.07	0.02	33	5.17

[a] Significant linear relationship between planted population and spike m^{-2}. MCPA applied at Zodoks' stage 12.

without reducing grain yields, the same grain weight would have been produced by significantly fewer spikes and would likely be filled in a shorter period of time. Plant height reductions associated with fall applications of MCPA could not be explained since height reductions are often associated with overall toxicity of chemical treatment. No visual toxicity was observed with any of the treatments.

In 1986–1987, a single rate of MCPA (0.5 kg ha^{-1}) and date of application (Zodoks' stage 12) was superimposed upon three planted population densities and four nitrogen rates. If the MCPA treatment is effective in retarding the later developing tiller primordia and thus in improving developmental synchrony by limiting the tillers per plant, then the productive spike number ha^{-1} should be related to the planted population. Wheat normally produces a relatively constant number of spikes regardless of the planted population when seeded above 1 million plants ha^{-1}. Any relationship between the number of productive spikes and the planted population would strongly suggest an effective response to MCPA treatment. Variations in nitrogen rates were expected to modify the number of spikes by providing nutrients to support variable tillering.

The 1986–1987 results were very similar to the 1985–1986 results, relative to the effect of MCPA on reducing the number of productive spikes (Table 2). MCPA treatment across all populations and nitrogen rates reduced the number of spikes m^{-2} an average of 19%. Total biomass was significantly reduced by MCPA treatment while grain yields with MCPA were slightly greater than the control grain yield mean. This differential in total biomass and grain yield resulted in an increase in harvest index. Kernel weight was unaffected by MCPA treatment; however, the number of kernels m^{-2} and the number of kernels spike^{-1} were both significantly increased by MCPA treatment.

When the planted population means were compared between the MCPA treatments and controls (means summed across nitrogen rates), a significant linear relationship existed between the number of productive spikes m^{-2} and the planted population when treated with MCPA (Table 3). These data would support the hypothesis that MCPA retards the development of spike primordia, limiting the number of spikes plant^{-1}. The number of spikes m^{-2} reflects the planted population when later tillering is restricted by MCPA treatment. Control means produced the same number of spikes m^{-2} regardless of the planted population.

There was no significant interactive effect of MCPA treatment and nitrogen rates relative to productive spikes m^{-2}. There was some significant (0.02) MCPA and nitrogen rate interactions on grain yield and total biomass (Table 4). Though there was no clear regressive relationship when nitrogen fertility means within MCPA treatment were compared, the MCPA-treated means maintained a higher yield potential at higher nitrogen rates. Control plot yield and total biomass dropped at higher nitrogen rates. MCPA-treated plots, irrespective of the planted population, maintained a constant yield potential at higher (90–120 kg-N ha^{-1}) nitrogen fertilities. Low nitrogen rates in MCPA-treated plots had lower yields, likely due to a restriction in tillering and a lack of nitrogen fertility to optimize the yield potential of the remaining tillers.

Much of the reduction of yield in higher nitrogen rates, control plots could be related to excessive lodging. There was a highly significant effect of MCPA treatment on lodging scores (Table 5) and a significant interactive effect of MCPA treatment and nitrogen fertility on lodging. Higher nitrogen fertility and higher planted populations induced greater lodging. Generally, MCPA treatment reduced lodging irrespective of the planted population or nitrogen rate. Higher nitrogen rates resulted in greater lodging in the control means which was

Table 4. The effect of nitrogen fertility and MCPA on wheat (cv. Caldwell) yield components, 1986–1987.

	Nitrogen fertility (kg ha^{-1})	Biomass	Yield	Harvest index
		(t ha^{-1})		
Control	30	13.5	5.2	0.38
	60	14.1	5.2	0.37
	90	12.4	4.3	0.34
	120	12.6	4.4	0.34
MCPA[a] (0.5 kg ha^{-1})	30	11.5	4.5	0.39
	60	13.3	5.1	0.39
	90	12.6	5.1	0.40
	120	13.3	5.1	0.39
LSD (0.05)		0.87	0.31	0.02

[a] MCPA applied at Zodoks' stage 12.

Table 5. A comparison of lodging scores for wheat (cv. Caldwell) treated with MCPA, 1986–1987.[a]

	Nitrogen fertility (kg ha^{-1})				
	Planted population (million ha^{-1})	30	60	90	120
		(% of plants lodged)			
Control	1	0	0	22	18
	2	0	41	87	99
	3	12	98	97	99
MCPA (0.5 kg ha^{-1})	1	0	0	0	0
	2	0	0	0	4
	3	0	0	0	14

[a] Average lodging scores across replicates.

likely the reason for the significant interactive effect of MCPA treatment and nitrogen rates relative to lodging, grain yield, and total biomass. Fall MCPA treatments in 1985–1986 significantly reduced plant height without reducing grain yield. Height measurements in 1986–1987 were invalidated by the excessive lodging in the control plots. The reduction in lodging in 1986–1987 season and the reduction of plant height in the 1985–1986 season may be related since growth inhibitors are commonly used to reduce lodging. Height reduction and lodging reduction may be secondary effects of tiller restriction. Spring applications of MCPA had little effect on plant height (Table 1). If height reduction was a direct effect of MCPA treatment, spring applications made before stem elongation would be expected to have some effect on plant height. Mechanical turbidations can reduce the height of plants and induce callose deposition in plant stems (Biro and Jaffe 1984, Jaffe 1980). With fewer secondary tillers to interfere with stem movement, MCPA-treated plants may be more responsive to seismomorphic stimuli induced by wind. This could account for plant height reduction and improved lodging resistance. Alternatively, restricted tillering could result in better light penetration causing a hormonal response for height reductions.

Improvements in spike synchrony were attained with fall applications of MCPA. A reduction in the total number of spikes m^{-2} without reducing grain yield or changing kernel density resulted in increasing the number of kernels spike^{-1}. Martin et al. (1989) have shown similar effects on tiller reduction when MCPA was included in the herbicide mixture; however, significant yields reductions were associated with these tiller reductions.

An increase in the number of kernels spike^{-1} results in a shorter period of reproductive development since kernels must go through reproductive development on fewer spikes developing in a similar time frame. More synchronous reproductive development would, intuitively, make any chemical treatment whose application is based on reproductive development more effective. Fungicide, insecticide, and gametocide treatments should be more effective since reproductive development would occur in a shorter time frame, thus reducing the time the chemical must be effective. Since most chemicals have limited time frames of effectiveness before the chemical dissipates, more synchronous development should improve chemical performance.

References

Biro RL, Jaffe MJ (1984) Thigmomorphogenesis: ethylene evolution and its role in the changes observed in mechanically perturbed bean plants. Physiol Plant 62:289–296

Coupland RT (1951) Effect of 2,4-D on spring wheat. Res Rep North Cent Weed Control Conf 8:58

Derscheid LA (1952) Physiological and morphological responses of barley to 2,4-dichlorophenoxyacetic acid. Plant Physiol 27:121–134

Friesen HA (1950) Effect of 2,4-D on spring wheat. Res Rep North Cent Weed Control Conf 7:73

Friesen HA, Harris MD (1951) Reaction of wheat to 2,4-D applied at various growth stages. Res Rep North Cent Weed Control Conf 8:59

Jaffe MJ (1980) Morphogenetic responses of plants to mechanical stimuli or stress. Bioscience 30:239–243

Martin DA, Miller SD, Alley HP (1989) Winter wheat (*Triticum aestivum*) response to herbicides applied at three growth stages. Weed Technology 3:90–94

Woodward EJ, Marshall C (1987) Effects of seed treatment with a plant growth regulator on growth and tillering in spring barley (*Hordeum distichum*) cv. Triumph. Ann Appl Biol 110:629–638

Zodoks JC, Chang TT, Konzak CF (1974) A decimal code for growth stages of cereals. Weed Research 14:415–421