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The Effect of N Fertilizer Placement and Timing on the Aboveground Biometric Characteristics of Spring Wheat (*Triticum aestivum* L. cv. Spectrum) on Leached Chernozem*

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Abstract: The maintenance of optimum levels of nitrogen (N) in the soil has a fundamental influence on biometric characteristics of spring wheat. A study was carried out to determine the effect of N fertilizer placement and timing on biometric characteristics of spring wheat at Krasnodar Agricultural Research Institute in Krasnodar County (45°5'N, 38°50'E, >400 m elev.) in Eastern Europe. The experiment was designed as Randomized Complete Block with four replicates, which were subjected to six N fertilizer treatments (T_1-T_6). Spring wheat was grown under rainfed conditions with treatments varying on N fertilizer placement and timing. Single split N fertilizer applied at tillering stage by broadcasting method (T_3 plots) had comparatively taller stems than other treatments for the first (85.4 cm) and second (84.9 cm) seasons of the study. Wheat plant stems in T_3 plots were 2.4-3.3 cm and 2.4-3.2 cm taller than in other N fertilizer treated plots for first and second seasons respectively. Single split and triple split applications of N_{45} at tillering (T_3) and N_{15} at tillering, N_{15} at stem elongation and N15 at heading (T_4) phenological stages both by broadcast method consistently amplified ($F<0.001$) the number of developed spikes per sample collected from 0.25 m^2. For both years of the study, T_3 and T_4 had 1.32-16.56% and 1.33-16.67% of developed spikes above those in other N fertilizer treated plots. For both seasons of the study, results show a distinct corrolation between the numbers of stems, spikes and spikeless stems per 0.25 m^2 sampled from each plot ($r^2 = 0.7605$). Generally, N fertilization diminished the prevalence of unproductive tillers per wheat plant station across almost all treatments subjected to N fertilizer treatments. Compared with the control plots, N fertilization increased the number of developed spikelets per plant station by 50%. The numbers of productive spikelets recorded in plots treated with triple split applications of N fertilizer at tillering, stem elongation and heading stages banded as a solution in the root system zone of both sides of plant rows were consistently higher than those in other N fertilizer treated plots.

Key words: Nitrogen fertilizer placement and timing, biometric characteristics of spring wheat

Introduction

Within genetically determined limits, spring wheat plant structure can be affected to no small degree by climatic conditions, soil water and nutrient status, among other factors (Russel, 1973). The plant growth conditions have a significant influence on the three major determinants of wheat yield. The number of plants per unit area represents the first wheat yield component, which in turn, is

**Originally Published in International Journal of Agricultural Research, 2006* determined by planting density, the fraction of seed successfully germinated and the fraction of seedlings that actually emerge. The number of heads per plant constitutes the second yield component, which is determined by tillering and tiller abortion that occurs between jointing and boot (Davidson and Chevalier, 1990). The third component, kernels per head, begins formation shortly after the double-ridge stage of epical meristem development, about the time of jointing. The number of kernels per head is ultimately determined by the rate and duration of floret generation and by the success of pollination (Brocklehurst *et al*., 1978).

Hot, dry winds or low soil moisture coupled with high temperature can prematurely terminate grain filling. If an early yield component is decreased by stress, later components compensate to bring yield closer to that expected from available resources. For instance, low stands or poor tillering often generate plants with increased kernels per head, or weight per kernel, or both (Sofield *et al*., 1977).

It has been shown by Puckridge (1968a) and Single (1964) that N rates and plant spacing influence spikelet numbers in spring wheats. According to Owen (1971a, b), temperatures over the range of 27 to 35°C do not significantly affect spikelet numbers. High day temperatures within this range set a limit to spikelet numbers while the critical temperature is below 27°C. Factors affecting spikelet productivity are not clearly understood, but the fact that the number of fertile spikelets per ear are highly correlated with mean maximum temperatures indicate that the fertility of the spikelet components is similarly related. High night temperatures reduce the percentage of florets, which successfully develop to kernels, particularly during pre-initiation period.

The emergence of leaves and tillers of cereals is orderly and follows a predictable sequence (Friend, 1965). In addition to its effect on canopy development, the rate of leaf emergence has a significant effect on the rate and sequence of tiller initiation. Early-formed tillers, such as T_1 and T_2, which are initiated by early leaf emergence, are more likely to produce heads (Kirby and Riggs, 1978; Rawson, 1971). There are conflicting reports in the literature about the effects of N supply on the rate of leaf emergence and hence the rate of tillering for cereals. In a field study, Bauer *et al.* (1984) found no effect on phyllochron (degree-days required to produce a leaf) of spring wheat. In a sand culture, Dale and Wilson (1978) observed decreased rates of leaf and tiller emergence in N-deficient barley (*Hordeum vulgare* L.).

Crop response to N fertilization varies with rate and timing of N application in relation to plant development. Cochran *et al.* (1978) reported increased biomass build-ups of soft white winter wheat due to accumulation of fall-applied N in the lower layers of the root profile, which can be available to the crop late in the growing season.

For spring wheat grown at temperate latitudes in typical continental environments, biomass accumulation and grain yield response generally is maximized when N is applied prior to stem elongation (Eilirich and Hageman, 1973; Langer and Liew, 1973; Darwinkel, 1983). This common response has been linked to observations that crop N demand increases sharply just prior to the onset of the most rapid phase of crop growth, stem elongation. Shortages of N during this period and subsequent shoot development lead to increased shoot mortality and smaller spike size, which limit the final number of kernels produced per unit (Hay and Kirkby, 1991). Thus, applications of N relatively early in the life cycle of spring wheat tend to enhance grain yields more than applications after heading.

Mahler *et al.* (1994), Johnston and Fowler (1991) and Toews and Soper (1978) reported better use of banded fertilizer by spring wheat and attributed this to the fact that the banded fertilizer is positionally more available to the crop than germinating weeds. In broadcasting the fertilizer is uniformly applied over the soil surface and may be incorporated in the soil or left on the soil surface and may reach the root zone by percolating rain or irrigation water. Application of N fertilizer by broadcasting method encourages vigorous and wider root network for absorption of available nutrients from the soil solution (Toews and Soper, 1978). N fertilizer placement by broadcasting method does not optimize the use of limited fertilizer resources, which may just be as available to the weeds as it is to the crop (Tisdale *et al*., 1985).

As early as 1957, foliar applications of urea solutions at rates ranging from 11 to 56 kg N ha^{-1} at flowering was shown to increase wheat grain protein by as much as 4.4% and number of kernels produced per unit (Finney *et al*., 1957). Recovery of N applied at planting ranged from 30 to 55% while that applied at anthesis ranged from 55 to 80% (Wuest and Cassman, 1992a). Foliar application of N increases grain protein when previous N applications have been suboptimal, particularly late in the season when soil moisture and root uptake are often low (Gooding and Davies, 1997; Wrigley, 1994; Barraclough and Haynes, 1996).

The effects of N fertilizer application rates on the growth, development and yield of spring wheats has been the subject of study by a host of research workers in many countries. However, there is scarcity of researched materials on the effect of timing and placement methods of N fertilizer on aboveground spring wheat plant structure, which has a significant influence on yield and grain quality. Consequently, the objective of the two-year study was to determine the effect of different N fertilizer placement methods and timing on spring wheat tillering, stem length, spike and spikelet numbers and their fertility.

Materials and Methods

The Field Study Site

The two-year study was conducted at Krasnodar Agricultural Research Institute in Krasnodar County (45°5'N, 38°50'E, >400 m elev.) in Eastern Europe to determine the effect of timing and placement methods of N fertilizer on the biometric parameters of wheat plant (*Triticum aestivum* cv. Spectrum) grown at continental latitude under rainfed conditions on a leached chernozem (black earth). The spring wheat crop was planted in the autumn and harvested in the summer.

The experimental site had moderately weathered, leached crumb-granular structured and deep black earth soils or chernozems with well developed humus-enriched A horizon (80-100 cm). They are classified as Udolls in the USDA system of soil classification. The pH_{H2O} and pH_{KCl} of the soil before the experiment ranged from 6.2-5.2 and 6.3-5.6, respectively. The institute is located in a region that has temperate climate with moderately cold winters. The winter season, which extends from November to March, has temperatures between –2.3 and 4.5°C. The summer season, which extends from April to October, is generally warm with temperatures ranging from 10.3 to 23.2°C. The area has 190-195 of snow-free days.

Weather conditions during the two-year study period, average monthly atmospheric temperatures were relatively similar to average long-term temperatures with the exception of the month of December (Table 1). The wheat crop was planted in March, where average monthly temperatures ranged from –0.7 to 6.6°C and harvested in July. From April to July average monthly temperatures oscillated between 8.8 and 24.3°C. Long-term monthly average rainfall totals have a relatively equal distribution throughout the year. However, during the two years of study, average monthly rainfall totals varied widely. The highest rainfall totals were received between May and June (Table 1).

Table 1: Precipitation and temperature data

	Atmospheric temperature (°C)				Rainfall totals (mm)			
Month	1986	1987	1988	Long-term average	1986	Season 1	Season 2	Long-term average
January	4.7	-1.7	-1.5	-2.3	88	0	51	35
February	-2.0	2.7	-1.7	-1.1	103	23	39	37
March	3.5	-0.7	6.6	4.5	1	36	64	35
April	12.7	8.8	12.2	10.3	46	71	34	43
May	15.3	16.7	15.9	16.5	159	46	111	54
June	21.1	19.5	20.7	20.0	68	132	307	61
July	23.1	23.2	24.3	23.2	6	70	53	65
August	25.2	20.7	22.8	22.5	1	26	47	47
Sept.	18.2	16.3	16.7	17.2	39	45	49	43
October	10.3	10.0	11.1	11.9	46	28	57	47
Nov.	2.9	6.7	8.0	5.1	57	80	107	47
Dec.	2.1	0.5	6.2	0.5	101	93	71	52
Total	137.1	122.7	142.3	128.3	715	650	990	566
Average	11.43	10.23	11.86	10.69	59.58	54.2	82.5	47.2

The mean annual rainfall total for the institute is 605 mm annually. During the study period average annual rainfall was 820 mm.

Treatments

The field experiments were conducted during two consecutive growing seasons 1 and 2 under rainfed conditions. The plot sites had been under continuous wheat production for several years using conventional tillage systems. Wheat was drill-seeded on 2 March of season 1 and 7 March of season 2 at a rate of 7 million germinated seeds per ha with 0.15 m row spacing. Plot size was 1.5 by 13 m.

The experiment was designed as Randomized Complete Block with four replicates, which were subjected to N fertilizer treatments in order to determine their effect on the biometric characteristics of spring wheat. Spring wheat was grown under rainfed conditions with six treatments: Treatment 1 (T_1) was the control (N_0 P_0 K_0), no fertilizer applied, T_2 where N_{90} P_{90} K_{60} was applied as incorporated basal fertilizers before planting, T_3 where N_{45} P_{90} K_{60} was applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method, T_4 where N_{45} P_{90} K_{60} was applied as incorporated basal fertilizers before planting, N_{15} at tillering, N_{15} at stem elongation and N15 at heading stages by broadcast method, T_5 where N45P90K60 was applied as incorporated basal fertilizers before planting, N_{15} at tillering, N_{15} at stem elongation and N_{15} at heading stages by foliar application method, T_6 where $N_{45}P_{90}K_{60}$ was applied as incorporated basal fertilizers before planting, N_{15} at tillering, N_{15} at stem elongation and N_{15} at heading stages banded as a solution in the root system zone of both sides of plant rows.

N fertilizer was applied in the form of ammonium nitrate while P and K were applied as single super phosphate (18.5% P_2O_5; 8.1% P) and muriate of potash (60% K2O; 49.8% K), respectively. N fertilizer treatments were undertaken at three phenological stages of wheat plants (tillering, stem elongation and heading) for T_3-T_6.

Plant Biomass Sampling and Measurements

Wheat plant samples of vegetative and reproductive parts above the ground were taken from a 0.25 m^2 area of each plot at mature phenological stage. Plant samples collected from 0.25 m^2 area constituted a bundle. The number of wheat plants, stems, spikes and spikelets for each spike (developed and undeveloped) was established and recorded in each bundle. The height of each stem was

Table 2: Biometric characteristics of aboveground biomass of spring wheat plants, Season 1

Treatment	Height of stems (cm)	Plants per bundle	Stems per bundle	Tillering ratio	Spikes per bundle	Stems without spikes	Length of spike (cm)	Spikelets per spike	
								Developed	Undeveloped
T_1	71.4	110	146	1.3	131	15	5.4	9	2
T_2	82.1	119	143	1.2	132	11	6.7	11	1
T_3	85.4	130	162	1.3	151	11	6.8	11	1
T_4	82.2	120	163	1.4	151	12	6.1	10	1
T_5	83.0	134	181	1.4	149	32	6.7	11	1
T_6	82.8	114	139	1.2	126	13	6.8	12	1

measured for determination of mean stem height in each bundle. The tillering ratio was determined by diving the number of stems by the number of plants per bundle.

Results and Discussion

Table 2 to 4 show the biometric characteristics of wheat tops biomass. In the first and second seasons of the study, a distinct pattern of the measured parameters of aboveground biomass was observed across all treatments ($F<0.005$). In the first season, there was generally a significant treatment effect on the wheat tops biomass characteristics. The difference between control and plots treated with different N fertilizer placements and timing was statistically significant for most of the biometric parameters of wheat plants ($F = 0.003$).

Single split N fertilizer applied at tillering stage by broadcasting method (T_3 plots) had comparatively taller stems than other treatments for the first (85.4 cm) and second (84.9 cm) seasons of the study. Wheat plant stems in T_3 plots were 2.4-3.3 cm and 2.4-3.2 cm taller than in other N fertilizer treated plots for first and second seasons, respectively (Table 2 and 3). This pattern in the aboveground biometric characteristics in plots treated with single split N fertilizer topdressing at tillering phenological stage was not particularly surprising as it was consistent with research findings elsewhere. Eilirich and Hageman (1973), Langer and Liew (1973) and Darwinkel (1983) reported maximized spring wheat biomass accumulation and grain yield response when N is applied prior to stem elongation. In addition to that, in a study on wheat development. Hay and Kirkby (1991) reported similar results which were linked to observations that wheat crop N demand increases sharply just prior to the onset of the most rapid phase of crop growth, stem elongation. Shortages of N during this period retard subsequent shoot development and increases shoot mortality. Thus, applications of N relatively early in the life cycle of spring wheat tend to enhance shoot development more than applications after heading. Smith and Whitfield (1990) reported 18-30% lower N uptake in wheat due to delayed application of N fertilizer until heading under rainfed conditions.

Highest plant and stem densities sampled from 0.25 m^2 of each plot were consistently observed in plots subjected to triple split N fertilizer top dressing by foliar application method (T_5) for the first (134/181) and second (133/180) seasons. Plant and stem densities in 0.25 m^2 sampled from T_5 plots were 2.99-14.93% and 3.01-15.04% higher than in other N fertilizer treated plots. Although wheat plants absorb limited quantities of foliar applied N, the foliar-applied N recovery rate by wheat plants is phenomenal. Wuest and Cassman (1992a) observed 55 to 80% recovery rates of foliar applied N at anthesis compared with a recovery rate of 30 to 55% of N applied at planting.

For the tillering ratio, which shows the relationship between the number of plants and the total number of developed tillers in the sample square, the dominance of T_5 plots over other treatments was coupled with that of T_4 plots. Triple split post-planting applications of N fertilizer by

Table 3: Biometric characteristics of aboveground biomass of spring wheat plants, Season 2

Treat.	Height of stems (cm)	Plants per bundle	Stems per bundle	Tillering ratio	Spikes per bundle	Stems without spikes	Length of spike (cm)	Spikelets per spike Developed	Undeveloped
T_1	71.0	109	145	1.3	130	15	5.4	9	2
T_2	81.6	118	142	1.2	131	11	6.7	11	1
T_3	84.9	129	161	1.3	150	11	6.8	11	1
T_4	81.7	119	162	1.4	150	12	6.1	10	1
T_5	82.5	133	180	1.4	148	32	6.7	11	1
T_6	82.3	113	138	1.2	125	13	6.8	12	1

Table 4: Biometric characteristics of aboveground biomass of spring wheat plants, Season 1 and Season 2 means

Treat.	Height of stems (cm)	Plants per bundle	Stems per bundle	Tillering ratio	Spikes per bundle	Stems without spikes	Length of spike (cm)	Spikelets per spike Developed	Undeveloped
T_1	71.2	110	146	1.3	131	15	5.4	9	2
T_2	81.85	119	143	1.2	132	11	6.7	11	1
T_3	85.15	130	162	1.3	151	11	6.8	11	1
T_4	81.95	120	163	1.4	151	12	6.1	10	1
T_5	82.75	134	181	1.4	149	32	6.7	11	1
T_6	82.55	114	139	1.2	126	13	6.8	12	2

broadcasting and foliar spraying at tillering, stem elongation and heading phenological stages significantly ($F<0.005$) enhanced the ratio of tillering by wheat plants. Triple split N fertilizer applications by broadcast method in T_4 plots encouraged rapid growth of wheat root systems for the efficient interception of N in drainage water, which caused the related increase in the tillering ratio. Triple foliar applications in T_5 plots had the same effect in the sense that wheat leaves absorb a portion of N in solution while the remainder that drips onto the soil surface is intercepted by the root system before being leached by excessive rain. This had the effect of improving the tillering ratio under rather humid conditions especially in the second season (Table 1).

Results presented in Table 2-4 show that single split and triple split applications of N_{45} at tillering (T_3) and N_{15} at tillering, N15 at stem elongation and N_{15} at heading (T_4) phenological stages both by broadcast method consistently amplified ($F<0.001$) the number of developed spikes per sample collected from 0.25 m^2. For both years of the study, T_3 and T_4 had 1.32-16.56 and 1.33-16.67% of developed spikes above those in other N fertilizer treated plots. However, the lowest number of developed spikes on plants sampled from 0.25 m^2 of each plot was recorded in T_6 plots. In T_3 and T_4 plots N fertilizer was applied by broadcasting method, which was reported by Toews and Soper (1978) to encourage vigorous and wider root network for absorption of available nutrients from the soil solution Application of N fertilizer by broadcasting method encourages vigorous and wider root network for absorption of available nutrients from the soil solution. Research results reported by Eilirich and Hageman (1973), Langer and Liew (1973) and Darwinkel (1983) showed that pre-stem elongation applications of N fertilizer (T_3) consistently increase spring wheat biomass accumulations in which the vigorous growth of developed spikes was observed. In addition to that, elevated content of N in the soil profile at early stages of wheat growth and development in T_3 plots vigorously encouraged growth of early-formed tillers, such as T_1 and T_2, initiated by early leaf emergence, which are more likely to produce heads (Kirby and Riggs, 1978; Rawson, 1971).

For both seasons of the study, results show a distinct corrolation between the numbers of stems, spikes and spikeless stems per 0.25 m^2 sampled from each plot ($r^2 = 0.7605$). Generally, N fertilization diminished the prevalence of unproductive tillers per wheat plant station across almost all treatments subjected to N fertilizer treatments. This trend, however, was effectively reversed ($F = 0.002$) in T_5

plots in both seasons of the study, where the prevalence of spikeless tillers bulged to 17.7% compared with an average of 6.8% representing the number of unproductive tillers in samples collected from 0.25 m^2 of each plot. It has been shown by Puckridge (1968a) and Single (1964) that N rates to no small degree influence spikelet numbers in spring wheats. Although wheat plants are capable of absorbing foliar-applied N, Cooke (1954) and Toews and Soper (1978) reported that wheat leaves could only absorb N applied as a solution in very limited quantities. This perhaps explains the bulge in the number of unproductive tillers observed in T_5 plots in both seasons of the study.

N fertilization significantly ($F<0.001$) amplified the lengths of spikes of sampled wheat plants by about 13.0-25.9% compared with those in the control plots for both seasons of the study. However, N treatment separation among T_2-T_6 plots was less convincing for both seasons of the study ($F>0.005$). This indicates that N fertilizer placement methods and timing have insignificant effect on the length of spikes of spring wheat grown at continental latitudes under rainfed conditions.

Compared with the control plots, N fertilization increased the number of developed spikelets per plant station by 50%. The numbers of productive spikelets recorded in plots treated with triple split applications of N fertilizer at tillering, stem elongation and heading stages banded as a solution in the root system zone of both sides of plant rows were consistently higher than those in other N fertilizer treated plots. Johnston and Fowler (1991), Toews and Soper (1978) and Mahler *et al.* (1994) reported better use of banded fertilizer by the crop and attributed this to the fact that the fertilizer is positionally more available to the crop than germinating weeds.

The means presented in Table 4 show that N fertilizer timing and placement method has significant effect on the biometric characteristics of aboveground biomass of spring wheat plants.

In conclusion, the results of the two-year research study clearly show a distinct pattern of N fertilizer placements methods and timing effects on the aboveground spring wheat biomass characteristics. An early application of N fertilizer synchronized with the peak absorption and assimilation of N by spring wheat plants significantly influences the aboveground wheat plant biomass structure which, as reported by a host of researchers, fundamentally determines the yield and grain quality. However, the effect of belowground biomass structure on yield and grain quality of wheats is huge. Accordingly, there is a need to carry out further studies on the effect of N fertilizer placement and timing on the structure of belowground biomass of spring wheat.

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