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The Effect of Nitrogen Fertilizer Placement and Timing on the Uptake of Nitrogen, Phosphorus and Potassium by Spring Wheat *(Triticum Aestivum* L. Cv. Spectrum) at Different Phenological Stages on Leached Chernozem

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Abstract: A study was carried out to determine the effect of N fertilizer placement and timing on accumulations of nitrogen, phosphorus and potassium in the aboveground wheat biomass 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 N fertilizer treatments. Spring wheat was grown under rainfed conditions with six treatments. In both seasons, results shows that T_4 plots recorded the highest N accumulations (177.4 and 156.6 kg ha^{-1}) in the plant biomass during the early growth stages of wheat (tillering and heading). In the post-heading period, highest N build-ups switched to T_3 plots where a peak of 271.4 and 258.6 kg ha^{-1} for the first and second seasons, respectively were attained at mature stage. Single split application of N into $N_{45}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method, supported comparatively higher build-ups of nitrogen, phosphorus and potassium in the plant biomass in almost all the phenological stages of spring wheat in both years of the study. Triple split applications of N fertilizer in the T_4 plots did not significantly improve nutrient accumulations in wheat tops compared with those in T_2 plots (184.2 and 186.0 kg ha^{-1}) where pre-planting single basal $N_{90}P_{90}K_{60}$ was applied. Split application of N fertilizers in early stages of growth and development of spring wheat, which coincides with the onset of the most rapid phase of biomass accumulations dramatically amplifies the content of nitrogen, phosphorus and potassium in the aboveground plant parts.

Key words: Synchronization, early N application, higher nutrient build-ups.

INTRODUCTION

Continuously increasing fertilizer costs and concern over the detrimental environmental effects of heavy fertilizer application in commercial agriculture have increased awareness of the need for the generation of appropriate agronomic practices which enhance efficiency in the plant uptake and utilization of mineral nutrients. Such practices should require less fertilizer to produce economic yields and also allow for increased crop production through the exploitation of nutritionally hostile environments[1].

Nitrogen is normally a key factor in achieving optimum wheat grain yields. Nitrogen use efficiency by wheat is to no small degree dependent on nitrogen (N) fertilizer application methods, timing, rate of N applied, precipitation and other climate-related variables. Maximum use efficiency of top-dressed N should be obtained by the latest possible application compatible with the stage of development that still permits rapid N uptake, thus avoiding unnecessary vegetative growth, which may result in lodged wheat plants and subsequent yield reduction[2]. Kumakov[3], Mossedaq and Smith[4] observed maximized plant biomass response when N is applied prior to stem elongation of winter wheat grown at temperate latitudes in typical continental environments. Both researchers concurred that 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 wheat plant growth (stem elongation). Shortages of N during this period and subsequent phenological phases may lead to reduced plant biomass accumulation and the related reduction of yield[5].

Responses to split N applications reported in North America and Europe however are inconsistent. Davies *et al.*[6] and Ellen and Spiertz[7] observed a higher recovery and efficiency of top-dressed N applied in spring by wheat as compared with all preplant N. Grant *et al.*[8] and Banfield *et al.*[9] reported no advantages in split application of N on spring wheat.

Cox and Reisenauer[10], Gubanov and Ivanov[5] and Kumakov[3] reported that the uptake of N by wheat begins a few days after germination and continues up to milky ripe stage. Peak uptake of N is observed between tillering and anthesis when, over a period of 25-30 days, wheat plants accumulate about 50-60% of total N requirements. The rapid uptake of N in the first half of the vegetative and reproductive period of spring wheat coincides with increased growth of roots and leaves which, will have accumulated about 3.5-7% N by dry mass before anthesis.

The degree of responsiveness by wheat to applied phosphatic fertilizers is relatively high on soils with a high phosphorus (P) immobilization capacity[11]. Anicst[12] indicated that the inefficient utilization of P by wheat plants has long been known. A spring wheat crop uses only 10-15% of the P added in fertilizers during the year the fertilizer is applied[5,13]. This is largely due to the tendency of the soil to fix P and the slow rate of movement of this element to plant roots in the soil. Gubanov and Ivanov[5], Tolstousov[13] and Anicst[12] reported peak P uptake by spring wheat between stem elongation and anthesis. They observed that P content in the aboveground biomass significantly dwindles towards full ripening of wheat grain due to the translocation of P materials to the root system.

According to Kumakov[3] and Gubanov and Ivanov[5] potassium (K) uptake from the soil by wheat crop is high, often being three to four times that of P and equaling that of N. Kumakov[3] and Gubanov and Ivanov[5] observed a comparatively high potassium requirement by wheat plants between seed germination and anthesis. The researchers observed maximum K buildups in wheat towards anthesis. In the post-anthesis phenological stages K requirements by wheat plants are often satisfied by internal redistribution of K reserves from senescing vegetative parts. Towards the end of the vegetative period a significant part of K in wheat plants is released in root secretions into the soil.

Extensive studies have been carried out on uptake of NPK by spring wheat. However, the effect of N fertilizer application methods and timing on the uptake of NPK by wheat at different phenological stages has not been adequately studied. The uptake of NPK at critical growth and development stages has a fundamental influence on the yield and grain quality of wheat. Consequently, the objective of the two-year fertility experiment was to determine the effect of N fertilizer application methods and timing on the uptake of nitrogen, phosphorus and potassium by spring wheat at different phenological stages under dry land conditions.

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 uptake of nitrogen, phosphorus and potassium by spring wheat (*Triticum aestivum* L. Cv. Spectrum) on a leached chernozem (black earth) under rainfed conditions. The spring wheat crop was planted in the autumn and harvested in the summer of the first and second seasons. 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 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.

Table 1: Precipitation and temperature data

	Atmospheric temperature (°C)				Rainfall totals (mm)			
Months	1986	1987	1988	Long-term average	1986	Season 1	Season 2	Long-term average
January	4.70	-1.70	-1.50	-2.30	88.00	0.0	51.0	35.0
February	-2.00	2.70	-1.70	-1.10	103.00	23.0	39.0	37.0
March	3.50	-0.70	6.60	4.50	1.00	36.0	64.0	35.0
April	12.70	8.80	12.20	10.30	46.00	71.0	34.0	43.0
May	15.30	16.70	15.90	16.50	159.00	46.0	111.0	54.0
June	21.10	19.50	20.70	20.00	68.00	132.0	307.0	61.0
July	23.10	23.20	24.30	23.20	6.00	70.0	53.0	65.0
August	25.20	20.70	22.80	22.50	1.00	26.0	47.0	47.0
September	18.20	16.30	16.70	17.20	39.00	45.0	49.0	43.0
October	10.30	10.00	11.10	11.90	46.00	28.0	57.0	47.0
November	2.90	6.70	8.00	5.10	57.00	80.0	107.0	47.0
December	2.10	0.50	6.20	0.50	101.00	93.0	71.0	52.0
Total	137.10	122.70	142.30	128.30	715.00	650.0	990.0	566.0
Average	11.43	10.23	11.86	10.69	59.58	54.2	82.5	47.2

Table 2: Uptake of N, P and K by spring wheat at different phenological stages, kg/ha, season 1

	Phenological stages											
	Tillering			Heading			Anthesis			Mature		
Treatments	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	23.6	3.9	15.9	72.0	13.1	88.5	105.0	17.9	93.80	149.8	42.1	171.3
T_2	40.6	10.8	43.7	101.1	27.7	114.7	132.6	37.5	122.50	174.5	77.4	210.3
T_3	50.5	6.0	25.3	123.5	33.3	145.5	133.6	34.1	150.50	271.4	63.4	217.6
T_4	84.0	8.6	34.2	177.4	46.8	160.5	123.5	54.5	143.30	218.8	59.0	218.8

Table 3: Uptake of N, P and K by spring wheat at different phenological stages, kg/ha, season 2

	Phenological stages											
	Tillering			Heading			Anthesis			Mature		
Treatments	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	16.0	3.4	14.4	73.1	15.1	97.6	95.4	19.5	105.3	146.4	47.7	159.4
T_2	31.3	8.4	35.4	118.3	36.8	144.7	138.3	42.5	152.3	205.4	67.4	195.1
T_3	40.3	5.3	24.8	135.6	38.7	167.0	142.3	41.2	170.1	258.6	59.1	207.1
T_4	53.3	9.9	29.9	156.6	44.7	153.9	134.3	52.2	157.8	205.4	32.7	201.5

Table 4: Uptake of N, P and K by spring wheat at different phenological stages, kg/ha, season 1 and 2

	Phenological stages											
	Tillering			Heading			Anthesis			Mature		
Treatments	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	8.4	2.8	12.8	74.2	17.1	106.9	85.7	21.0	116.7	143.1	53.4	134.2
T_2	22.1	6.2	27.1	135.4	45.8	174.7	144.0	47.5	182.2	231.5	57.4	186.0
T_3	30.0	4.6	24.3	147.8	44.0	188.5	151.1	48.3	189.8	245.9	54.8	196.7
T_4	22.5	11.2	25.6	135.7	40.7	147.4	145.3	49.8	172.2	192.1	60.4	184.2

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

Treatments: The field experiments were conducted during two consecutive growing seasons 1 and 2. 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 uptake of nitrogen, phosphorus and potassium by spring wheat at different phenological stages. Spring wheat was grown under rainfed conditions with six treatments: Treatment 1 (T_1) was the control ($N_0P_0K_0$), 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 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% K_2O; 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_4.

Determination of nitrogen, phosphorus and potassium in the above ground plant biomass: Aboveground (vegetative) plant biomass samples collected from 0.25 m^2 of each plot at tillering, heading, anthesis and mature phenological stages were oven-dried at 85°C, ground to pass a 0.5 mm sieve, and analysed for total N, P, and K by micro-Kjeldahl method in which sulphuric acid, potassium sulphate, and copper sulphate were used in the digestion followed by auto-analysis[14].

RESULTS AND DISCUSSION

Table 2 to 4 show the distribution of nitrogen, phosphorus and potassium in the aboveground (vegetative) plant biomass at different phenological stages. Results show that there was a clear pattern of treatment effect on the uptake of nitrogen, phosphorus and potassium by the aboveground wheat plant biomass for both seasons of the study.

T_4 plots recorded the highest N accumulations (177.4 and 156.6 kg ha^{-1}) in the plant biomass during the early growth stages of wheat (tillering and heading) in both seasons. In the post-heading period, highest N buildups switched to T_3 plots where a peak of 271.4 and 258.6 kg ha^{-1} for the first and second seasons, respectively were attained at mature stage. This trend was attributed to the fact that in the pre-heading period the wider root network commonly encouraged by uniform fertilizer application by broadcasting method (T_3) was not sufficiently developed for the effective interception of soil N. After the heading phenological stage, N fertilizer applied uniformly by broadcasting method had sufficient time to encourage development of wider root network, which greatly enhanced N uptake in the post-heading period observed in this study (Table 2).

Generally, a similar trend was observed in the accumulation of K in the aboveground biomass of spring wheat for the same reasons. Single split application of N into $N_{45}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method, supported comparatively higher build-ups of nitrogen, phosphorus and potassium in the plant biomass in almost all the phenological stages of spring wheat in both years of the study (Table 2 and 3). This pattern in the accumulations of N, P and K in wheat plant biomass was consistent with observations by Kumakov[6], Mossedaq and Smith[7] who reported maximized plant biomass response when N is applied prior to stem elongation of wheat grown at temperate latitudes in typical continental environments.

The means for two seasons of the study presented in Table 4 show that triple split applications of N fertilizer (T_4) into $N_{45}P_{90}K_{60}$ applied as incorporated pre-planting fertilizers, 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 does not significantly improve nutrient accumulations in wheat tops over those of pre-planting single basal (T_2) applications (184.2 and 186.0 kg ha^{-1}). Split application of N fertilizers in early stages of growth and development of spring wheat, which coincides with the onset of the most rapid phase of biomass accumulations dramatically amplifies the content of nitrogen, phosphorus and potassium in the aboveground plant parts.

While Cox and Reisenauer[10], Gubanov and Ivanov[5] and Kumakov[3] reported accumulations of 50-60% of total N over a period of 25-30 days in wheat tops between tillering and anthesis, this study observed higher buildups of 62-76% (Table 4) of total N between the two phenological stages. The rapid uptake of N in the first half of the vegetative and reproductive period of spring wheat coincides with increased growth of roots and leaves which, will have accumulated about 3.5-7% N by dry mass before anthesis[3,5,10].

Results presented in Table 4 show that by anthesis period, spring wheat subjected to N fertilizer treatments will have accumulated 82-88% and 93.5-98.1% of total P and K, respectively. The post-anthesis stages accumulate 12-18% and 1.9-6.5% of total P and K, respectively. This observed pattern is consistent with research results reported by Gubanov and Ivanov[5], Tolstousov[13] and Anicst[12] who observed peak P and K uptake by spring wheat between stem elongation and anthesis. They reported dwindling P content in the aboveground biomass towards full ripening of wheat grain due to the translocation of P materials to the root system. Towards the end of the vegetative period a significant part of K in wheat plants is released in root secretions into the soil, which explains the retarded P and K buildups between anthesis and mature phonological stages observed in this study.

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