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The Effect of N Fertilizer Placement and Timing on Soil Profile Dynamics of Available Phosphorus and Exchangeable Potassium at Different Growth Stages of Spring Wheat (*Triticum aestivum* L. cv. Spectrum) on Leached Chernozem*

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Abstract: The maintenance of optimum levels of nitrogen (N), phosphorus (P) and potassium (K) in the soil encourages vigorous growth of spring wheat root systems, which in turn significantly enhances uptake of other nutrients in the soil. A study was carried out to determine the effect of N fertilizer placement and timing on accumulations and distributions of available P and exchangeable K in the soil profile at different phenological stages of the wheat crop 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 in N fertilizer placement and timing. N treatments (T_2-T_6) triggered an available P bulge of 2.7-6.4 mg 100 g^{-1} soil when compared with accumulations in the control plots during the first season. In the second season, available P build-ups of 2.7-6.3 mg 100 g^{-1} soil were observed. This was attributed to increased concentration of H^+ ions associated with the use of ammoniacal fertilizers, which promoted the solubility of immobile P into relatively available forms. There was a bulge of available P content in the topsoil of about 0.1-2.8 mg 100 g^{-1} soil and 0.2-3.0 mg 100 g^{-1} soil compared with its content in the upper subsoil in the first and second seasons, respectively. This was largely due to the rapid fixation of P, which curtailed its mobility to lower layers of the soil. Peak build-ups of available P (11.0-17.3 mg 100 g^{-1} soil) and exchangeable K (19.1-28.1 mg 100g^{-1} soil) in the soil profile were observed at tillering stage before rapidly dwindling to as low as 9.0 and 16.6 mg 100 g^{-1} soil, respectively at anthesis in the first season of the study. In the second season this trend was largely distorted by excessive rainfall. This pattern was attributed to the peak P uptake by wheat plants between stem elongation and anthesis, which caused the P depletion in the soil profile. Comparatively high potassium requirement by wheat plants between seed germination and anthesis accounted for corresponding depletion of exchangeable K in the soil profile at anthesis. However, at milky ripe stage the content of exchangeable K exceeded that at tillering stage by as much as 8.9 mg 100 g^{-1} soil, which was attributed to the release of K by wheat plant roots into the soil towards the end of the vegetative period. Single basal application of N (T_2) had the lowest accumulations of available P (9.4-16.1mg 100 g^{-1} soil) compared with other treatments in which N was applied. T_3 plots in which $N_{45}P_{90}K_{60}$ was applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method, recorded the highest

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content of available P (19.9 mg 100 g^{-1} soil). The single split application of N (N_{45}) as ammonium nitrate may have created a rather acidic environment, which is conducive for the temporary solubility of P coupled with a rather subdued growth of wheat plants and the related low uptake of P under dwindling supply of N in post-tillering period. The same trend was perpetuated in the accumulations of exchangeable K during the growth and development of the wheat crop. T_3 plots had the highest content of K (13.0-20.6 mg 100 g^{-1} soil). This was largely attributed to the reduced plant growth associated with this treatment and the related subdued uptake of this nutrient by N-starved wheat plants in the post-tillering period.

Key words: Nitrogen fertilizer placement and timing, available P and exchangeable K influence, spring wheat growth and development

Introduction

With the intensification of agriculture in the temperate regions, especially after the Second World War, livestock and arable farming have became increasingly divorced, so that animal manures are not plentiful in areas where they are most needed. Inevitably, there has been an increasing reliance on chemical fertilizers in place of traditional manuring and fallowing (Bock and Hergert, 1991). The need to make high economic returns has meant that green manure crops as natural sources of nitrogen (N) could not be grown on a large scale; nor is this approach feasible for profitable agriculture in developed countries (FAO, 1993).

The soil is not a limitless reserve of plant nutrients especially under intensive cropping systems where essential soil profile plant nutrients are extensively ‘mined’ by root uptake and éxported’ to distant locations in crop produce (Cooke, 1954; Tisdale *et al.,* 1985; Harper *et al.,* 1987). Consequently, the need for replacement of nutrients extracted from the soil in order to achieve a positive soil nutrient balance is unquestionable. Such replenishments often come in the form of fertilizers impregnated with essential plant nutrients, the management of which is of fundamental importance not only from an economic standpoint, but also from an environmental position (Ritter and Chirnside, 1987). Tisdale *et al.* (1985) and Harper *et al.* (1987) and reported that three macronutrients-nitrogen (N), phosphorus (P) and potassium (K) are commonly applied in commercial fertilizers and for this reason are often referred to as the fertilizer elements.

Next to nitrogen (N), phosphorus (P) and potassium (K) are the most critical essential elements in determining plant growth, development and production throughout the world (Harper *et al.,* 1987; Tisdale *et al.,* 1985; Cooke, 1954). Phosphorus is a component of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), which are vital compounds in energy transformations in plants. ATP, which is synthesized from ADP in both respiration and photosynthesis processes, carries a high-energy phosphate bond that drives most biochemical reactions including the energy consuming active uptake of other nutrients from the soil solution by plant roots (Gubanov and Ivanov, 1988; Kumakov, 1988).

Arnon (1953), Sakar and Uppal (1994) and Tomar and Pundir (1996) observed that inorganic phosphorus compounds in soil exist either as calcium or iron/aluminum containing substances. They reported that the availability of P to plants is determined to no small degree by the ionic form of this element, which in turn is influenced by the soil pH. Thus, in highly acidic soil conditions only $H_2PO_4^-$ exists and as pH increases, first HPO_4^{2-} ions and finally PO_4^{3-} ions dominate (Sanchez and Uehara, 1980). In very acidic soil conditions the presence of soluble aluminum, iron and manganese and their compounds (hydrous oxides) largely precipitate P into non-available forms (Khasauneh, 1980; Fox, 1981).

In a study on the behavior of P in soils, Olsen *et al.* (1977) reported significant influence of soluble P-containing calcium compounds in alkaline soil conditions on availability of P. Amongst a host of P-containing compounds, the most significant is tricalcium phosphate [$Ca_3(PO_4)_2$], which is of limited solubility (Velarde *et al.,* 2005). According to Olsen and Khasawneh (1980) the concentration of labile P in the soil solution is a measure of the intensity factor of P nutrition and if this factor is maintained at about 0.2 mg kg^{-1} soil or above, maximum yield of most crops will occur. P uptake by wheat plant root systems affects the net balance of available P in the soil profile (Anicst, 1986; Tolstousov, 1987; Gubanov and Ivanov, 1988). Anicst (1986) 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 (Tolstousov, 1987; Gubanov and Ivanov, 1988). 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.

Numerous research studies have confirmed that the maintenance of optimum levels of P in the soil encourages vigorous growth of spring wheat root systems, which in turn significantly enhances uptake of other nutrients in the soil. Mengel and Kirkby (1982) and Vavilov (1986) observed that the availability of P is particularly necessary during periods of intensive early growth phases and synthesis of biomass materials during grain filling period when protein and starch synthesis are intensive. Anicst (1986), Tolstousov (1987) and Gubanov and Ivanov (1988) reported peak P uptake by wheat plants 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. Kumakov (1988) observed that elevated contents of soil N in nitrate forms, which cannot be assimilated by wheat plants into protein in that state, require relatively higher content of available P for synthesis of high-energy releasing materials (ATP) for the energy-consuming transformation of nitrate N into protein components.

Potassium (K), often referred to as the third fertilizer element, received relatively recent attention for the reason that supply of available K was so high in most soils that it took many years of cropping for a serious depletion to appear (Orbon *et al.,* 2005). Additionally, even in soils having insufficient K for optimum crop yields, production was more drastically limited by the lack of N and P (Richards and Bates, 1988; Portela, 1993). As the use of N and P fertilizers expanded, crop yields increased and so did the removal of soil K. As a consequence, the drain on soil K has been greatly amplified. This, coupled with considerable loss by leaching, has significantly elevated the demand for K (Douglas, 1982).

According to Kumakov (1988) and Gubanov and Ivanov (1988) K uptake from the soil by wheat crop is high, often being three to four times that of P and often equaling that of N. The measure of the capacity of the soil to maintain the level of available K in the soil solution in a complete life cycle of the wheat crop is a quantity factor (Anicst, 1986; Tolstousov, 1987). Kumakov (1988) and Gubanov and Ivanov (1988) observed a comparatively high potassium requirement by wheat plants between seed germination and anthesis. They 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. For this reason it is extremely difficult to plan K fertilization using data from K uptake in harvested wheat grain (Cooke, 1954; Tisdale *et al.,* 1985; Harper *et al.,* 1987).

Extensive studies have been carried on the behavior of P and K in the soil under wheat. However, there has been scarcity of researched materials on the influence of N fertilizer timing and placement methods on accumulations and distributions of available P and exchangeable K in the soil profile at different phenological stages of the wheat crop. Maintenance of optimum levels of available P and K in the soil has fundamental influence on wheat grain yield and quality. Consequently, the objective of the two-year study was to determine the effect of N fertilizer placement and timing on accumulations and distributions of available P and exchangeable K in the soil profile at different phenological stages of the wheat crop. We reasoned that different methods of N fertilizer placements and timings coupled with phenologically determined uptake of P and K presented variations in the dynamics of these nutrients in the soil profiles.

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. 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 (Brady, 1990). The pH_{H2O} and pH_{KCl} of the soil before the experiment ranged from 6.2-5.2 and 6.3-5.6, respectively.

Weather Conditions

The institute is located in a region that has temperate climate with moderately cold winters. The winter season, extending 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.

During the two-year study period, average monthly atmospheric temperatures were relatively similar to average long-term temperatures. 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 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 Hectare 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 grain quality of spring wheat. Spring wheat was grown under rainfed conditions with six treatments: Treatment1 (T_1) was the control ($N_0P_0K_0$), 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 $N_{45}P_{90}K_{60}$ as applied as incorporated basal fertilizers before planting, N_{15} at tillering, N_{15} at stem elongation and N_{15} at heading stages by broadcast method, T_5 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 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% 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_6.

Determination of Available P and Exchangeable K

Soil samples were collected from 0-20 and 20-40 cm depths of each at tillering, stem elongation, heading, anthesis, milky ripe and mature phenological stages of the wheat crop. Available phosphorus in soil samples was analysed using Olsen's extractant 0.5 M $NaHCO_3$, pH 8.5 (Brady, 1990). Exchangeable K in soil samples was determined using the neutral 1M-ammonium acetate (NH_4OAc) method (Olsen, *et al.,* 1954; Jackson, 1958). Analysis of variance (ANOVA) was used to test the significance of treatments effects on available P and exchangeable K in the soil profile at different phenological stages of the wheat crop (MSTAT, 1988).

Results and Discussion

Tables 2 to 4 show the dynamics of available phosphorus and exchangeable potassium in the soil profile at different phenological stages of wheat. In the first and second years of the study, a distinctive pattern of available phosphorus and exchangeable potassium distribution was observed in the soil profile across all phenological stages ($F<0.005$).

There were comparatively higher accumulations of available P in the soil profile of plots (Tables 2, 3 and 4) treated with N fertilizers ($F = 0.003$). N treatments (T_2-T_6) triggered an available P bulge of 2.7-6.4 mg 100 g^{-1} soil when compared with accumulations in the control plots in the first season of the study (Table 2). This trend was maintained in the second season of the study where available P build-ups of 2.7-6.3 mg 100 g^{-1} soil were observed. This pattern was linked with the acidifying effect of ammoniacal fertilizer applied to a soil. Arnon (1953), Sakar and Uppal (1994) and Tomar and Pundir (1996) reported elevated content of mobile P in acidified soil conditions where, a higher concentration of H^+ ions increase the presence of relatively soluble HPO_4^{2-}. K fertilization and N treatment effects on exchangeable K in the soil profile were not significantly different from those in the control plots ($F>0.005$). Richards and Bates (1988) and Portela (1993) reported a relatively high K content and fixation capacities of most soils. The comparatively high K fixing abilities of the soil perhaps contributed to low exchangeable K content in the K-fertilized plots. For the same reason,

Table 1: Recipitation and temperature data

	Atmospheric temperature (°C)				Rainfall (mm)			
Months	1996	1997	1998	Long-term average	1996	Season1	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

Source: Kuban Agricultural Research Institute: 1998

Table 2: Dynamics of available P and exchangeable K in the soil at different phenological stages, mg 100 g^{-1} soil (Season 1)

		Phenological stages											
		Tillering		Stem elongation		Heading		Anthesis		Milk yripe		Mature	
Treatment	Depth (cm)	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O5	K_2O
T_1	0-20	10.9	22.3	11.8	16.5	14.4	18.6	11.7	20.6	13.6	28.3	14.5	20.6
	20-40	11,2	19.1	11.8	15.1	11.6	17.6	9.0	20.1	11.9	28.0	11.5	20.5
T_2	0-20	13.4	23.6	13.8	18.1	15.4	19.0	12.2	20.8	14.7	29.3	13.2	21.8
	20-40	13.5	20.6	13.7	16.8	13.5	19.5	10.2	21.8	14.3	28.6	10.5	21.0
T_3	0-20	15.9	23.0	16.2	18.5	16.7	16.6	14.5	22.3	13.5	29.5	13.0	22.8
	20-40	16.4	24.0	16.4	16.6	14.4	18.0	11.1	24.8	12.3	29.6	11.9	26.0
T_4	0-20	16.5	28.1	17.0	18.6	16.9	17.8	10.7	20.3	13.4	29.5	15.8	23.1
	20-40	15.8	23.3	15.8	15.6	16.6	21.0	10.0	20.0	11.7	28.8	15.0	24.8
T_5	0-20	14.7	23.3	16.2	17.3	13.3	24.1	15.5	26.3	14.0	29.6	12.7	24.8
	20-40	13.9	25.1	14.2	16.6	10.9	21.3	9.9	20.5	13.7	29.6	12.6	22.5
T_6	0-20	17.3	25.1	17.4	15.0	14.9	17.6	10.1	23.7	14.4	29.6	14.3	23.6
	20-40	15.2	23.1	15.1	16.5	15.9	18.0	10.8	21.8	11.9	34.0	12.4	23.0

Table 3: Dynamics of available P and exchangeable K in the soil at different phenological stages, mg 100 g^{-1} soil (Season 2)

		Phenological stages											
		Tillering		Stem elongation		Heading		Anthesis		Milk yripe		Mature	
Treatment	Depth (cm)	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
T_1	0-20	12.8	6.4	5.2	6.2	13.7	10.2	10.3	10.8	11.3	11.2	14.3	13.4
	20-40	10.7	6.0	5.0	7.4	12.9	10.2	8.1	12.2	10.9	10.9	13.5	12.6
T_2	0-20	12.0	6.5	7.2	6.2	16.9	10.4	9.8	11.7	12.5	10.9	18.9	12.6
	20-40	13.5	6.7	7.4	6.2	14.1	11.2	8.6	12.0	11.6	10.2	17.8	11.9
T_3	0-20	13.0	5.6	9.7	5.5	16.8	10.8	10.8	13.0	11.3	10.2	19.3	15.4
	20-40	14.5	5.8	7.7	6.2	17.8	10.5	8.9	13.0	12.2	10.3	16.1	13.8
T_4	0-20	12.6	6.2	8.8	7.4	16.4	10.3	10.9	11.2	10.9	10.2	19.8	15.4
	20-40	13.1	6.9	8.7	6.8	17.2	10.2	8.5	11.9	12.2	10.5	18.0	13.4
T_5	0-20	14.7	6.7	8.0	5.8	15.7	10.4	9.8	11.5	12.4	11.2	19.5	16.4
	20-40	11.5	6.7	9.3	6.6	12.7	10.3	7.9	10.9	11.4	11.2	17.5	14.0
T_6	0-20	13.2	6.2	9.3	6.3	16.8	10.1	9.0	12.0	13.0	10.5	19.25	15.0
	20-40	14.1	6.7	7.5	6.9	16.6	10.0	8.7	11.8	11.4	11.5	18.6	13.8

Table 4: Dynamics of available P and exchangeable K in the soil at different phenological stages, mg 100 g^{-1} soil (Season 1 and 2 means)

		Phenological stages											
		Tillering		Stem elongation		Heading		Anthesis		Milk yripe		Mature	
Treatment	Depth (cm)	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
T_1	0-20	11.9	14.4	8.5	11.4	14.1	14.4	11.0	15.7	12.4	19.8	14.4	17.0
	20-40	10.9	12.6	8.4	11.3	12.2	13.3	8.5	16.2	11.4	19.5	12.5	16.6
T_2	0-20	12.7	15.1	10.5	12.1	16.2	14.7	11.0	16.3	13.6	20.1	16.8	17.2
	20-40	13.5	13.7	10.5	11.5	13.8	15.4	9.4	16.9	12.9	19.4	14.1	16.5
T_3	0-20	14.5	14.3	12.9	12.0	16.7	13.7	12.6	17.7	12.4	19.9	14.6	19.1
	20-40	15.4	14.9	12.0	11.4	16.1	14.3	10.0	18.9	12.3	20.0	15.8	19.9
T_4	0-20	14.6	17.2	12.9	13.0	16.7	14.1	10.8	15.8	12.2	19.9	16.9	18.5
	20-40	14.5	15.1	12.3	11.2	19.9	15.6	9.3	16.0	11.9	19.7	17.2	20.6
T_5	0-20	14.7	15.0	12.1	11.6	14.5	17.3	11.6	18.9	13.2	20.4	15.1	19.4
	20-40	12.7	15.9	12.8	11.6	11.8	15.8	8.9	15.7	12.5	20.4	15.0	18.3
T_6	0-20	15.3	15.7	13.4	10.6	15.8	13.85	9.5	17.9	13.7	20.1	16.8	19.3
	20-40	14.6	14.9	11.3	11.7	16.2	14.0	9.7	16.8	11.6	22.8	15.5	18.4

treatment separation on the content of exchangeable K did not have a clear pattern during the first season of the study (F>0.005).

Generally, results shown in Tables 2-4 indicate that there was an accumulation of available P in the topsoil (0-20 cm) and its reduced content in the upper subsoil (20-40 cm) across all phenological stages. There was a bulge of available P content in the topsoil of about 0.1-2.8 mg 100 g^{-1} soil and

0.2-3.0 mg 100 g^{-1} soil compared with its content in the upper subsoil in the first and second seasons, respectively. This observed pattern was not particularly surprising as it confirmed the relatively rapid fertilizer-P-fixing capacities of most soils reported by Olsen *et al.* (1977) and Olsen and Khasawneh (1980). The immobility of P from topsoil to lower subsoil caused the apparent accumulation of this element in the topsoil where, depending on the prevailing soil conditions, it is slowly released into available forms observed in this study.

Results presented in Tables 2 and 3 show that the content of labile P and exchangeable K in the soil profile dwindled by as much as 8.1 mg 100 g^{-1} soil or 46.6% and 21.9 mg 100 g^{-1} soil or 77.9% between tillering and stem elongation phenological stages in the second season, respectively. This was largely attributed to rather excessive rain (Table 1) received in April and May (34 and 111 mm) of the second season compared with that received during the same period (71 and 46 mm) of the first season. Douglas (1982) and numerous other citations reported increased leaching of soluble K and other basic cations by excessive drainage water thereby creating a relatively acidic environment. Under such conditions, the presence of soluble aluminium and iron increases the fixation of P into non-available forms.

Peak build-ups of labile P (11.0-17.3 mg 100^{-1} soil) and exchangeable K (19.1-28.1 mg 100 g^{-1} soil) in the soil profile were observed at tillering stage before rapidly dwindling to as low as 9.0 and 16.6 mg 100 g^{-1} soil, respectively at anthesis in the first season of the study. In the second season this trend was largely distorted by excessive rainfall. For the first season, this pattern was consistent with research results elsewhere. Anicst (1986), Tolstousov (1987) and Gubanov and Ivanov (1988) reported peak P uptake by wheat plants between stem elongation and anthesis, which caused the P depletion in the soil profile. Kumakov (1988) and Gubanov and Ivanov (1988) observed a comparatively high potassium requirement by wheat plants between seed germination and anthesis. However, at milky ripe stage the content of exchangeable K exceeded that at tillering stage by as much as 8.9 mg 100 g^{-1} soil. This was attributed to the release of K by wheat plant roots into the soil towards the end of the vegetative period reported by Gubanov and Ivanov (1988), Tolstousov (1987) and Anicst (1986).

The means presented in Table 4 show that N fertilizer timing and placement method has significant effect ($F<0.005$) on the accumulations of P and K in the soil profile. Single basal application of N (T_2) had the lowest accumulations of available P (9.4-16.1 mg 100 g^{-1} soil) compared with other treatments in which N was applied. T_3 plots in which $N_{45}P_{90}K_{60}$ was applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method, recorded the highest content of available P (19.9 mg 100 g^{-1} soil). The single split application of N (N_{45}) as ammonium nitrate may have created a rather acidic environment, which is conducive for the temporary solubility of P compounds coupled with a rather subdued growth of wheat plants and the related low uptake of P under dwindling supply of N in post-tillering period. The same trend was perpetuated in the accumulations of exchangeable K during the growth and development of the wheat crop. T_3 plots had the highest content of K (13.0-20.6 mg 100 g^{-1} soil). This was largely attributed to the reduced plant growth associated with this treatment and the related subdued uptake of this nutrient by N-F starved wheat plants in the post-tillering period.

In both seasons of the study, the distribution of exchangeable K in the soil profile showed distinct accumulations ($F<0.005$) of exchangeable K in the topsoil (0-20 cm) despite the widely reported downward mobility of cationic K in aqueous soil environments. Peak build-ups of exchangeable K in the top soil of 26.3-28.1 mg 100 g^{-1} soil against 20.5-23.3 mg 100 g^{-1} soil in the subsoil were observed in T_4 and T_5 plots at tillering and anthesis phenological stages, respectively in the first season. In the second season of the study, the same trend was observed in dynamics of mobile K in the soil profile. However, the accumulations of K in the topsoil against those in the subsoil dwindled significantly in the second season of the study. This was, perhaps, attributed to rather excessive precipitation received in the second season of the study compared with that received in the first season (Table 1). Results presented in Tables 1, 2 and 3 indicate that total annual rainfall totals are highly correlated ($r^2 = 0.8942$) with the distribution and dynamics of exchangeable K in the soil profile.

Results of the two-year research study clearly show a distinct pattern of N fertilizer placements methods and timing effects on the distribution of available phosphorus and exchangeable potassium in the soil profile across all phenological stages ($F<0.005$). An early application of N fertilizer in $N_{45}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method recorded the highest contents of available P (19.9 mg 100 g^{-1} soil) and exchangeable K (13.0-20.6 mg 100 g^{-1} soil). However, the effect of dynamics of available P and exchangeable K in the soil profile under the influence of different methods of placements and timing of N fertilizer on rainfed spring wheats yield and grain quality requires further investigations.

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