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The Effect of Timing and Placement Method of N Fertilizer on Soil Profile NO_3-N and NH_4-N Fluctuations and Distribution in a Leached Chernozem under Spring Wheat (*Triticum aestivum*, Cv. Spectrum)

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Abstract: Field experiments were carried out to determine the effect of timing and N fertilizer placement methods on NO_3-N and NH_4-N fluctuations and distribution in a leached chernozem under spring wheat (*Triticum aestivum*, Cv. Spectrum) in 1987 and 1988 summer seasons in Eastern Europe. Spring wheat was grown under rainfed conditions with the following treatments. Control $N_0P_0K_0$ No fertilizer applied (T_1); $N_{90}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting (T_2); $N_{45}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method (T_3); $N_{45}P_{90}K_{60}$ 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_4); $N_{45}P_{90}K_{60}$ 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_5) and $N_{45}P_{90}K_{60}$ 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 (T_6). Data showed that there was a distinct pattern of nitrate movement down the soil profile as the nitrate bulge became more pronounced with depth across all phenological stages of wheat plants in both years of the study. During the first and second seasons of study soil profile NO_3-N content steadily decreased from tillering to anthesis before rapidly increasing just after anthesis to mature stages. Single basal N fertilizer applications before planting (T_2) and single split application of N_{45} at tillering stage by broadcasting (T_3) had the most significant decline in nitrate content (0.13 mg/100 g soil) between tillering and anthesis. Comparatively small decreases in nitrate content between the two growth stages were recorded in T_5 and T_6 (0.07 mg/100 g soil). The decline in nitrate content from tillering to anthesis coincided with peak uptake of N from the soil by wheat plants. Highest and lowest decreases in soil nitrate indicated the lowest and highest NUE associated with the treatments respectively. Wheat plants normally cease uptake of N from the soil by the boot stage even at higher N application rates. N fertilizer placements by broadcasting have been reported to be least efficient in recent reviews on N fertility management. This study, however, recorded the most significant maintenance of elevated amounts of NO_3-N in the soil profile even at peak N uptake by wheat plants in plots where triple split applications of N were undertaken by broadcasting (T_4). Triple split applications of N fertilizer by broadcasting method maintain comparatively higher amounts of NO_3-N in the soil profile than single split N applications by broadcasting (T_3). Foliar triple split applications (T_5) and triple split applications of N by banding in solution form (T_6) had similar effects on the distributions and fluctuations of NO_3-N and NH_4-N in the soil profile. Soil profile NH_4-N accumulations were highest at tillering (3.97 mg/100 g soil) before rapidly thinning out to 0.12 mg/100 g soil in the plough layer in plots where all N was applied as incorporated basal fertilizer before planting in the second season of the study. Single split applications of N_{45} at tillering stage had significant bulge of NH_4-N in both the plough (0.40 mg/100 g soil) and upper subsoil (0.31 mg/100 g soil) compared with triple split applications in rates of N_{15} in the first season of the study.

Key words: N fertilizer, placement, timing, N use efficiency

INTRODUCTION

Much of the increase in world agricultural production and production per capita can largely be attributed to a rapid increase in the use of mineral fertilizers. In the 1950s global fertilizer use was in the region of 14 Mt (NPK) and 146 Mt in 1989 [1].

FAO[1] reported that in many developing countries both higher yields per ha and more land under cultivation have contributed to the rise in production; but in the developed world and much of the South and East Asia, there have been dramatic increases in the yield per ha through introduction of better crop varieties, which inevitably require high fertilizer, pesticides and water inputs. More money and effort has been and are being spent on the study and management of nitrogen than any other mineral nutrient. Nitrogen deficiency fore bodes crop failure, financial ruin and hunger for people in all corners of the world[2]. Ritter and Chirnside[3], Bock and Hergert[4] observed that the management of N is critical in all crop production systems from both economical and environmental standpoints. Excess nitrogen in the soil- water-atmosphere system can lead to dying forests, declining fisheries, increased risks of toxicity to humans and other widespread environmental problems[5].

Numerous physiological processes associated with wheat growth are influenced by N fertility. In many wheat-growing areas increasing the N fertility results in greater maximum Leaf Area Index (LAI), vegetative dry matter and leaf N concentrations[6].

Today, the maximization of Nitrogen Use Efficiency (NUE) is rapidly becoming an important aspect of crop management systems because of both economic and environmental pressures. There is overwhelming empirical evidence that improper N fertilizer management may be responsible for NO_3- contamination of numerous important aquifers in the USA and European countries[3,5,7]. Placement of N fertilizers is an integral component of efficient crop management. Fertilizer placement can affect both crop yield and NUE[4,5,7,8].

There are numerous recommendations in literature aimed at improving N utilization by wheat plants. N fertilizer placement that correlates with plant needs is acknowledged to best increase plant N use efficiency[9]. Evidence gathered from solution culture[10] and pot culture studies[11] have proved beyond doubt that the yield of wheat was higher in the presence of both ammonium and nitrate forms of N compared to either alone. The physiological basis for a positive plant response to combined ammonium-nitrate nutrition was summarized by Bock[11].

Several research studies have supported the idea that banding generally produces more efficient plant utilization of fertilizer N than broadcasting. In banding, the N fertilizer is applied in bands before planting or at the side of the plant. Soper *et al.*[12], Toews and Soper[13], Tomar and Soper[14] observed a 20% increase in NUE for band placement compared with surface broadcast.

Mahler *et al.*[15], Bock[11], Severson and Mahler[16] reported that band applications of N fertilizers on wheat are generally preferred over applications by broadcast method for at least five reasons: the fertilizer is placed where small seedling root systems can more readily utilize the N nutrient; the amount of fertilizer needed per unit area is lower than with broadcasting; fertilizer is positionally more available to the wheat crop than to germinating weeds; only one operation is needed with planting and there is less loss of N due to erosion and immobilization.

Small amounts of seed-banded N, when used with other placement methods, can also be used to improve wheat yield[14]. Maximum safe N rates for seed banding vary, but are usually small (<30 kg N ha^{-1}) and are dependent on soil moisture, texture, temperature, and N source[16,17]. Increased yields associated with placement of N fertilizers either with or below the seed has been attributed to an accelerated rate of early plant growth[18,19]. Johnston and Fowler[8], Toews and Soper[13], Mahler *et al.*[15] 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. However if the fertilizer is banded at planting germination may be affected, especially when rainfall is inadequate.

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[5]. The broadcasting method, compared with other placement methods, is relatively fast and distribution of fertilizer encourages a wider root network and it is the only practical fertilizer application method to established forage, close growing crops and extensive areas under cropping[19,20]. Tisdale *et al.*[21] reported a major disadvantage of the placement of N fertilizer by broadcasting in that it does not optimize the use of limited fertilizer resources and may just be as available to the weeds as it is to the crop. Ritter and Chirnsside[3], Keeney and Follet[5], Bock and Hergert[4] concurred that when N fertilizer is left on the surface after broadcasting it is easily washed away with runoff during heavy rains into unprotected (with no buffer strips) rivers and lakes, where it causes eutrophication.

There are numerous citations and published materials which suggest that N fertilizer, especially ammonium nitrate, can be applied to crops as liquid fertilizer or solutions of N using three primary methods: direct application of N solution by banding near the root zones of growing plants; application in irrigation water and spraying plants with N fertilizer solutions as foliar applications. Plants are capable of absorbing nutrients through their leaves in limited quantities[13,18]. They reported that foliar application of N fertilizer involves spraying a dilute solution directly onto plant leaves. While a few spray applications may deliver the entire season's requirement for micronutrient, only a small portion of the N nutrient needs can be applied in this manner. It should be noted, however, that what drips or is washed off the leaves is not lost, for it falls on the soil and may later be absorbed by the plants.

With the use of labeled ^{15}N Harper *et al.*[22] highlighted that about one-third of the total nitrogen in the grain was derived from fertilizer N when 112 kg ha^{-1} was applied as a split application of 39.2 kgha^{-1} in November and 72.8 kg ha^{-1} in March in a loamy soil in Eastern USA. Olson and Swallow[23] reported that the grain removed approximately 30% of applied N fertilizer. The differential was attributed to immobilization of fall-applied fertilizer N. Residual soil N in the 1.8 m profile accounted for approximately 50% of applied fertilizer N at the end of the trial.

Jury and Nielson[24], Gubanov and Ivanov[20], Ritter and Chirnside[3], Keeney and Follet[5] confirmed that the time of N fertilizer application is of fundamental importance from an environmental point of view, because N present as NO_3-N can leach below the crop root zone if the soil profiles are saturated and precipitation exceeds evapo-transpiration for extended periods. They reported that timing of N fertilizer applications is governed by several basic considerations: making the nutrient available when the plant needs it; avoiding excess availability of N before and after the principal period of plant uptake; making N available when it strengthens, not weaken, long-season and perennial plants; conducting field operations when conditions make them practical and feasible.

Many researchers have confirmed that the distribution and fluctuations of soil mineral N reflect the net effect of inputs from mineralization, atmospheric deposition and fertilizer inputs and removal by plant uptake, immobilization and leaching and gaseous losses. Consequently, all natural conditions that affect the above processes, also affect the fluctuations of concentrations and distribution of NO_3-N and NH_4-N in the soil profile. Amongst a host of factors, of great importance are temperature and rainfall. Besides affecting microbial activities associated with N conversions, moisture is the medium for the leaching of mineral N down the soil profile thereby affecting its profile distribution[25]. The movement of dissolved NO_3 ion through the soil is governed by two mechanisms: convection or mass flow of the ion with moving soil solution and diffusion of the chemical within the solution[24]. Preferential (macropore) flow may not significantly affect the concentration and distribution of residual mineral N in the soil because the later is found predominantly in the micropores[25].

The synchronization of supply of N and crop demand is pivotal in controlling the NO_3-N and NH_4-N accumulation in the soil. Smith and Whitfield [26] reported 18-30% lower N uptake in wheat due to delayed application of N fertilizer until heading under rainfed conditions. They noted that N uptake ceased by the boot stage even at high N rates and further growth depended entirely on remobilization of N in the vegetative tissue.

Several studies have indicated that grain N in wheat is translocated primarily from vegetative parts after anthesis[27,28]. Evaluations of N uptake and remobilization within the plant throughout the crop-growing season provide information that can be used to predict N fertilizer requirements and timing[29,30].

Cox and Reisenauer[10], Gubanov and Ivanov[20], Kumakov[31] 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.

While it is generally accepted that soil mineral N content is a result of the net effects of inputs from mineralization, atmospheric deposition, immobilization, leaching and gaseous losses, the role played by fertilizer inputs (rates, placement methods and timing) and N uptake by plants (over vegetative and reproductive growth stages) with the direct influence of climatic conditions is of great significance in determining the fluctuations and distribution of soil mineral N[2,4,6,21] in agro-ecosystems. Consequently, the objective of the 2 year study was to determine the effect of N fertilizer placement methods and timing on the soil profile distribution of mineral N (NO_3-N and NH_4-N) during the vegetative and reproductive periods of spring wheat on leached chernozems. Because climatic conditions have significant influence not only on growth and development of spring wheat, but also the distribution and fluctuations of soil mineral N monthly data on temperature and precipitation were recorded and analyzed.

There has been extensive research on the residual aspects of N fertilization, but few relate effects of timing and placements methods on profile NO_3-N and NH_4-N distribution and fluctuations at different phenological stages of wheat plants.

MATERIALS AND METHODS

The field study site: The two-year study (1987-1988) was conducted at Krasnodar Agricultural Research Institute in Krasnodar County (45°5'N, 38°50'E, >400 m elev.) of the Federal Republic of Russia (Eastern Europe) to determine the effect of timing and placement methods of N fertilizer on profile NO_3-N and NH_4-N content and distribution in a leached chernozem (black earth) under rainfed spring wheat (*Triticum aestivum* Cv. Spectrum). The spring wheat crop was planted in the autumn and harvested in the summer of 1987 and 1988.

Soils: 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[2].

Weather conditions: 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.

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.

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

Treatments: The spring wheat cultivar Spectrum was used in this study. Prior to the experiment, the plots were under continuous wheat production for several years using conventional tillage systems. Wheat was drill-seeded on 2 March 1987 and 7 March 1988 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 replications. The following N fertilizer treatments were applied to determine their effect on soil profile distribution and fluctuations of mineral N at tillering, stem elongation, heading, anthesis, milky ripe and mature vegetative and reproductive stages of spring wheat: Control $N_0P_0K_0$. No fertilizer applied (T_1); $N_{90}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting (T_2); $N_{45}P_{90}K_{60}$ applied as incorporated basal fertilizers before planting and N_{45} applied at tillering stage by broadcasting method (T_3); $N_{45}P_{90}K_{60}$ 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_4); $N_{45}P_{90}K_{60}$ 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_5) and $N_{45}P_{90}K_{60}$ 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 (T_6).

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 treatments 3-6.

Soil sampling: Soil sampling was designed to coincide with the six major phonological growth and development stages of wheat plants. Soil cores were taken by auguring at tillering, stem elongation, heading, anthesis, milky ripe and mature stages. The augur samples were collected at 0-20 and 20-40 cm from three augur positions in each plot. Considering the small size of the plots three augur positions were deemed adequate. Three augur sub-samples from corresponding horizons (e.g. 0-20 cm) were thoroughly mixed to constitute a soil sample.

Determination of NO_3-N and NH_4-N in soil samples: Field moist soils (10 g) were extracted in 50 mL 0.5 M KCl. The NH_4-N phenate method was used for NH_4-N determination while the NO_2-N cadmium reduction method[32] was used for NO_3-N determination.

RESULTS AND DISCUSSION

Generally, there was a significant treatment effect on the soil profile distribution and content of NO_3-N and NH_4-N in the first (March-July 1987) and second (March-July 1988) growing seasons.

There was a clear pattern of nitrate movement down the soil profile as the nitrate bulge became more pronounced with depth. The concentration of NO_3-N in the plough layer (0-20 cm) was lower than that in the upper subsoil (20-40 cm) by about 3.4-40.1% (0.01-0.09 mg/100 g soil) for all the treatments, except T_3, throughout the six phenological phases of wheat plants during the first season of study (Table 2). Accumulation of NO_3-N below the plough layer observed in almost all the treatments in this study is consistent with findings elsewhere. Roth and Fox[25], Jury and Nielsen[24] reported significant movement of dissolved NO_3 ion through the soil profile by convection or mass flow with moving soil solution and by diffusion of the chemical within the soil solution under natural and cropped systems. This study reconfirmed NO_3-N leaching losses into the subsoil where the wheat crop root system is not sufficiently developed to effectively intercept the nitrate ions thereby exposing them to possible translocation into underground water systems where, they pose pollution hazards.

Table 1: Precipitation and temperature data

Months	Atmospheric temperature (°C) 1986	1987	1988	Long term average	Rainfall totals (mm) 1986	1987	1988	Long term average
Jan.	4.7	-1.7	-1.5	-2.3	88	0	51	35
Feb.	-2.0	2.7	-1.7	-1.1	103	23	39	37
Mar.	3.5	-0.7	6.6	4.5	1	36	64	35
Apr.	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
Jun.	21.1	19.5	20.7	20.0	68	132	307	61
Jul.	23.1	23.2	24.3	23.2	6	70	53	65
Aug.	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
Oct.	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	42.3	128.3	715	650	990	566
Average	11.43	10.23	11.86	10.69	59.58	54.2	82.5	47.2

Table 2: Profile NO_3-N and NH_4-N distribution for each treatment at different stages of wheat plant growth and development, mg/100 g soil, 1987

		Phenological stages of wheat plants											
		Tillering		Stem elongation		Heading		Anthesis		Milky ripe		Mature	
Treat-ment	Depth (cm)	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
1	0-20	0.19	2.33	0.16	2.28	0.17	1.53	0.13	1.70	0.13	1.06	0.19	1.0
	20-40	0.24	2.13	0.18	2.03	0.18	1.67	0.15	2.66	0.15	1.23	0.25	1.27
2	0-20	0.21	1.97	0.27	3.17	0.21	2.22	0.15	2.0	0.21	0.93	0.23	1.05
	20-40	0.28	1.19	0.22	3.10	0.23	2.53	0.15	1.79	0.16	1.30	0.26	1.42
3	0-20	0.22	2.37	0.24	2.83	0.24	2.06	0.18	1.80	0.19	1.32	0.28	1.26
	20-40	0.31	2.50	0.25	3.12	0.23	2.61	0.18	2.20	0.18	1.22	0.20	1.32
4	0-20	0.26	2.14	0.24	3.01	0.19	2.57	0.24	1.88	0.15	1.40	0.24	1.14
	20-40	0.26	2.07	0.26	3.17	0.21	2.86	0.25	1.83	0.30	1.19	0.25	1.25
5	0-20	0.26	2.15	0.21	2.83	0.27	3.24	0.19	1.99	0.17	1.21	0.28	1.23
	20-40	0.29	2.26	0.29	3.71	0.27	2.50	0.21	2.63	0.23	1.64	0.34	1.27
6	0-20	0.27	2.20	0.18	3.41	0.23	1.89	0.20	1.93	0.29	2.10	0.25	1.09
	20-40	0.21	2.27	0.25	2.54	0.27	2.31	0.23	2.89	0.30	1.95	0.30	0.98

Data presented in Table 2 show a steady decrease of NO_3-N content from tillering to anthesis before rapidly increasing just after anthesis to the mature stages. The most significant decline in nitrate content from tillering to anthesis was observed in T_2 and T_3 (0.13 mg/100 g soil) followed by T_5 and T_6 (0.07 mg/100 g soil) in the upper subsoil (Table 1), respectively. Distinct rapid decline in nitrate content in the soil profile in plots where N fertilizerwas applied once as basal fertilizer before planting (T_2) and as a single split application of N_{45} at tillering stage by broadcasting (T_3) is a clear indication of lower NUE associated with the broadcasting method and single basal N fertilizer applications reported by Soper *et al.*[12], Toews and Soper[13], Tomar and Soper[14]. They observed 20% NUE for band placement T_6 compared with surface broadcast. T_6 had lower decline in nitrate content during peak N assimilation by wheat plants because of improved NUE associated with band placement.

Triple split applications of N to wheat plants (T_5) had comparatively similar effects on the content and distribution trend of NO_3-N from tillering to anthesis and late anthesis to mature stages as those in T_6 (Table 2). This finding was not particularly surprising as the N fertilizer in both cases was split applied in solution form. In addition to that, Toews and Soper[13], Cooke [18] and Brady[2] reported very limited quantities of fertilizer N that can be absorbed by plant leaves after foliar applications. The larger quantities of foliar applied N drips or are washed off the leaves by rain to the soil surface where its effects on the distribution and fluctuations of NO_3-N and NH_4-N in the soil profile are similar with those from band placements in solution form.

In the study triple split applications of N fertilizer by broadcasting method (N_{15}x3 in T_4) significantly maintained elevated contents of NO_3-N in the soil profile even at peak assimilations of N by wheat plants during the first season of study.

Nitrate depletion from tillering to anthesis growth and development stages was lowest in T_4 plots in both the plough (0.02 mg/100 g soil) and upper subsoil (0.01 mg/100 g soil). While Soper *et al.*[12], Toews and Soper[13] and Tomar and Soper [14]observed 20% increase in N use efficiency (NUE) for band placement (T_6) compared with surface broadcast (T_3 and T_4) this study reported improved maintenance of higher of NO_3-N in the soil profile even at peak assimilation of N by wheat

Table 3: Profile NO_3-N and NH_4-N distribution for each treatment at different stages of wheat plant growth and development, mg/100g soil, 1988

		Phenological stages of wheat plants											
		Tillering		Stem elongation		Heading		Anthesis		Milky ripe.		Mature	
Treat-ment	Depth (cm)	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
1	0-20	0.14	1.93	0.01	0.78	0.04	0.47	0.06	0.98	0.09	0.90	0.10	0.68
	20-40	0.15	1.71	0.02	0.65	0.04	0.37	0.12	1.14	0.09	0.87	0.09	0.26
2	0-20	0.34	3.97	0.03	0.30	0.12	1.08	0.14	1.68	0.13	1.48	0.12	1.03
	20-40	0.23	1.42	0.02	0.69	0.12	1.01	0.14	1.55	0.13	1.23	0.13	1.25
3	0-20	0.19	2.14	0.04	1.60	0.10	1.00	0.14	2.00	0.12	1.22	0.16	1.85
	20-40	0.32	2.79	0.05	0.93	0.08	0.76	0.13	1.50	0.10	0.98	0.17	1.25
4	0-20	0.29	1.99	0.02	1.41	0.09	1.12	0.23	1.41	0.14	1.15	0.22	0.64
	20-40	0.25	2.86	0.02	1.11	0.08	0.89	0.13	1.91	0.11	1.17	0.15	0.77
5	0-20	0.25	2.19	0.02	1.33	0.07	1.20	0.12	1.69	0.15	1.81	0.19	0.88
	20-40	0.20	1.94	0.02	1.05	0.08	1.22	0.12	1.57	0.14	1.17	0.16	1.07
6	0-20	0.28	2.37	0.03	1.28	0.08	0.71	0.14	1.64	0.13	0.99	0.54	0.95
	20-40	0.20	2.07	0.02	0.55	0.07	0.31	0.13	2.00	0.12	0.87	0.18	0.98

plants when N fertilizer is split into three applications at tillering (N_{15}), stem elongation (N_{15}) and heading (N_{15}) by surface broadcast (T_4). Higher maintenance of N in the soil at peak uptake is probably associated with greater N use efficiency by plants. Keeney and Follet[5] reported that surface broadcasting method, compared with other methods, encourages a wider root network which efficiently absorbs N from the soil.

The steady decline in nitrate content from tillering to anthesis observed in this research is consistent with findings elsewhere. Rao and Dao [33], Mahler *et al.*[15] and Kumakov [31] observed maximum uptake of N from the soil by wheat plants between tillering and anthesis phenological stages when wheat plants accumulate 70-80% of total N requirements over a period 25-30 days. On the other hand, towards the end of anthesis the plants will have accumulated only 50-60% of dry matter. This explains the rapid decline in nitrate content in the soil from tillering to anthesis phenological stages observed in this research.

Table 2 shows that single split applications of N_{45} at tillering stage had significant bulge of NH_4-N in both the plough (0.40 mg/100 g soil) and upper subsoil (0.31 mg/100 g soil) compared with triple split applications in rates of N_{15} in the first season of study. Treatments separation on the effect of single split and triple split N fertilizer applications on the content of NO_3-N in the soil profile was not significant. Rapid adsorption of NH_4-N and mobility of NO_3-N in the soil profile probably explains this finding of the study.

Treatment separation on the basis of soil profile distribution and accumulation of NH_4-N over all the growth and development stages of spring wheat has been less convincing for the 1987 season. This was, perhaps, due to lower precipitation received during March to July period in 1987 compared with same period in 1988 (Table 1). Roth and Fox[25] indicated that moisture has fundamental influence on the distribution of NH_4-N and NO_3-N in the soil profile.

Data presented in Table 3 shows comparatively higher amounts of NH_4-N in the plough layer (0-20 cm) and lower amounts in the upper subsoil (20-40 cm) in almost all the treatments in the 1988 season. In this respect, the findings of this study were consistent with research results elsewhere. The NH_4-N ion being positively charged is effectively adsorbed by the negatively charged clay micelles and is therefore comparatively less susceptible to translocation into subsoil zones.

Soil profile NH_4-N accumulations were highest in the plough layer in T_2 plots where N was applied once as incorporated basal fertilizer (N_{90}) at tillering stage (3.97 mg/100 g soil) before rapidly thinning out to 0.12 mg/100 g soil at milky ripe phenological stage in the second season of study (Table 3). This trend was maintained in all the treatments. The finding of this research was consistent with research results elsewhere as spring wheat plants were reported by Kumakov[31], Gubanov and Ivanov[20], Harper *et al.*[22] to have maximum assimilation of N from the soil between tillering and anthesis stages (50-60%N over 25-30 days). Maintence of higher levels of NH_4-N in the plough layer between tillering and milky ripe stages were observed in the plots in which all the N fertilizer was applied as a basal application (T_2). At milky ripe N uptake from the soil by the wheat plants is significantly low. Smith and Whitfield[26] observed that N uptake ceased by the boot stage even at higher N rates and further growth depended entirely on remobilization of N in the vegetative tissue. T_2 has extended periods in which elevated contents of NH_4-N may be of no significance to the growth and development of spring wheat and in the case of NO_3-N may pose environmental problems.

Table 4: Profile NO_3-N and NH_4-N distribution for each treatment at different stages of wheat plant growth and development, mg/100 g soil, 1987-1988 (Average)

		Phenological stages of wheat plants											
		Tillering		Stem elongation		Heading		Anthesis		Milky ripe		Mature	
Treat-ment	Depth (cm)	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
1	0-20	0.17	2.13	0.09	1.53	0.11	1.00	0.10	1.34	0.11	0.98	0.15	0.84
	20-40	0.70	1.92	0.10	1.34	0.11	1.02	0.14	1.90	0.12	1.05	0.17	0.77
2	0-20	0.28	2.97	0.15	1.74	0.17	1.65	0.15	1.84	0.17	1.21	0.18	1.04
	20-40	0.25	1.81	0.12	1.91	0.18	0.20	0.15	1.67	0.15	1.27	0.20	1.34
3	0-20	0.21	2.26	0.14	2.26	0.17	1.53	0.16	1.90	0.16	1.27	0.22	1.34
	20-40	0.29	2.65	0.15	2.03	0.16	1.69	0.16	1.85	0.14	1.10	0.19	1.56
4	0-20	0.28	2.07	0.12	2.21	0.14	1.85	0.19	1.65	0.16	1.28	0.23	1.29
	20-40	0.25	2.47	0.14	2.14	0.15	1.88	0.19	1.87	0.13	1.18	0.20	0.89
5	0-20	0.25	2.17	0.12	2.08	0.14	2.22	0.16	1.84	0.16	1.01	0.24	1.01
	20-40	0.25	2.10	0.16	2.38	0.18	1.86	0.17	2.10	0.19	1.41	0.25	1.05
6	0-20	0.27	2.29	0.16	2.35	0.18	1.30	0.17	1.79	0.21	1.55	0.40	1.02
	20-40	0.21	2.17	0.10	1.55	0.15	1.31	0.18	2.45	0.21	1.41	0.24	0.98

In the second season of the study NO_3-N soil profile distribution trend of the first season was less convincing in most of the treatments (Table 3). In the T_4 and T_6 the concentration of NO_3-N in the plough layer was significantly higher than that in the upper subsoil by about 7.1-33.3% (0.01-0.08 mg/100 g soil) over the six vegetative and reproductive periods of spring wheat for the reasons given above. In T_2 and T_5 this trend of NO_3-N distribution in the soil profile did not have a definite trend before or after stem elongation, at heading, anthesis and before or after milky ripe phenological stages. The control treatment did not show a definite trend of soil profile distribution of nitrate nitrogen in the second season of study. The concentration of NO_3-N in the both soil layers, except at tillering stage, was significantly depleted by about 50% in the second season compared with first season of study.

A combined analysis of data (Table 4) show a significant depletion of NO_3-N in the plough layer and its accumulation in upper subsoil for almost all the treatments over all phenological phases for the reasons given in Table 4.

The lowest amounts of mineral nitrogen accumulations were recorded in control plots across all phenological phases of spring wheat for two seasons of study. Higher nitrate N concentrations were also recorded in the mature growth stage. Numerous research findings elsewhere have confirmed that at anthesis wheat plants cease assimilation of N from the soil and hence the significant bulge in the NO_3-N concentrations from this phenological phase to mature stage. The residual N left in the soil profile after milky ripe stage may find its way into the underground water systems where it poses an environmental hazard.

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