CHANGES IN AVAILABLE NITROGEN OVER A FALLOW SEASON IN AN UNDULATING LANDSCAPE IN SOUTHWESTERN SASKATCHEWAN

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Abstract

Spatial and temporal bioavailability of mineral N (NO_3-N) over the fallow season as influenced by conventional and no-till herbicide (chemfallow) tillage systems was studied at the landscape-scale in the Brown soil zone, near Central Butte, Saskatchewan. Irrespective of tillage systems, average soil temperature for the 5 cm depth increased over the summer and gradually declined as the fall approached. Although the chemfallow site showed slightly lower soil temperature, no significant differences were observed either at the landscape-scale or at the landform-scale. A distinct spatial pattern of soil moisture distribution was observed among the different slope positions: shoulder < level < footslope. Gravimetric soil moisture content over the season was always higher in chemfallow compared with conventional fallow. The bioavailability of mineral N was assessed by continuous ***in situ*** burial of anion exchange membranes and soil extraction with 2M KC1 solution over the fallow season. Greater soil moisture content and lack of incorporation of crop residue into the soil in the chemfallow system caused significantly higher bioavailable N compared to conventional fallow. At the landform scale, footslope positions had significantly higher NO_3-N compared with level, which was in turn higher than that of shoulder positions.

Introduction

In the semiarid regions of Saskatchewan, summer fallowing, in which the land is left uncropped and weed free, is commonly practiced by farmers to improve soil-water reserves for the succeeding crop. Traditional method of controlling weeds by soil tillage (conventional tillage) during the fallow season has some deleterious effect on soil properties by leaving the soil prone to erosion. For example, soil loss by wind and water erosion has seriously reduced the amount and quality of the soil organic matter (McGill et al., 1981; Campbell et al., 1986). Concern over the cost and need for soil tillage both from an economical and ecological point of view has encouraged some farmers to adopt no-till herbicide fallow systems (chemfallow). Soil management practices such as soil tillage can modify some of the physicochemical and biological properties of soil, thereby affecting plant nutrient turnover in soil. Previous studies conducted elsewhere suggest that among the major plant nutrients, nitrogen (N) mineralization-immobilization processes are more sensitive to changes in tillage system.

To enhance our knowledge of N dynamics and thereby assure greater effective utilization of soil and fertilizer N in chemfallow systems short-term characterization of temporal and spatial N mineralization patterns from decomposing crop residue and soil humus over the fallow season is needed. Although considerable information is available on the effect of tillage systems on N dynamics during the cropping season, very little or no information is available on the bioavailability of N over the fallow season at the landscape-scale under field conditions. Hence, this study was conducted to determine the interactive effects of two fallow systems with different slope positions in a typical soil landscape of the study region on the spatial and temporal mineral N availability over the fallow season.

Materials and Methods

Description of the Experimental Site: A nitrogen mineralization study at the landscape-scale was conducted in the spring of 1994, near Central Butte, Saskatchewan, in the Brown soil zone. A variable undulating to rolling topography (150 X 150 m) which has been under conventional fallow for about 70 yr was selected for establishing chemfallow and conventional tillage fallow cropping systems. A 10 m square systematic grid design was laid out on the surface. The point of intersection of the grid constituted the sampling point. Based on the topography survey and digital elevation model, the points were quantitatively classified into either shoulder (SH), footslope (FS), or level (LE) landform element complexes (Pennock et al., 1987, 1994). This landscape (0.5 to 3.0 m slope) was further divided equally into two parts to establish two fallow systems. From each of the landform element complexes, ten sampling points were randomly selected for the subsequent study.

Soil Management Practices: Over the fallow season weed growth was controlled by soil tillage on the conventional site or by applying herbicide on the chemfallow system. On the conventional site soil was tilled using a John Deere 610 Heavy Duty Cultivator with 18" sweeps, 12' spacing, no rod and no harrows for two times: May 25, June 28, and as outlined previously but with rod and harrows on July 27 and September 6. For the chemfallow site, a mixture of glyphosate, Dicamba and Agral 90 surfactant @ 0.25 L/acre, 0.13 L/acre and 0.07 L/acre, respectively was applied with a Melroe 210 spray coupe @ 2 gallons of water/acre on May 24 and September 4.

Soil **Temperature and Soil Moisture Determination:** Average soil temperatures (5 cm depth) at three slope positions were monitored using copper constantan thermocouples which were in turn connected to a Campbell Scientific CR 10 digital recorder. The percent moisture in soil samples (O-10 cm) collected at two-week intervals was determined gravimetrically (w/w) by drying soil samples in an oven at 105°C for 24 hr.

Bioavailability of Mineral N: Changes in available N over the season was studied by extracting soil samples with 2M KC1 solution and using anion exchange membranes (AEM) buried directly in the field. The 2-mm air- dried surface soil samples (O-10 cm) collected at two-week intervals were extracted by shaking 5 g of soil with 50 mL of 2M KC1 solution for one hour on a horizontal shaker. Nitrate-N ($KCl\text{-}NO_3$) concentration in the extract was determined using Technicon automated colorimetry. Continuous *in situ* burial of AEM in NaHC03 form for two-week periods at randomly selected sampling points in the field was carried out eleven times over the season. During the two-week burial period, nitrate initially present plus that liberated by mineralization in the vicinity of the membrane is sorbed on the membrane surface. The membranes were removed from the soil after the burial period, washed free of adhering soil with deionized water and carried to the laboratory in ziploc plastic bags. The ions adsorbed on the membranes were eluted as described by Qian et al., 1992. Nitrate-N ($AEM\text{-}NO_3$) concentrations in the HC1 eluants was determined similar to that of KCl-N03.

Statistical Analysis: Descriptive statistics were calculated for the response variables. Based on highly positive skewness and non-normal distribution of the data set, a non-parametric Mann-Whitney U test ($p=0.20$) was used to test the significant differences between the fallow treatments and among the landform element complexes. And, only for $AEM\text{-}NO_3$, comparison between the fallow systems was made at the landscape-scale at each of the sampling periods. Soil temperature data was analyzed by analysis of variance. Least significant differences (LSD, $p=0.05$) was used to compare treatments.

Results and Discussion

Soil Temperature: Irrespective of the fallow systems, mean soil temperature patterns followed similar trends over the season (Fig. la, b). Soil temperatures were slightly lower at 5 cm depth under chemfallow than conventional fallow. Although conventional fallow maintained slightly higher mean temperatures, statistically no significant difference was observed, either between or within the fallow systems. Mean surface soil temperatures under chemfallow and conventional fallow were 17.61 and 18.02°C, respectively. Slightly greater water content and presence and maintenance of crop residue in the chemfallow system may be responsible for slightly lower surface soil temperature in comparison to conventional fallow. Absence of statistically significant differences between the fallow systems might be due to recent initiation of the experiment. Among the different landform element complexes, shoulder positions showed slightly higher temperature compared with level, which is in turn higher than that of footslope positions. These differences may be attributed to differences in soil moisture content and amount of crop residue present at different landform element complexes.

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Figure 1. Average soil temperature over the season for the 5 cm depth, under (a) conventional fallow and (b) chemfallow.

Soil Moisture: Gravimetric soil moisture content over the season followed a similar trend in the two fallow systems (Fig. 2a, b). Soil moisture content fluctuations over the season followed precipitation (data not shown) and soil temperature patterns. However, soil moisture under chemfallow always exceeded that under conventional fallow, based on eleven samplings of the surface (O-10 cm) soil samples, during the season. This pattern resulted in significantly higher median soil moisture content during the fallow period in chemfallow (16.45%) compared to conventional (15.96%) (Table 1). The higher soil moisture content in chemfallow compared to conventional fallow agrees with the findings of Nyborg and Malhi (1989), who observed higher soil moisture in zero tillage plots, at least in the O-15 cm layer, during summer fallow and in May of every year.

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Figure 2. Gravimetric soil moisture content over the season under (a) convential fallow and (b) chemfallow.

Spatially, very distinct patterns of soil moisture distribution were observed among the three slope positions in the fallow landscapes. Soil moisture content within the landscape of the two fallow systems was found to be in the following order: shoulder<level<footslope (Table 2). As reported by Zaslavsky and Sinai (1981), the direction of flow of water on and within the soil is greatly influenced by the slope gradient and form. Hence, movement of water out of convex shoulder portions due to lateral flow results in greater accumulation of water in concave footslope portions of the landscape (Pennock et al., 1994). In a field experiment near Birch Hills, Saskatchewan, Stevenson and van Kessel(l994) also observed 31% greater soil moisture content on footslopes compared to shoulders.

However, in the lower footslopes of the two systems higher soil moisture content was found in conventional fallow (18.82%) than that of chemfallow (17.8 1%). This finding supports earlier observations that the presence of crop residue on the surface helps to increase infiltration and thereby reduce runoff into depressions (Campbell et al., 1988).

2M KC1 Extractable NO_3-N: Surface soil samples (O-10 cm) extracted with 2M KC1 solution gives the concentration of mineral N (KCl-NO_3) at the time of sampling. Changes in KCl-NO_3 content over time indicates losses or gains of nitrate over the time interval. This is different from the AEM, which acts as a continuous sink over the burial period similar to a plant root.

Nitrate-N determined by 2M KC1 extraction showed significant differences between the fallow systems across and within the landscape (Table 1, 2). Median nitrate (O-10 cm) over the season in chemfallow and conventional fallow was 8.50 ug/g and 7.20 μg/g, respectively (Table 1). Overall, nitrate concentration in the O-10 cm layer increased over the fallow season, but exhibited marked spatial and temporal variations during the season. At the landform scale, footslope complexes, due to higher soil moisture content and higher organic N content, showed higher mineral N availability compared to level and shoulder positions. Nitrate was low in the early spring and gradually increased over the summer. A sudden drop was observed on September 6 in the both fallow systems (Fig. 3 , b). Increased soil moisture content, due to a large rainfall on August 27 and possible associated N loss by denitrification, along with intense volunteer cereal growth would have contributed to the low mineral N values observed on September 6.

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Figure 3. 2M KC1 extractable No3-N over the season under (a) conventional fallow and (b) chemfallow.

Bioavailability of NO_3-N as Determined by AEM (AEM-NO_3): The process of nutrient release and its availability for plant uptake is largely controlled by the prevailing soil environment, which is in turn modified by the management practices. Since the mode of extraction of plant nutrients by AEM closely simulates the action of plant roots when buried in the soil, and can also include the effect of environmental parameters and soil conditions as they exist in the field (Qian et al., 1992), continuous *in situ* burial of AEM over the season may help to predict precisely the changes in bioavailability of N that occur. The nitrate accumulated on an AEM during a two-week burial integrates the initial nitrate content., plus mineralization/immobilization gains and losses as they affect bioavailable nitrate over the two-week period.

Both spatial and temporal data on mineral N availability is important in understanding the factors that control N mineralization/immobilization from decomposing crop residues and soil organic matter. During the fallow season, NO_3-N accumulated on burial resin strips continued to increase over the successive two-week burials, reflecting continued mineralization and increased bioavailability of N over the fallow season particularly in the footslope positions (Fig. 4a, b). The median net two-week AEM sorbed NO3 for the whole season (May to October) in chemfallow (13.01 $\mu g/cm^2$) was significantly higher than that of conventional fallow (10.23 $\mu g/cm^2$) (Table 1). This difference may be attributed to the differences in the crop residue management.

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Figure 4. Bioavailability of nitrate determined by AEM in situ burial at two-week intervals over the season under (a) conventional fallow and (b) chemfallow.

In conventional fallow, tillage during the fallow season induces incorporation of low N crop residue into the soil and thereby increases the rate of its decomposition and potential immobilization. Greater moisture content of the chemfallow site would be expected to enhance mineralization and bioavailability of NO_3-N. Drying out of the surface soil during tillage operations in conventional fallow would reduce NO_3-N movement to the resin strip surface.

In contrast to our findings, on a Black Chernozemic and a Dark Grey Chemozemic soil Nyborg and Malhi (1989) observed greater net mineralization with conventional tilled plots compared to zero tilled plots. That is, conventional tillage plots contained greater amounts of nitrate than with zero-tillage plots. Unlike their study, where the cause is predominantly due to tillage treatment alone, in an undulating to rolling landscape like the Central Butte site, apart from tillage treatments, variations in the slope positions also control N mineralization-immobilization processes. As well in our study the comparison is made in the first year of moving to no-till.

Similar trends in mineral N bioavailability were observed in the two systems over the season (Fig. 4a, b). However the bioavailability of NO_3-N as detected by two-week burial did show significant differences between the two fallow systems over May 25 - June 8, June 14 - June 28 and September 6 - September 21 time intervals. Incorporation of fresh crop residue in conventional fallow due to soil tillage on May 25 would lead to immobilization of initial mineral N, leading to low AEM extractable NO_3-N. Brown and Dickey (1970) also observed lower N immobilization potential of surface residue than when residue is mixed in soil, because surface managed crop residues decompose more slowly than the incorporated residues.

From June 28, irrespective of fallow system, potential bioavailability of mineral N increased over the season, corresponding to a period of rapid increase in soil temperature. However, a sudden drop was observed over the September 6 - September 21 interval. As already discussed for KCl-N03, intense volunteer cereal growth due to high soil moisture during the August 24 to September 6 period and possible losses associated with the August 27 rainfall, resulted in very low initial nitrate content on September 6 (Fig. 3a, b), which would explain the low AEM sorbed NO_3-N over the next 2 weeks, along with low soil moisture and low mineralization.

In the later part of the season (October), although soil temperature started decreasing, it was apparently not so low as to cease microbial activity completely. Precipitation and also slower evaporation rate resulted in a fair amount of soil moisture. Greater soil moisture and and mineralization would contribute to an increasing trend in the bioavailability of nitrate in both fallow systems towards the end of the season.

Similar to KCl-NO_3, spatially distinct trends in N bioavailability over two-week intervals over the season were associated with the landform element complexes within each fallow system. Significantly higher N bioavailability occured at footslope complex compared to level and shoulder positions. This is again explained by higher N content and moisture content contributing to higher mineralization rates and nitrate accumulation in this position. The relationship between resin sorbed nitrate and landform element complexes in conventional and chemfallow was shoulder (5.23 and 4.83 $\mu g/cm^2$) < level (11.76 and 17.67 $\mu g/cm^2$) < footslope (18.54 and 23.75 $\mu g/cm^2$), respectively (Table 2). Consistently higher soil moisture content over the season, and initial higher fertility status at footslope compared to level and shoulder, resulted in higher nutrient turnover over the season. These findings agree with other results reported by Goovavaerts and Chiang (1993), in which higher rates of N mineralization or mineral N availability were found in the lower areas of a landscape.

Table 1. Median values for the response variables measured over the season at the landscape scale

Response Variables	Fallow Systems	
	Conventional	Chemfallow
AEM-NO_3 ($\mu g/cm^2$)	10.23 a	13.01 b
KCl-NO_3 ($\mu g/g$)	7.20 a	8.50 b
Gr. H20 (%)	15.96 a	16.45 b

Median values with different letters in each row are significantly different.

Table 2. Median values for the response variables measured over the season at the landform scale

Response Variables	Fallow Systems					
	Conventional			Chemfallow		
	SH	FS	LE	SH	FS	LE
AEM-NO_3 ($\mu g/cm^2$)	5.23a	18.54b	11.76c	4.83a	23.75b	17.67c
KCl-NO_3 ($\mu g/g$)	4.15a	11.00b	8.45c	5.55a	11.35b	9.80b
Gr. H_2O (%)	13.38a	18.82b	15.86c	15.88a	17.81b	16.46a

Median values with different letters in each row under each fallow system are significantly different.

Conclusions

Until now, most studies investigating the effect of different tillage systems on nutrient availability have concentrated on long-term effects and exclusively during the crop season. Results reported in the present study indicate important short-term changes in mineral N availability at the landscape scale following the introduction of different fallow treatments. From the results obtained for the fallow season, the following points may be made:

1. Implementation of no-till herbicide fallow in the first year results in slight but significant differences in mineral N availability between the fallow systems.
2. There was greater availability of mineral N, higher soil moisture content and slightly lower soil temperature under chemfallow as compared to conventional fallow over the season.
3. At the landform scale, the order of mineral N availability and soil moisture content was shoulderdevelcfootslope. This reflects greater mineralization potential and moisture content in the footslope positions of the landscape.
4. Continuous *in situ* burial of anion exchange membranes over the season can provide insight into how management and landscape affects mineral N availability. A good relationship between mineral N availability as predicted by AEM and the existing soil conditions over the season may strengthen its use in nutrient turnover studies.

Practical Significance of Findings to Farmers

1. Mechanical tillage is not necessary to induce N mineralization and increase available N during a fallow period.
2. Growth of volunteer cereals in fall on fallow fields will immobilize N which is readily re-released by tillage or plant death.
3. Greater accumulation of bioavailable N in footslopes, much less in shoulders, is related to N mineralization differences at the landscape.
4. These differences in mineral N availability at different slope positions should be considered in variable fertilizer rate application.

Acknowledgement

The authors gratefully acknowledge the support of the Canada-Saskatchewan Agriculture Green Plan Project.

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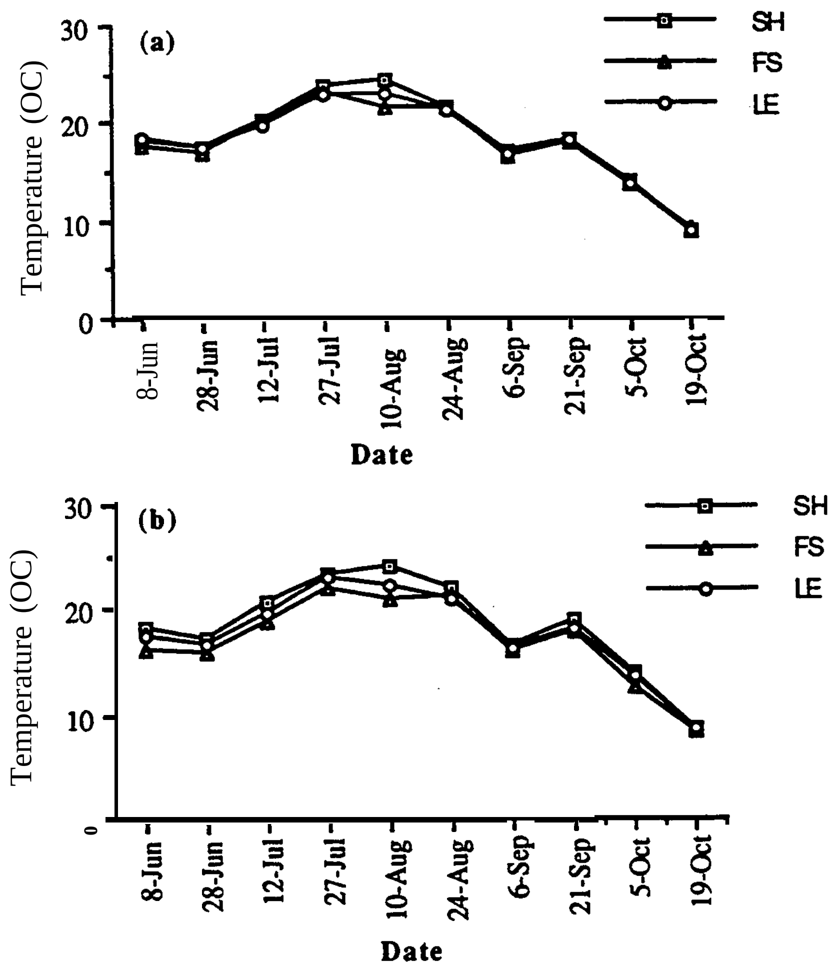


Fig. 1. Average soil temperature over the season for the 5 cm depth, under (a) conventional fallow and (b) chemfallow

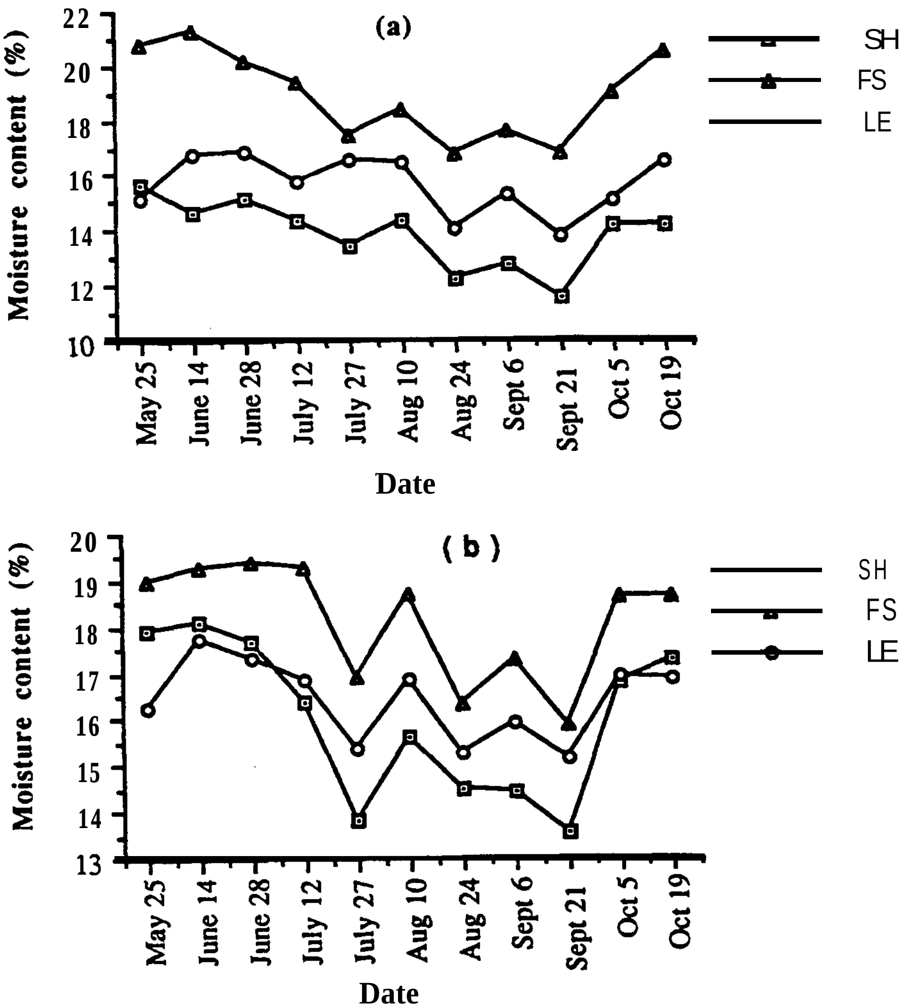


Fig.2 Gravimetric soil moisture content over the season under (a) conventional fallow and (b) chemfallow

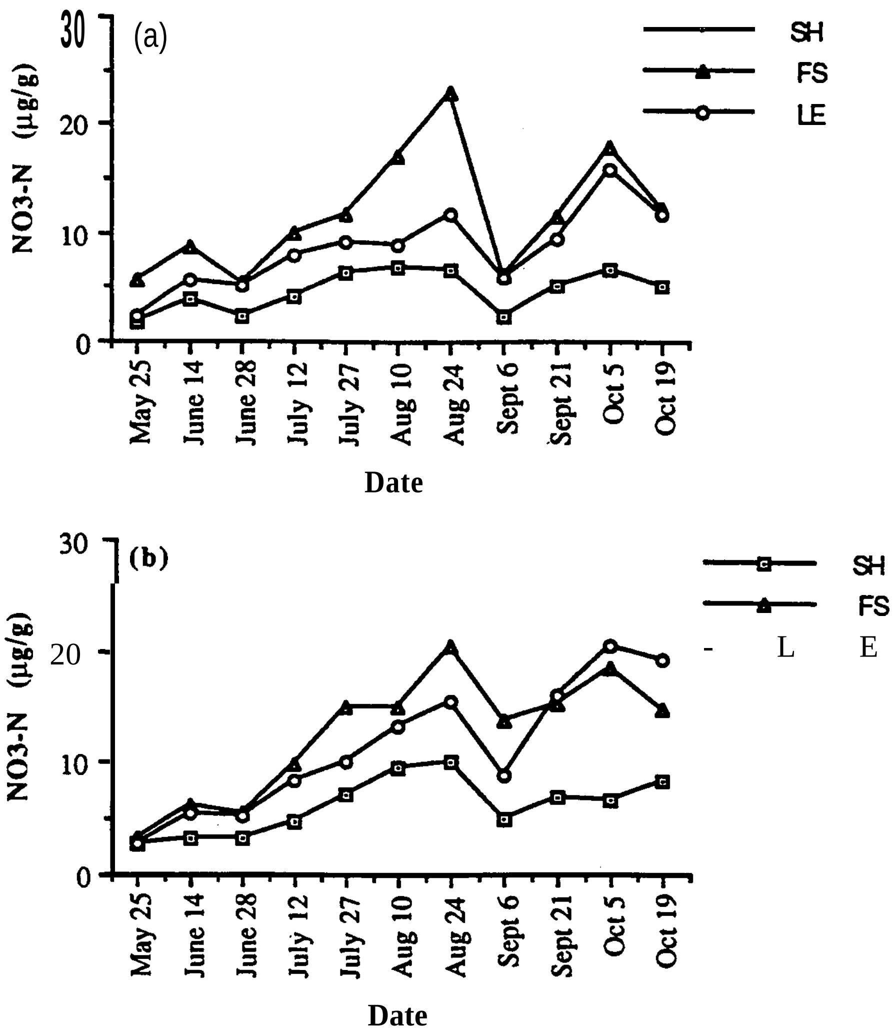
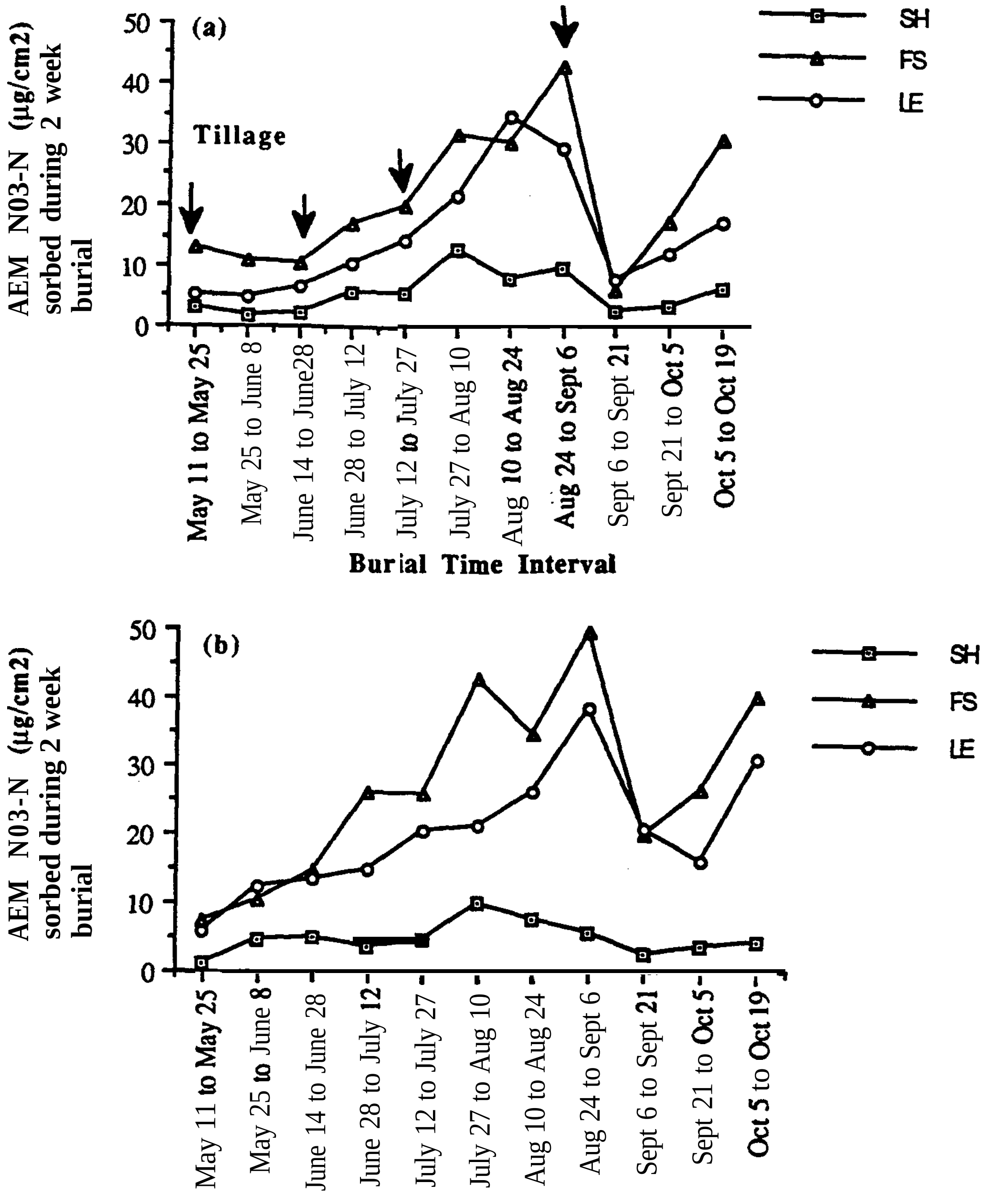


Fig. 3.2M KC1 extractable NO3-N over the season under (a) conventional fallow and (b) chemfallow



Burial Time Interval

Fig. 4. Bioavailability of nitrate determined by AEM in situ burial at two-week intervals over the season under (a) conventional fallow and (b) chemfallow