QUANTIFYING AND MODELLING NITRATE LEACHING FROM A LETTUCE FIELD IN ANNAPOLIS VALLEY NOVA SCOTIA

by

Negar Sharifi Mood

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ABSTRACT

Nitrate leaching (NO_3^-) from vegetable fields has become significant environmental issue in North America. The objective of this study was to evaluate the effect of timing and rate of nitrogen (N) fertilizer on lettuce yield and NO_3^- leaching. LEACHN model also was used to simulate NO_3^- leaching. Nitrogen fertilization treatments include preplant application; 90 kg N ha^{-1} a week prior to planting and 30 kg N ha^{-1} two weeks after planting and split application; 60 kg N ha^{-1} both before and two weeks after planting with four levels of sidedress N fertilizers (0, 15, 30, 45 kg N ha^{-1}) for split and two levels of 0 and 30 kg N ha^{-1} for preplant treatments. Extra irrigation (8 cm) was applied to preplant treatments late in the season. Results showed no significant yield differences but 11% greater residual mineral N in top 30 cm of soil for preplant treatments which indicates increased risk of NO_3^- leaching in the following fall and winter. The LEACHN predicted average of 101 and 61 kg N ha^{-1} leaching from 1 June 2012 to 31 March 2013 in preplant and split treatments respectively. This showed major leaching during non-growing season so the management practices should focus on methods preserving N in the soil after harvest.

LIST OF ABBREVIATIONS USED

AET	Actual Evapotranspiration
B	Base fertilizer
B0SD0	Control Treatment
C	Carbon
C:N	Carbon to Nitrogen ratio
$Ca(NO_3)_2$	Calcium nitrate
F	Furrow
GS	Growing Season
H	Hill
LEACHM	Leaching Estimation and Chemistry Model
ME	Mean Error
N	Nitrogen
N_2	Dinitrogen
N_2O	Nitrous Oxide
NGS	Non-growing season
NH_3	Ammonia
NH_4^+	Ammonium
NH_4NO_3	Ammonium nitrate
NO	Nitric Oxide
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_3-N	Nitrate-Nitrogen
NSEF	Nash-Sutcliff modeling efficiency
OM	Organic Matter
PET	Potential Evapotranspiration
PSD30+R	Preplant+ 30 kg N ha^{-1} sidedress + extra irrigation treatment
R	Extra Irrigation
SD	Sidedress
SSD45	Split+ 45 kg N ha^{-1} sidedress treatment

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CHAPTER 1 INTRODUCTION

1.1. Background

Nitrogen (N) is one of the most important nutrients required for plant growth and development. Nitrogen losses can occur as a result of excessive nitrate (NO_3^-) in the soil due to over application of N fertilizers (Canter, 1996). Nitrate is water soluble and hence susceptible to losses by leaching to the groundwater (Drury et al. 1996; Tan et al. 2002) or by surface runoff and erosion (Gilliam and Hoyt, 1987; Drury et al. 1993). There are also health concerns over the high levels of NO_3^- in drinking water (Johnson et al. 1999).

In Canada, the risk of water contamination by N has increased by 2.3% per year from 6.7 in 1981 to 10.6 in 2006. This occurred mainly in Manitoba, Northern Ontario, in Eastern Quebec and in Atlantic provinces (De Jong et al. 2009). The Atlantic Provinces with the average of more than 700 mm of precipitation during the non-growing season are the wettest provinces in Canada with the most variable non-growing season drainage estimates (6-yr mean: 399 mm, CV: 23%) and spring soil-water content of about 210 mm (95% of field capacity). In the Atlantic Provinces, application of 67% more N fertilizer resulted in a 62% increase non-growing season N losses (13.9 kg N ha^{-1} in 1981 to 36.8 kg N ha^{-1} in 2006; De Jong et al. 2009). Atlantic Canada also has the highest growing season N leaching of 4.7 kg N ha^{-1} (De Jong et al. 2009). Annapolis valley is the most intensively managed agricultural region in Nova Scotia with reported concerns regarding groundwater NO_3^- pollution from agricultural production on predominantly sandy soils overlying an unconfined aquifer used for drinking water extraction (Blair 2001 and Gauthier et al. 2009 in Amon-Amrah et al. 2013).

Lettuce is an important crop in Nova Scotia, with 63 and 111 hectares area planted under leaf and head lettuce in 2010 and 2011, with farm gate value of $798,000 and $1,440,000 in 2010 and 2011 respectively (Statistics Canada, Catalogue 22-003 (February 2012). The Annapolis Valley is the largest commercial lettuce production area in Atlantic Canada with over 40 hectares under lettuce production (Nova Scotia Department of Agriculture, 2010).

Ensuring a steady supply of N during the growing season is very important in lettuce production. This is complicated by the relatively short growing season of lettuce, a shallow rooting plant that is commonly grown in sandy soils, and is sensitive to soil N supply. Sufficient soil N stimulates root development and activity, aids in the uptake of other essential nutrients, promoting rapid plant growth and optimizing crop yield (Stevenson 1986). Unpredictable magnitude of rainfall events during the growing season often leads to N leaching from root zone, causing the lettuce crop to become N deficient and lose marketability.

LEACHN, the N version of LEACHM (Hutson and Wagenet, 1992) model (Leaching Estimation And CHemistry Model) was selected from a number of similar models to simulate water and N in this study. It is a process-based model that simulates N transformation and dynamics in the root zone and reported to be more straightforward to use in a field level study. It needs a smaller parameter set and uses a daily time step which provide better estimates of NO_3^- leaching. It has been tested in different part of the world in NO_3^- leaching estimation studies (Ramos and Carbonell, 1991 Jabro et al. 1993; Jemison et al. 1994; Borah and Kalita, 1999).

1.2. Objectives

The overall objective of this research is to assess the effect of delaying 50% of N fertilizer application to post planting on field lettuce yield, N uptake and NO_3^- leaching from lettuce crop root zone (i.e. 45 cm) in Annapolis Valley, Nova Scotia. Specifically a 90/30 split application of N fertilizer (90 Kg N ha^{-1} a week before planting and 30 Kg N ha^{-1} at week two (W2) after planting and will be compared with a 60/60 split application (60 Kg N ha^{-1} a week before planting and 60 Kg N ha^{-1} at W2 after planting).

The specific objectives of this research are to study:

1. The effect of N fertilizer application timing (preplant versus split application) and sidedress N fertilizer rates on lettuce yield and NO_3^- leaching.
2. The effect of sidedress N fertilizer rates on yield and NO_3^- leaching from lettuce field in split treatments.
3. The effect of an extra irrigation (8 cm on W4) that simulated a heavy rainfall on yield and NO_3^- leaching.
4. Use of LEACHN model for predicting NO_3^- leaching from field lettuce.

To address these objectives four specific questions will be answered:

i. Does timing of N fertilizer application influence lettuce yield and NO_3^- leaching?
ii. Does rate of side dress N fertilizer application influence lettuce yield and NO_3^- leaching?
iii. What is the effect of an extra irrigation event on NO_3^- leaching from the soil and how does this affect yield?
iv. How accurate are the LEACHN model simulations for NO_3^- leaching from field lettuce?

CHAPTER 2 LITERATURE REVIEW

2.1. Soil nitrogen forms and transformation

Organic nitrogen (ON) is the major form of N that exists in soil. Application of organic matter (OM) and its mineralization make additional quantities of N available to the plant, which has a beneficial effect on the yield but organic N forms are not easily available to plants and must be mineralized. Inorganic N forms on the other hand exist in association with clay, organic colloids, soil solution and soil air and are available to plants (Havlin et al. 2005). Inorganic forms of N can be produced by the decomposition of soil OM or added as inorganic or organic fertilizer. The availability of mineral forms of N during the growing season depends on the balance between mineralization of OM in soil and immobilization of inorganic N by plants and soil microorganisms. The C:N ratio of OM indicates whether ON is mineralized to plant available form (NH_4^+ and NO_3^-) or if mineral N is immobilized into ON forms.

Soil N mineralization rate increases with higher soil moisture, but it varies in different soils depending on the slope of soil moisture retention curve, porosity and OM concentration (Paul and Polglase, 2003). Microbial activity in sandy soils is higher than clay soils, mainly due to larger soil pore sizes that leads to an intense wetting-drying pattern (Van Veen et al. 1984 in Sugihara et al. 2010).

Nitrogen fixation and nitrification are also two important N transformations in the soil. Microorganisms such as bacteria can convert N_2 to ammonia (NH_3), these bacteria are either free-living such as Azotobacter and blue-green algae or are in symbiotic associations with plants like some legume crops including alfalfa, soybean and pea or symbiotic associations with other organisms such as termites and protozoa (Havlin et al.

2005). The amount of biological symbiosis N_2 fixation is affected by rhizobia-host symbiosis effectiveness, the host plant ability to accumulate N, availability of N in soil and environmental conditions that control pH and photosynthesis (Van Kessel and Hartley, 2000). In Ottawa Canada, alfalfa plants fixed an average of 93, 258 and 227 kg N ha^{-1} y^{-1} in the first, second and third year, respectively (Burity et al. 1989). In this study it is assumed that the N fixation was negligible and was not considered in establishing the N balance.

Nitrification is a two-step process that converts NH_4^+ to NO_2^- and then NO_2^- to NO_3^-.

Step 1 $$2\,NH_4{}^+ + 3\,O_2 \xrightarrow{Nitrosomonas} NOH_2{}^- + 2\,H_2O\ + 4\,H^+$$

Step 2 $$2\,NO_2{}^- + O_2 \xrightarrow{Nitrobacter} 2\,NO_3{}^-$$

The five main factors that control nitrification are; population of nitrifying organisms, soil pH, soil moisture, soil aeration, soil temperature and availability of NH_4^+. Once NH_4^+ is converted to NO_3^-, rainfall during the growing season can leach NO_3^- from root zone, Thus to reduce risk of NO_3^- leaching, other managements need to be considered such as reduced N inputs or localized irrigation (Waddell and Gupta, 2000).

2.2. Nitrogen losses

Nitrogen output pathways occur through crop removal, ammonia (NH_3) volatilization, denitrification and leaching. In some occasions, application of NH_4^+ fertilizers to calcareous soils favor NH_3 volatilization but it is likely to be small in acidic soils such as one considered in this study. Leaching and denitrification are the two main processes of NO_3^- loss from acidic agricultural soils.

Denitrification is the process of reduction of NO_3^- to NO_2^- and subsequent reduction of NO_2^- to gaseous forms of N such as NO, N_2O and N_2. The pathway is as following:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \uparrow \rightarrow N_2 \uparrow$$

Denitrification is a respiratory process that occurs in bacteria under anaerobic conditions. The main factors that control the rate of denitrification are availability of oxygen, organic carbon (C) supply and NO_3^- concentration. Therefore, more denitrification occurs in poorly drained soil. Organic C compounds such as soil OM, crop residues and manure can provide energy for denitrifying microorganisms (Havlin et al. 2005). Finally availability of NO_3^- can determine how much NO_3^- can potentially be denitrified. We did not anticipate high denitrification rates in this study, due to the prevalence of aerobic conditions in the sandy loam soil and dry conditions during 2012 growing season.

Nitrate is highly soluble in water and is repelled by negatively charged soil particles which makes it susceptible to leach out of the soil (Drury et al. 1996; Tan et al. 2002), or to discharge to streams or water bodies (Lowrance and Pionke, 1989) and becomes unavailable for plants. Nitrate may come from application of N fertilizer, N rich effluent or from mineralization of soil OM (Addiscott 1996). Nitrate leaching from agricultural production is considered to be the primary environmental impact resulting from excessive use of synthetic N fertilizers (Power and Schepers 1989; Breschini and Hartz, 2002; Di and Cameron 2002; Cambouris and Zebarth, 2008; Smith and Kellman, 2011; Amon-Armah et al. 2013). The amount of leaching is correlated with both the concentration of NO_3^- present in the soil and the amount of water movement through the soil profile

(Chesnaux and Allen, 2008), these two factors are very important for NO_3^- leaching measurement during and after the growing season.

There are several methods to estimate NO_3^- leaching below the root zone. Paul and Beauchamp (1995) used a N budget model on a dairy farm in Ontario. This approach makes a balance between N outputs and inputs which estimates the surplus N content. They found only 19% of farm N resources is utilized which represented huge environmental and economic loss to the farmer. They concluded that the farm N budgets method lack the quantitative measurement of leaching losses. An alternate method is to monitor water table fluctuations during the year in a water well, in this method the average NO_3^- concentration during a specific period is measured and multiplied by the changes in water table level during a recharge period. This method is very expensive to perform and sample but is more useful for measuring N fluxes that reach the groundwater table to indicate the groundwater contamination by NO_3^-. In Ontario, the groundwater NO_3^- concentration under many agricultural areas exceeded the drinking water standard of 10 mg L^{-1} (Goss et al. 1995). Nova Scotia also faces groundwater NO_3^- contamination in agricultural areas which requires more consideration (Sterling et al. 2014).

Water balance is another method to estimate NO_3^- leaching; it is calculated based on mass conservation equation; water that infiltrates into the soil can be calculated based on (precipitation- evapotranspiration- runoff- soil moisture changes), once it is multiplied by the average concentration of NO_3^- in soil solution it gives the NO_3^- leaching values. Measuring NO_3^- concentration in the unsaturated zone requires sampling soil solutions with solution samplers such as lysimeters.

Nitrate leaching can also be calculated by multiplying the average concentration of NO_3^- in soil solution by the calculated drainage from Darcy flow equation:

$$q = -Ki = -K\ \frac{dh}{dL}$$

Where q is water flux, K is saturated/unsaturated hydraulic conductivity, i is hydraulic gradient, H is the hydraulic head and L is depth.

There are also some sampling methods for quantifying NO_3^- leaching below the root zone. Passive capillary samplers (PCAPs) can be used to measure soil water drainage and flux in the field (Jabro et al. 2008) and NO_3^- leaching can be calculated by multiplying NO_3^- concentration in the water and drainage volume divided by surface area of PCAPs. Soil cores, ceramic solution sampler, shallow piezometers and tile drains are other methods of sampling. Everts and Kanwar (1988) compared these four sampling methods and indicated no differences in the results however much of the variability was due to distribution and number of samples rather than differences in the method. In this study N balance, soil sampling, suction lysimeter and LEACHN method is used to quantify NO_3^- leaching.

Risk of NO_3^- leaching is greater during fall and winter when the amount of water within the soil exceeds soil water holding capacity (Olsen et al. 1970), or early in the season when evapotranspiration is minimal (Shrestha et al. 2010; Cameron et al. 2013) and there is a delay in plant N uptake (Zebarth and Milburn 2003 in Burton et al. 2008). Di et al. (1999) measured 58% more NO_3^- leaching following N fertilizer applications in fall than spring. In Quebec, Canada, high NO_3-N concentration in early spring in soil solution (up to 10 mg N L^{-1}) was associated with rapid snow thawing events (Zhang et al. 2004). After the crop harvest, early autumn rainfall can leach residual soil NO_3^- that is left in the soil or released by mineralization. Conversely, large rainfall events (usually greater than 400 mm) during the growing season, exceed crop water uptake and soil water holding capacity, and can leach substantial amounts of NO_3^- from the root zone especially in sandy soils immediately following fertilizer application (Di and Cameron 2002). Split application of N fertilizer during the growing season, could be an effective strategy to reduce NO_3^- leaching. For example, growing season rainfall in a potato field in Minnesota resulted in 4.5 kg N ha^{-1} of NO_3^- leaching in treatments with five splits of 225 kg urea N ha^{-1} compared to 9.7 kg N ha^{-1} for conventional treatments with three splits of 225 kg urea N ha^{-1} (Waddell and Gupta (2000). Silva et al. (1999) studied NO_3^- leaching from a grass/clover mixture on sandy soil and showed that by splitting 400 kg urea N ha^{-1} into four applications, NO_3^- leaching ranged from 6 to 17 kg N ha^{-1} while by two split NO_3^- leaching increased to 13-49 kg N ha^{-1}. De Jong et al. (2009) used IROWC-N model (Indicator of the Risk of Water Contamination by Nitrogen) to describe soil water balance, NO_3^- leaching and NO_3^- concentration in drainage water. Nitrate leaching losses during the growing season at a national scale in Canada during 6 years were averaged 0.8 kg N ha^{-1} which is smaller than N leaching during the winter period for the same duration of time (2.4 kg N ha^{-1}) because of lower cumulative growing season drainage of around 15 mm compared to 31 mm during non-growing season.

During the non-growing season other management practices such as planting a cover crop following the main crop can increase evapotranspiration, decrease drainage and crop uptake which will eventually reduce NO_3^- leaching. Studies in North America have reported 11 to 107 kg N ha^{-1} NO_3^- leaching annually in corn production, with greater loss being attributed to bare fallow period in off season; reminalization of earlier incorporated

N fertilizer is blamed for most of the leaching in this period (Drury et al. 1996). Goss and Howse (1998) also showed greater NO_3^- leaching losses in winter in fields that were fallowed (40 kg N ha^{-1}) than those planted to a cover crop (24 kg N ha^{-1}). Johnson et al. (2002) also showed that the protective system with cover crop, delayed autumn cultivation and straw incorporation resulted in the minimum average annual N leaching losses of about 25 kg N ha^{-1} compared to 49 and 35 kg N ha^{-1} for standard and intermediate systems.

In Nova Scotia large recharge rates, produced more than 10 mg L^{-1} NO_3-N concentrations from October through December (Kinley et al. 2010). During the past three decades, tile drainage has become a significant part of agricultural land in Nova Scotia with a wide range of NO_3-N concentrations reported in drainage water from 5 to 25 mg L^{-1} in corn production outside the growing season (Gordon et al. 2005; Mkhabela et al. 2008; Fuller et al. 2010). Similar result has been reported in Iowa (Bjorneberg et al. 1996 in Gordon et al. 2005), PEI (Jiang et al. 2011), Valencia (de Paz and Ramos, 2004). Nila Rekha et al. (2011) showed that under corn-soybean production in Iowa, USA, 16, 14 and 11 mg L^{-1} of NO_3^- concentration leached past the subsurface drain depth of 1.2, 1.8 and 2.4 m respectively into the shallow groundwater. In a study by Drury et al. (2007) NO_3^- loss in tile drainage was equally split between growing and non-growing seasons (9.18 and 9.92 kg N ha^{-1}, respectively). They found that controlled drainage system with subsurface irrigation reduced NO_3^- losses in tile drainage by 68% (i.e. 4.93 compared to 14.4 kg N ha^{-1} yr^{-1}). The reduction in NO_3^- leaching losses in tile drainage from a clay loam soil was attributed to lower volume of drainage due to shallower effective tile depth. Fuller et al. (2010) showed that permanent forage (PF) significantly reduced NO_3-

N loading during the growing season with total of 33 kg ha^{-1} when compared to corn-soybean-wheat rotation with zero tillage (CSW-ZT) with 83 kg ha^{-1} over a 5 year period in Kentville, NS (189, 0, 173, 140 and 0 kg N ha^{-1} N fertilizer applied as liquid dairy manure for corn, soybean, wheat, corn and fallow during 2002 to 2006). The values were much higher during the non-growing season, ranging from 151 to 262 kg ha^{-1} for PF and CSW-ZT, respectively.

Table 1.1 summarizes measured NO_3-N leaching losses for different cropping system with application of either inorganic fertilizer or manure. Slow release of nutrient from manure or compost not only increases SOM but it also increases N leaching to surface and groundwater. Increasing potentially mineralizable N increases the risk of NO_3^- leaching especially during fall and winter in soils with free drainage (Chamber et al. 2000 in Basso and Ritchie 2005). Basso and Ritchie (2005) measured higher NO_3-N leaching in maize-alfalfa rotation in Michigan, USA with manure application than compost and inorganic N fertilizer (55, 30 and 25 kg NO_3-N ha^{-1} for manure, compost and inorganic N respectively).

Table 1.1. Measured NO_3-N leaching losses for different cropping system

Location	cropping system	soil texture	N applied kg N ha^{-1}	Leaching kg N ha^{-1}	References
Annapolis Valley, Nova Scotia	potato–barley–winter wheat feed–potato–corn	Sandy loam	125	65(GS)	Amon-amrah et al. (2013)
Kentville Nova Scotia	corn-soybean-wheat (NT)	Sandy loam	502 (LDM)	83 (5 yrs.-GS)	Fuller et al. (2010)
Kentville, Nova Scotia	corn-soybean-wheat (NT)	Sandy loam	502 (LDM)	262 (5 yrs.-NGS)	Fuller et al. (2010)
Streets Ridge, Nova Scotia	silage corn	Sandy clay loam	168 (SSBM)	7 (yr.)	Mkhabela et al. (2008)
Truro, Nova Scotia	soybean	Sandy loam	63 (LDM)	15 (yr.)	Mkhabela et al. (2008)
Truro, Nova Scotia	barely	Sandy loam	159 (LDM)	22 (yr.)	Mkhabela et al. (2008)
Truro, Nova Scotia	carrot	Sandy loam	70 (LHM)- 70 (IF)	16-13 (GS)	Gordon et al. (2004)
UK	cereal rotation: spring wheat	Loamy sand	200 (IF)	17-87 (yr.)	Shepherd and Lord (1996)

LDM= Liquid Dairy manure; NT= no tillage ; GS= Growing season ; NGS= Non-growing season; IF= Inorganic fertilizer , SSBM= semi-solid beef manure

According to what has been discussed so far, applying N fertilizer in rates and times that match plant N demand and using split applications of N fertilizer during the growing season and cover crops in non-growing season are common methods that have been practiced in different regions to reduce NO_3^- leaching. Despite climate and soil variability, farm management strategies such as time of sowing and rate of N fertilization can have considerable impact on NO_3^- leaching. A range of 0-70 kg NO_3-N ha^{-1} in wheat production during 1980 to 1999 with variable sowing dates, N fertilizer rates and soil variability has been reported by Lilburne et al. (2003). They observed a trend of greater NO_3^- leaching with later sowing dates, greater fertilizer application and shallower soil depths.

2.3. Nitrogen management in lettuce production

Lettuce is the main salad crop grown and marketed in most parts of the world (Deshpande and Salunkhe, 1998). Raised beds are ideal for lettuce production, they prevent damage from soil compaction and flooding. Lettuce is a short season, shallow-rooted crop which is sensitive to fluctuations in N supply in the soil (AgraPoint 2008). Application of sufficient amount of N assures proper lettuce growth and quality and good color (Abu-Rayyan et al. 2004). High levels of NO_3^- uptake enhances accumulation of NO_3^- in the leaves and boosts leaf length and width but reduces leaf thickness (Tittonell et al. 2001). Roots are mainly distributed near the soil surface with 78% of the total root length in the 20 cm of soil surface (Jackson, 1995). Lettuce allocated 9% of total biomass to the root system with only 35% of final root length in the 20-80 cm layer (Gallardo et al. 1996).

Lettuce typically takes up 54 to 63 kg of N ha^{-1} in the above ground biomass (Smith 2010). The amount of NO_3-N taken up is determined mainly by the plant species/variety, the age of the plant and the amount of available NO_3^- in the soil. More than 65% of lettuce N uptake occurs in the last third (last 22 days) of growing season (Gardner and Pew 1979; Welch et al. 1983; Sosa et al. 2012).

Lettuce yield increases in response to water and N fertilizer (Maynard et al. 1976; Rolf 1985; Thompson and Doerge 1996; Sanchez 2000). Nitrogen deficiencies in lettuce results in leaf yellowing, yield losses and deficiency of other nutrients such as calcium (Huett and White, 1992). In contrast, excess N can result in rapid growth and tip burn. Strategies for N fertilizer management are regional. Application of up to 390 mg N kg^{-1} (760 kg N ha^{-1}) soil of ammonium nitrate fertilizer on lettuce resulted in 33% increase of plant yield compared to when no fertilizer is applied, while higher rates of N fertilizer decreased plant dry weight (Fontes et al. 1997). In USA, 100-150 kg N ha^{-1} is suggested to obtain maximum lettuce yield (Lorenz and Minges 1942; Gardner and Pew 1972), however the combination of N and P fertilizers (225 kg N ha^{-1} and 112 kg P ha^{-1}) in California, USA also improved yield and postharvest quality of lettuce (Hoque et al. 2010). In Nova Scotia 120 Kg N ha^{-1} is recommended for lettuce production. It is further recommended that this application be split in two applications, 90 kg N ha^{-1} before planting and 30 kg N ha^{-1} after planting (AgraPoint 2008). The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) recommend a split application of 60 kg N ha^{-1} before planting and 60 kg N ha^{-1} after planting.

In Arizona, the use of drip irrigation and controlled release N fertilizers has been successful in enhancing water and N use efficiency in lettuce production on sandy soils

(Sanchez 2000). Breschini and Hartz (2002) introduced a pre-sidedress soil NO_3^- test (PSNT) as a management tool to reduce unnecessary N fertilization in lettuce production in coastal California. They reported reductions of 43% and 57% of total seasonal and sidedress N applications in PSNT plots. There was however no significant difference in marketable yield. According to Hartz et al. (2000), a 20 mg kg^{-1} (39 kg ha^{-1}) PSNT threshold is sufficient to maintain lettuce productivity and quality. To know about crop N status during growth the midrib NO_3^- test is widely used by lettuce growers. Hartz et al. (2000) reported that soil testing has been a more effective tool than midrib testing, as the small size of midrib samples at early growth stages limited the correlation between midrib and soil NO_3-N.

As can see from the review in the last two sections, split application of fertilizer is not practiced in Canada for vegetable production and most of the studies evaluated the single application of N fertilizer with the focus on increasing yield than reducing environmental risks. It is necessary to study the effect of split N management on yield and NO_3^- leaching in lettuce production.

2.4. Nitrogen Modeling

Mathematical models range from the very simple with limited input data to very complex requiring extensive parameterization. Mechanistic models are based on the knowledge of a system's component behaviors, while empirical models are based on direct observation of the system as a whole. A further differentiation of mechanistic models are deterministic and stochastic models. In deterministic models for every set of data there is a unique result, conversely, in stochastic model randomness exists, and variable states are not defined by unique values, but rather by probability distributions (Addiscott et al. 1991).

Nitrogen transport and transportation in heterogeneous soil is difficult to predict due to variability in soil and climate, hydrological parameters, soil OM quantity and quality and other farm management strategies (crop type, fertilizer, irrigation, tillage, etc.) (Actus et al, 2002). On the other hand, it is very important to predict and prevent N transformation and losses to the environment. Application of models to N management has increased rapidly worldwide in the past two decades (Shaffer and Ma, 2001). Recently eighteen models have been established in North America and Europe to simulate N cycling in cropping system (Shaffer and Ma, 2001; Donald and Gillian, 2004). Although they may require extensive input data and field calibration, they save time and effort expended for field studies especially for investigations in N losses to the environment such as NO_3^- leaching.

Most of the soil N models are based on field data results and are used to be simulate the fate of N in the root zone. Some models apply soil, climate and management practices and their interactions to predict NO_3^- leaching beyond root zone (e.g. CREAMS: Leonard et al., 1980; GLEAMS: Leonard, 1987; NTRM: Shaffer and Larsen, 1987; LEACHN: Hutson and Wagenet, 1989; SOILN: Jansson and Ckersten., 1991, Bergstrom and Jarvis, 1991; CREAMS-NT: Deizman and Mostanhimi,1991; NLEAP: Shaffer. et al. 1991; CENTURY: Metherell et al. 1993; MANIMEA: Henginirun, 1996; and DRAINMOD-N, Breve et al. 1997). Table 1.2 summarize a brief description of each of the models.

Table 1.2. Descriptions and comparisons of different nitrogen models in agriculture

Model	Simulation	Description
CREAMS (Chemicals, runoff, and Erosion from Agricultural Management Systems	Field scale nutrients, pesticide and soil losses	Required parameters are easily available or estimated
GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)	Impact of management practices on pesticide and nutrient leaching within, through and below the root zone	Assumes a field with homogeneous land use, soil and precipitation but is not developed as an absolute predictor of pollutant loadings
NTRM (Nitrogen-Tillage-Residue Management)	N, tillage, and crop-residue management	It has sub-routine for soil carbon and N transformations, solute transport, and crop residues
LEACHM (Leaching Estimation And Chemistry Model)	LEACHW for water regime, LEACHN for N, LEACHP for pesticides, and LEACHC for chemicals	Describes water and solute movement and chemical reactions in unsaturated soil zones within four different subroutines
SOILN (Soil water and heat model)	Transport and transformations of N in the soils, and its uptake by plants	Consider homogeneous multi-layer soil profiles and is very similar to LEACHN
CREAMS-NT (Nitrogen version of CREAMS)	N transformations and transport following land application of organic waste	N input through fertilizer applications and N losses through volatilization, Denitrification, plant uptake and leaching
NLEAP (The Nitrate Leaching and Economic Analysis Package)	Potential NO_3^- leaching associated with agricultural practices	Calculate N budget and NO_3^- leaching as a function of soil, management, and climatic factors
CENTURY (plant-soil ecosystem model)	Plant production, soil carbon dynamics, soil nutrient dynamics and soil water and temperature	Requires major input variables such as monthly precipitation and air temperature, soil texture, lignin, N, S and P content of plant material and soil and atmospheric N inputs
MANIMEA (Manurial Nitrogen Management: Environmental Aspects)	N transformations and N transport through runoff, leaching and plant uptake	Assumes homogeneous, unsaturated soil
DRAINMOD-N (Nitrogen version of Drainage model)	Movement and fate of N in the shallow water table	Mainly for artificially drained soils

Among all of the mentioned models, NLEAP, CENTURY and LEACHM were developed to use at the farm and regional scale (Wylie et al. 1994). LEACHN needs less input parameters compared to other models and uses a daily time step and therefore provide better estimates of N leaching. Moreover, it has a well-described algorithms for N simulations and has been used in many regions of the world (Ramos and Carbonell, 1991). During the past two decades it has been used by several researchers for NO_3^- leaching estimation (Sexton and Moncrief 1996; Acutis et al. 2000; Dadfar 2004; Jiang et al. 2011).

2.4.1. LEACHN Model

LEACHN, the N version of the water and solute transport model, LEACHM (**L**eaching **E**stimation **A**nd **Ch**emistry **M**odel) can predict major chemical, physical and biological processes in the root zone throughout the year (Huston, 2003). LEACHM consists of five sub models: LEACHN describes N and P transport and transformation; LEACHP simulates pesticide degradation, transformation and movement; LEACHW is a water-flow model and LEACHC simulates the movement of inorganic ions associated with salinity.

LEACHN consists of a group of subroutines, each of which simulates a process that affects water and solute behavior. LEACHN, directs and controls the model operation by calling subroutines, reading the data file and printing results. Subroutines involve different process such as water and solute flow, evapotranspiration, sinks, sources, plant growth, heat flow and also with data input with respect to depth and time. LEACHN has a number of limitations. The model is not intended to use unequal depth increments. It cannot predict crop yield and simulate the transport of immiscible liquids and solute distribution in two or three dimensional flow patterns (Huston, 2003). The model can be calibrated experimentally by using N transformation rate constants, drainage and soil N concentration data in the field.

2.4.2. Simulation of NO_3-N leaching by LEACHN

The LEACHM model has been widely used and validated for several crops during the past two decades. The effects of fertilization, irrigation, cropping system and soil type on leaching have been discussed and many researchers have concluded that the simulated leaching was higher when fertilizer and irrigation were higher (Sogbedji et al. 2001a; Ramos and Carbonell, 1991; Jabro et al. 1997).

Some studies reported the satisfactory performance of LEACHN to predict water flow (Jabro et al. 1995; Dadfar et al. 2004), although the limitations of LEACHN to predict water flow have been noted (Jabro et al. 1993; Mutch et al. 1992; Jemison, 1994; Nolan et al. 2005, in Jiang et al. 2011). The inability of LEACHN to model macro pore flow effects its estimates of solute transport, resulting in poor simulation of soil physical and hydraulic properties. This can be improved by accurate measurements of saturated hydraulic conductivity (K_s) and water retention parameters within each plot. In a field study on a sandy loam in in Georgia under corn; Johnson et al. (1999) reduced the estimate of upper layer (0-7.5 cm) K_s to 1 mm day^{-1} which resulted in better agreement between predicted cumulative drainage (370 mm) with field measured values (385 mm).

Some studies demonstrated that using van Genuchten retentivity function instead of Campbell parameters generated more accurate simulation of soil water changes in the soil

(Ramos and Carbonell, 1991; Dadfar et al. 2004; Akinremi et al. 2005). Campbell and van Genuchten are two models for describing soil water retention characteristics, they varies in the number of variables and complexity (Sommer and Stockle 2010). Ramos and Carbonell (1991) reported the overestimation of soil water content, they found that the hydraulic retention function used in the model did not adequately describe the actual soil conditions with shallow water table (1-1.5m) especially at higher soil water content (matric potential < 100 cm). Akinremi et al. (2005) used field lysimeter data on a medium-textured soil in southwestern Saskatchewan, Canada under prairie condition; with incorporation of van Genuchten into LEACHN the model was able to represent changes in soil water content with time, as well as the distribution of water throughout the soil profile. Dadfar et al. (2004) also recommended van Genuchten water content θ(h) and hydraulic function k(h) over the Campbell function in LEACHN particularly in the dry conditions (h= -35 to -1500 Kpa).

To identify the sources of the simulation errors, several studies focused on adjusting constants rates of mineralization, nitrification and denitrification to improve the model simulations (Johnson et al. 1999; Jabro et al. 1995; Sogbedji et al. 2001a). Nitrogen transformation rate constants are mainly influenced by temperature, water content, C:N ratio of residue, C:N ratio of manure and C:N ratio of humus (Jabro et al. 1993). Also any management practices such as tillage or irrigation that influence soil water content, nutrient availability and mineralization would indirectly affect N transformation.

Information about volatilization rate constants are very limited; According to Sogbedji et al. (2001a) volatilization rate constant was not affected by application of inorganic fertilizer and by soil type. The value of 0.40 d^{-1} was suggested by Hutson

(2003). Jemison (1994) and Jiang et al. (2011) assumed no NH_3 loss in their experiment. Values in the range of 0.00127 to 0.00154 d^{-1} were determined in laboratory experiments evaluating volatile loss of NH_3 from urea (Chin and Kroontje, 1963 in Sogbedji et al. 2001a).

Mineralization rate constants refer to transformation of organic C in to three pathways; humus, biomass or CO_2, therefore the mineralization rate constants of manure, residue and humus pools need to be specified for each pool in LEACHN. Laboratory measurements is the common way to determine the mineralization rate constants for different pools, however Johnson et al. (1999) found that even laboratory measurements were inaccurate due to estimation being based on disturbed soil samples which overestimate the rate constant of mineralization and those derived from laboratory incubation cannot be used at all times due to mineralization changes through the year. Therefore they indicated that by doubling the rate of humus mineralization (Table 4.3), during the cold season of a drier than normal year a better agreement was achieved for NO_3^- leaching, but still LEACHN overestimated NO_3^- leaching in a wetter than normal year.

Among all rate constants, LEACHN is more sensitive to changes in nitrification and denitrification rate constants than mineralization rate constant (Lotse et al. 1992; Hutson and Wagenet, 1991). Sogbedji et al. (2001a, 2001b) calibrated nitrification and denitrification rate constants for two soil types of clay loam and loamy sand and found that rate constants based on measured values resulted in a better prediction of growing season cumulative NO_3-N leaching losses. They also used the average rate constants for 3 years for each site which resulted in satisfactory prediction of NO_3-N leaching losses in clay loam site but not in loamy sand soil. They suggested that N transformation rate constants are more affected by cropping history and soil type than N application rates, therefore single N transformation rate constants can be used to estimate N fate and transport within a given soil type and cropping system. Hutson (2003) suggested values of 0.2 and 0.10 d^{-1} for nitrification and denitrification in the LEACHM manual. N transformation rate constant used in Jiang et al. (2011) were similar or close to those from other literature and no adjustment was done for the rate constants.

Some studies compared the evaluation of LEACHN to predict NO_3^- leaching losses in summer and winter months. Johnson et al. (1999) concluded that LEACHN better estimated cumulative NO_3-N leaching in Watkinsville, GA, USA during the warm months (May through October with 833 mm of precipitation and mean temperature of 21.7 °C) than cold months (November through April with 447 mm of precipitation and mean temperature of 11.8 °C), they also compared NO_3^- leaching in plots with and without cover crop. Their results showed more NO_3^- leaching in plots without a rye cover crop (19 kg ha^{-1}) than plots with a rye cover cop (1 kg NO_3-N ha^{-1}) in cold season but it did not affect NO_3^- leaching during the warm months (29 and 37 kg NO_3-N ha^{-1} in plots with and without rye cover crop). The model estimation of NO_3^- leaching in warm months was closer to field measurement (37 and 39 kg ha^{-1} from May to October for filed and model values, respectively). In contrast Jemison et al. (1994) showed overestimation of summer NO_3^- leaching which leaves little NO_3^- in the soil for spring losses. They attributed this to inability of the model to simulate dual-pore water flow in soil and lack of plant growth representation by the model. They found that a separate calibration for each treatment and year resulted in a better correlation between predicted and measured

NO_3^- leaching. Jabro et al. (1997) related the difference between measured and simulated NO_3^- leaching in winter months to restricted water flow in frozen soil condition and snow accumulation in winter.

Most of the studies that have been discussed so far were under corn, no study has been reported yet on use of LEACHN to simulate NO_3^- leaching losses from a lettuce field. In Canada use of LEACHN to simulate NO_3^- transport showed overestimation of NO_3^- leaching in Ontario (Dadfar et al. 2004) and Nova Scotia (Crooks, 1997) and underestimation in PEI (Jiang et al. 2011) as leaching occurred a few weeks earlier in the autumn compared with tile drainage measurements. Dadfar et al. (2004) used LEACHN under continuous corn during 1999 to 2002 in Woodslee, Ontario. They showed that NO_3^- leaching at 70 cm depth of soil profile was overestimated in both non-fertilized (18 kg ha^{-1}) and fertilized treatments (192 kg ha^{-1}) while the measured NO_3^- leaching in tile drains were 8 and 80 kg ha^{-1} for non-fertilized and fertilized treatments, respectively.

In Atlantic Canada there are two studies regarding using LEACHN. Crooks (1997) evaluated the use of LEACHN in winter wheat field in Truro, Nova Scotia and calibrated the model with measured cumulative drainage, θ level, soil NO_3-N concentration and crop N uptake. They found large error in validation of the model due to poor calibration of model subroutines governing θ levels, soil NO_3-N concentrations and NO_3^- leaching. They attributed the overestimated NO_3^- leaching to poor simulation of soil NO_3-N content and inability of the model to account for the effect of macro pore water flow. They suggested this rapidly moving water in the macro pores would cause less interaction of rain water with the soil matrix and hence resulted in overestimation of NO_3^- leaching. The sensitivity analysis showed that air entry value (a), BCAM; exponent in Campbell's water retention equation (b) and pore interaction parameters (p) in Campbell water retention function had the most impact on drainage as 10% decrease in a, b and p increased drainage by 6%, 16% and 38% respectively. Crop cover fraction and the plant maturity date also affected total drainage; 35% decrease in crop cover fraction increased drainage by 16.2% and 10% increase in plant maturity date increase total drainage by 12%. The BCAM, p and crop N uptake, plant maturity date and the crop cover fraction found to have the most effect on soil NO_3-N concentrations in the soil as the 10% decrease in specified N uptake increase soil NO_3-N concentrations by 8%. They concluded that the LEACHN model could not be validated for the trial field due to the poor calibration that was achieved for different parameters including θ, soil NO_3-N concentrations, drainage and NO_3^- leaching.

In another study in PEI by Jiang et al. (2011) LEACHN was used to simulate NO_3^- leaching from a potato field with sandy loam soil. They used long term water table measurements to predict drainage with the coupled LEACHN and MODFLOW modeling and calibrated the model using NO_3^- concentration from a tile drain leaching experiment of potato rotation with barely and red clover in PEI from 1999 to 2003. They suggested that the model only can be used for NO_3^- leaching prediction once both observed drainage and NO_3^- concentration of tile drainage being within acceptable error changes. They found that the annual tile drain flow were 71-152 mm which is 7.3% to 14.7% of annual precipitation therefore predicted drainage data used as recharge in MODFLOW and simulated water table elevation from MODFLOW were then compared with measured water table in the site for assessment of LEACHN model on simulating drainage. They used bulk density and particle size distribution data for soil water retention parameter prediction. They firstly used the N transformation constants from other papers and optimized it until there is minimum differences between measured NO_3^- concentration in tile drainage and simulated NO_3^- leaching concentration. Once the model was calibrated it was used to evaluate the effect of weather condition and fertilization N rate for conventional potato rotation in PEI. In this case soil and hydraulic properties and N transformation parameters remained unchanged and parameters of management and N fertilizer application (200, 60 and 0 kg N ha^{-1} for potato, barley and red clover respectively) were used to adjust the experimental situation. For both NO_3^- leaching and drainage, the simulated values occurred a few weeks earlier compared with actual tile drainage measurements during the same period (October to December). The model predicted low NO_3^- leaching early in autumn, rapidly increased to peak level in December and then gradually decreased to a minimum before planting of the next crop. They suggested that part of the NO_3^- that is leached after harvest was NO_3^- remaining in the soil from the growing season and derived in part from in-season mineralization. They attributed the deviation in NO_3^- leaching and drainage to inability of LEACHN model to consider the effect of macro pore flow, however except the timing of NO_3^- leaching, the total simulated NO_3^- leaching was considered to be acceptable. The annual NO_3^- leaching from May to April was in the range of 22 to 94 kg ha^{-1} depending on soil, climate and management practices. Predicted NH_4^+ leaching was very low (0.23 kg N ha^{-1}) and annual denitrification loss was 2.2 kg N ha^{-1}. Long-term simulations also indicated the possibility of high NO_3^- leaching occurred not only during the potato phase of the rotation but also in red clover and barely phases. They suggested that adapting the crop growth and N uptake as a function of weather and soil conditions would improve LEACHN performance.

As can see from the review above, N transformation prediction in natural soil is difficult, yet very important to predict and hinder N losses in to the environment. Although computer simulation models may require extensive data input, they can notably diminish the field time and effort to study N cycle in the ecosystem. The information which further will be an asset to make recommendations for management practices in each specific area. There are a large number of models for predicting N transformation and NO_3^- leaching losses through the unsaturated zone which vary widely in their input parameter requirement, output representation, conceptual approach and degree of complexity (Borah and Kalita, 1999). LEACHN was selected for this study as it needs less input parameters compared to other models and uses a daily time step and therefore provide better estimates of N leaching through the year. Moreover, it has a well described algorithms for N simulations and has been used in many regions of the world and also in Atlantic Canada. A review of the model and relevant input data and output results are summarized in Chapter 4.

CHAPTER 3 NITROGEN MANAGEMENT IN LETTUCE PRODUCTION

3.1. Introduction

Annapolis Valley region of Nova Scotia is a major lettuce production region in Atlantic Canada with more than 40 hectares of lettuce production (Nova Scotia Department of Agriculture, 2010). However, limited information is available on N requirement by the lettuce crop and the influence of different N management practices on the yield and N uptake under this climate. The effects of N fertilizer application rate and timing on NO_3^- leaching have not been examined under these conditions. In this study two N management strategies for field lettuce were considered. Nova Scotia standard treatment involves application of 90 kg N ha^{-1} as NH_4NO_3 a week prior to planting and 30 kg N ha^{-1} two weeks after planting. An improved N management program suggested by OMAFRA involves application of 60 kg N ha^{-1} a week prior to planting and 60 kg N ha^{-1} two weeks after planting.

In Annapolis valley NO_3^- leaching has become an important issue (Blair 2001 and Gauthier et al. 2009 in Amon-Amrah et al. 2013). The objective of this study were to (i) investigate the effect of N rates and timing of N application on lettuce yield, N uptake and N balance in the top 30 cm of soil as well as NO_3^- concentration at 45 cm depth in suction lysimeters, and (ii) assess the effect of extra irrigation on lettuce yield, N uptake and N balance in the top 30 cm of soil as well as NO_3^- concentration at 45 cm depth in suction lysimeters.

3.2. Methodology

3.2.1. Site description

The study was conducted at Vermeulen farms located in Canning, Nova Scotia, Canada (45° 09' N and 64° 25' W) in summer 2012. The mean monthly temperature and total precipitation at Kentville climate station (about 14 km from Canning) during May to October 2012 is provided in Table 3.1. The mean temperature during the months of May to October was close to 30-year normal values. May and July were the driest months, receiving less than 50% of normal precipitation. In May and July (2012) the precipitation was 75 and 73% below 30-year normal, respectively.

Table 3.1. Mean monthly air temperature and precipitation for Kentville during 2012 season and the long-term (30 years; 1981-2010) average

Month	Air Temperature (°C)		Precipitation (mm)	
	2012	30-year normal *	2012	30-year normal *
May	13	11	26	102
June	15	16	91	82
July	20	20	23	84
August	20	19	73	77
September	16	15	173	84
October	11	9	96	89
November	4	4.1	54	122
December	0	-2.3	140	122
January	-5	-5.6	28	116
February	-4	-4.9	91	101
March	1	-1	58	110
April	5	5.3	45	93
Mean/Total	16	15	482	518

*long-term average data were recorded at the Kentville Climate Station (Environment Canada, 2014)

Total average estimated potential evapotranspiration (ET) and precipitation from July 1st to mid-September is shown in the Figure 3.1. Potential ET calculated for a grass reference crop using a modified Penman Monteith equation (extracted from http://farmwest.com/climate/et). Except for a few days in mid-August, potential evapotranspiration was higher than precipitation during this period.

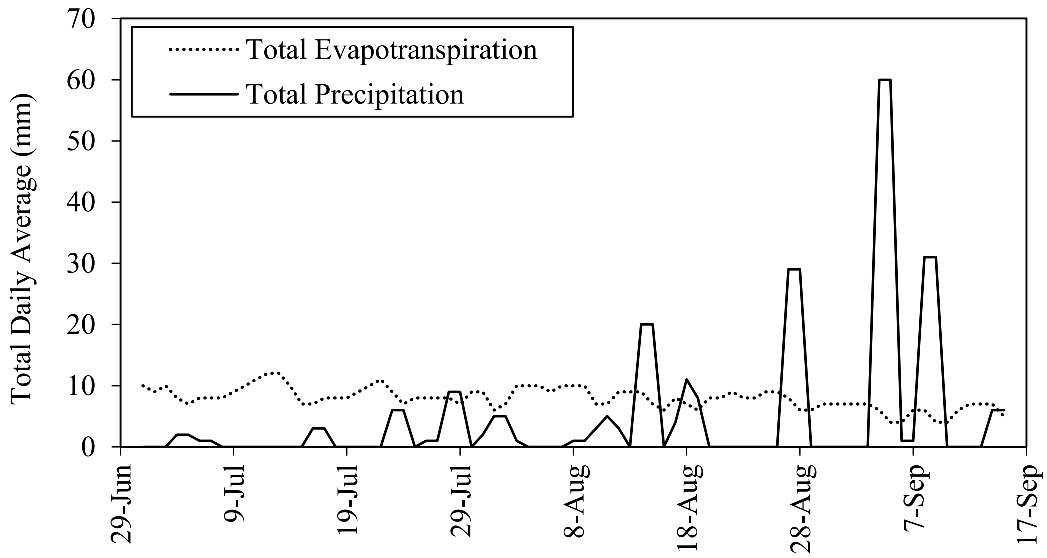


Figure 3.1. Total daily average precipitation and estimated potential evapotranspiration for Kentville during growing season

In the Canada Land Inventory this soil is classification as “Class 2”, capable of sustained use for agricultural crops, the soils are deep and hold moisture well (MacDougall et al. 1969). The surface and subsoil is dark brown, very friable sandy loam, over dark-brown sandy and yellowish-red loamy sand. In the Canadian soil classification system is classified as an Eluviated Dystric Brunisol. The parent material is deep with red to yellowish-red water deposited fine loamy sand. The limitations for cultivation are moderate and under good management they are productive for a wide range of crops (Langeville et al. 1993). The soil texture was determined to be a sandy loam (SL) with 71% sand, 15% clay, 14% silt and 1.82% of soil OM with less than 0.1% of N. Some physical properties of the soil are presented in Table 3.2.

Table 3.2. Soil physical properties of the field

Depth	Grain size (%)			Bulk Density
(cm)	sand	clay	silt	(g cm^3)
0-15	70	15	15	1.51
15-30	69	15	16	1.50
30-45	70	16	14	1.51
45-60	74	14	12	1.52
Standard deviation	2.22	0.82	1.71	0.01

3.2.2. Treatments and experimental designs

The experiment consisted of 27 plots in 3 blocks, the location of the treatments in each block is shown in Table 3.3. Each block was 6 m long and 11 m wide. Each plot was 3 m in length contained 3 raised beds, 53 cm wide and 20 cm high, spaced 95 cm from center to center. The middle raised bed was considered as the data row. The design was a completely randomized block design. Crop management treatments included timing of N fertilizer application, sidedress N fertilizer rates and an extra irrigation event. Treatments were analyzed in 4 contrast in line with objectives of the project.

Nitrogen fertility treatments included a control (zero-N) and two split application schedules. The recommended rate of N fertilizer for lettuce in Nova Scotia is 120 kg N ha^{-1}. The preplant schedule was application of 90 kg N ha^{-1} a week before planting plus 30 kg N ha^{-1} two weeks after planting. The split schedule treatment included application of 60 kg N ha^{-1} a week before planting followed by 60 kg N ha^{-1} two weeks after planting (Table 3.3). Ammonium nitrate (NH_4NO_3; 34%N) was used for preplant N applications. Additional treatments examined the potential for sidedress N fertilizer treatments over and above the 120 kg N ha^{-1} application rate to increase yield. Those treatments includes 0, 15, 30 and 45 kg ha^{-1} N fertilizer in form of calcium nitrate ($Ca(NO_3)_2$) and were applied three weeks after transplanting.

The data were subjected to analysis of variance (ANOVA) using SAS version 9.3 for Windows (SAS Institute, 2011). Least significant difference (LSD) at $P < 0.05$ was used to evaluate significant differences among means. Two different leaf lettuce cultivars (iceberg and romaine varieties) were planted in the experiment; Block 1 was planted with romaine and blocks two and three with iceberg. Lettuce cultivar was considered as a covariate in analysis of the data in all four experiments. Extra irrigation was applied at two different dates and volumes. Irrigation date and volume were treated as a covariate for contrast 1 and was not used in contrast 2 or 3 analyses.

Contrast 1 tested the effect of sidedress fertilizer at rates of zero and 30 kg N ha^{-1} and extra irrigation (no extra irrigation vs. 8 cm irrigation) on yield, N uptake, and Mineral N balance in top 30 cm of soil in preplant treatment in a 2 × 2 factorial arrangement with two sidedress fertilizer levels (0 and 30 kg N ha^{-1}) and two extra irrigation levels (0 and 8 cm).

Contrast 2 tested the effects of sidedress fertilizer three weeks after transplanting, at rates of 0, 15, 30, and 45 kg N ha^{-1} on yield, N uptake, and Mineral N balance in top 30 cm of soil in split treatment.

Contrast 3 tested the effects of base fertility treatments (Preplant vs. Split vs. control) on yield, N uptake, and Mineral N balance in top 30 cm of soil.

Contrast 4 tested the effects of base fertility treatments (Preplant vs. Split) and two sidedress N rates (0 and 30 kg N ha^{-1}) on yield, N uptake, and Mineral N balance in top 30 cm of soil with 2 × 2 factorial arrangement with two base N fertilizer levels (Preplant vs. Split) and two sidedress levels (0 and 30 kg N ha^{-1}).

Table 3.3. Experimental plot layout

Block	1 (kg N ha^{-1})			2 (kg N ha^{-1})			3 (kg N ha^{-1})		
Base Fertilization	90/30	90/30	60/60	60/60	0/0	90/30	90/30	60/60	60/60
Sidedress	0	30	30	30	0	0	0	0	15
Experimental Unit	1	4	7	10	13	16	19	22	25
Base Fertilization	60/60	90/30	90/30	60/60	90/30	60/60	60/60	60/60	0/0
Sidedress	0	0	30	15	0	0	45	30	0
Experimental Unit	2	5	8	11	14	17	20	23	26
Base Fertilization	0	60/60	60/60	90/30	60/60	90/30	90/30	90/30	90/30
Sidedress	0	15	45	30	45	30	30	30	0
Experimental Unit	3	6	9	12	15	18	21	24	27

Plots with the application of extra irrigation after 5 weeks of transplanting are underlined

Lettuce crop was established from transplants at the 3-4 leaf stage. No fertilizer was added before transplanting. After planting they received 5 cm of water two times through sprinkler irrigation during the growing period and an extra irrigation was applied to preplant treatments five weeks after transplanting.

Figure 3.2. Lettuce transplants at their 3-4 leaf stage

Forty two micro-lysimeters (suction lysimeters) were installed at 45 cm soil depth in the hill and in the furrow for all experimental plots. They were installed on July 18, 2012 and were sampled on a weekly basis until mid-September, 2012. Soil water samples were collected from the lysimeters by applying a suction of 0.8 bar using a mobile vacuum pump (Bouman et al. 2010). To install micro-lysimeters first a hole was drilled in soil with an auger drill bit (1 m×22 mm diameter) powered by cordless drill (18V). While drilling, water was added to the hole. The hole needs to be narrower than lysimeter diameter and shallower in depth than the lysimeter tube in order to assure good contact between the porous cup and the soil. By using a hammer, the lysimeter was inserted into the hole until the top of the lysimeter tube was approximately 3 cm above ground level. Then a thin plastic tube with the stopper and connector was inserted into the lysimeter tube to prevent entering dirt. Bentonite was used around the lysimeter tube to prevent preferential water flow from reaching the porous cup of the lysimeter and the bottle was attached with a plastic tube to the top of the lysimeter. The collector bottle had a 500 mL capacity. The length of the plastic tubes used for sample transfer to the collector bottle were 50 cm. This specific design of lysimeters makes installation easy. When compared to Pcaps lysimeters, the installation and removal of a suction lysimeter allows for minimum disturbance to both soil and crop (Love, 2011). Also it should be noted that ceramic lysimeters are not as durable as stainless steel lysimeters and cannot stay in the ground throughout the year (Love, 2011). Figures 3.4 and 3.5 show the locations of the lysimeters in an experimental unit.

Figure 3.3. Lysimeter placement in the field

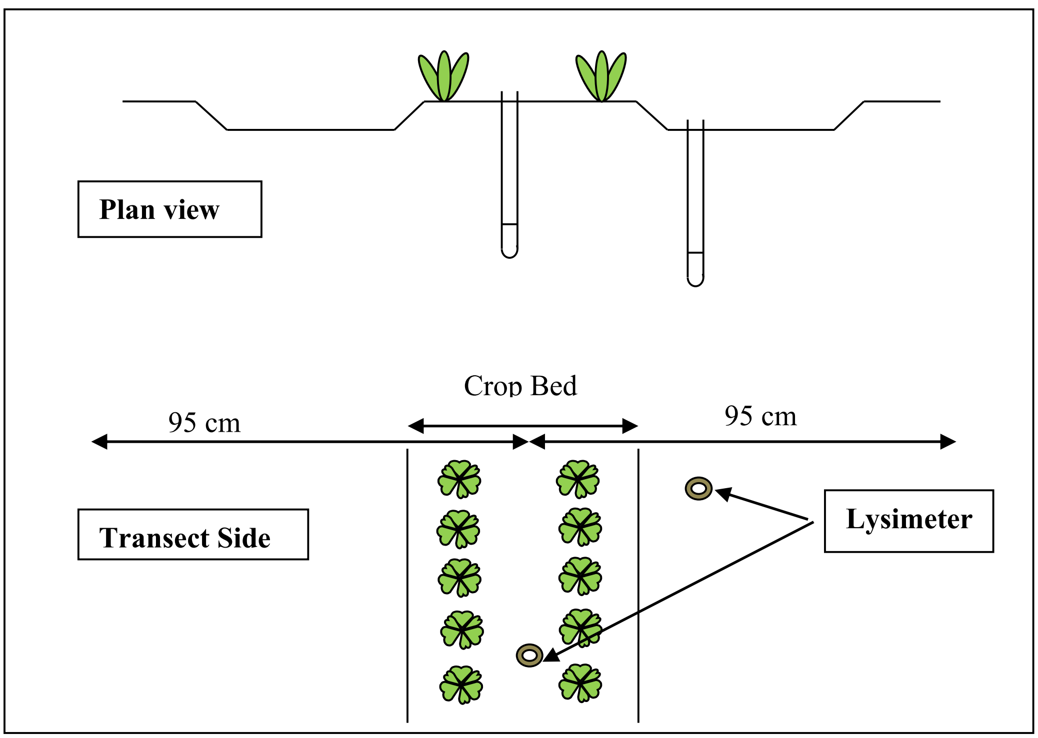


Figure 3.4. The schematic location of the lysimeters in the experimental plot

3.2.3. Field data collection and analysis

3.2.3.1. Soil samples

Soil mineral N content was determined in samples taken at the beginning and end of the experiment at 15 cm increments to a depth of 60 cm with a Dutch Auger (1m × 22 mm diameter). Soil samples were extracted with 2*M* KCl for the determination of NH_4^+ and NO_3^-. Ten grams of fresh soil was weighed and extracted with 50 mL of 2*M* KCl solution and shaken for an hour and filtered with Watman 42 filter paper. The filtrate was collected and stored at -18 °C before being analyzed colorimetrically for NO_3^- and NH_4^+ using a Technicon Auto-Analyzer II in Greenhouse Gas Lab at Dalhousie Faculty of Agriculture. For NH_4^+, Industrial Method No. 791- 86T and for NO_3^- Industrial Method No. 487-77A were used. These data were used for N balance calculation to estimate the amount of N leached from the root zone.

Soil properties before planting have been reported in Table 3.4. Analysis of variance (ANOVA) was conducted to assess the effect of depth of accumulation of nutrients. Except for NH_4^+ and sulfur (S), the concentration of other nutrients in the top 30 cm of soil was significantly different with lower depth. The top 30 cm of soil had 65% and 64% higher C and N compared with 45-60 cm soil depth, respectively. The concentration of NH_4^+ and NO_3^- were similar in the top 30 cm of soil but there were 56% more NH_4^+ than NO_3^- in 45-60 cm of soil depth. Also NO_3^- concentration were 38% more in the top 30 cm compared with 45-60 cm of soil depth. The accumulation of nutrients in the top 30 cm of soil can be attributed to the incorporation of previous crop residue in to the soil with tillage.

Table 3.4. Soil properties in 15 cm soil intervals up to 60 cm depth before transplanting

Depth		pH	Organic Matter	N	C	NH_4^+	NO_3^-
cm		mmohs cm^{-1}		%		kg N ha^{-1}	
15		6.4±0.1 a	3.2±0.1 a	0.15±0.01 a	1.7±0.16 a	9±4	10±1.5 a
30		6.2±0.1 a	3.0±0.2 a	0.13±0.01 a	1.43±0.01 a	10.2±3.5	8.4±1.3 ab
45		5.4±0.2 b	2.1±0.5 b	0.07±0.03 b	0.75±0.34 b	12.3±2.3	6.6±1.5 bc
60		5.2±0.3 b	1.7±0.1 b	0.03±0.01 b	0.36±0.13 b	9.1±4.3	4.8±0.8 c
Source of variation				Analysis of variance			
	df			P-value			
depth	3	0.00	0.00	0.00	0.00	0.658	0.005

Depth		P_2O_5	K_2O_5	Ca	Mg	Na	S
cm				kg ha^{-1}			
15		2522±231 a E	462±53 a H	4205±374 a M+	540±58 a H-	34±4 a	60±20
30		2116±367 a E	378±35 a H-	3688±91 a M+	570±45 a H-	39±4.5 a	73±18
45		585±179 b H-	259±29 b M	1747±373 b L+	344±39 b M+	25±3.1 b	98±13
60		339±68 b M-	255±10 b M	1427±252 b L+	288±25 b M	25±1.2 b	86±6
Source of variation				Analysis of variance			
	df			P-value			
depth	3	0.00	0.00	0.00	0.00	0.002	0.07

Depth		Al	Fe	Mn	Cu	Zn	B	CEC
cm					ppm			meq/100gm
15		1435±34 a	373±16 a	39±5 a	13±1 a	9±2 a	0.98±0.17 a	16.6±1.4 a
30		1473±64 a	359±24 a	28±1 b	11±1 a	7±1 a	0.59±0.13 b	15.7±0.1 a
45		1672±53 b	289±23 b	12±5 c	4±2 b	2±1 b	<=0.5 c	10.4±1.5 b
60		1718±41 b	267±20 b	9±2 c	3±2 b	1±0 b	<=0.5 c	9.1±0.5 b
Source of variation					Analysis of variance			
	df				P-value			
depth	3	0	0.01	0.00	0.00	0.00	0.03	0.00

Mean ± Standard deviation of 3 replications within columns followed by same letter are not significantly different at 5% level of significance L=Low M=Medium H=High E=Excessive

3.2.3.2. Plant samples

Lettuce plants were harvested 49 days after planting on August 29, 2012. The number and weight of both marketable and unmarketable plants per plot were recorded. Six representative marketable plants per plot were collected for further analysis. The grading was done based on weight, size and color. The marketable plants were larger in size, weighed more and were greener with no tip burn or chlorosis and no insect damage.

Plant samples were dried in oven at 55°C for 48 hours and were ground in a Wiley mill to 1mm. Total N concentration in plant samples was determined by combustion using an Elementar Vario Max CN analyzer. Plant N uptake then calculated by multiplying N concentration and dry above ground biomass. Plant N uptake was considered as N output in N budget calculations.

3.2.3.3. Leachate samples

Leachate samples were collected at 45 cm depth both on hill and furrow using micro-lysimeter on 8 different sampling dates throughout the growing period on July 26th and 30th, August 2nd, 7th, 14th, 21st and 27th and September 12th. Leachate samples were collected from the lysimeters by applying a vacuum of 0.8 bar using a mobile vacuum pump. This was done weekly as well as after each rainfall. Samples of irrigation water also were collected twice during the study period.

All leachate samples were stored at -20 °C until further analysis. Samples were analyzed for NO_3^- and NH_4^+ concentrations colorimetrically using a Technicon Auto-Analyzer II. The effect of treatment and sampling date on NO_3^- and NH_4^+ concentrations was analyzed in ANOVA using a repeated measures. For repeated measures analysis, the factor of sampling date was added. In repeated measures analysis, five covariance structures; Compound Symmetry, Heterogeneous Compound Symmetry, Toeplitz, Heterogeneous Toeplitz and Ante-dependence were compared. The covariance structure which gave the smallest corrected Akaike information criterion (AICC) and Bayesian information criterion (BIC) numbers, was selected to run the ANOVA test. The experimental design was a completely randomized block design and treatments were analyzed in 4 contrasts in line with objectives of the project.

3.3. Result and Discussion

3.3.1. Soil samples

Soil samples were collected before planting on 12 June, 2012 and after harvesting on 12 September, 2012. Table 3.5 shows the mean NO_3^- and NH_4^+ content for different soil depth at harvest for preplant treatments with and without extra irrigation. The NO_3^- content in different depths (0-15, 15-30, 30-45, 45-60 cm) was not affected by sidedress fertilizer application, irrigation and soil depth or their interactions (Table 3.5). The low residual NO_3^- content in the top 60 cm of the soil can be related to large precipitation of 91.5 mm that has occurred after harvesting and before soil sampling in September 2012. The lack of significant differences among treatments can be attributed to small difference in N rate and/or high spatial and vertical variability of mineral N in field. The NH_4^+ content was very low in all depths ($\leq$2 kg N ha^{-1}) and was not affected by treatments, soil depth or their interactions at harvest.

Table 3.5. Mean NO_3^- and NH_4^+ content (kg N ha^{-1}) in different soil depths after harvest for preplant treatments with and without extra irrigation

Treatment		NO_3^-	NH_4^+
		kg N ha^{-1}	
Sidedress (kg N ha^{-1}) (n=3)			
	0	4.59±2.72	1.66±0.67
	30	3.86±1.22	1.47±0.55
Irrigation (cm) (n=3)			
	0	4.30±2.14	1.55±0.56
	8	4.15±2.15	1.57±0.68
Depth (cm) (n=3)			
	15	4.03±1.41	1.63±0.62
	30	4.75±2.90	1.59±0.66
	45	3.78±1.90	1.55±0.66
	60	4.36±2.15	1.48±0.58
Source of variation		Analysis of variance	
	df	P- value	
Block	2	0.602	0.079
Sidedress (SD)	1	0.302	0.290
Irrigation (I)	1	0.828	0.907
SD*I	1	0.418	0.642
Depth (D)	3	0.778	0.942
SD*D	3	0.890	0.177
I*D	3	0.932	0.567
SD*I*D	3	0.710	0.306

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

The effect of different levels of sidedress application in split treatments on soil NH_4^+ and NO_3^- content is presented in Table 3.6. The interaction of sidedress and depth had no significant effect on soil NH_4^+ and NO_3^- content, whereas greater application of NO_3^- fertilizer as sidedress had marked effect on NO_3^- content in the soil (Figure 3.5). The mass of NO_3^- in the soil profile increased with increasing the sidedress rates up to 30 kg N ha^{-1}. This increase in NO_3^- content in the soil can be attributed to more accumulation of NO_3^- in the top 60 cm of the soil which were not used by the plants, while in SSD45, lower NO_3^- was measured in the top 60 cm of the soil compared to SSD30, there is a possibility that NO_3^- has been leached to deeper layers of the soil in this treatment.

Table 3.6. Mean NO_3^- and NH_4^+ content (kg N ha^{-1}) in different soil depths after harvest for split treatments

Treatment		NO_3^-	NH_4^+
		kg N ha^{-1}	
Sidedress (kg N ha^{-1}) (n=3)			
	0	3.56±1.14 b	1.67±0.98
	15	3.80±1.43 b	1.42±0.74
	30	5.66±1.97 a	1.50±0.74
	45	4.23±1.36 b	2.02±0.88
Depth (cm) (n=3)			
	15	4.66±1.04	1.64±0.10
	30	4.23±1.27	1.64±0.81
	45	4.09±2.13	1.71±0.94
	60	4.27±2.12	1.60±0.74
Source of variation		Analysis of variance	
	df	P- value	
Block	2	0.106	0.297
Sidedress (SD)	3	0.004	0.331
Depth (D)	3	0.779	0.993
SD*D	9	0.126	0.315

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

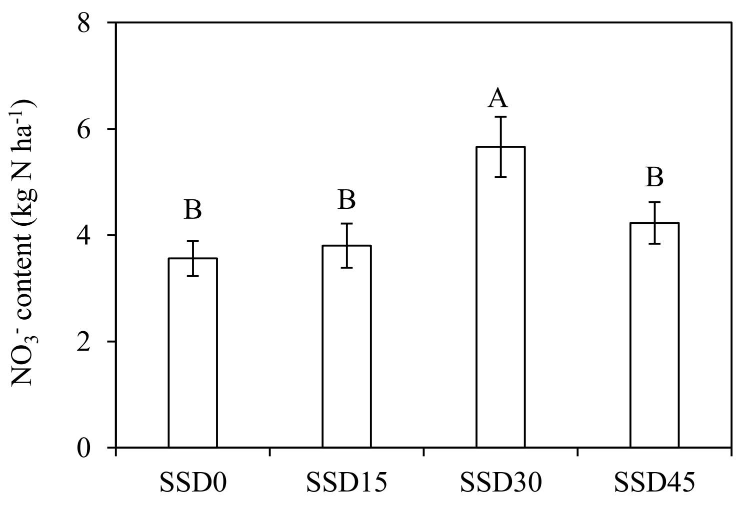


Figure 3.5. The effect of sidedress (SD) on soil NO_3^- content in split treatments. Bars represent standard errors

Table 3.7 presents the effect of base N fertilizer (Preplant, Split and control treatments) on NO_3^- and NH_4^+ content (kg N ha^{-1}) in different soil depths. There were no significant differences in NO_3^- and NH_4^+ content between different treatments and depths. Also, the interaction between base N fertilizer and depth was not significant. This may show that the applied N fertilizer either taken up by the plant or lost from top 60 cm.

Table 3.7. Mean NO_3^- and NH_4^+ content (kg N ha^{-1}) in different soil depths after harvest for base fertilizer treatments

Treatment		NO_3^-	NH_4^+
		kg N ha^{-1}	
Base N fertilizer (kg N ha^{-1}) (n=3)			
	0	3.95±0.68	1.75±0.80
	60	3.56±0.33	1.67±0.98
	90	4.38±0.78	1.60±0.70
Depth (cm) (n=3)			
	15	3.92±0.48	1.35±0.39
	30	4.46±0.94	2.08±1.04
	45	3.28±0.55	1.39±0.48
	60	4.20±0.85	1.89±0.99
Source of variation		Analysis of variance	
	df	P- value	
Block	2	0.084	0.131
Base N fertilizer (B)	2	0.659	0.912
Depth (D)	3	0.703	0.174
B*D	6	0.723	0.828

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

Table 3.8 shows the statistical analysis for the effect of base fertilizer and two sidedress rates on NO_3^- and NH_4^+ content at harvest at different soil depths. The effect of base fertilizer, sidedress, depth and their interactions on NO_3^- and NH_4^+ content was not significant, except for interaction of base fertilizer×sidedress on NO_3^- content (Figure 3.6). The higher NO_3^- content at top 60 cm of SSD30 compared with PSD30-R can be related to the effect of N fertilizer application timing in SSD30 that leaves more NO_3^- in the soil at harvest, this amount of NO_3^- has not being used by lettuce plants either because it is accumulated in the deeper layers of the soil or sidedress N fertilizer was applied in excess of plant N requirements. This has been regarded as a risk for NO_3^- leaching in the following winter and spring.

Table 3.8. Mean NO_3^- and NH_4^+ content (kg N ha^{-1}) in different soil depths after harvest for base fertilizer treatments with application of N sidedress

Treatment		NO_3^-	NH_4^+
		kg N ha^{-1}	
Base N fertilizer (kg N ha^{-1}) (n=8)			
	60	4.61±1.90	1.59±0.85
	90	4.30±2.14	1.55±0.56
Sidedress (kg N ha^{-1}) (n=8)			
	0	3.97±2.08	1.64±0.83
	30	4.94±1.85	1.50±0.59
Depth (cm) (n=4)			
	15	4.18±1.06	1.42±0.40
	30	4.62±2.37	1.73±0.86
	45	4.16±2.08	1.55±0.76
	60	4.88±2.39	1.58±0.82
Source of variation		Analysis of variance	
	df	P- value	
Block	2	0.074	0.520
Base N fertilizer (B)	1	0.573	0.874
Sidedress (SD)	1	0.079	0.530
B*SD	1	0.043	0.879
Depth (D)	3	0.732	0.806
B*D	3	0.492	0.643
SD*D	3	0.147	0.361
B*SD*D	3	0.590	0.397

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

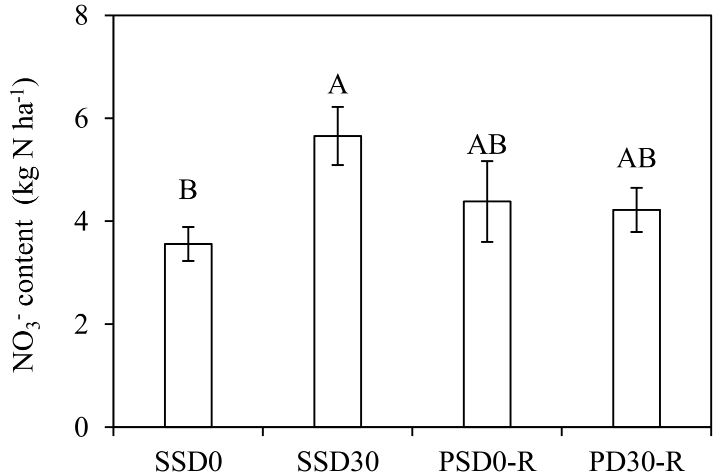


Figure 3.6. The effect of base N fertilizer and sidedress interaction (B*SD) on NO_3^- content. Bars represent standard errors

3.3.2. Leachate samples

Nitrate concentration was monitored at 45 cm soil depth at hills and furrows using micro-lysimeters. Nitrate concentration in hill and furrow were different; N fertilizer was applied to hills and plants were grown on hills, whereas furrows were more compacted and wet compared to hills. Concentration of NH_4^+ was less than NO_3^- in the leachate for all treatments (< 0.1 mg N L^{-1}). Ammonium adsorbs on soil exchangeable sites, fix between clay layers and rapidly oxidized to NO_2^- and NO_3^- through nitrification. There was less NO_3^- concentration in the furrows than hill as fertilizer was applied to hills.

There was also a constant decrease during the growing season for NO_3^- concentration in the leachate at hill locations, which can be associated with plant N uptake. The peak of the NO_3^- concentration occurred in mid-season right after application of sidedress fertilizer (Table 3.9). Concentration of NO_3^- peaked to >80 mg NO_3-N L^{-1} a month after fertilizer application in preplant treatments in the hills and gradually decreased to ~ 40 mg NO_3-N L^{-1} at the end of the season (Table 3.9). Concentrations of NO_3^- in preplant treatments in the furrow were relatively constant during the growing period with average of 40 mg NO_3-N L^{-1}. The interaction of sidedress (SD), Irrigation (I) and sampling date (D) on NO_3^- concentration were not significant. The effect of sampling date on NO_3^- concentration both at hill and furrow was significant and decreased after harvest in September (29 and 27 mg NO_3-N L^{-1} at furrow and hill, respectively).

Figure 3.7 shows the interaction of sidedress and irrigation on NO_3^- concentration in furrow. Preplant treatment without sidedress and extra irrigation (PSD0-R) had lower NO_3^- concentrations in furrow but there is not the same trend at the hill. This can be attributed to more compact soil and hence less permeability in the furrow compared with hill location.

Table 3.9. Mean NO_3^- and NH_4^+ concentration (mg L^{-1}) in different dates for preplant treatments with and without extra irrigation

Treatments	Sampling date	NH_4-F	NH_4-H	NO_3-F	NO_3-H
		mg L^{-1}			
PSD0-R	1	0.61±0.50	0.02±0.06	34.5±11.3	58.5±13.9
	2	0.11±0.34	-	32.6±6.2	-
	3	0.25±0.40	0.04±0.07	31.6±7.7	70.3±19.3
	4	0.04±0.34	0.06±0.00	28.5±6.2	50.7±13.9
	5	0.39±0.34	0.04±0.00	39.8±6.2	78.8±11.4
	6	0.01±0.34	0.01±0.00	27.5±6.2	63.0±11.4
	7	0.00±0.34	0.03±0.00	34.7±6.2	71.5±11.4
	8	0.09±0.34	0.13±0.00	22.2±6.2	14.1±13.9
PSD30-R	1	0.02±0.45	0.02±0.06	56.1±7.7	61.1±14
	2	0.03±0.44	0.05±0.09	51.1±7.7	84.8±19.2
	3	0.02±0.39	0.01±0.00	43±7.7	93.1±14
	4	0.05±0.39	0.04±0.00	45.9±7.7	77.5±11.4
	5	0.03±0.34	0.01±0.00	49.7±6.2	74.7±14
	6	0.01±0.34	0.00±0.00	31.2±6.2	57.0±14
	7	0.01±0.34	0.06±0.00	46.0±6.2	55.5±11.4
	8	0.02±0.34	0.07±0.00	24.7±6.2	48.8±11.4
PSD0+R	1	0.36±0.36	0.50±0.06	49.4±7.7	45.2±13.8
	2	1.21±0.34	0.33±0.05	40.8±6.2	74.6±19.2
	3	0.10±0.35	0.17±0.07	34.1±7.7	34.7±19.2
	4	0.82±0.35	0.07±0.00	52.8±7.7	63.7±11.4
	5	0.02±0.34	0.01±0.00	51.8±6.2	61.5±11.4
	6	0.02±0.35	0.10±0.00	39.3±7.8	45.4±11.4
	7	0.20±0.34	0.01±0.03	56.2±6.2	32.1±11.4
	8	0.07±0.34	0.03±0.05	36.7±6.2	12.4±11.4
PSD30+R	1	-	0.02±0.09	-	72.5±13.8
	2	0.05±0.44	0.03±0.00	47.5±7.6	48.6±19
	3	0.05±0.55	0.02±0.00	42.2±11	52.5±11.4
	4	0.04±0.43	0.04±0.00	42.7±7.6	81.0±11.4
	5	0.01±0.44	0.00±0.00	30.8±7.6	88.6±11.4
	6	0.32±0.43	0.01±0.00	36±11	61.5±11.4
	7	0.15±0.43	0.02±0.00	-	54.2±11.4
	8	0.53±0.56	0.01±0.00	-	31.1±11.4
Sampling date	1			-	59.5±7.7 ab
	2			43±3.5 ab	-
	3			37.3±4.3 ab	63.6±8.8 ab
	4			42.5±3.6 ab	68.2±7 ab
	5			43±3.3 ab	76.3±7 a
	6			33.5±4 ab	57.1±7 ab
	7			50±3.8 a	53.3±6.7 b
	8			29.8±3.3 b	27±7 c
		Analysis of variance			
Source of Variation	df	Pr > F	Pr > F	Pr > F	Pr > F
Block	2	0.56	<.0001	0.42	0.59
Sidedress (SD)	1	0.77	0.31	0.07	0.21
Irrigation (I)	1	0.26	0.79	0.02	0.11
SD*I	1	0.70	0.79	0.04	0.44
Date (D)	7	0.87	0.27	0.01	<.0001
SD*D	7	0.87	0.48	0.61	0.45
I*D	7	0.85	0.24	0.48	0.19
SD*I*D	6	0.79	0.14	0.68	0.47

Mean ± Standard error within columns followed by same letter are not significantly different at 5% level of significance using tukey multiple comparison test

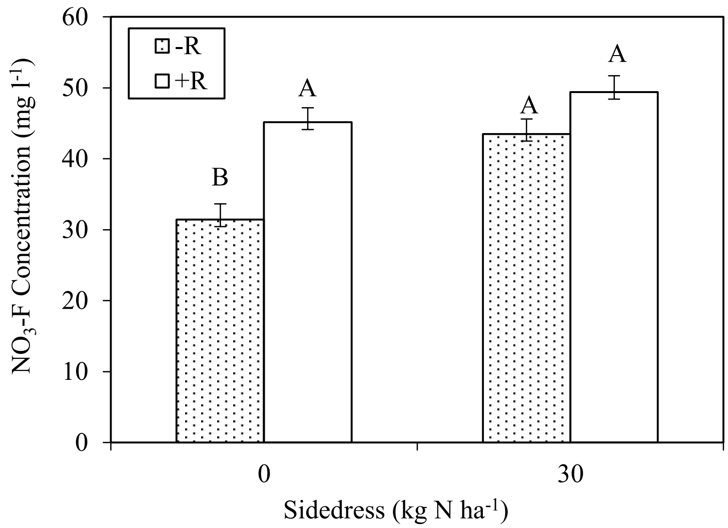


Figure 3.7. The effect of sidedress and irrigation interaction (SD*I) on NO_3^- concentration of leachates collected at 45 cm below the furrow location for preplant treatments. Bars represent standard errors

Ammonium concentrations were low in leachates collected below the furrow and were not affected by base fertilizer, sampling date and interaction of them while it shows a significant difference in hill ($P<0.05$) (Table 3.10).

Similar patterns to preplant treatments were observed for base N fertilizer treatments; although the interaction of base fertilizer (B) and sampling date (D) on NO_3^- concentration was not significant at hill, it was significantly different in various sampling dates and was lower after harvest (the 8th sampling date) (Table 3.10). This significant decrease shows that either NO_3^- was taken up by the plant or moved to deeper layers of the soil. Cambouris et al. (2008) also reported no significant effect of N fertilizer rate on NO_3-N concentration in leachate from porous suction lysimeter in the first year of study.

The interaction of B*D was significant for NO_3^- concentration of leachates collected below the furrow and was higher on the first sampling date for B0SD0, PSD0-R and SSD0 with 51, 35 and 117 mg NO_3-N L^{-1} and it decreased during the growing period (Table 3.10). This is because no N input was added to the soil to disturb the balance in the soil, and therefore the supply of NO_3^- was through mineralization of soil organic matter in B0SD0 and through base fertilizer application at the beginning of the growing period in PSD0-R and SSD0.

Table 3.10. Mean NO_3^- and NH_4^+ concentration (mg L^{-1}) in different sampling dates for base N fertilizer treatments

Treatments	Sampling date	NH_4-F	NH_4-H	NO_3-F	NO_3-H
		mg L^{-1}			
B0SD0	1	0.04±0.13	0.08±0.03 ab	50.9±13.9 ab	47.8±15.4
	2	0.03±0.13	0.00±0.00 b	-	54.2±15.4
	3	0.01±0.13	0.02±0.09 ab	-	49.2±15.4
	4	0.02±0.13	0.01±0.04 ab	-	51.8±15.4
	5	0.01±0.10	0.01±0.02 b	16.2±14.2 b	65.1±13.7
	6	0.02±0.13	0.01±0.01 b	-	55.1±15.4
	7	0.00±0.10	0.00±0.08 ab	29.8±9.6 b	70.1±13.7
	8	0.01±0.10	0.01±0.09 ab	31.7±9.6 b	25.5±13.7
SSD0	1	0.05±0.13	0.03±0.03 b	117±13.6 a	59.6±12.2
	2	0.23±0.09	0.25±0.01 a	34.6±9.5 b	74.6±18.7
	3	0.31±0.19	0.14±0.09 ab	45.4±9.5 b	65.3±15.2
	4	0.14±0.13	0.06±0.03 ab	48.2±7.7 b	82.3±13.7
	5	0.06±0.10	0.01±0.02 b	48.1±7.7 b	63.3±13.7
	6	0.01±0.10	0.01±0.00 b	29.9±7.7 b	49.7±13.7
	7	0.15±0.10	0.15±0.08 ab	34.7±7.7 b	51.5±13.7
	8	0.17±0.10	0.17±0.09 ab	15.2±7.7 b	42.9±13.7
PSD0-R	1	0.33±0.19	0.03±0.03 b	34.7±13.5 ab	62.0±15.3
	2	0.11±0.10	-	32.6±7.7 b	-
	3	0.01±0.13	0.00±0.13 ab	32.5±9.5 b	71.1±18.9
	4	0.04±0.10	0.06±0.04 ab	28.5±7.7 b	47.7±15.2
	5	0.39±0.10	0.04±0.02 b	39.8±7.7 b	78.8±13.7
	6	0.01±0.10	0.01±0.00 b	27.5±7.7 b	63.0±13.7
	7	0.00±0.10	0.03±0.08 ab	34.7±7.7 b	71.5±13.7
	8	0.09±0.10	0.12±0.12 ab	22.2±7.7 b	17.6±15.3
Sampling date	1				56.5±8.8 a
	2				-
	3				61.9±9.6 a
	4				60.6±8.5 a
	5				69.1±7.9 a
	6				56±8.3 a
	7				64.4±7.9 a
	8				28.7±8.2 b

Analysis of variance

Source of variation	df	Pr > F	df	Pr > F	df	Pr > F	df	Pr > F
Block	2	0.15	2	0.61	2	0.77	2	0.93
Base fertilizer (B)	2	0.15	2	0.09	2	0.10	2	0.85
Date (D)	7	0.75	7	0.01	7	0.00	7	0.00
B*D	14	0.63	13	0.00	10	0.02	13	0.15

Mean ± Standard error within columns followed by same letter are not significantly different at 5% level of significance using tukey multiple comparison test

Table 3.11 presents the NO_3^- and NH_4^+ concentration for base fertilizer treatments with application of N sidedress. Ammonium concentration was low and not affected by interaction of base fertilizer (B) and sidedress (SD) throughout the growing period. However, NO_3^- concentration at hill was affected by B*SD*D and was significantly higher in PSD0-R in the fifth and seventh sampling date (after sidedress application) with 72 and 79 mg NO_3-N L^{-1} compared with PSD30-R, SSD0 and SSD30. Also harvest NO_3^- concentration was lower (17 mg NO_3-N L^{-1}) in PSD0-R (Table 3.11). This showed that NO_3^- concentration in PSD0-R plots was more variable and although it has the maximum concentration mid-season it reached 17 after harvest. As no sidedress was added to this plot, it can be concluded that NO_3^- has been consumed by the plant, moreover there was neither extra irrigation applied to this plot nor heavy rain occurred during the growing period, therefor leaching to deeper layers is not very probable.

Figure 3.8a showed the interaction of sidedress and sampling date on NO_3^- concentration in furrow. Although the fertilizer was not applied to the furrow, the concentration of NO_3^- was significantly higher in treatments with sidedress, which shows that NO_3^- has moved to furrow in 45 cm depth of the soil. There is the same results for the effect of B*D which shows higher NO_3^- concentration in furrow for split treatment (Figure 3.8b).

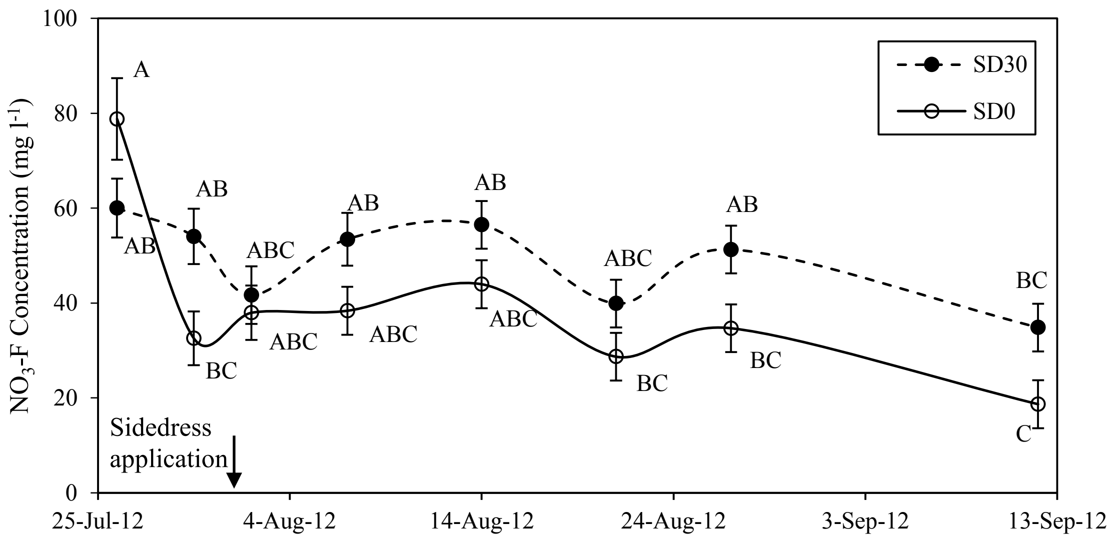
Table 3.11. Mean NO_3^- and NH_4^+ concentration (mg L^{-1}) in different sampling dates for base fertilizer treatments with application of N sidedress

Treatments	Sampling date	NH_4-F	NH_4-H	NO_3-F	NO_3-H
		mg L^{-1}			
SSD0	1	0.00±0.02	0.03±0.03	122±12.0	59.7±13.2 ab
	2	0.15 ±0.09	0.27±0.03	32.5±8.9	74.7±16.5 ab
	3	0.13±0.09	0.10±0.79	43.4±8.20	65.3±13.2 ab
	4	0.06±0.03	0.06±0.79	48.2±7.10	82.3±11.9 ab
	5	0.01±0.20	0.01±1.32	48.1±7.10	63.3±11.9 ab
	6	0.01±0.01	0.01±0.78	29.9±7.10	49.7±11.9 ab
	7	0.15±0.07	0.15±0.79	34.7±7.10	51.5±11.9 ab
	8	0.17±0.08	0.17±0.79	15.2±7.10	42.9±11.9 ab
PSD0-R	1	0.30±0.04	0.03±0.78	35.3±12.1	61.7±13.3 ab
	2	0.11±0.06	-	32.6±7.10	-
	3	0.09±0.08	0.05±0.79	32.5±8.10	70.9±16.7 ab
	4	0.04±0.03	0.07±0.79	28.5±7.10	47.9±13.3 ab
	5	0.39±0.20	0.04±1.32	39.8±7.10	78.8±11.9 a
	6	0.01±0.01	0.01±0.78	27.5±7.10	63.0±11.9 ab
	7	0.00±0.07	0.03±0.79	34.7±7.10	71.5±11.9 a
	8	0.09±0.08	0.11±0.79	22.2±7.10	17.3±13.3 b
SSD30	1	0.02±0.02	0.07±0.78	70.3±8.50	77.3±13.3 ab
	2	0.02±0.06	0.04±1.09	58.7±7.10	47.6±16.6 ab
	3	0.01±0.08	0.01±0.79	43.8±8.10	45.4±13.3 ab
	4	0.02±0.03	0.00±0.79	60.4±7.10	55.5±13.3 ab
	5	0.01±0.20	1.98±1.32	63.3±7.10	60.1±11.9 ab
	6	0.01±0.01	0.09±0.78	48.6±7.10	49.6±11.9 ab
	7	0.01±0.07	0.01±0.79	56.6±7.10	66.0±11.9 ab
	8	0.04±0.08	0.05±0.79	45.0±7.10	52.0±11.9 ab
PSD30-R	1	0.01±0.02	0.04±0.78	49.8±9.00	62.9±13.4 ab
	2	0.01±0.08	0.02±1.09	49.4±9.30	86.2±16.7 ab
	3	0.03±0.09	0.03±0.79	39.6±9.00	94.6±13.4 a
	4	0.08±0.04	0.04±0.79	46.5±8.60	77.5±11.9 ab
	5	0.03±0.20	0.04±2.10	49.7±7.10	76.4±13.4 ab
	6	0.01±0.01	0.00±0.79	31.2±7.10	58.8±13.4 ab
	7	0.01±0.07	0.06±0.79	46.0±7.10	55.5±11.9 ab
	8	0.02±0.08	0.07±0.79	24.7±7.10	48.8±11.9 ab

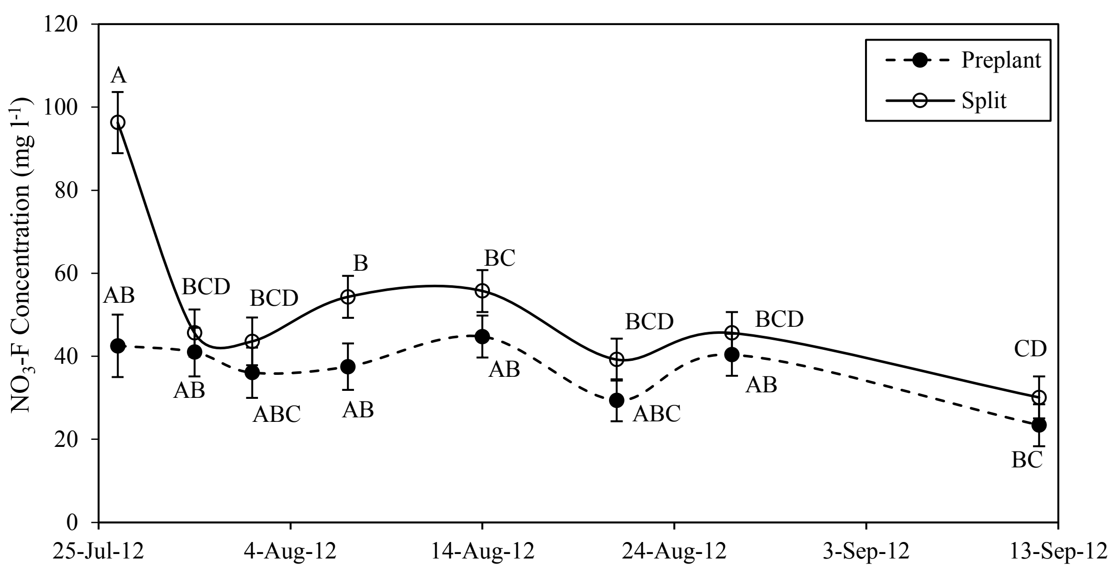
Analysis of variance

Source of variation	df	Pr > F	df	Pr > F	df	Pr > F	df	Pr > F
Block	2	0.50	2	1.00	2	0.49	2	0.90
Base fertilizer (B)	1	0.67	1	0.48	1	0.02	1	0.48
Sidedress (SD)	1	0.03	1	0.71	1	0.06	1	0.89
B*SD	1	0.83	1	0.56	1	0.86	1	0.61
Date (D)	7	0.16	7	0.89	7	0.00	7	0.00
B*D	7	0.12	7	0.98	7	0.03	7	0.03
SD*D	7	0.15	7	0.82	7	0.02	7	0.38
B*SD*D	7	0.11	6	0.82	7	0.13	6	0.01

Mean ± Standard error within columns followed by same letter are not significantly different at 5% level of significance using tukey multiple comparison test



(a)



(b)

Figure 3.8. The effect of (a) sidedress and sampling date interaction (SD*D) and (b) base fertilizer and sampling date interaction (B*D) on NO_3^- concentration in leachates collected at a 45 cm depth in the furrow location. Bars represent standard errors

3.3.3. Nitrogen balance

A mass balance approach was done to approximate N surplus in the top 30 cm of the soil (ΔN) by estimating N inputs (i.e. fertilizer N, mineralized N, and initial soil N) and N removals (N uptake by the crop) and the N left in the soil at the end of the growing period (residual soil N). Mineralized N from soil organic matter was estimated from the total N uptake in the control treatment as follows:

$$N_{min} = N_{plant} + N_{final} - N_{initial} - N_{fert0}$$

$$\Delta N = N_{Fert} + N_{min} + N_{initial} - N_{plant} - N_{final}$$

Where N_{fert}= N input from fertilizer; N_{min}= N input from mineralization of soil organic matter, calculated from the control treatment; $N_{initial}$= inorganic N initially present in the soil (0-60 cm); N_{plant}=N uptake by the plant; and N_{final}= inorganic N present in the soil after harvest (0-60 cm). The above mass balance approach assumes:

(I) Nitrogen contribution from rainfall or losses through volatilization, immobilization and denitrification processes were negligible.

(II) Nitrogen accumulation in the roots of all treatments was nearly same as that of the control, and

(III) There was no priming effect of added N fertilizer on soil N mineralization.

Table 3.12 summarizes the N balance calculations. Considering the input and output from the field, inputs have exceeded outputs in all the treatments. The maximum and minimum net inputs were 240 and 72 kg N ha^{-1} for SSD45 and B0SD0, respectively. The magnitude of difference was mainly as a result of fertilizer application. The applied N fertilizer exceeded the crop N uptake, ranging from 58 to 93 kg ha^{-1}. Nitrogen uptake was calculated using N concentration in the tissue multiplied by the yield of each plot. Nitrogen concentration in the plant ranged from 3.03% for control to 4.17% for split treatment with 45 kg N ha^{-1} sidedress (SSD45), PSD30, SSD30 and SSD15 are the highest after that (Table 3.12). Additional N contribution from irrigation water was 3 kg N ha^{-1}. Initial N content in the top 30 cm of soil depth was decreased by 33% at the end of the growing season. The residual NO_3^- in the soil can be leached by heavy rainfall during the fall/winter or early spring. The percentage of plant uptake to total input N was more than 50% for all treatments except for control treatment which was 19%. Similarly, Frink et al. (1999) reported a ratio of 2:1 for total input N to crop uptake. The greatest surplus was 150 and 134 kg N ha^{-1} in PSD30-R and SSD45, respectively, these surpluses are mainly a consequence of large (165 kg N ha^{-1}) N fertilizer addition.

A linear regression is observed between ΔN and total N input in this study (Figure 3.9). The slope indicates that above 60 kg N ha^{-1}, about 83% of each N unit input is lost out of the root zone and may stay in lower soil depths enhancing the probability of leaching in the coming fall/winter or spring. The simplified N balance approach that has been used in this study does not indicate the pathway of N losses. There are more complicated N balance methods that consider a high number of components and hence are more effective to help assess the mechanisms of N losses from the agricultural field.

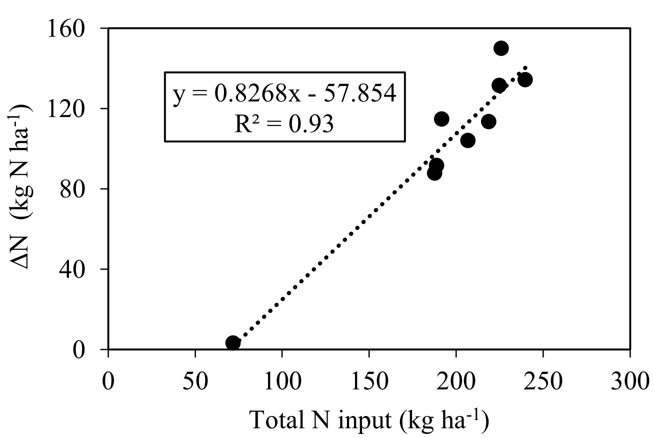


Figure 3.9. A linear regression between ΔN and total N input (kg N ha^{-1})

Table 3.12. Nitrogen balance (kg N ha^{-1}) in top 30 cm during the study period

N flux	**Input (kg N ha^{-1})**				Total	N%*	**Output (kg N ha^{-1})**		Total	**Surplus**
Treatment	soil mineral N at planting	NH_4NO_3+$Ca(NO_3)$ Fertilizer	Irrigation	Mineralization	input		Uptake	soil mineral N after harvest	output	
B0SD0	38	0	3	31	72	3.03	58	11	69	3
PSD0+R	35	120	3	31	189	3.68	84	13	97	92
PSD0-R	38	120	3	31	192	3.47	63	14	77	115
PSD30+R	41	150	3	31	225	4.10	84	10	93	132
PSD30-R	42	150	3	31	226	4.03	65	11	76	150
SSD0	34	120	3	31	188	3.70	89	11	100	88
SSD15	38	135	3	31	207	3.93	91	12	103	104
SSD30	35	150	3	31	219	4.02	93	12	105	113
SSD45	41	165	3	31	240	4.17	91	14	105	134
Mean	38	123	3	31	195	3.79	80	12	92	103
SD	2.9	49.1	0	0	49.8	0.36	13.9	1.6	14.1	42.7

* N concentration in plant tissue

PSD0-R= pre-plant fertilizer application of 90/30 with no sidedress and no extra irrigation; PSD30-R= pre-plant fertilizer application 90/30 with 30 kg N ha^{-1} sidedress and no extra irrigation; PSD0+R= pre-plant fertilizer application 90/30 with no sidedress and extra irrigation; PSD30+R= pre-plant fertilizer application 90/30 with 30 kg N ha^{-1} sidedress and extra irrigation; SSD0=no sidedress application; SSD15= 15 kg N ha^{-1} sidedress application; SSD30= 30 kg N ha^{-1} sidedress application; SSD45= 45 kg N ha^{-1} sidedress application; B0SD0= No fertilizer and sidedress application SD= standard deviation

3.3.4. Yield, N uptake and N surplus in the top 30 cm of soil (ΔN)

There was no significant treatments' effect on yield. Table 3.13 summarizes the effect of sidedress N fertilizer and extra irrigation on yield and N uptake and ΔN. Sidedress, irrigation and their interactions had no significant effect on yield and N uptake. Extra irrigation treatment did not affect marketable yield probably due to late application of extra irrigation. On the other hand the lack of yield response to sidedress N fertilizer can be related to sufficient soil N supply due to low precipitation and consequently low risk of leaching during the growing season. The ANOVA results showed that sidedress N application substantially increased ΔN by 27% compared with when no sidedress is applied (Figure 3.10).

Table 3.13. Effect of sidedress N fertilizer and irrigation on yield, N uptake and N surplus in the top 30 cm of soil (ΔN)

Treatment		Yield Mg ha^{-1}	N Uptake kg ha^{-1}	ΔN kg ha^{-1}
Sidedress (kg N ha^{-1}) (n=3)				
	0	2.04±0.67	73.3±11.0	103±11.6 b
	30	1.82±0.35	74.2±6.65	141±7.39 a
Irrigation (cm) (n=3)				
	0	1.73±0.53	63.9±6.63	132±9.96
	8	2.14±0.47	83.7±9.03	112±13.7
Source of variation			Analysis of variance	
	df		P- value	
Block	2	0.137	0.087	0.149
Sidedress (SD)	1	0.444	0.929	0.016
Irrigation	1	0.168	0.086	0.117
SD*I	1	0.995	0.935	0.842

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

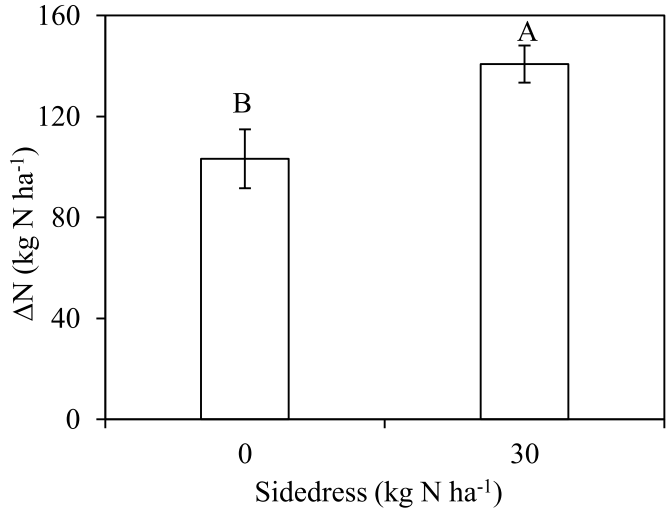


Figure 3.10. The effect of sidedress (SD) on ΔN in top 30 cm of soil in preplant treatments. The same letter denotes no significant difference according to LSD comparison test at the 5% level. Bars represent standard errors

Sidedress treatments did not affect total dry biomass and N uptake in split treatments (Table 3.14). Applying more sidedress had a significant effect on ΔN in the top 30 cm of the soil profile, the highest ΔN was observed in SSD45 with 134.4 (Figure 3.11).

Table 3.14. Effect of different sidedress N fertilizer rates on yield, N uptake and N surplus in the top 30 cm of soil (ΔN)

		Yield	N Uptake	ΔN
Treatment		Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Sidedress (kg N ha^{-1}) (n=3)				
	0	2.39±0.48	89.1±23.2	87.8±20.7 b
	15	2.32±0.30	91.1±11.8	104±19.3 b
	30	2.33±0.29	93.3±10.4	114±9.41 ab
	45	2.19±0.22	91.1±8.50	134±7.65 a
Source of variation			Analysis of variance	
	df		P- value	
Block	2	0.538	0.694	0.371
Sidedress (SD)	3	0.915	0.989	0.045

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

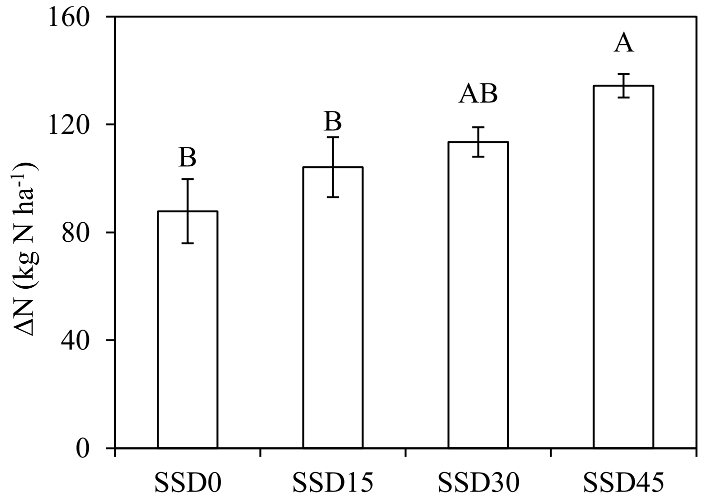


Figure 3.11. The effect of sidedress (SD) on N balance in top 30 cm of soil in split treatments. The same letter denotes no significant difference according to LSD comparison test at the 5% level. Bars represent standard errors

Table 3.15 presents the effect of base N fertilizer on yield, N uptake and ΔN. The timing of base fertilizer did not have a significant effect on yield and N uptake but it significantly affected ΔN. In control treatment there was 97% less ΔN compared to split and preplant treatments (Figure 3.12). This showed that there was sufficient N supplied by the soil to fulfill crop requirement, likely as a result of water deficiency limiting growth and did not allow N movement and uptake.

Table 3.15. Effect of different base N fertilizer on yield, N uptake and N surplus in the top 30 cm of soil (ΔN)

Treatment		Yield	N Uptake	ΔN
		$Mg\ ha^{-1}$	$kg\ ha^{-1}$	$kg\ ha^{-1}$
Base N fertilizer ($kg\ N\ ha^{-1}$) (n=3)				
	0	1.71±0.53	57.8±14.6	3.29±22.9 b
	60/60	2.39±0.48	89.1±23.2	87.8±20.7 a
	90/30	2.19±0.66	63.0±24.0	115±21.2 a
Source of variation		Analysis of variance		
	df		P- value	
Block	2	0.325	0.089	0.085
Base N fertilizer (B)	2	0.405	0.102	0.001

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

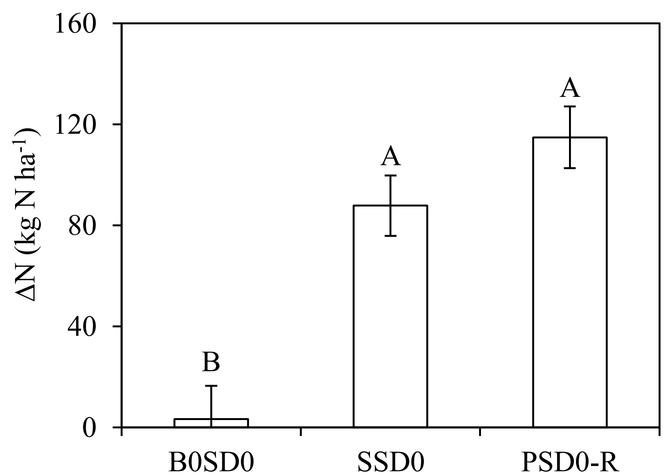


Figure 3.12. The effect of base N fertilizer on ΔN in top 30 cm of soil. The same letter denotes no significant difference according to LSD comparison test at the 5% level. Bars represent standard errors

Table 3.16 summarizes the effect of timing of base fertilizer and two rates of sidedress. However the interaction of base N fertilizer × sidedress did not have a significant effect on yield and N uptake, but applying 30 $kg\ N\ ha^{-1}$ of sidedress N fertilizer increased ΔN by 23% compared to when no sidedress is applied (Figure 3.13).

Table 3.16. Effect of base N fertilizer and sidedress N fertilizer on yield, N uptake and N surplus in the top 30 cm of soil (ΔN)

Treatment		Yield	N Uptake	ΔN
		Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Base N fertilizer (kg N ha^{-1}) (n=3)				
	60/60	2.36±0.36	91.2±16.3	101±23.9 b
	90/30	1.73±0.53	63.9±16.3	132±21.9 a
Sidedress (kg N ha^{-1}) (n=3)				
	0	2.11±0.65	76.1±25.5	101±20.1 b
	30	1.97±0.47	79.0±17.9	132±24.4 a
Source of variation		Analysis of variance		
	df		P- value	
Block	2	0.796	0.682	0.754
Base N fertilizer (B)	1	0.093	0.052	0.023
Sidedress (SD)	1	0.679	0.800	0.027
B*SD	1	0.814	0.914	0.666

Mean ± Standard deviation within columns followed by same letter are not significantly different at 5% level of significance

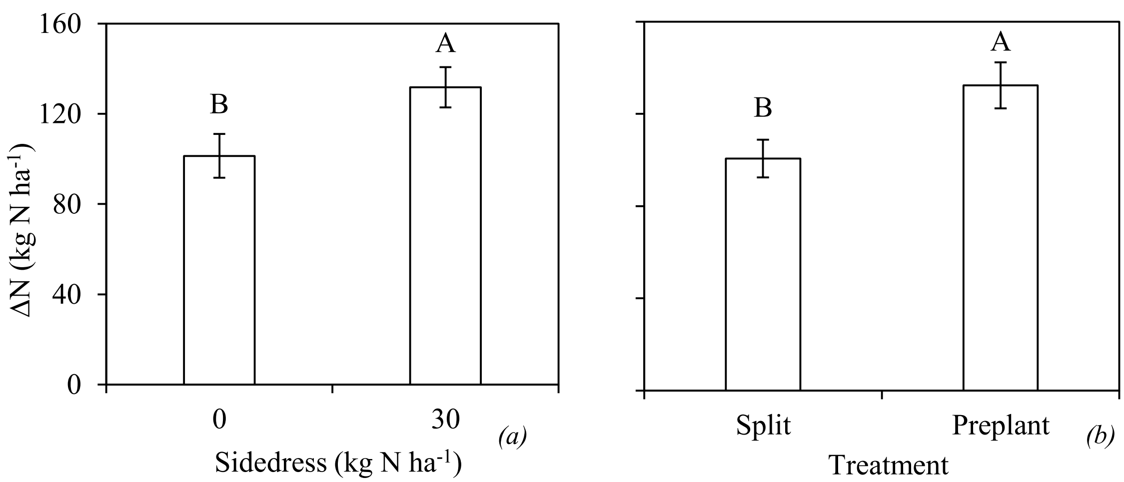


Figure 3.13. The effect of a) sidedress (SD) and b) base N fertilizer on N surplus in top 30 cm of soil. The same letter denotes no significant difference according to LSD comparison test at the 5% level. Bars represent standard errors

3.4. Conclusions

The primary objective of this study was to determine the effects of N fertilizer application timing i.e. preplant vs. split application on yield. Our results showed that under the conditions of this experiment in the dry summer of 2012, splitting application of N fertilizer did not affect yield and N uptake. Sidedress fertilizer application also did not affect yield and N uptake although in split treatments it resulted in greater accumulation of NO_3^- in the top 60 cm of soil profile than did preplant treatments. This suggests that under condition of high evapotranspiration and low precipitation, application of high levels of N fertilizers could not affect the lettuce yield and plant uptake. In this case irrigation frequency needs to be increased to compensate for intense surface evaporation. The extra irrigation event neither affect lettuce yield nor NO_3^- content in the top 60 cm of soil. It can be concluded that the surface evaporation was so high during the growing season that the extra irrigation event could not affect plant uptake and soil NO_3^- content.

According to dry condition and moisture deficit in the growing period of lettuce where 40% less precipitation occurred during the lettuce growing period in July and August of 2012 compared to the 30 year normal, no NO_3^- leaching is assumed to be occurred during growing period. However N balance calculation showed high amount of NO_3^- left in the top 30 cm of the soil that were not consumed by the plant. This is more pronounced when high rates of sidedress were applied i.e. 30 and 45 kg N ha^{-1}. The surplus N in the top 30 cm of the soil are subjected to leach with following fall and winter rainfall.

Practical implication of N management method that has been used in this study suggested neither sidedress application nor splitting N fertilizer in dry growing period such as one in the study experiment could affect lettuce yield otherwise the extra amount of fertilizer that will remain in the soil after harvest considered to increase the risk of NO_3^- leaching in the fall and winter. More precise N management recommendations in lettuce field, requires long term observations and careful measurements of all N input and output parameters.

CHAPTER 4 TESTING LEACHN MODEL FOR PREDICTING WATER AND NITRATE TRANSPORT

4.1. Introduction

Low N use efficiency in vegetable crops results in economic and environmental concerns and exploring more efficient fertility management strategies is necessary. Mathematical simulation models are useful tools for predicting N in agricultural systems. These models bring together several factors that influence soil N cycle and water cycle and simulate the potential for NO_3^- leaching. Simulation models, when calibrated to regional conditions, allow the testing of the effect of management practices on N leaching without extensive fieldwork.

LEACHN, the N version of the water and solute transport model, LEACHM (**L**eaching **E**stimation **A**nd **Ch**emistry **M**odel) predicts major chemical, physical and biological processes in the root zone throughout the year (Huston, 2003). The objective of this study was to use LEACHN to estimate cumulative drainage and NO_3^- leaching in a field under leaf lettuce in 2012 and compare the results with field measurements. For those input parameters that were not directly measured in the field the model default values were used. As there was no drainage system in the study site, the cumulative simulated drainage was compared with the closest tile drained field data in Kentville.

4.2. Model input data

LEACHN model requires a variety of input data included soil data, soil surface boundary conditions, crop data and rate constants. The model uses a daily time step and requires daily, weekly and seasonal inputs. The meteorological data were collected from Environment Canada weather station in Kentville, Nova Scotia (Table 4.1). The data included daily precipitation, minimum and maximum daily temperature and potential evapotranspiration. Initially, input data for time steps, profile depth and node spacing and output file specification needed to be specified.

Table 4.1. Monthly, Growing period and annual precipitation (mm), evapotranspiration (mm) and 30-year normal (1981-2010) at Kentville station, NS, Canada

Month	2012-2013		30-year average precipitation
	Precipitation	PET*	
June	92	111	82
July	23	137	84
August	73	125	77
September	173	79	84
October	96	45	89
November	54	24	122
December	139	19	122
January	35	17	116
February	91	19	101
March	58	33	110
April	45	67	93
May	73	97	102
Growing period total (July- August)	95	262	161
Yearly total	950	773	1181

* PET is potential evapotranspiration calculated for a grass reference crop using a modified Penman Monteith equation

4.2.1. Soil data

Soil parameters required for the model included: Initial water content or water potential, hydrological constants for the moisture retentivity and hydraulic conductivity curves. LEACHM has been developed in two versions; the research version and the management version. In research version, field measured values such as hydraulic conductivity and soil water retention parameters are used for water flow simulation while in management version, bulk density and particle size distribution data are used to predict soil water retention parameters. Bulk density and particle size distribution data were used for soil water retention parameters prediction in this study (Table 3.2). Also initial values for inorganic N, P and C pools in the soil were set for each segment of soil profile. Initial inorganic N was measured in the field before planting (Table 3.4). The soil layers divided to 12 horizontal layers of equal thickness, each 5 cm thick. The depth of the soil profile was set at 60 cm. the values for each segment varies with depth in all plots to reflect the specified layer properties and the transition between horizons.

4.2.2. Soil boundary condition

The simulation was run from June 1, 2012 (060112) to October 31, 2013 (103113). The number of time intervals per day, was set at 0.1 day time step, (default value). To simulate flow and transport of water and solute in soil, LEACHN uses finite difference techniques. The nodes used in the finite-differencing in LEACHN are in the center of the segments, therefore there are two extra nodes; the top node (i=1) and the lowest node (i=k) are outside of the soil profile and used for maintaining the desired boundary conditions. They have the same characteristics as specified for upper and lower segments, thus in this study a 60 cm deep soil profile was divided into twelve 5 cm intervals with 14 nodes, one for each segment and two boundary nodes. The two boundary nodes are not included in the mass balance calculations.

For the lower boundary condition, LEACHN has been developed with several options: 1) fixed pressure potential or fixed depth water table, 2) free drainage, 3) lysimeter, 4) zero flux, or 5) fluctuating water table boundary within specified limits. In this study the lower boundary condition was set at free drainage, therefore, when the lower layer of soil profile becomes saturated, the excess water that reaches this layer is subject to drainage. Sogbedji et al (2001a, 2001b) used free drainage option in their study on clay loam and loamy sand soils at the Cornell University Experimental Farm at Willsboro, New York with drain lines installed at 0.9 m depth and alfalfa-maize rotation in 1991 and 1992 and the predicted drainage flow rate and volume were acceptable.

4.2.3. Water flow

The model uses a one-dimensional finite difference approach to model water flow using Richards' equation and the convection-dispersion equation to model solute transport. In this study the Richards' equation was selected for predicting water contents, fluxes and potentials in soil. Ramos and Carbonell (1991) tested LEACHN to build a N balance in the prairie in southwestern Saskatchewan, Canada. The model was then incorporated with the van Genuchten retentivity function and was found to underestimate soil water content during dry periods mainly due to overestimation of evaporation. In a study by Akinremi et al (2005) they incorporated the van Genuchten retentivity function into LEACHN and used the same soil water retention data to generate the van Genuchten parameters. They found the modified model better compatible with the soil condition at Swift Current, Saskatchewan. In a study by Jabro et al (1995), the ability of Richard's equation was tested for water flow simulation in a 5-year nitrate leaching study in Pennsylvania on a silt loam soil planted with corn and their simulations were significantly correlated with actual data.

Richard's equation is derived from Darcy's law and the equation of continuity;

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\frac{\partial H}{\partial z}\right] - U(z,t)$$

θ = volumetric water content (cm^3 cm^3)

H= hydraulic head (cm)

K = hydraulic conductivity (cm s^{-1})

Z = depth (cm)

U = sink term representing water lost per unit time by uptake into plant or by evapotranspiration (s^{-1})

The convection-dispersion model applies when solute molecules transport either by diffusion or dispersion in to the zones with different water velocity. The convection-dispersion equation (CDE) is one of the most popular models for defining solute transport. The combined convection-dispersion-diffusion is used where flux and concentration can vary both in time and space, it can be written as;

$$\frac{\partial (c\theta)}{\partial t} = \frac{\partial}{\partial z}\left(D_{sh}\frac{\partial c}{\partial z}\right) - \frac{\partial (v\theta c)}{\partial z}$$

c = mass of solute per unit volume of solution (g cm^{-3})

θ = volumetric water content (cm^3 cm^3)

t = time (s)

z = depth (cm)

D_{sh} = diffusion-dispersion coefficient as a function of θ and v (cm s^{-1})

v = average pore water velocity (cm s^{-1})

A complete description of all equations and descriptions of N transformation processes (mineralization, nitrification, denitrification and volatilization) used in the model can be found in the LEACHM manual (Huston, 2003).

4.2.4. Crop data

In this part the number of crops needs to be specified, the model is run for 2012 and 2013, it is assumed that the same crop has been cultivated in 2013, thus, two crops were grown during the simulation period (2012-2013) and at both years they were set as annual crops. If perennial is used, only 50% of root N and C would be considered as an addition to plant residue pool but for annual crops all non-harvested C, N and P are added to root residue. For root growth, the model considers either root distribution is constant so that the GROWTH subroutine is ignored and the crop cover values at maturity will be used in the simulations. Alternatively the GROWTH subroutine for root growth can be used which describes crop cover as a function of time, and root density as a function of time and depth.

For nutrient uptake period there were two options; a) to maturity b) to harvest. The nutrient uptake by lettuce happens throughout the growing period, however the rate of uptake varies in each growing stage, N uptake starts to increase considerably from mid-vegetation to harvest time (Manojlovic et al. 2010). Hence the nutrient uptake parameter was set to harvest in this study.

Time of germination and emergence were set according to field observations to June 15th and June 20th of each year, lettuce plants were transplanted in the field on July 13th. In order to consider plant water uptake, the date of roots and crop cover (canopy cover) at maturity needs to be specified, which was set to July 30th. The relative root depths (relative to profile depth of 60 cm) was set to 50 cm, it results in the roots being compressed into a depth of about 50 cm, with most being above 30 cm. The harvest date was set according to actual harvest time in the field (August 29th). Crop cover fraction is the fraction of the ground surface shielded by leaves at that time and determines the split of potential evapotranspiration into potential evaporation from the soil surface (Hutson, 2003). For all of the treatments, crop cover fraction was set at 0.8, but for control treatment, due to poor plant growth in these plots it was set to 0.6. The pan factor which adjusts the potential evapotranspiration (ET) for converting pan evaporation to potential crop evapotranspiration was set to 1. Wilting point of the soil and minimum root water potentials for water extraction by plants and crop uptake were all specified based on the default values for sandy loam soil. (-1500 and -3000 Kpa, respectively).

4.2.5. Initial nitrogen, phosphorus and carbon pools

Initial values of NO_3^- and NH_4^+ concentrations were determined in the top 60 cm depth of the soil, before planting on June 8th and were used as the initial NO_3^- and NH_4^+ contents for modeling. The values were set for each increment of the soil layer, which are listed in Table 3.4. Also C and P pools were assumed to be negligible (Table 3.4).

4.2.6. Rate constant

LEACHN requires depth-wise mineralization, nitrification and denitrification rate constants. According to acidic condition of the field being studied here, it is assumed that no NH_3 loss is occurred in the soil and hence the value of volatilization rate constant is set to 0 d^{-1} (Table 3.4). Mineralization rate constant values of 0.01 and 0.00001 (default value in LEACHN) were used for residue and humus respectively (Table 4.2) and then the mineralization of residue and humus were increased by four and eight times according to Jiang et al. (2011) as there were reasonably similar soil condition at both sites (Table 4.3). For the nitrification and denitrification rate constants the values of 0.2 and 0.1 were used (Table 4.2) and then they were reduced to 0.05 and 0.009 according to Jiang et al. (2011) in Table 4.3. This has been done first because they both have similar climatological conditions and second to understand how decreasing the rate constants affects NO_3^- leaching simulation during the year. Table 4.3 listed the rate constants used in different studies. In this study the rate constants were derived from other published studies. The initial rate constants used for simulation were the model's default values (Hutson, 2003) (Table 4.2).

Table 4.2. LEACHN initial input rate constant values (day^{-1}) used for the simulation period

Rate constant	Input value (day^{-1})
Nitrification	2.00E-01
Denitrification	1.00E-01
Residue Mineralization	1.00E-02
Humus Mineralization	1.00E-05

As discussed in Chapter 2, slight changes in nitrification and denitrification rate constants proved to have a considerable effect in cumulative N loss and N transformation

(Hutson and Wagenet, 1989), but less sensitivity to mineralization rate constants changes (especially to humus mineralization rate constant) has been reported (Jabro et al. 1993). Some of the adjusted rate constants used in other studies are listed in Table 4.3. The rate constant in North America averaged at 2.00E-01, 4.00E-02, 1.00E-02 and 5.00E-05 for nitrification, denitrification, residue mineralization and humus mineralization, respectively. After the model is run for initial rate constants, it is run again with rate constants used in Jiang et al. (2011). This has been done first because they both have similar climatological condition and second to understand how changes in rate constants affects NO_3^- leaching simulation during the year.

Table 4.3. Input rate constant data (day^{-1}) reported in literature

Rate Constant	Nitrification	Denitrification	Residue mineralization	Humus mineralization	
LEACHN default	2.00E-01	1.00E-01	1.00E-02	1.00E-05	
Jiang (2011)	5.00E-02	9.00E-03	4.00E-02	8.00E-05	Canada
Campbell (1984)	NR	NR	2.00E-03	NR	Canada
Kunjikutty (2007)	6.00E-01	1.00E-01	1.00E-02	1.00E-07	Canada
Dadfar (2004)	1.00E-01	4.00E-03	9.00E-03	3.00E-05	Canada
Jabro (1995)	2.00E-01	8.00E-02	1.00E-02	3.00E-05	USA
Allen (1994)	9.30E-02	NR	8.30E-03	7.00E-05	USA
Sogbedji (2006)	2.00E-01	3.30E-02	1.00E-02	5.00E-05	USA
Johnson (1993)	5.00E-02	5.00E-03	NR	NR	USA
Johnson (1999)	2.52E-02	5.40E-04	6.00E-03	9.00E-05	USA
Ramos 1991	1.00E-01	5.00E-03	7.50E-02	NR	Spain
Lidon (2013)	6.00E-01	2.00E-01	2.00E-03	9.00E-05	Spain
Acutis (2000)	6.20E-02	1.00E-03	1.50E-03	6.00E-05	Italy
Hu (2010)	1.75E-01	1.50E-02	3.00E-03	1.00E-05	China
Jung (2010)	9.14E-01	1.11E-01	1.00E-02	7.00E-05	Korea
Max	9.14E-01	2.00E-01	7.50E-02	9.00E-05	
Min	2.52E-02	5.40E-04	1.50E-03	1.00E-07	

NR = not reported

4.2.7. Nutrients application

The depth of incorporation defines the number of layers that the fertilizer assumed to be mixed. In this study a value of 0 is defined which shows a surface application. In this case the fertilizer will infiltrate into the soil profile after dissolving in irrigation water or rain. Number of nutrient applications (dry application which was not dissolved in irrigation water) and detail of N, P and C application were set according to field practices. The fertilizer application rates for preplant fertilized treatment were 90 kg N ha^{-1} in the form of ammonium nitrate (45 kg ha^{-1} as NH_4-N, and 45 kg ha^{-1} as NO_3-N) before planting and 30 kg N ha^{-1} (15 kg ha^{-1} as NH_4-N, and 15 kg ha^{-1} as NO_3-N) two weeks after planting. In split fertilized treatment 60 kg N ha^{-1} (30 kg ha^{-1} as NH_4-N, and 30 kg ha^{-1} as NO_3-N) was applied both before and two weeks after planting. Sidedress N fertilizer rates of 15, 30 and 45 kg N ha^{-1} were applied in form of calcium nitrate three weeks after planting.

4.2.8. Cultivation

At the start of a day for which cultivation is specified, the chemical in the soil segment within the cultivated zone is mixed, resulting in a uniform total concentration. Right after cultivation a new sorption equilibrium is established. In the latest version of LEACHN only the chemical is mixed and no changes to water content or physical properties is considered (Huston, 2003). The number and depth of the cultivation events were specified in this section. In this study there were two cultivation events; one in 2012 and one in 2013 and 10 cm was selected as the depth of cultivation.

4.2.9. Meteorological data

The starting time, amount, and rate of application of rain or irrigation water is specified in this section. There is no distinction between rain and irrigation water except the differences in composition, rates and application times. Water application dates must be equal to or greater than the start of the simulation and must be entered in chronological order. The amount of rain or water applied and the rate of application must be specified. They could be the same, but application rate should not exceed the soil's infiltration capacity otherwise it is assumed to be saturated with a surface potential of 0 Kpa.

The Irrigation water composition, measured in the lab using Technicon Auto-Analyzer II for both NH_4^+ and NO_3^-, was 0.03 and 6.5 mg L^{-1} respectively.

Estimating evapotranspiration depends on many factors including temperature, solar radiation, vapor pressure and wind speed. For most of the stations in study area, only daily temperature data was available (Environment Canada, 2014), hence the daily potential evapotranspiration was estimated from Penman Monteith equation by FAO (Allen et al. 1998). Temperature data were recorded at the Kentville Climate Station (Environment Canada, 2014). Then the weekly total of estimated actual evapotranspiration were calculated and used in this study. Also mean weekly temperature and mean weekly temperature amplitudes (maximum-minimum temperature) were calculated from the daily temperatures. The meteorological data used in the model are listed in Appendix A.

4.2.10.Model Accuracy

LEACHN accuracy was evaluated using different statistical parameters. Mean error (ME) and Maximum error (MaxE) defined as:

$$ME = \frac{\sum_{i}^{n}(S_i - M_i)}{n}$$

$$MaxE = \max_{i=1}^{n}(S_i - M_i)$$

Where, n is the number of sampling dates, *i* is the measurement date, M_i is the measured (Drainage data, soil NH_4^+ and NO_3^- concentrations) values and S_i is the simulated values. ME measures average deviation of the simulated and measured values during the study period. The positive and negative signs of ME indicates whether the model overestimate or underestimate the measured values, respectively. MaxE is the maximum error between measured and simulated values. Akinremi et al. (2005), Sogbedji et al. (2001a, 2001b) and Jabro et al. (1995) found ME and MaxE useful statistical parameters for model evaluation. The other parameter is root mean square error (RMSE), the closer the RMSE is to 0, the more accurate the model predictions are. Lower value of RMSE means that the error between predicted value and measured value is small. It is defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(S_i - M_i)^2}{n}}$$

Nash-Sutcliff modeling efficiency (NSEF) is also used to determine how accurate the model is. It is defined as:

$$NSEF = 1 - \frac{\sum_{i=1}^{n}(M_i - S_i)^2}{\sum_{i=1}^{n}(M_i - M)^2}$$

Where M is the mean of measured values. It can range from -∞ to 1. When it is equal to 1 it shows a perfect match between simulated and measured values. When E is less than zero ($-\infty < E < 0$), the observed mean is a better predictor than the model which shows that the residual variance (the numerator in the equation) is larger than the data variance (the denominator in the equation). Generally, if NSEF is closer to 1, the efficiency of a model is higher. Intercept and slope also have determined for all treatments, Slope and intercept have the best fit at 1 and 0 respectively.

4.3. Result and discussion

4.3.1. Water Balance

The water balance for the growing study period (1 June 2012- 15 September 2012) in 21 plots for 7 treatments is presented in Table 4.5. Also the water balance for longer period of June 2012 to March 2013 for both field data and LEACHN prediction is showed in Table 4.6. Actual evapotranspiration (AET) values were estimated based on Penman Monteith equation. The water flux is affected by the amount of precipitation and evapotranspiration, therefore the difference between precipitation and evapotranspiration will determine the amount of water that infiltrates to the soil. In this study total drainage is calculated by: precipitation- evapotranspiration. In this study runoff was not measured in the field, therefore the runoff predicated by the model was used in water balance calculations. Also, soil water storage was not considered in the calculation. It is assumed that soil water storage changes over the long period over which the model is run is insignificant. According to Table 4.5 during 1 June to September 15 2012, there is a negative balance in all plots both in field and model, this along with meteorological data during the study period prove a dry period in which no drainage existed (Precipitation during July and August was 40% lower than 30-year normal (Table 4.1)). Potential evapotranspiration (PET) estimated by model is about 10% higher than those estimated by Penman Monteith equation. However for longer period from 1 June 2012 to 31 March 2013 as shown in Table 4.6, the total amount of water available for infiltration calculated based on the field data very closely match to LEACHN equivalent depth of water at 60 cm when the runoff (model prediction) was included in water balance calculations. But on the other hand according to field observation, the estimated runoff by the model does not seem to be accurate. It can be concluded that the estimated hydraulic conductivity by Campbell equation in the model was not accurately match the field conditions and especially in sandy soils, the inability of LEACHN to account for macro pore water flow is more pronounced. This also has been reported in other studies (Jabro et al. 1993; Mutch et al. 1992; Jemison, 1994; Nolan et al. 2005 in Jiang et al. 2011). The statistical parameters for total drainage data are listed in Table (4.4).

Table 4.4. Statistical comparisons of simulated and measured total drainage (mm) between 1 June 2012- 31 March 2013 according to water balance calculations

Statistical Parameters	Total Drainage
ME	-6.13
MaxE	-4.3
R^2	0.97
RMSE	6.42
Slope	0.91
Intercept	2.57
NSEF	0.63

Table 4.5. Water balance calculation for field data and LEACHN prediction in different treatments from 1 June 2012 to September 15 2012

Treatment	B0SD0		PSD0+R		PSD0-R		PSD30+R		PSD30-R		SSD0		SSD30	
Parameter	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model
Precipitation (mm)	283.8	266.2	283.8	291.4	283.8	266.2	283.8	294.0	283.8	266.2	283.8	266.2	283.8	266.2
Irrigation (mm)	76.2		152.4		76.2		152.4		76.2		76.2		76.2	
Runoff (mm)	ND	88.1	ND	137.5	ND	88.1	ND	140.7	ND	88.1	ND	88.1	ND	88.1
Actual Evaporation	ND	140.7	ND	147.1	ND	140.7	ND	147.3	ND	140.7	ND	140.7	ND	140.7
Actual Transpiration	ND	134.5	ND	131.3	ND	134.5	ND	130.9	ND	134.5	ND	134.5	ND	134.5
AET	418*	275.3	418	278.5	418	275.3	418	278.2	418	275.3	418	275.3	418	275.3
Total Drainage	-146.1**	-155.5	-119.3	-153.2	-146.1	-155.5	-122.5	-151.9	-146.1	-155.5	-146.1	-155.5	-146.1	-155.5

* Potential Evapotranspiration for the field data was calculated from Penman Monteith
** Total Drainage = precipitation + Irrigation – Runoff – AET, in LEACH total drainage was simulated at 60 cm depth (It may have some mass error)
ND=Not Determined

Table 4.6. Water balance calculation for field data and LEACHN prediction in different treatments from 1 June 2012 to March 31 2013

Treatment	B0SD0		PSD0+R		PSD0-R		PSD30+R		PSD30-R		SSD0		SSD30	
Parameter	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model	Field	Model
Precipitation (mm)	832	693.9	832	717.3	832	693.9	832	719.8	832	693.9	832	693.9	832	693.9
Irrigation (mm)	76.2		152.4		76.2		152.4		76.2		76.2		76.2	
Runoff (mm)	ND	213.9	ND	265.2	ND	213.9	ND	268.6	ND	213.9	ND	213.9	ND	213.9
Actual Evaporation	ND	308.3	ND	314.9	ND	308.3	ND	315	ND	308.3	ND	308.3	ND	308.3
Actual Transpiration	ND	134.5	ND	131.3	ND	134.5	ND	130.9	ND	134.5	ND	134.5	ND	134.5
AET	610*	442.8	610	446.3	610	442.8	610	445.9	610	442.8	610	442.8	610	442.8
Total Drainage	84.3**	78.7	109.2	98.6	84.3	78.7	105.8	101.5	84.3	78.7	84.3	78.7	84.3	78.7

* Potential Evapotranspiration for the field data was calculated from Penman Monteith
** Total Drainage = precipitation + Irrigation – Runoff – AET, in LEACH total drainage was simulated at 60 cm depth (It may have some mass error)
ND=Not Determined

4.3.2. Drainage simulation

The cumulative simulated drainage data in the study field is compared to the closest tile drained field data at the Atlantic Food and Horticultural Research Station, Kentville, NS (Fuller et al. 2010). The LEACHN model simulated the general trend in fluctuations of the measured bi-weekly drainage (n=33). During the months of June 2012 to March 2013 the cumulative simulated drainage was 267 and 245 mm for treatments with and without extra irrigation. Although both climate and drainage data derived from the same location in Kentville, the simulated drainage data followed the same trend as observed data in tile drainage except from mid-December to early January that the model simulated a high values of 63 mm of drainage compared to 26 mm observed in tile drainage (Figure 4.1); this demonstrates that the model may not be able to accurately simulate water movement under freezing conditions of the soil profile; during winter months the permeability of the soil will be diminished and less drainage would occur. Moreover the inability of LEACHN to account for the effect of macro-pore flow has been reported in other studies (Jabro et al. 1993; Mutch et al. 1992; Jemison, 1994). Statistical comparison of simulated and measured drainage is summarized in Table 4.7. Correlation of determination (R^2) values were 0.47 and 0.39 for treatments with and without extra irrigation, respectively (Figure 4.2). For treatments without extra irrigation the RSME slightly increased to 16.17. The negative values of ME for both treatments showed that the model underestimated actual drainage. The largest RMSD (16.17) and ME (-2.20), and the smaller R^2 (0.39), and MaxE (36.68) were observed in treatments without extra irrigation.

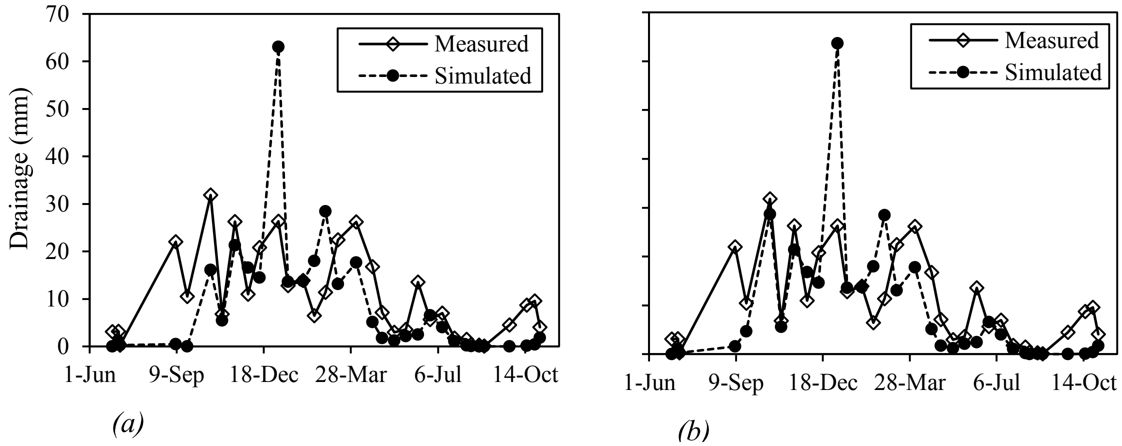


Figure 4.1. Measured tile drainage data at the Atlantic Food and Horticultural Research Station and simulated drainage data by LEACHN in treatments (a) without extra irrigation (-R) (b) with extra irrigation (+R)

Table 4.7. Statistical comparisons of simulated and measured drainage (mm) between 1 June 2012- 31 October 2012 for treatments with and without extra irrigation

	Treatments without extra irrigation (-R)	Treatments with extra irrigation (+R)
ME	-2.20	-1.51
MaxE	36.68	37.34
R^2	0.39	0.47
RMSE	16.17	12.89
Slope	0.44	0.47
Intercept	6.77	6.21
NSEF	0.34	0.45

Simulated drainage (water flux at 60 cm depth) over the period of 1 June 2012 to 31 March 2013 were ±12 to 16 mm of the measured values (Table 4.7). Several studies were used ME and RMSE for evaluation of simulated model values. Jabro et al. (1995) reported ME equal to -9.7 mm in a silt loam corn field for 5 years. Dadfar et al. (2004) reported values in the same range for ME (-10.6) in a clay loam soil with conventionally-tilled non-fertilized continuous corn. Field measurement and model simulation for the period of June 2012 to March 2013 suggest that the majority of drainage below the root zone occurs in the non-growing season, and the rapid drying of soil during the summer months and especially dry summer season of 2012 led to negative balance for treatments without extra irrigation (Table 4.5).

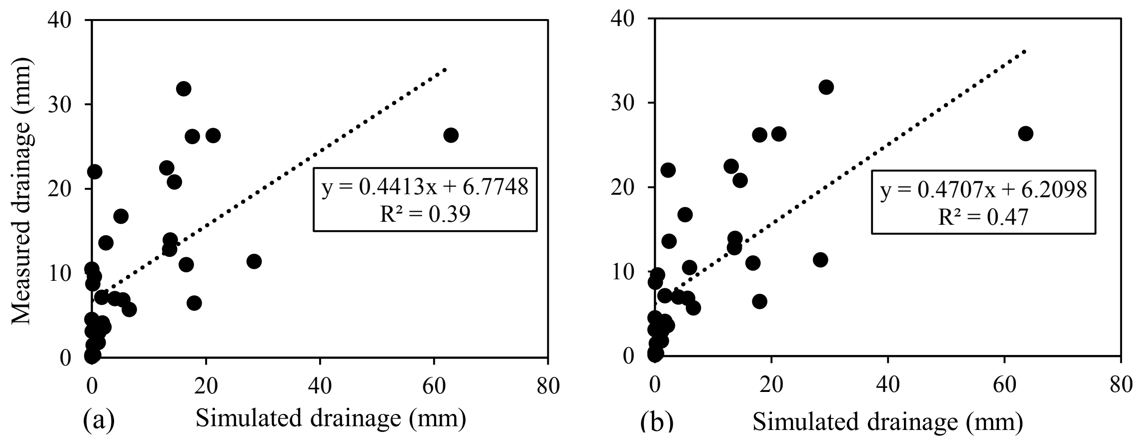


Figure 4.2. The relationship between measured and simulated drainage in treatments (a) without extra irrigation (-R) (b) with extra irrigation (+R)

4.3.3. NO_3^- and NH_4^+ concentration in soil solution

Nitrate and ammonium concentration in the soil solution at 45 cm depth of the soil during the study period were measured and compared with simulated values at the same depth and dates. Statistical evaluation for NO_3^- and NH_4^+ in both hill and furrow for different treatments are given in Table 4.8 and 4.9.

Overall, the model simulations did not match the measured values of NO_3^- concentrations. Nitrate concentrations was overestimated in furrow as indicated with positive ME values (ME=5.4) while in the hill it is underestimated (ME=-21) (Figure 4.3). The overestimation of NO_3^- in furrow probably related to underestimation of the amount of NO_3^- lost through denitrification whereas in hill the plant uptakes the nitrates.

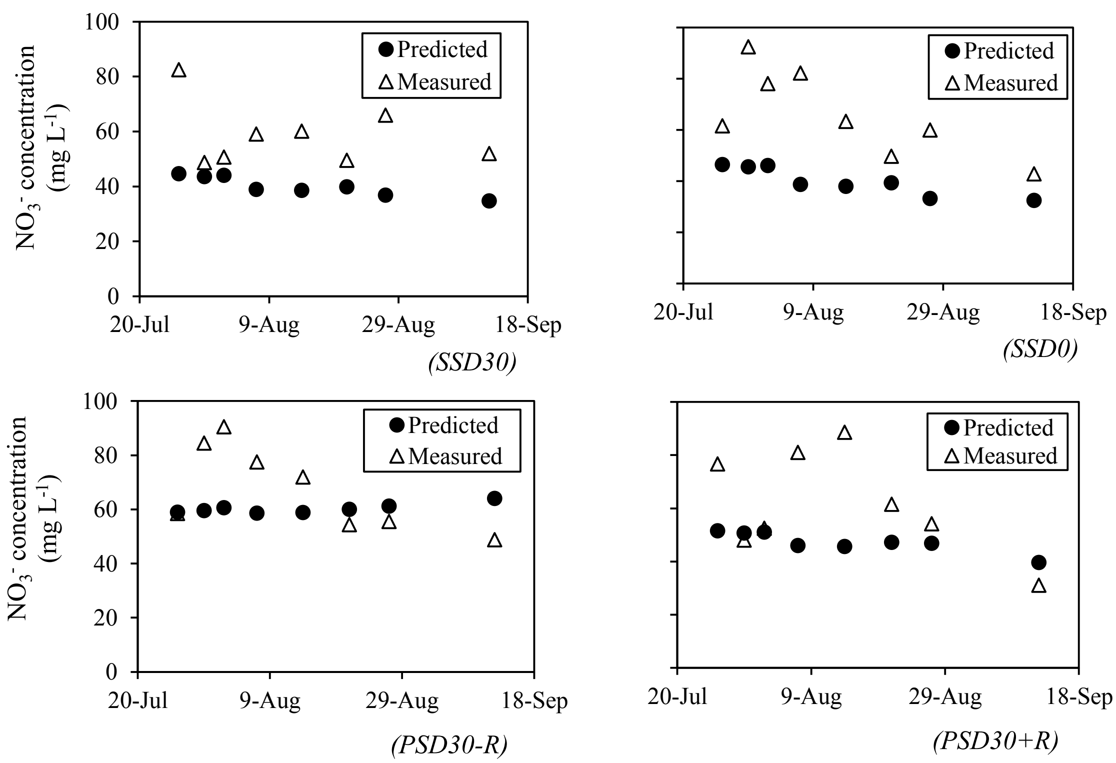
NH_4^+ concentrations in hill and furrow showed closer correlation (ME= 0.31) (Table 4.9). The main input factors that affect NO_3^- and NH_4^+ concentration in the soil are the retentivity parameters such as BCAM and p. Therefore by changing these parameters it is expected to get better fit with observed data, also changing crop N uptake and plant maturity date as well as crop cover fraction reported to give closer correlation between simulated soil NO_3^- and NH_4^+ concentration with observed data (Crooks, 1997).

Table 4.8. Statistical evaluation of simulation by LEACHN of NO_3^- concentration (mg N L^{-1}) in soil solution (n=6) for different treatments in hill and furrow

Treatment		ME	MaxE	R^2	RMSE	Slope	Intercept
SSD30	NO_3-F	-24.2	-7.94	0.28	23.6	1.67	30.2
	NO_3-H	-24.6	-5.06	0.03	24.6	0.58	36.7
SSD0	NO_3-F	1.56	17.3	0.33	11.9	1.36	30.5
	NO_3-H	-35.0	-10.3	0.37	33.9	1.85	26.4
PSD30-R	NO_3-F	21.7	39.3	0.60	22.9	-4.62	65.8
	NO_3-H	-9.99	15.2	0.24	19.8	-4.23	63.9
PSD30+R	NO_3-F	5.40	14.7	0.05	11.6	0.56	43.6
	NO_3-H	-19.1	8.58	0.08	25.9	1.41	43.7
PSD0-R	NO_3-F	35.3	38.0	0.29	31.3	-1.93	63.4
	NO_3-H	-4.33	43.0	0.16	21.6	-5.18	60.5
PSD0+R	NO_3-F	-0.93	18.0	0.02	12.1	-0.19	48.3
	NO_3-H	0.26	21.9	0.13	17.1	1.03	38.8
B0SD0	NO_3-F	-1.02	32.4	0.52	24.8	0.49	-20.7
	NO_3-H	-54.86	-10.7	0.00	52.3	0.05	11.5

Table 4.9. Statistical evaluation of simulation by LEACHN of NH_4^+ concentration (mg N L^{-1}) in soil solution (n=6) for different treatments in hill and furrow

Treatment		ME	MaxE	R^2	RMSE	Slope	Intercept
SSD30	NH_4-F	0.33	0.36	0.10	0.30	-0.05	0.29
	NH_4-H	0.31	0.32	0.01	0.28	-0.04	0.27
SSD0	NH_4-F	0.32	0.32	0.20	0.29	0.13	0.23
	NH_4-H	0.24	0.35	0.02	0.24	0.15	0.25
PSD30-R	NH_4-F	0.38	0.38	0.01	0.33	0.03	0.30
	NH_4-H	0.37	0.36	0.15	0.33	-0.16	0.33
PSD30+R	NH_4-F	0.35	0.35	0.27	0.31	0.18	0.25
	NH_4-H	0.35	0.35	0.24	0.31	0.10	0.23
PSD0-R	NH_4-F	0.33	0.34	0.36	0.29	0.65	0.27
	NH_4-H	0.36	0.35	0.17	0.32	0.12	0.26
PSD0+R	NH_4-F	0.30	0.34	0.22	0.27	0.46	0.26
	NH_4-H	0.31	0.34	0.12	0.28	0.30	0.26
B0SD0	NH_4-F	0.24	0.35	0.59	0.26	-0.25	0.33
	NH_4-H	0.26	0.33	0.38	0.25	0.12	0.16



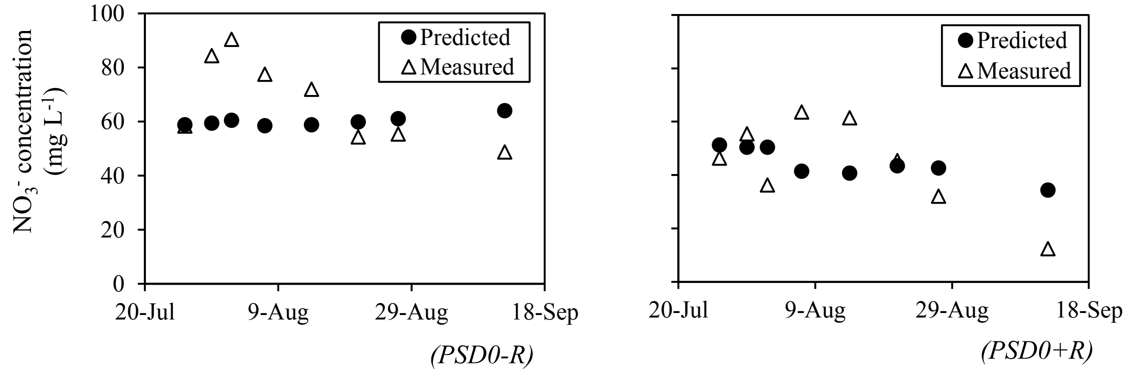


Figure 4.3. Mean NO_3^- concentration (mg L^{-1}) in hill for different treatments

4.3.4. NO_3^- leaching prediction by LEACHN

The amount of leaching is correlated with both the concentration of NO_3^- present in the soil and the amount of water movement through the soil profile (Chesnaux and Allen, 2008). Table 4.10 shows simulated drainage, NO_3^- leaching and flow weighted mean (FWM) NO_3^- concentration at 60 cm depth in different plots from 1 June 2012 to 31 March 2013. Both drainage and NO_3^- fluxes have the same pattern during the simulation period in all plots and 97% of NO_3^- leaching occurred during the non-growing season. The simulated data were subjected to analysis of variance (ANOVA) using SAS version 9.3 for Windows (SAS Institute, 2011). Least significant difference (LSD) at $P < 0.05$ was used to evaluate significant differences among means (Table 4.10). Statistical analysis showed that the effect of base fertilizer and sidedress as well as their interaction did not have a significant effect on cumulative NO_3^- leaching. The same results have been achieved for preplant treatments with extra irrigation.

Table 4.10. Total simulated cumulative drainage volume, NO_3^- loss, and flow weighted mean (FWM) nitrate concentration from 1 June 2012 to 31 March 2013

Treatment		1 June 2012- 31 March 2013		
		Cumulative drainage volume (mm)	Cumulative NO_3^- leaching (kg N ha^{-1})	FWM* NO_3^- concentration (mg N L^{-1})
PSD30+R		267	34.4+9.36	13
PSD30-R		245	53.7+5.67	22
PSD0+R		264	30.4+11.6	12
PSD0-R		245	46.1+12.1	19
Source of variation			Analysis of variance	
	df		P- value	
Block	2		0.260	
Sidedress (SD)	1		0.552	
Irrigation (I)	1		0.108	
SD*I	1		0.850	
B0SD0		245	3.9+0.42	2
PSD0-R		245	46.1+12.1	19
SSD0		245	22.7+10.1	9
Source of variation			Analysis of variance	
	df		P- value	
Block	2		0.343	
Base N fertilizer (B)	2		0.061	
PSD0-R		245	46.1+21	19
PSD30-R		245	53.7+9.85	22
SSD0		245	22.7+17.5	9
SSD30		245	24.1+16.2	10
Source of variation			Analysis of variance	
	df		P- value	
Block	2		0.981	
Base N fertilizer (B)	1		0.053	
Sidedress (SD)	1		0.695	
B*SD	1		0.788	

*FWM nitrate concentration is calculated as cumulative nitrate loss divided by the corresponding cumulative drainage volume. Mean ± Standard error within columns followed by same letter are not significantly different at 5% level of significance.

In the next step of NO_3^- leaching prediction, rate constants were changed using the N transformation rate constant from previous work with inorganic fertilizer in PEI (Table 4.3). It was done to see how the results for NO_3^- leaching will change once the nitrification and denitrification rate constants were decreased and residue and humus mineralization rate constants increased. The selected rate constant for nitrification and denitrification were changed according to commonly used rate constants in previous papers (Table 4.3) and specifically the values reported for agricultural soils in Canada, therefore the model was re-run for rate constants used in Jiang et al. (2011) (Table 4.3).

The cumulative drainage, NO_3^- leaching and FWM NO_3^- concentration for the new rate constants are presented in Table 4.11. More than 98% of NO_3^- leaching occurred in non-growing period and a very little amount during the growing period. The simulated data were subjected to analysis of variance and the results showed that preplant fertilizer application has significant effect on NO_3^- leaching ($P<0.05$) (Table 4.10). Simulated NO_3^- and NH_4^+ concentration in soil solution were also compared with measured field data and statistical evaluation is reported in Table 4.12 and 4.13.

Table 4.11. Total simulated cumulative drainage volume, NO_3^- loss, and flow weighted mean (FWM) nitrate concentration from 1 June 2012 to 31 March 2013

Treatment		1 June 2012- 31 March 2013		
		Cumulative drainage volume (mm)	Cumulative NO_3^- leaching (kg N ha^{-1})	FWM* NO_3^- concentration (mg N L^{-1})
PSD30+R		267	85.2+15.6	32
PSD30-R		245	112.7+9.43	46
PSD0+R		264	75.1+22.2	28
PSD0-R		245	101.1+19.1	41
Source of variation			Analysis of variance	
	df		P- value	
Block	2		0.169	
Sidedress (SD)	1		0.491	
Irrigation (I)	1		0.120	
SD*I	1		0.961	
B0SD0		245	30.4+4.52 b	12
PSD0-R		245	101.1+19.1 a	41
SSD0		245	61.4+16.9 ab	25
Source of variation			Analysis of variance	
	df		P- value	
Block	2		0.22	
Base N fertilizer (B)	2		0.04	
PSD0-R		245	101.1+33	41
PSD30-R		245	112.7+16	46
SSD0		245	61.4+29.3	25
SSD30		245	67.1+21.2	27
Source of variation			Analysis of variance	
	df		P- value	
Block	2		0.917	
Base N fertilizer (B)	1		0.046	
Sidedress (SD)	1		0.629	
B*SD	1		0.867	

*FWM nitrate concentration is calculated as cumulative nitrate loss divided by the corresponding cumulative drainage volume. Mean ± Standard error within columns followed by same letter are not significantly different at 5% level of significance.

Concentration of NO_3^- and NH_4^+ concentration in soil solution for preplant treatments showed R^2 of 0.63 and average RMSD of 29 mg N L^{-1}. Nitrate concentration in hill was underestimated in all of the plots (ME= -28.71). The highest maximum error (MaxE =45 mg N L^{-1}) was observed in the hill for preplant fertilizer without sidedress and extra irrigation. Simulated NH_4^+ concentrations using the modified rate constants were not very different from the initial rate constants used for simulation. There were only small changes in NH_4^+ concentration during the sampling period and the model prediction of NH_4^+ concentration in all plots was well (ME= 1.3, MaxE=1.27, RMSD=1.13, intercept=0.9). There was a better correlation between simulated and measured data in hill than in furrow. The differences in simulated LEACHN values for soil NO_3^- concentration and those measured under field conditions are not surprising; some of model input parameters were not based on field measurement and model default values were used, secondly the climate data were derived from the closest weather station in Kentville (14 km far from the studied field), which also may generate errors. Moreover R^2 is not always sufficient to characterize the fitness of the data. The R^2 in most of the treatments shows very low values as it was expected. Using several statistical parameters gives us better understanding of model performance. Sometimes two data might have the same R^2 but one data fit the model better. For NH_4^+ or NO_3^- concentration, the ME and RMSE are better parameters to measure model performance.

Table 4.12. Statistical evaluation of simulation by LEACHN of NO_3^- concentration (mg N L^{-1}) in soil solution (n=6) with new rate constant for different treatments in hill and furrow

Treatment		ME	MaxE	R^2	RMSD	Slope	Intercept
SSD30	NO_3-F	-24.51	-5.23	0.05	24.40	1.30	37.85
	NO_3-H	-24.86	-7.30	0.04	24.71	1.17	38.08
SSD0	NO3-F	-8.38	22.52	0.54	18.22	-3.43	38.65
	NO_3-H	-45.00	-5.14	0.30	43.79	-3.22	38.64
PSD30-R	NO_3-F	7.42	40.20	0.70	19.77	-1.22	74.37
	NO_3-H	-24.34	16.08	0.45	31.07	-1.43	70.87
PSD30+R	NO_3-F	-4.16	12.74	0.07	11.37	0.50	34.04
	NO_3-H	-28.72	18.00	0.47	35.29	-2.49	51.87
PSD0-R	NO_3-F	21.95	40.27	0.49	22.30	-0.57	76.39
	NO_3-H	-17.75	45.24	0.61	30.61	-2.32	64.90
PSD0+R	NO_3-F	-8.30	8.32	0.09	12.78	-1.06	42.64
	NO_3-H	-7.10	25.86	0.26	20.82	-3.51	42.11
B0SD0	NO_3-F	0.62	24.98	0.75	19.92	1.25	-2.95
	NO_3-H	-53.23	-12.12	0.01	49.34	-0.17	19.57

Table 4.13. Statistical evaluation of simulation by LEACHN of NH_4^+ concentration (mg N L^{-1}) in soil solution (n=6) with new rate constant for different treatments in hill and furrow

Treatment		ME	MaxE	R^2	RMSE	Slope	Intercept
SSD30	NH_4-F	0.63	0.58	0.13	0.55	-0.06	0.52
	NH_4-H	0.60	0.54	0.01	0.53	-0.05	0.49
SSD0	NH_4-F	1.48	1.21	0.18	1.28	0.09	1.08
	NH_4-H	1.40	1.23	0.00	1.22	0.02	1.13
PSD30-R	NH_4-F	1.52	1.27	0.02	1.32	0.03	1.15
	NH_4-H	1.51	1.24	0.27	1.31	-0.14	1.22
PSD30+R	NH_4-F	1.50	1.23	0.33	1.30	0.13	1.09
	NH_4-H	1.51	1.24	0.21	1.31	0.06	1.08
PSD0-R	NH_4-F	1.47	1.22	0.17	1.28	0.29	1.13
	NH_4-H	1.51	1.24	0.20	1.31	0.09	1.09
PSD0+R	NH_4-F	1.17	1.01	0.17	1.01	0.29	0.90
	NH_4-H	1.17	1.01	0.11	1.02	0.22	0.90
B0SD0	NH_4-F	1.34	1.23	0.62	1.18	-0.19	1.20
	NH_4-H	1.36	1.22	0.35	1.19	0.09	0.97

4.4. Conclusions

The model was run with soil and crop data from the lettuce field in 2012. The total observed drainage (Precipitation- Evapotranspiration- runoff) were 106 and 84 mm for treatments with and without extra irrigation respectively. The LEACHN simulated drainage (water flux at 60 cm depth) over the same period, were ±6 mm of the observed value with R^2 of 0.97. The simulated drainage data were also compared to tile drainage in Kentville with total drainage of 230 mm from June 2012 to March 2013. The comparison did not show the correlation of the measured and simulated data however according to both measured and simulated cumulative drainage data, the majority of drainage occurred off-growing season. The greater values in the tile drains at the Atlantic Food and Horticultural Research Station, may be related to dry condition of the soil which favors preferential flow to tile drains after rainfall or irrigation event. In order to get a better match with tile drainage data, the pan factor and soil retentivity parameters need to be calibrated.

The effect of base fertilizer on cumulative NO_3^- leaching during the period of 1 June 2012 to 31 March 2013 showed 40% more leaching in preplant application than in split plots (101 compared with 61 kg ha^{-1}). This is also in accordance with N balance results from field data. This suggests that when N fertilizer was added as preplant application, the risk of NO_3^- leaching after the growing season from lettuce field is higher. Testing the model with two sets of rate constants resulted in the range of 4-54 kg N ha^{-1} to 30-113 kg N ha^{-1} of cumulative NO_3^- leaching with rate constants from Hutson (2003) and Jiang (2011) respectively. According to our findings in this study, it is concluded that decreasing the denitrification rate constant and increasing mineralization rate constant resulted in greater cumulative NO_3^- leaching in the top 60 cm of soil profile, therefore calibration of rate constant that fit the actual condition of field study can become very helpful to achieve more accurate result.

In future LEACHN application in Atlantic Canada, additional attention needs to be directed towards the calibration of rate constants; calibration of rate constant should be done using the field soil samples so that each of the model subroutines could be tested individually. Also characterizing the soil hydraulic properties would help to estimate Campbell water retention parameters. Accurate measurements of θ and soil potential would help to limit the errors in simulating drainage. In addition soil N concentration should be measured during the year from different soil intervals to be able to evaluate the simulated N concentrations.

CHAPTER 5 CONCLUSION

The main objective of this project was to compare two N management strategies in lettuce production in Canning, Nova Scotia on yield and N losses from the soil. The amount of leaching was also tested using LEACHN model. Our results showed that under the conditions of this experiment in the dry summer of 2012, N application did not affect yield. Sidedress fertilizer application also did not affect yield and N uptake. However in split treatments, application of sidedress resulted in greater accumulation of NO_3^- in the top 60 cm of soil profile compared with preplant treatments. This suggests that under condition of high evapotranspiration and low precipitation, application of N fertilizers may have limited effect on lettuce yield and plant N uptake. According to dry condition and moisture deficit in the growing period of lettuce where 40% less precipitation occurred during the lettuce growing period in July and August of 2012 compared to the 30 year normal, no NO_3^- leaching was occurred during growing period. Model results also showed that less than 2% of NO_3^- leaching occurred during the growing season. Nitrogen balance calculation showed high amount of NO_3^- left in the top 30 cm of the soil that were not consumed by the plant. This is more pronounced when high rates of sidedress were applied i.e. 30 and 45 kg N ha^{-1}. The surplus N in the top 30 cm of the soil are subjected to leach with following fall and winter rainfall.

The LEACHN Model results for off season NO_3^- leaching showed the range of 4-54 kg N ha^{-1} to 30-113 kg N ha^{-1} with rate constants from Hutson (2003) and Jiang (2011) respectively. Base fertilizer effect on N surplus in top 30 cm of soil as well as on NO_3^- leaching was significant and 3.29 kg N ha^{-1} remained in the soil after harvest in control treatment. LEACHN results showed values of 3.9 kg N ha^{-1} of NO_3^- leaching in the same treatment, however increasing mineralization rate constant by 4 times and decreasing denitrification rate constant by 10 times, showed better fit for simulated NO_3^- leaching with N balance data in both split and preplant treatments with no sidedress and/or irrigation. Nitrate leaching estimation by N balance method for SSD0 and PSD0-R showed 87 and 114 kg N ha^{-1} losses, respectively, while the simulated NO_3^- leaching for SSD0 and PSD0-R were 61 and 102 kg N ha^{-1}.

In this study the water balance method was used to measure the total drainage in the field which showed a good match with the simulated water flux at the depth of 60 cm. Also tile drainage data at the Atlantic Food and Horticultural Research Station in Kentville, NS was compared to simulated cumulative drainage data which did not show good agreement especially during the winter months. This suggested that comparing the tile drainage with simulated drainage data is not helpful to discovering the amount of water flow in the soil profile and the LEACHN model was not specifically designed to simulate tile drainage flow.

In comparison with the values from previous studies of NO_3^- leaching in PEI and Kentville, we can see that the simulated annual NO_3^- leaching in PEI was 22-94 kg ha^{-1} in 2007 (depending on crop species) with the highest following a potato crop (with 200 kg N ha^{-1} N fertilizer application), while in Kentville, the measured NO_3^- leaching values for the growing season were in the range of 33 to 83 kg N ha^{-1} for permanent forage (PF) and corn-wheat-soybean rotation with zero tillage (CSW-ZT). The values ranged from 150 to 262 kg N ha^{-1} during the non-growing season (NGS) for PF and CSW-ZT, respectively during 2001 to 2006. The highest NO_3^- leaching during NGS was for CSW-ZT in 2002 with 77 kg NO_3-N ha^{-1} while it was 56 kg NO_3-N ha^{-1} in PF. The highest GS NO_3^-

leaching for CSW-ZT and PF were 27 and 8.5 kg NO_3-N ha^{-1} in 2005. Comparing the observed values for NO_3^- leaching in Kentville with simulated values for studied field showed greater leaching during the NGS in the studied field. Results from the three sites showed that the major part of the leaching occurred at NGS so that the management practices should focus on using methods to preserve N in the soil.

More precise N management recommendations in lettuce field, requires long-term observations and careful measurements of all N input and output sources. LEACHN model simulations can be approved through the calibration of rate constants, characterizing the soil hydraulic properties, soil moisture and matric potential and also measuring soil N concentration at different depth throughout the year.

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APPENDIX A. SAMPLE OF LEACHN INPUT FILE

```
LEACHN NITROGEN AND PHOSPHORUS DATA FILE.
**********************************************************************
 1      <Date format (1: month/day/year;  2: day/month/year).  Dates
  must be 6 digits, 2 each for day, mo, yr.
 060112 <Starting date.  No date in the input data should precede this
  date.
 103113 <Ending date or day number.  The starting date is day 1. (A
  value <010101 is treated as a day number).
  0.1   <Largest time interval within a day (0.1 day or less).
 1      <Number of repetitions of rainfall, crop and chemical
  application data.
 600    <Profile depth (mm), preferably a multiple of the segment
  thickness.
 50     &lt;Segment thickness (mm).  (The number of segments should be
  between about 8 and 30.
 2      <Lower boundary condition: 1:fixed depth water table; 2:free
  drainage, 3:zero flux 4:lysimeter.
 1000   <If the lower boundary is 1 or 4: initial water table depth
  (mm).
----------------------------------------------------------------------
The steady-state flow option uses constant water fluxes during the
  application
periods specified in the rainfall data table, and a uniform water
  content
specified here.  Steady-state flow implies a lab column, and crop and
  evaporation data are ignored.
----------------------------------------------------------------------
  1     < Water flow: 1: Richards; 2: Addiscott tipping bucket; 3:
  steady-state.
  0.4   < Steady-state flow water content (volume fraction); 999:
  saturated column.
**********************************************************************
 3     <Number of output files: 1: OUT only; 2: OUT + SUM; 3: OUT + SUM
  + BTC
--------------------------------------
--- For the *.OUT file :
 4      <Units for depth data: 1: mg/kg, 2: mg/m2 per segment, 3: g/m2,
  4: kg/ha
 1      <Node print frequency (print data for every node (1), alternate
  nodes (2).
 1      <Print option: Select one of the following two (enter 1 or 2)
 1      <Option 1: Print at fixed time intervals (days between prints).
  999 for monthly print.
 1      <Option 2: No. of prints (the times for which are specified
  below)
 3      <Tables printed: 1: mass balance; 2: + depth data; 3: + crop
  data
 0      <Reset cumulative values in .OUT after each print? 0: No, 1:
  Yes
---------------------------------------
--- For the * .SUM file :
 001    <Summary print interval (d) (for calendar months use 999)
 150    <Surface to [depth 1?] mm     ( Three depth segments for the
```

```
 300    <Depth 1 to [depth 2?] mm      summary file. Zero defaults to
  nodes
 450    <Depth 2 to [depth 3?] mm      closest to thirds of the
  profile)
   2    <4th segment: Root zone (1); profile (2); Depth 3 to lower
  boundary (3); Surface to shallowest of lower boundary or water table
  (4)
---------------------------------------
--- For the *.BTC (breakthrough) file :
 10.0    <Incremental depth of drainage water per output (mm)
----------------------------------------------------------------------
-- List here the times at which the *.OUT file is desired for print
  option 2.
-- The number of records must match the 'No. of prints' under option 2
  above.
        Date or    Time of day          (At least one must be
  specified,
        Day no.  (to nearest tenth)      even if print option is 1)
        --------  ----------------
        103113         .2        (These dates can be past the last day)
**********************************************************************
                  SOIL PHYSICAL PROPERTIES
----------------------------------------------------------------------
-- Retentivity model 0 uses listed Campbell's retention parameters,
  otherwise
-- the desired particle size-based regression model is used.
----------------------------------------------------------------------
 Soil  |                     |Retention|   Starting    |   Roots   |
  Starting
 layer | Clay  Silt  Organic |  model  |theta or  potl|  (for no  |
  temperature (C)
 no.   |             carbon  |         |(one is used) |  growth)  |
  (not read in
       |   %     %     %     |                    kPa | (relative)|
  LEACHC)
  ---    ----  ----   ----     ------   -----   -----    ------    ----
   1     14.7  15.1   2.91        5      .000    -10.0     .00      5.
   2     14.7  15.1   2.91        5      .000    -10.0     .00      5.
   3     14.7  15.1   2.91        5      .000    -10.0     .00      5.
   4     15.4  15.4   2.46        5      .000    -10.0     .00      5.
   5     15.4  15.4   2.46        5      .000    -10.0     .00      5.
   6     15.4  15.4   2.46        5      .000    -10.0     .00      5.
   7     15.3  13.5   1.28        5      .000    -10.0     .00      5.
   8     15.3  13.5   1.28        5      .000    -10.0     .00      5.
   9     15.3  13.5   1.28        5      .000    -10.0     .00      5.
   10    14.8  12.9   0.63        5      .000    -10.0     .00      5.
   11    14.8  12.9   0.63        5      .000    -10.0     .00      5.
   12    14.8  12.9   0.63        5      .000    -10.0     .00      5.
  (Add or delete rows here and in following tables to match number of
  segments)
----------------------------------------------------------------------
    2  < Use water contents (1), potentials (2)
  Particle density:  Clay    Silt and sand    Organic matter
                     2.65         2.65           1.10
****************************************************
For a uniform profile: Any non-zero value here will override those in
the table below.
```

```
--------------------------------------------------------------------
  0.0   0.0 <Soil bulk density and particle density (kg/dm3) .
 -0.0       <'Air-entry value' (AEV) (kPa).
  0.0       <Exponent (BCAM) in Campbell's water retention equation.
  0.0  -0.0 <Conductivity (mm/day) and corresponding matric potential
  (kPa) (for potential-based version of eq. 2.5).
  0.0       <Pore interaction parameter (P) in Campbell's conductivity
  equation.
  0.0       <Dispersivity (mm).
  0.0       <For Addiscott flow: Matric potential (kPa) at field
  capacity
  0.0       <                  : Division between mobile and immobile
  water (kPa)
**********************************************************************
 Soil  |  Soil retentivity |   Bulk  |  Match K(h) curve at: |
  Dispersivity |  For Addiscott flow option:
 segment      parameters   | density |   K    Matric  using  |
  |  Field     Mobile/immobile
 no.   |    AEV     BCAM   |         |         potl      P   |
  | capacity      threshold
      |    kPa             |  kg/dm3 |  mm/d    kPa          |     mm
  |   kPa            kPa
 -----    ------   -----     ------    ----  -----   -----       -----
   1       -0.18    3.96      1.33       0.02   -33.      1.       100.
  -5.0          -200.
   2       -0.18    3.96      1.39       0.02   -33.      1.       100.
  -5.0          -200.
   3       -0.18    3.96      1.39       0.01   -33.      1.       100.
  -5.0          -200.
   4       -0.27    5.97      1.54       0.01   -33.      1.       100.
  -5.0          -200.
   5       -0.27    5.97      1.60       0.01   -33.      1.       100.
  -5.0          -200.
   6       -0.27    5.97      1.60       0.01   -33.      1.       100.
  -5.0          -200.
   7       -0.37    5.78      1.79       0.01   -33.      1.       100.
  -5.0          -200.
   8       -0.37    5.78      1.79       0.01   -33.      1.       100.
  -5.0          -200.
   9       -0.37    5.78      1.79       0.01   -33.      1.       100.
  -5.0          -200.
  10       -0.37    5.78      1.79       0.01   -33.      1.       100.
  -5.0          -200.
  11       -0.37    5.78      1.79       0.01   -33.      1.       100.
  -5.0          -200.
  12       -0.37    5.78      1.79       0.01   -33.      1.       100.
  -5.0          -200.
**********************************************************************
Runoff according to the SCS curve number approach.  Curve number listed
  here will be
adjusted by slope. During periods of crop growth, CN2 replaced by value
  for crop.
(Procedure according to J.R. Williams (1991). Runoff and Water Erosion.
Chap 18, Modeling Plant and Soil Systems, Agronomy 31.)
----------------
 75    <Curve number (CN2).  In LEACHM, water content use to adjust CN2
  based on top 20 cm.
```

```
  5    <Slope, %. Used to adjust CN2 according to equation of Williams
  (1991).
** (Set slope to 0 to bypass the runoff routine.  Runoff owing to
  profile saturation will still be accumulated)
**********************************************************************
                          CROP DATA
----------------------------------------------------------------------
  --
  Data for at least one crop must be specified, even if no crop
  desired.
  For fallow soil, set flag below to 0, or germination past the
  simulation end date.
---------------------------------------------------------------------
  1      <Plants present: 1 yes, 0 no.
  02     <No. of crops (>0)
  -1500  <Wilting point (soil) kPa.
  -3000  <Min.root water potl(kpa).
  1.1    <Maximum ratio of actual to potential T.
  1.05   <Root resistance.
----------------------------------------------------------------------
  --
Growth  Perennial  N_uptake              Date or day of          Rel.
  Crop    Pan   |  Crop    Min   Harvested
1: No   1: Yes   1:to maturity                 Maturity         root
  cover  factor | uptake    N    fraction
2: Yes  2: No    2:to harvest  Germ. Emerg.   Root  Cover  Harv. depth
  fraction       |  N   P   fixed
------  -------  ------------  --------------------------------- -----
  ------  ----    -----kg/ha---- ----------
   2       2       2           61512  62012  73012  73012  082912 .5
  .8     1.00     87.  0.  0.     .5   A1
   2       2       2           61513  62013  73013  73013  082913 .5
  .8     1.00     87.  0.  0.     .5   A2
**********************************************************************
    INITIAL NITROGEN, PHOSPHORUS AND CARBON POOLS (excluding soil
  humus)
----------------------------------------------------------------------
      |          NITROGEN POOLS       | CARBON POOLS   |   PHOSPHORUS
  POOLS    | (Humus C, N, & P calculated from org.C)
 SOIL |UREA  NH4    NO3 Residue Manure| Residue Manure | Labile Residue
  Manure | (Fertilizer P absent at start)
LAYER |   ----mg N/kg dry soil----    | -- mg C/kg --  |   mg P/kg dry
  soil    | (Bound P pool in equilibrium with labile P.
----------------------------------------------------------------------
   1     0.    3.44   6.12   0.     0.     0.      0.       000.    0.
  000.
   2     0.    3.44   6.12   0.     0.     0.      0.       000.    0.
  000.
   3     0.    3.44   6.12   0.     0.     0.      0.       000.    0.
  000.
   4     0.    3.81   5.03   0.     0.     0.      0.       000.    0.
  000.
   5     0.    3.81   5.03   0.     0.     0.      0.       000.    0.
  000.
   6     0.    3.81   5.03   0.     0.     0.      0.       000.    0.
  000.
```

```
  7     0.    5.4    3.72   0.     0.     0.      0.       000.    0.
 000.
  8     0.    5.4    3.72   0.     0.     0.      0.       000.    0.
 000.
  9     0.    5.4    3.72   0.     0.     0.      0.       000.    0.
 000.
  10    0.    2.15   2.91   0.     0.     0.      0.       000.    0.
 000.
  11    0.    2.15   2.91   0.     0.     0.      0.       000.    0.
 000.
  12    0.    2.15   2.91   0.     0.     0.      0.       000.    0.
 000.
-----------------------------------------------------------------------
  Concentration (mg/l) below profile, used with lower boundary 1.
           0         0         0   (NH4, NO3 and P)
   0    < Depth (mm) of water in mixing cell.  Enter 0 for no mixing
  cell.
*****************************************************
     CHEMICAL PROPERTIES
     -------------------
                   Kd
         Name     L/kg
      ---------- --------
     '   Urea-N'    0
     '    NH4-N'    3
     '    NO3-N'    0
     'Residue-N'        (Plant 'residues' and 'manure' pools
  representing
     '  Humus-N'          added organic sources of N, P and C.  They
     ' Manure-N'          differ in that the plant residue pool is
  supplied
     'Residue-C'          by the non-harvested portion of annual
  crops,
     '  Humus-C'          and the non-harvested, non-perrenial portion
  of
     ' Manure-C'          perennial crops)
     '    CO2-C'
     '   Fert-P' 10000  .693         <Solubility; Dissolution rate
  (d**-1)
     ' Labile-P'     1   100  .6     <1: Freundlich or 2: Langmuir;
  [Freundlich Kd; Exponent  OR  Langmuir Qm; k]
     'Residue-P'
     '  Humus-P'
     ' Manure-P'
     '  Bound-P' 300  0.4  .05  .50  <Freundlich sorption: Kd;
  Exponent; Phase transfer: Dissolution rate, precipitation rate,
  (days^-1)
 *****************************************************
 Diffusion
 -----------------------------------------------------
  120    <Molecular diffusion coefficient
 *****************************************************
        NITROGEN TRANSFORMATIONS
 -----------------------------------------------------
   .5    <Synthesis efficiency factor.
   .2    <Humification fraction.
  10.0   <C/N ratio:biomass and humus.
```

```
  50.0   <C/P ratio:biomass and humus.
   ------Temperature and water content adjustments------
      1  <Temperature subroutine? yes(1), no(0). If no, base
  temperature used.
     20  <Base temperature, degrees C
      3  <Q10: rate constant adjustment factor per 10C temperature
  change.
    .08  <High end of optimum water content range, air-filled porosity.
   -300  <Lower end of optimum water content, kPa
  -1500  <Minimum matric potential for transformation, kPa
    0.6  <Relative transformation rate at saturation (except
  denitrification), days^(-1)
 *****************************************************
       RATE CONSTANTS  [days^(-1)]
 -----------------------------------------------------
            Urea  NH4->NO3 NO3->N           Mineralization
  Layer  hydrolysis                        Residue    Manure    Humus
  -------    -----   ------   -----          -----     -----     -----
     1    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     2    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     3    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     4    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     5    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     6    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     7    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     8    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
     9    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
    10    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
    11    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
    12    .0000e-0  .200E-0  .10e-00       .010e-0   .020e-0   .100e-4
 -----------------------------------------------------
 Additional rates and constants used for calculating N transformations:
   0 <Ammonia volatilization from the surface, days^(-1)
  10 <Denitrification half-saturation constant (mg/l).
   8 <Limiting NO3/NH4 ratio in solution for nitrification
************************************************************************
                NITROGEN, PHOSPHORUS AND CARBON APPLICATIONS (kg/ha)
                      -----------------------
 6    < No. of nutrient applications
------------------------------------------------------------------------
Date or   Incorp n                 NITROGEN                  CARBON
  PHOSPHORUS
day no.   segments     Urea   NH4    NO3 Residue Manure  Residue Manure
  Fertilizer Residue  Manure
-------   ---------   -----   ---    ---  ------ ------  ------- ------
  ------   ------  ------
061212       0           0   45.00   45.00   0      0        0       0
  0       0       0
072412       0           0   15.00   15.00   0      0        0       0
  0       0       0
080212       0           0   00.00   20.00   0      0        0       0
  0       0       0
061213       0           0   45.00   45.00   0      0        0       0
  0       0       0
072413       0           0   15.00   15.00   0      0        0       0
  0       0       0
```

```
080213       0           0    00.00   20.00   0     0         0      0
  0       0       0
***********************************************************************
                    CULTIVATIONS
                    ------------
 02  < Number of cultivations.  At least one must be specified.  Can be
  past last day.
-----------------------------------------------------
 Date or   Depth of cultivation
 day no.        mm
 -------      -----
  061512        100
  061513        100
***********************************************************************
      RAIN AND RAIN WATER COMPOSITION (Include irrigation here, or
  specify
      -------------------------------    in a separate file.)
 226 < Number of water applications.  Some or all can be past last day.
  (See manual on setting automated irrigation thresholds)
  0  < For a separate irrigation file, set to 1 and edit and rename
  NITRTEST.SCH.
----------------------------------------------------------------------
      Start      Amount  Surface flux      Dissolved in water (can be
  0)
Date/day  Time             density          Urea-N  NH4-N  NO3-N    P
-------  --day-  --mm--  ---mm/d----     ----------  mg/l  ---------
060412      0.3   3.3   16.5  0.000 0.000 0.000 0.000
060512      0.3   4.0   20.0  0.000 0.000 0.000 0.000
060612      0.3   2.6   13.0  0.000 0.000 0.000 0.000
060712      0.3   0.3   1.5   0.000 0.000 0.000 0.000
060912      0.3   5.3   26.5  0.000 0.000 0.000 0.000
061712      0.3   0.6   3.0   0.000 0.000 0.000 0.000
062312      0.3   19.0  95.0  0.000 0.000 0.000 0.000
062412      0.3   1.5   7.5   0.000 0.000 0.000 0.000
062612      0.3   49.8  249.0 0.000 0.000 0.000 0.000
062812      0.3   5.1   25.5  0.000 0.000 0.000 0.000
070212      0.3   0.3   1.5   0.000 0.000 0.000 0.000
070512      0.3   1.7   8.5   0.000 0.000 0.000 0.000
070712      0.3   0.5   2.5   0.000 0.000 0.000 0.000
071612      0.3   38    190   0.000 0.010 3.280 0.000
071712      0.3   3.1   15.5  0.000 0.000 0.000 0.000
072412      0.3   6.4   32.0  0.000 0.000 0.000 0.000
072712      0.3   1.2   6.0   0.000 0.000 0.000 0.000
072912      0.3   9.4   47.0  0.000 0.000 0.000 0.000
080112      0.3   1.6   8.0   0.000 0.000 0.000 0.000
080212      0.3   3.4   17.0  0.000 0.000 0.000 0.000
080312      0.3   1.2   6.0   0.000 0.000 0.000 0.000
080912      0.3   38.5  192.5 0.000 0.010 3.280 0.000
081112      0.3   2.8   14.0  0.000 0.000 0.000 0.000
081212      0.3   2.5   12.5  0.000 0.000 0.000 0.000
081512      0.3   19.8  99.0  0.000 0.000 0.000 0.000
081712      0.3   0.3   1.5   0.000 0.000 0.000 0.000
081812      0.3   4.0   20.0  0.000 0.000 0.000 0.000
081912      0.3   7.4   37.0  0.000 0.000 0.000 0.000
082012      0.3   0.3   1.5   0.000 0.000 0.000 0.000
082712      0.3   0.4   2.0   0.000 0.000 0.000 0.000
082812      0.3   28.5  142.5 0.000 0.000 0.000 0.000
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090512	0.3	59.9	299.5	0.000	0.000	0.000	0.000
090712	0.3	0.9	4.5	0.000	0.000	0.000	0.000
090912	0.3	30.7	153.5	0.000	0.000	0.000	0.000
091512	0.3	5.5	27.5	0.000	0.000	0.000	0.000
091912	0.3	11.1	55.5	0.000	0.000	0.000	0.000
092012	0.3	0.6	3.0	0.000	0.000	0.000	0.000
092112	0.3	8.1	40.5	0.000	0.000	0.000	0.000
092212	0.3	18.7	93.5	0.000	0.000	0.000	0.000
092712	0.3	9.6	48.0	0.000	0.000	0.000	0.000
092912	0.3	17.5	87.5	0.000	0.000	0.000	0.000
093012	0.3	10.1	50.5	0.000	0.000	0.000	0.000
100112	0.3	3.0	15.0	0.000	0.000	0.000	0.000
100412	0.3	4.1	20.5	0.000	0.000	0.000	0.000
100512	0.3	0.3	1.5	0.000	0.000	0.000	0.000
100712	0.3	0.8	4.0	0.000	0.000	0.000	0.000
100812	0.3	3.0	15.0	0.000	0.000	0.000	0.000
101112	0.3	3.3	16.5	0.000	0.000	0.000	0.000
101212	0.3	7.1	35.5	0.000	0.000	0.000	0.000
101612	0.3	6.8	34.0	0.000	0.000	0.000	0.000
102012	0.3	0.3	1.5	0.000	0.000	0.000	0.000
102212	0.3	1.1	5.5	0.000	0.000	0.000	0.000
102812	0.3	1.7	8.5	0.000	0.000	0.000	0.000
102912	0.3	0.7	3.5	0.000	0.000	0.000	0.000
103012	0.3	16.8	84.0	0.000	0.000	0.000	0.000
103112	0.3	46.6	233.0	0.000	0.000	0.000	0.000
110112	0.3	0.6	3.0	0.000	0.000	0.000	0.000
110512	0.3	0.4	2.0	0.000	0.000	0.000	0.000
110712	0.3	6.6	33.0	0.000	0.000	0.000	0.000
110812	0.3	15.7	78.5	0.000	0.000	0.000	0.000
111312	0.3	5.9	29.5	0.000	0.000	0.000	0.000
111412	0.3	11.7	58.5	0.000	0.000	0.000	0.000
112012	0.3	0.3	1.5	0.000	0.000	0.000	0.000
112412	0.3	3.4	17.0	0.000	0.000	0.000	0.000
112512	0.3	4.5	22.5	0.000	0.000	0.000	0.000
112612	0.3	2.4	12.0	0.000	0.000	0.000	0.000
112912	0.3	2.5	12.5	0.000	0.000	0.000	0.000
120212	0.3	2.4	12.0	0.000	0.000	0.000	0.000
120312	0.3	3.4	17.0	0.000	0.000	0.000	0.000
120512	0.3	0.7	3.5	0.000	0.000	0.000	0.000
120812	0.3	14.3	71.5	0.000	0.000	0.000	0.000
121012	0.3	9.5	47.5	0.000	0.000	0.000	0.000
121112	0.3	1.3	6.5	0.000	0.000	0.000	0.000
121812	0.3	13.9	69.5	0.000	0.000	0.000	0.000
121912	0.3	28.7	143.5	0.000	0.000	0.000	0.000
122112	0.3	9.4	47.0	0.000	0.000	0.000	0.000
122212	0.3	8.7	43.5	0.000	0.000	0.000	0.000
122312	0.3	0.5	2.5	0.000	0.000	0.000	0.000
122712	0.3	18.7	93.5	0.000	0.000	0.000	0.000
122812	0.3	9.2	46.0	0.000	0.000	0.000	0.000
123012	0.3	18.5	92.5	0.000	0.000	0.000	0.000
010113	0.3	3.0	15.0	0.000	0.000	0.000	0.000
010413	0.3	0.9	4.5	0.000	0.000	0.000	0.000
010513	0.3	1.0	5.0	0.000	0.000	0.000	0.000
010613	0.3	3.5	17.5	0.000	0.000	0.000	0.000
010913	0.3	2.6	13.0	0.000	0.000	0.000	0.000
011013	0.3	0.3	1.5	0.000	0.000	0.000	0.000
011213	0.3	0.3	1.5	0.000	0.000	0.000	0.000

011613	0.3	7.3	36.5	0.000	0.000	0.000	0.000
011813	0.3	2.1	10.5	0.000	0.000	0.000	0.000
011913	0.3	4.1	20.5	0.000	0.000	0.000	0.000
012013	0.3	0.9	4.5	0.000	0.000	0.000	0.000
012213	0.3	1.2	6.0	0.000	0.000	0.000	0.000
013013	0.3	0.8	4.0	0.000	0.000	0.000	0.000
013113	0.3	6.7	33.5	0.000	0.000	0.000	0.000
020313	0.3	6.3	31.5	0.000	0.000	0.000	0.000
020413	0.3	3.2	16.0	0.000	0.000	0.000	0.000
020613	0.3	0.9	4.5	0.000	0.000	0.000	0.000
020713	0.3	0.3	1.5	0.000	0.000	0.000	0.000
020813	0.3	2.7	13.5	0.000	0.000	0.000	0.000
020913	0.3	17.2	86.0	0.000	0.000	0.000	0.000
021013	0.3	0.6	3.0	0.000	0.000	0.000	0.000
021113	0.3	5.7	28.5	0.000	0.000	0.000	0.000
021213	0.3	2.6	13.0	0.000	0.000	0.000	0.000
021413	0.3	0.3	1.5	0.000	0.000	0.000	0.000
021613	0.3	7.0	35.0	0.000	0.000	0.000	0.000
021713	0.3	30.9	154.5	0.000	0.000	0.000	0.000
021813	0.3	0.8	4.0	0.000	0.000	0.000	0.000
022013	0.3	7.9	39.5	0.000	0.000	0.000	0.000
022613	0.3	0.3	1.5	0.000	0.000	0.000	0.000
022713	0.3	1.1	5.5	0.000	0.000	0.000	0.000
022813	0.3	3.6	18.0	0.000	0.000	0.000	0.000
030113	0.3	5.9	29.5	0.000	0.000	0.000	0.000
030213	0.3	1.0	5.0	0.000	0.000	0.000	0.000
030313	0.3	0.4	2.0	0.000	0.000	0.000	0.000
030513	0.3	5.1	25.5	0.000	0.000	0.000	0.000
031313	0.3	25.1	125.5	0.000	0.000	0.000	0.000
031513	0.3	5.0	25.0	0.000	0.000	0.000	0.000
031713	0.3	0.3	1.5	0.000	0.000	0.000	0.000
032013	0.3	4.8	24.0	0.000	0.000	0.000	0.000
032413	0.3	1.7	8.5	0.000	0.000	0.000	0.000
032613	0.3	2.9	14.5	0.000	0.000	0.000	0.000
032713	0.3	5.3	26.5	0.000	0.000	0.000	0.000
040113	0.3	3.0	15.0	0.000	0.000	0.000	0.000
040213	0.3	0.9	4.5	0.000	0.000	0.000	0.000
040513	0.3	3.2	16.0	0.000	0.000	0.000	0.000
040613	0.3	0.9	4.5	0.000	0.000	0.000	0.000
040913	0.3	3.3	16.5	0.000	0.000	0.000	0.000
041213	0.3	2.9	14.5	0.000	0.000	0.000	0.000
041313	0.3	5.0	25.0	0.000	0.000	0.000	0.000
041413	0.3	2.6	13.0	0.000	0.000	0.000	0.000
041613	0.3	5.2	26.0	0.000	0.000	0.000	0.000
041713	0.3	3.7	18.5	0.000	0.000	0.000	0.000
042013	0.3	2.9	14.5	0.000	0.000	0.000	0.000
042213	0.3	0.3	1.5	0.000	0.000	0.000	0.000
042313	0.3	5.0	25.0	0.000	0.000	0.000	0.000
042413	0.3	5.6	28.0	0.000	0.000	0.000	0.000
042513	0.3	0.7	3.5	0.000	0.000	0.000	0.000
050913	0.3	1.0	5.0	0.000	0.000	0.000	0.000
051013	0.3	4.0	20.0	0.000	0.000	0.000	0.000
051113	0.3	1.0	5.0	0.000	0.000	0.000	0.000
051213	0.3	26.6	133.0	0.000	0.000	0.000	0.000
051413	0.3	6.2	31.0	0.000	0.000	0.000	0.000
051513	0.3	3.4	17.0	0.000	0.000	0.000	0.000
051613	0.3	1.6	8.0	0.000	0.000	0.000	0.000

051713	0.3	0.2	1.0	0.000	0.000	0.000	0.000
051813	0.3	0.2	1.0	0.000	0.000	0.000	0.000
052013	0.3	1.6	8.0	0.000	0.000	0.000	0.000
052113	0.3	0.4	2.0	0.000	0.000	0.000	0.000
052213	0.3	4.0	20.0	0.000	0.000	0.000	0.000
052313	0.3	0.4	2.0	0.000	0.000	0.000	0.000
052413	0.3	1.4	7.0	0.000	0.000	0.000	0.000
052513	0.3	10.6	53.0	0.000	0.000	0.000	0.000
052613	0.3	0.8	4.0	0.000	0.000	0.000	0.000
052913	0.3	7.0	35.0	0.000	0.000	0.000	0.000
053013	0.3	2.2	11.0	0.000	0.000	0.000	0.000
060313	0.3	2.2	11.0	0.000	0.000	0.000	0.000
060413	0.3	1.0	5.0	0.000	0.000	0.000	0.000
060713	0.3	0.6	3.0	0.000	0.000	0.000	0.000
060813	0.3	62.8	314.0	0.000	0.000	0.000	0.000
061013	0.3	0.4	2.0	0.000	0.000	0.000	0.000
061113	0.3	6.2	31.0	0.000	0.000	0.000	0.000
061213	0.3	12.2	61.0	0.000	0.000	0.000	0.000
061313	0.3	0.2	1.0	0.000	0.000	0.000	0.000
061413	0.3	2.2	11.0	0.000	0.000	0.000	0.000
061513	0.3	0.2	1.0	0.000	0.000	0.000	0.000
061713	0.3	0.2	1.0	0.000	0.000	0.000	0.000
061813	0.3	1.0	5.0	0.000	0.000	0.000	0.000
061913	0.3	2.4	12.0	0.000	0.000	0.000	0.000
062313	0.3	2.4	12.0	0.000	0.000	0.000	0.000
062413	0.3	0.2	1.0	0.000	0.000	0.000	0.000
062613	0.3	0.8	4.0	0.000	0.000	0.000	0.000
062713	0.3	0.2	1.0	0.000	0.000	0.000	0.000
062813	0.3	18.8	94.0	0.000	0.000	0.000	0.000
062913	0.3	10.0	50.0	0.000	0.000	0.000	0.000
070113	0.3	8.0	40.0	0.000	0.000	0.000	0.000
070213	0.3	3.0	15.0	0.000	0.000	0.000	0.000
070813	0.3	20.2	101.0	0.000	0.000	0.000	0.000
070913	0.3	0.2	1.0	0.000	0.000	0.000	0.000
071113	0.3	0.4	2.0	0.000	0.000	0.000	0.000
071713	0.3	5.2	26.0	0.000	0.000	0.000	0.000
071813	0.3	4.6	23.0	0.000	0.000	0.000	0.000
071913	0.3	4.4	22.0	0.000	0.000	0.000	0.000
072313	0.3	22.2	111.0	0.000	0.000	0.000	0.000
072413	0.3	1.0	5.0	0.000	0.000	0.000	0.000
072513	0.3	1.8	9.0	0.000	0.000	0.000	0.000
072613	0.3	13.6	68.0	0.000	0.000	0.000	0.000
072713	0.3	0.2	1.0	0.000	0.000	0.000	0.000
073013	0.3	5.2	26.0	0.000	0.000	0.000	0.000
073113	0.3	0.2	1.0	0.000	0.000	0.000	0.000
080913	0.3	24.6	123.0	0.000	0.000	0.000	0.000
081013	0.3	4.6	23.0	0.000	0.000	0.000	0.000
081313	0.3	0.6	3.0	0.000	0.000	0.000	0.000
081413	0.3	6.4	32.0	0.000	0.000	0.000	0.000
082613	0.3	1.4	7.0	0.000	0.000	0.000	0.000
082713	0.3	0.2	1.0	0.000	0.000	0.000	0.000
082913	0.3	1.0	5.0	0.000	0.000	0.000	0.000
083013	0.3	0.2	1.0	0.000	0.000	0.000	0.000
090113	0.3	6.4	32.0	0.000	0.000	0.000	0.000
090213	0.3	5.8	29.0	0.000	0.000	0.000	0.000
090313	0.3	24.0	120.0	0.000	0.000	0.000	0.000
090513	0.3	6.0	30.0	0.000	0.000	0.000	0.000

090813	0.3	9.4	47.0	0.000	0.000	0.000	0.000
090913	0.3	0.2	1.0	0.000	0.000	0.000	0.000
091313	0.3	36.2	181.0	0.000	0.000	0.000	0.000
091413	0.3	0.2	1.0	0.000	0.000	0.000	0.000
091613	0.3	1.2	6.0	0.000	0.000	0.000	0.000
092213	0.3	6.6	33.0	0.000	0.000	0.000	0.000
092313	0.3	1.2	6.0	0.000	0.000	0.000	0.000
092513	0.3	3.6	18.0	0.000	0.000	0.000	0.000
092613	0.3	0.6	3.0	0.000	0.000	0.000	0.000
092713	0.3	0.2	1.0	0.000	0.000	0.000	0.000
092913	0.3	0.2	1.0	0.000	0.000	0.000	0.000
100113	0.3	43.7	218.5	0.000	0.000	0.000	0.000
100213	0.3	0.6	3.0	0.000	0.000	0.000	0.000
100713	0.3	0.3	1.5	0.000	0.000	0.000	0.000
100813	0.3	7.0	35.0	0.000	0.000	0.000	0.000
100913	0.3	0.3	1.5	0.000	0.000	0.000	0.000
101613	0.3	33.8	169.0	0.000	0.000	0.000	0.000
102013	0.3	0.3	1.5	0.000	0.000	0.000	0.000
102213	0.3	18.0	90.0	0.000	0.000	0.000	0.000
102613	0.3	1.4	7.0	0.000	0.000	0.000	0.000
102713	0.3	3.2	16.0	0.000	0.000	0.000	0.000
102813	0.3	4.2	21.0	0.000	0.000	0.000	0.000
102913	0.3	0.3	1.5	0.000	0.000	0.000	0.000
103113	0.3	3.2	16.0	0.000	0.000	0.000	0.000

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POTENTIAL ET (WEEKLY TOTALS, mm), DEPTH TO WATER TABLE (mm)
MEAN WEEKLY TEMPERATURES AND MEAN WEEKLY AMPLITUDE (degrees C)

Week	ET	Water table	Mean temp	Amplitude
060112	20.0	0.0	11.7	8.1
060812	28.0	0.0	14.7	12.1
061512	31.0	0.0	15.9	13.4
062212	22.0	0.0	17.8	6.8
062912	36.0	0.0	20.9	12.0
070612	32.0	0.0	20.0	12.5
071312	30.0	0.0	21.5	10.5
072012	31.0	0.0	19.4	13.4
072712	26.0	0.0	19.8	9.7
080312	34.0	0.0	22.5	14.2
081012	28.0	0.0	22.6	10.5
081712	27.0	0.0	20.7	11.3
082412	26.0	0.0	19.0	12.9
083112	22.0	0.0	17.0	11.6
090712	20.0	0.0	17.6	10.8
091412	19.0	0.0	15.0	11.6
092112	16.0	0.0	16.0	9.3
092812	14.0	0.0	14.7	9.2
100512	11.0	0.0	11.8	7.8
101212	11.0	0.0	8.5	11.1
101912	8.0	0.0	9.2	9.0
102612	8.0	0.0	11.8	6.8
110212	6.0	0.0	4.8	6.2
110912	6.0	0.0	7.1	7.5

111612	6.0	0.0	2.3	9.9
112312	4.0	0.0	0.4	7.7
113012	5.0	0.0	-0.5	9.7
120712	6.0	0.0	2.3	11.4
121412	3.0	0.0	-1.2	7.2
122112	4.0	0.0	-0.9	7.7
122812	2.0	0.0	-5.8	5.1
010413	3.0	0.0	-5.2	12.2
011113	4.0	0.0	-0.9	8.0
011813	3.0	0.0	-8.8	8.0
012513	5.0	0.0	-5.1	10.6
020113	4.0	0.0	-8.6	8.7
020813	4.0	0.0	-4.6	7.6
021513	5.0	0.0	-0.5	6.0
022213	6.0	0.0	-3.1	9.5
030113	5.0	0.0	1.3	3.4
030813	8.0	0.0	3.1	6.7
031513	7.0	0.0	-3.6	8.0
032213	7.0	0.0	1.1	5.3
032913	11.0	0.0	2.4	9.6
040513	18.0	0.0	3.5	9.4
041213	14.0	0.0	4.1	9.4
041913	20.0	0.0	9.0	12.3
042613	21.0	0.0	8.1	13.9
050313	26.0	0.0	11.8	14.6
051013	20.0	0.0	12.5	8.5
051713	18.0	0.0	8.4	8.8
052413	22.0	0.0	13.5	9.4
053113	31.0	0.0	18.0	12.7
060713	20.0	0.0	13.3	7.1
061413	28.0	0.0	15.7	11.3
062113	30.0	0.0	18.1	11.3
062813	21.0	0.0	20.3	7.5
070513	24.0	0.0	21.7	9.3
071213	35.0	0.0	21.7	13.6
071913	26.0	0.0	20.5	9.0
072613	27.0	0.0	20.6	9.7
080213	20.0	0.0	18.3	12.7
080913	26.0	0.0	19.3	11.0
081613	30.0	0.0	19.8	13.8
082313	25.0	0.0	17.4	12.2
083013	17.0	0.0	18.4	6.7
090613	20.0	0.0	15.8	11.1
091313	18.0	0.0	14.8	11.7
092013	14.0	0.0	14.9	7.9
092713	17.0	0.0	13.0	12.7
100413	15.0	0.0	10.8	12.8
101113	12.0	0.0	10.1	13.8
101813	10.0	0.0	9.6	8.8
102513	8.0	0.0	4.6	9.6
110113	14.0	0.0	7.6	8.3