How to Calculate a Partial Nitrogen Mass Budget for Potato[1]

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Purpose

This publication provides information on the importance of nitrogen (N) budgets for potato cultivation and discusses the steps in preparing the budget. This publication will allow growers to understand the inputs, cycling, and exports of nutrients within and away from the farm, develop a nutrient budget, and analyze best management practices (BMPs) for their farm. The results will be increased N fertilizer use efficiency, increased environmental protection, and reduced economic losses associated with potato cultivation. This document will also aid county agents, environmental management advisors, and government agency staff members who help farmers improve and implement nutrient BMPs to protect water quality.

Figure 1. Center-pivot-irrigated potato in Florida.
Credits: George Hochmuth, UF/IFAS

Introduction

Nitrogen lost from agricultural fields is considered a potential nonpoint source pollutant of water bodies. Nitrogen losses through leaching, especially from Florida sandy soils, have been associated with surface and groundwater pollution. When nitrate is introduced to surface water through point and nonpoint sources and where light and other nutrients are abundant, excess aquatic plant growth may result in water body deterioration or eutrophication (SRWMD 2013). Some of the major issues with nutrient enrichment include: excessive growth of algae, loss of oxygen in water resulting from algal decay, loss of water clarity, and changes in the array of plant and animal species inhabiting the water body (SRWMD 2013). A body of water is impaired when its designated uses (recreation, fishing, drinking) are negatively impacted because the desired water quality criteria are not met. Consumption of water with nitrate-N concentrations exceeding 10 ppm can lead to methemoglobinemia and increased birth defects in infants, as well as increased incidence of stomach cancer in adults (Andrews 1994). Therefore, growers need to understand the N input, output, and cycling within agricultural systems, so BMPs can be developed or improved and eutrophication can be reduced. Growers can improve their farm N efficiency by accounting for the imports and exports of N in a nutrient budget. Once the pools of N on the farm are

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quantified, it will be easier to implement proper management strategies to avoid N loss from these pools into the environment.

Potatoes are among the top 10 vegetable crops in Florida. In 2019, around 27,000 acres of land were harvested in potato with an average yield of 260 cwt./acre and a market value of 160 million dollars (NASS 2019). Potatoes require N fertilization to produce high-quality tubers and profitable yields. The current N recommendations for potato include a seasonal target of 224 kg/ha N applied in split applications, along with tissue testing, replacing leached N, and carefully managing irrigation (Zotorelli et al. 2018).

What is a nitrogen budget?

A farm N budget is an account of the major inputs and outputs of N for a farm. It is an evaluation tool that identifies pools of excess N on the farm and leads to strategies to prevent N buildup or losses. A positive N balance or surplus reflects N inputs that are in excess of crop needs; hence, extra N could result in pollution through leaching loss. The budget is considered in balance if inputs and outputs are equal.

Components of the N Budget for Potato Cultivation

Table 1. Possible inputs and outputs of N for potato cultivation on typical potato farms in Florida

Inputs (Expressed in kg/ha)		Outputs (Expressed in kg/ha)	
	Your value		Your value
1. Nitrogen from fertilizer		1. Crop N uptake (a+b+c)	
2. Mineral N from organic soil amendments or soil organic matter		a. Roots	
3. Initial soil mineral N (0–15 cm depth)		b. Shoots	
4. Nitrogen in irrigation water		c. Tubers	
5. Nitrogen from atmospheric deposition (wet + dry)		2. Soil mineral N after crop harvest (0–15 cm depth)	
		3. Nitrogen losses (d+e+f+g)	
		d. Leaching loss of N	
		e. Volatilization loss of N	
		f. Denitrification loss of N	
		g. Runoff loss of N	
∑ Inputs		∑ Outputs	
Unaccounted N = ∑Inputs -∑Outputs (expressed as kg/ha N)			

Obtaining Data for the Budget

To prepare a sound N budget, data on inputs and outputs shown in Table 1 should be collected with accuracy. The data can be gathered from various sources such as a farmer's record book, actual measurement of parameters, previously published literature values, and data from weather stations or state and federal agencies. In preparing N budgets, the accuracy is limited by the estimations and assumptions, which must be clearly addressed. For example, limited sample numbers may be used to estimate the tissue N concentrations and irrigation measurements. Also, incidence of disease or pest damages might reduce the N recovery in plants. Hence the sample size should be representative of field conditions.

Some components, such as denitrification or volatilization, in Table 1 are difficult to measure. Leaching can be measured on a commercial farm with zero-tension drainage lysimeters. Drainage lysimeters are buried below crop root zone to collect soil water draining past the root zone. A partial N budget is used to describe the budget that does not contain estimates of all the components. An example of a partial N budget is demonstrated in this publication. This budget accounts for most parts of the budget, except for leaching and gaseous N losses.

The components of a potato N budget can be calculated with English or metric system units. Conversions between systems are given in Table 2.

Table 2. These formulas can be used for changing between standard and metric units.

kg/ha × 0.89 =	lb/acre
$m^3 \times 1.6 \times 10^{-5}$ =	cu. in.
m × 0.30 =	foot
mg ×1,000,000 =	kg
1 acre-inch =	27,154 gallons
L × 3.78	gallons
cm × 2.54 =	inch
ha × 0.404 =	acre
g × 454 =	lb
(9/5)°C + 32 =	°F
$m^{-3} \times 102.8$ =	acre-inches
1 ppm =	mg/kg

The budget described below is a partial N budget that is typically the easiest to construct without a significant investment in equipment and resources. The materials and methods required for collecting data for use in the input and output columns for potato N budget are as follows:

Data Sources for the Input Side of the N Budget

1. **Fertilizer:** Data on fertilizer amounts and application methods can be obtained from the cooperating farmer.

2. **Initial Soil Mineral N:** The initial mineral N in the soil is easily used by the potato plants, assuming it is not leached early in the season. While more mineral N will be made available through mineralization during the season (from organic matter in the soil), this N source is not accounted for in this budget. Organic matter content of sandy soils is low; therefore, total N mineralized in Florida sandy soils probably contributes a relatively small amount of N to the total budget. More research is needed to determine the total amount of N mineralized during the season. Soil samples are taken from the top 15 cm of the soil (representing a large part of the root zone) at several locations in the field. The samples are combined to form a composite sample. The soil is dried at 105°F (40°C) for 24 to 48 hours. The soil sample is sent to the UF/IFAS Analytical Research Laboratory located in Gainesville, Florida, for analyses of NH_4-N and NO_3-N + NO_2-N contents. The sample analysis request form can be downloaded from http://arl.ifas.ufl.edu/ARL_files/SoilAnalysesSubmissionForm.pdf or can be collected in person by visiting the lab. Commercial labs also may be employed for these analyses.

CALCULATIONS

The lab reports NH_4-N and NO_3-N + NO_2-N values in mg/kg soil. This value can be converted to a field area basis (kg/ha) using Formula 1 below. Soil bulk density will be needed for this conversion. To estimate soil bulk density, a sharp soil core sampler is used to remove an intact soil core with negligible compaction of the soil during the sampling procedure. Several samples should be taken in the field. The soil is dried in a drying oven at 221°F (105°C), and its weight is recorded after 48 hours. The volume of the soil core sampler is calculated as $V = \Pi r^2 h$, where V = volume (m^3), r = the radius of the core sampler (m), and h = height of core sampler (m). The bulk density (kg/m^3) of the soil is calculated as $BD = M/V$, in which M = mass of oven-dried soil (kg) and V = volume of core sampler in m^3. You will need to convert the N soil content into an area basis (kg/ha) using the Formula 1 that includes the information provided in the soil test report and the bulk density result, as well as the soil depth. The conversion factor 100 in the denominator of the equation comes from converting m^2 to ha and mg to kg. There are 10,000 m^2 in a hectare and 1,000,000 mg in a kg.

Total mineral N in upper 0.15 m soil kg/ha

$$= \frac{(NH_4\text{–}N) + (NO_3\text{–}N + NO_2\text{–}N)\ (mg/kg) \times \text{soil depth (m)} \times \text{Soil bulk density kg/m}^{-3}}{100}$$

3. **N in Irrigation Water:** To estimate the total N that is supplied with the irrigation water, the amount of irrigation water applied during the season will be needed. This information can be obtained from the farmer and is usually expressed as inches (1 acre-inch = an acre of land covered by 1 inch of water) per application. There are 27,154 gallons in an acre-inch of water. Second, collect an irrigation water sample three to four times during the growing season in 20-mL new scintillation vials (or clean, new plastic bottles), add a drop of half-strength sulfuric acid to each 20 mL of sample, and cap each container. Preserve and transport the sample vial in ice water (4°C) to the UF/IFAS Analytical Research Laboratory. Request analyses for NH_4-N and NO_3-N + NO_2-N. The sample analysis request form can be downloaded from http://arl.ifas.ufl.edu/ARL_files/SolutionSubmissionForm.pdf or can be collected in person by visiting the lab. Typically, NH_4-N is negligible in irrigation water.

CALCULATIONS

The lab reports NH_4-N and NO_3-N + NO_2-N values in mg/L. Convert this number to kg/ha N using the following conversion.

Total mineral N applied through irrigation water (kg/ha) =

(Total inches of irrigation water applied during the entire growing season) × ([(NH_4-N)+(NO_3-N + NO_2-N)]in mg/L) × 0.253

The conversion factor of 0.253 in Formula 2 is derived by converting mg/L and acre/inches to kg/ha as follows:

$$\frac{\text{acre–inches}}{\text{acre}} \times \frac{27154\ \text{gallon}}{1\ \text{acre–inch}} \times \frac{1L}{0.265\ \text{gallon}} \times \frac{2.47\ \text{acre}}{1\text{ha}} \times \frac{mgNH_4{+}NO_x\text{–}N}{} \times \frac{kg}{10^6 mg} = 0.253$$

4. **Rainfall and Wet Atmospheric Deposition:** Estimates of total rainfall for the growing period can be obtained from a local weather station, such as FAWN (https://fawn.ifas.ufl.edu), or from farmer records. The amount of NH_4-N and NO_3-N + NO_2-N in rainfall can be obtained from the national atmospheric wet deposition program (NADP), which can be found at http://nadp.sws.uiuc.edu/data/. Use the following equation to convert the number into kg/ha N.

Total N recieved through rainfall or wet atmospheric deposition (kg/ha)=[(NH_4-N)+(NO_3-N + NO_2-N)](mg/L) × (total inches of rainfall) × 0.253

The conversion factor of 0.253 is derived as explained in the previous equation.

Data Sources for the Output Side of the N Budget

1. **Crop Uptake**: Estimates of the plant N uptake can be obtained through a two-step process.

Step I: Near harvest (before herbicide desiccation of the crop), three or four 5 ft or 1.5 m sections are randomly chosen in the field, and all the plants in each selected section are harvested. A shovel can be used to dig deep enough (usually 12 inches or 30 cm) to capture most of the root system. Separate plants into tubers, roots, and shoots (stems plus leaves). Soil should be gently washed from roots and tubers.

The plant parts are processed as follows: Roots are placed in a paper bag for drying. The plant shoots are placed in a paper bag **without chopping**. Samples are dried at 158°F (70°C) for 48 hours, and the dry mass is recorded (g).

Tubers require more effort as follows: The fresh weight of all harvested tubers is recorded, a random subsample of 10 tubers is then selected, and the fresh weight is recorded. The subsample is chopped to facilitate quicker drying. The subsample is dried, and the dry weight of the subsample fresh weight is calculated as a percent. This factor is used with the entire plot fresh weight yield. The plot fresh weight and the percent dry weight can be used to calculate total dry mass in kg/ha.

CALCULATION

Use the following equation to convert the dry weight (grams) in each 5 ft or 1.5 m section to dry weight in kg/ha.

Dry weight (kg/ha) =

$$\frac{\text{(Dry wt. in 5 ft or 1.5m section (g)) x 43,560} \times 1.12}{\text{(bed spacing (foot))} \times \text{5 (length of plant sampling section))} \times 453.5}$$

The factor 43,560 in the above equation comes from conversion of an acre into sq. ft. There are 43,560 ft^2 in an acre. The factor 453.5 is used for converting grams into pounds. There are 453.5 grams in a pound. Finally, the factor 1.12 is used for converting lb/acre to kg/ha.

Step II: The individual plant parts are ground separately in a Wiley mill to pass through a 2 mm screen, and then mixed well, and a subsample is saved in a sealed container. Individual tissue samples (tubers, roots, and shoots) can be sent to the UF/IFAS Analytical Research Laboratory or a commercial lab for determination of total tissue N. The sample analysis request form can be downloaded from http://arl.ifas.ufl.edu/ARL_files/TissueAnalysesSubmissionForm.pdf or can be collected in person by visiting the lab.

CALCULATION

The lab reports the N values as a percentage N on a dry weight basis. The following equation is used to convert the N% in the specific plant part in a 5 ft or 1.5 m section to plant part N uptake in kg/ha. **Total crop uptake is the sum of the amounts of N in the roots, shoots, and tubers.**

Plant part N update (kg/ha) =

$$\frac{\text{Dry wt. (kg/ha) calculated in step 1} \times \text{N\%}}{100}$$

Or, plant part N uptake (kg/ha) can also be calculated as:

Plant part N uptake (kg/ha) =

$$\frac{\text{(dry wt. in 5 ft section (g))} \times \text{N\% x 43560} \times 1.12}{100 \times \text{((bed spacing (ft.))} \times \text{(5 (length of plant sampling section))} \times 453.5}$$

2. **Soil Residual Mineral N left at harvest:** Soil samples are collected at the same time when plant samples are harvested from the top 15 cm depth at several locations in the field. The samples are mixed and subsampled to form a composite sample. The soil is dried at 104°F (40°C) for 24 to 48 hours or until dry. The sample is sent to the UF/IFAS Analytical Research Laboratory located in Gainesville, FL, with a request for a NH_4-N and NO_3-N + NO_2-N analysis. The sample analysis request form can be downloaded from http://arl.ifas.ufl.edu/ARL_files/SoilAnalysesSubmissionForm.pdf or can be collected in person by visiting the lab.

CALCULATIONS

The lab reports NH_4-N and NO_3-N + NO_2-N values in mg/kg air-dry soil. The laboratory results can be converted into an area basis (kg/ha) using the following equation. The soil bulk density can be obtained by using the method described above. The conversion factor 100 is derived by converting m^2 to ha and mg to kg. There are 10,000 m^2 in one ha and 1,000,000 mg in a kg.

Soil residual mineral N in upper 0.15 m soil (kg/ha)

$$= \frac{\text{([}NH_4\text{–N) + (}NO_3\text{–N + }NO_2\text{–N)] (mg/kg))} \times \text{(soil depth (m))} \times \text{(Soil bulk density (kg/}m^3\text{))}}{100}$$

3. **Nitrogen Lost:** Estimating N losses to the environment gives an indicator of the farm N management practice performance. Most farm budgets estimate N loss as the unaccounted for N in the budget. The difference between the total N input and measured N output gives an estimate of the N loss. Nitrogen can be lost through leaching, volatilization, runoff, or denitrification. These parameters are difficult to measure in commercial field conditions. Hence, we often estimate N losses as the unaccounted-for N in the budget.

Interpretation of N Budget

Once the N budget is developed, the information will help the growers evaluate their management practices and find the pools where maximum N inputs occur and where losses might occur. The budget will also help the environmental management advisors refine the BMPs. Some of the following parameters can be calculated to interpret the budget and evaluate the farm performance:

Crop N Uptake Efficiency: Higher crop N uptake efficiency is a good indicator of crop performance, and hence, management practices that lead to improved crop N uptake efficiency can be considered sound. Crop N uptake efficiency (CNUE) is expressed as a percentage and can be calculated as Formula 7:

$$\textbf{CNUE} = \frac{\textbf{Total plant N uptake (kg/ha) x 100}}{\textbf{Total N input (kg/ha)}}$$

Crop N uptake efficiency can be increased by:

- Splitting applications of N that reduce the risk of large-scale losses of N (for example, rainfall leaching loss).
- Avoiding the application of excessive amounts of fertilizer.
- Applying N when crop demands are high, which is early (before 40 days after planting) in the growth cycle for potato.
- Timing N applications to meet crop nutrient needs.
- Application of fertilizer close to the root zone, minimizing N applications to areas between the rows where few roots are located.
- Managing irrigation to prevent excess irrigation to minimize leaching of N below the root zone.

Nitrogen Recycled within the Farm: The leftover shoots and roots of potato in the field serve as a source of organic matter and supply N via decomposition. Hence, N present in these shoots and roots is recycled back into the farm. The N recycled within the farm can be estimated by summing the N values for shoots and roots in the output column of the N budget. Mineralized N from crop residues can be lost during the fallow period between crops if no cover crop is planted to utilize the N.

Nitrogen Leaving the Farm with the Sold Crop: Nitrogen leaves the farm in the sold tubers. This N is exported off the farm and can be estimated from the N values in tubers in the output column of the N budget. The amount of N exported from the farm in a high-yielding potato crop can be significant—on the order of 40% to 50% of the applied fertilizer N.

Nitrogen Lost to the Environment: The unaccounted-for N in the budget is the difference between input and output. Unaccounted-for N typically is comprised of N lost by gaseous means, including denitrification and volatilization or from leaching losses. A high proportion of unaccounted-for N is indicative of N losses from the production system and potentially poorer nutrient management on the farm or large rainfall events beyond the control of the farmer. The loss percentage can be calculated as Formula 8.

$$\textbf{Percent Nitrogen lost} = \frac{\textbf{Unaccounted N in the budget (kg/ha) x 100}}{\textbf{Total N input (kg/ha)}}$$

How to Control N Losses to the Environment

- Minimize leaching losses by not overirrigating; keeping the water in the root zone will ensure that N will stay in the root zone.
- Apply the right rate of fertilizer.
- Minimize volatilization of N from fertilizers by incorporating ammonium fertilizers in the soil by tillage or by knifing the fertilizer in the soil near the plant roots.
- Use sprinkler irrigation to "water-in" fertilizer or inject fertilizer through the irrigation system.

Limitations of the N Budget

1. Representative soil and plant samples must be obtained for developing the N budget.

2. The budgets are site-specific and subject to change with seasons; hence, information on potato varieties, fertilizer amounts, row spacing, and irrigation must be considered before implementing major N management changes. Weather differences among seasons can have a large impact on crop growth and nutrient use efficiency.

3. Plant sample collection, drying, grinding, and shipping to the laboratory are laborious and require caution to prevent mixing samples.

4. The budget described above does not include leached N or N lost by gaseous forms—these sources of N require significant investment in equipment and resources to estimate.

5. Nitrogen budgets can be affected by several factors, such as incidence of heavy rainfall, disease, and pest incidence, etc.

Summary

The N budget can be a useful nutrient management tool on the farm. A partial budget is rather simple to estimate using farm records and a minimal amount of plant and soil analyses. A more complete budget can be developed if estimates of leaching can be obtained with drainage lysimeters, and estimates of N volatilization and denitrification can be made. Denitrification is often assumed to be negligible in the unsaturated, sandy root zone of most potato fields in Florida. Volatilization could represent a significant N loss pathway in the field. While the unaccounted-for N may be large and the leaching loss low, this scenario still represents a significant loss of N to atmospheric paths. Thus, this is a serious economic loss to the farmer. N budgets similar to the one described above can be estimated solely from literature values, but these budgets may not be representative of the specific farming practices of the farm(s) under consideration. It would be preferable, if time and resources are available, to estimate a crop budget using as many direct measurements as possible.

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