DRAFT

Alberta Farm Fertilizer Information and Recommendation Manager (AFFIRM)

Version 3

User Guide

October 3, 2018

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A. What is AFFIRM v3?

1. Introduction

AFFIRM v3 is a decision support application designed to assist the user in evaluating nutrient management options for fertilizers and livestock manure for crop production and making nutrient management decisions. Crop nutrient requirements are dependent upon various nutrient sources such as soil nutrient levels, previous crop residue management, manure, biosolids and fertilizer, plus agro-climatic variables such as spring soil moisture status, anticipated growing season precipitation or irrigation management and any crop growth soil limiting factors. Determining the appropriate rate of fertilizer nutrients aimed at optimizing crop production is dependent upon on the principles of limiting factor identification and diminishing economic returns based on crop price, fertilizer nutrient costs and the farm fertilizer budget. AFFIRM v3 will assist in understanding the factors that influence crop requirements and in formulating a fertilizer program that fits within the farm budget. AFFIRM v3 allows the user to compare nutrient management options based on Nutrient Stewardship options for nutrient source, time of application, placement and rate. AFFIRM v3 is developed from Alberta research and can recommend fertilizer rates for over 160 different cereal, oilseed, pulse, forage and specialty crops grown on either dryland or irrigation within the province.

AFFIRM v3 requires agronomic and economic information for the farm. Various cropping, nutrient management, moisture and economic scenarios can be evaluated to optimize management decisions. The effects of spring soil moisture and anticipated growing season precipitation or irrigation has a significant impact for managing crop nutrient requirements. Crop price, fertilizer cost and the farm fertilizer budget provides AFFIRM v3 with the necessary information to conduct an economic analysis to determine the economic optimum rate of nitrogen fertilizer. With high fertilizer costs and variable soil moisture conditions, AFFIRM v3 is a tool to make informed nutrient management decisions that will enhance crop production efficiency and sustainability.

This user manual explains the 4 modules making up AFFIRM v3. Each variable within each module is explained and measurement techniques are provided. A schematic diagram is presented for each module to give a general understanding of the flow of calculations involved. Economic calculation equations and examples are provided within this manual. Current references are supplied with the software for further information on those factors impacting crop nutrients requirements.

2. Required information

AFFIRM v3 requires the following information to generate recommendations and record keeping:

- Field legal land location or soil group
- Previous crop grown (yield, residue management, soil and growing season or irrigation moisture, fertilizers used including rates, time of application and placement)
- Current crop to be grown
- Irrigation (if applicable)
- Soil test results and sampling technique (time and depths)
- Soil test laboratory used for soil analyses
- Manure test results or selected book values for each source of manure
- Manure management (rate, time and placement of manure application; weather conditions)
- Spring soil moisture conditions
- Fertilizer products (for N, P_2O_5, K_2O, S and micronutrients) for crop to be grown
- N fertilizer time of application and placement (method of application)
- Fertilizer nutrient costs
- Expected crop price
- Farm fertilizer budget

B. What's new for version 3?

1. User access

AFFIRM v3 has been reprogrammed to be a web-based application, which has allowed for the development of a stable application, compatible with current computer and tablet web browsers. The re-design of the software layout has resulted in easy navigation, with functions for faster data input. Many of the features from the previous version has been maintained or enhanced.

2. MyAlberta Digital Identification (MADI)

3. AFFIRM v3 is now a web-based application accessed through My Alberta Digital Identity (MADI). By registering for My Alberta Digital Identity, you are creating an account that allows you to be identified by government online without paper documents or face-to-face visits, while protecting your information and privacy. There is no cost for a MyAlberta Digital Identity. Your MyAlberta Digital Identity contains only the information needed to create and register your account. When you access another participating Alberta government online service, only the portions of your Digital Identity needed by that service are shared.
https://account.alberta.ca/#/

4. User menu

The user menu has been redesigned to incorporate new features and web-based format.
The Help menu item provides access to the User Guide.

5. Supporting documents

The User Guide, Frequently Asked Questions (FAQs) and Tutorial Guide have been updated to support the new version of AFFIRM v3. The User Guide provides background information about AFFIRM v3 and how it generates nutrient management recommendations. The FAQs provides information on commonly asked questions. The Tutorial Guide provides instructions and examples that will lead the user through the program.

6. Interpretation of results

The alert messages have been enhanced to provide information and interpretation of the information being entered, corrective actions and the recommendations being generated. Alert messages highlight important details that the user should consider when making fertilizer decisions.

7. Agronomic information

New agronomic nutrient management knowledge has become available and has been incorporated into the AFFIRM v3 recommendation process. This includes nutrients from the soil, crop residues, manures and fertilizers. The crop selection list has been expanded to include new alternative crops and traditional crops that were previously not included in the previous version.

8. Laboratory information

The list of soil test laboratories have been updated with current names, addition of new laboratories and removal on non-existent laboratories. Soil test calibrations for each laboratory method is linked through the specific laboratory used for soil analyses. In some cases, a laboratory may use more than one method to determine a nutrient concentration (particularly phosphorus). If this occurs, it is recommended to use the method that is most appropriate test for Alberta conditions (Table 1).

9. Nutrient sources

a. Estimated soil nitrogen release (ENR)

The Estimated Nitrogen Release (ENR) provides an indication of the soil to mineralize (release) nitrogen over the growing season. The ENR is related to the soil organic matter level, and influenced by soil moisture and soil temperature, residue management and landscape position. As a first approximation, the ENR calculator uses the legal location and soil test area organic matter levels to predict the nitrogen release. With specific soil organic matter tests or ENR soil tests, better predictions of ENR can be calculated. There are several laboratory soil tests to measure the ENR. These tests will provide field specific estimates of nitrogen release that are more precise than estimates based on regional soil organic matter levels. The calibration for the nitrogen recommendation and or yield response to applied nitrogen fertilizer in AFFIRM v3 is based on soil groups and the typical ENR for cultivated soils in Alberta. Fields or sub-fields within soil zones may have higher ENR due to higher organic matter levels or the result of management practices such as manure applications. Soil group estimates supplied in the user guide will allow you to compare these averages with your field estimates. The ENR values are used as a basis to adjust nitrogen fertilizer applications and the crop yield response to nitrogen fertilizer. The ENR has been updated with more current research, and integrated into the AFFIRM v3 nitrogen fertilizer recommendation and crop yield response model.

b. Previous crop residue nitrogen credit

Above and below ground residues from previous crop in rotation can provide a source of N to the crop to be grown in the current cropping year. If the above ground crop residue remains on the field and incorporated into the soil, then the nitrogen mineralized from the above and below ground residue is taken into account to adjust fertilizer nitrogen requirements. If the above ground crop residue is removed, then only the nitrogen that would be mineralized from the below ground crop residue is taken into account to adjust fertilizer nitrogen requirements.

c. Manure nutrients

AFFIRM v3 calculates the nutrients available from manure application as a contributing source for crop production and determining fertilizer requirements. AFFIRM v3 can utilize specific laboratory manure analysis or book values for manure sources, combined with how the manure is applied, the weather conditions at the time of manure application and the rate of manure application to calculate the quantity nutrients available from manure sources for crop production. AFFIRM v3 also factors in the previous 2 years application of manure to gauge the nutrients available for crop production.

d. Fertilizer sources

The range of fertilizer produces has been expanded for all nutrients. Availability of these products will vary among fertilizer dealers. Some new products are considered to be enhanced efficiency fertilizers. These products have been developed in an attempt to reduce nutrient losses with the hope of better synchronizing nutrient uptake with crop nutrient demand. There is limited research on these products and as more research becomes available, AFFIRM v3 will be updated.

10. Nutrient stewardship

Nutrient stewardship requires the implementation of nutrient beneficial management practices (BMPs) that optimize the efficiency of nutrient use. The goal of nutrient BMPs is to optimize crop productivity by matching nutrient supply with crop requirements and to minimize nutrient losses. Selection of BMPs varies by location, and those chosen for a given farm are dependent on local soil and climatic conditions, crop choice, management decisions and other site specific factors. The nutrient stewardship factors that influence of 1) nutrient source; 2) time of nutrient application; 3) placement of nutrient application; and 4) rate of nutrient application, for making nutrient management decisions.

AFFIRM v3 allows the user to select nutrient stewardship options that includes:

- Nutrient source – fertilizer products
- Time of application – fall, spring, in-season
- Nutrient placement – method of application (i.e. broadcast, seed-placed, banding, injection)
- Fertilizer economics – nutrient costs, crop prices, economic return and fertilizer budget.

AFFIRM v3 uses these factors in conjunction with soil test nutrient levels, soil mineralization, crop residue, manure applied nutrients to determine the rate of nutrient application.

11. **Crop yield response**
    AFFIRM v3 now utilizes the Harmsen-Mitscherlich equation to predict crop yield response where research is available. This equation that combines nitrogen supply with water supply to predicted crop yield response. This equations utilizes the principle of diminishing returns for nitrogen supply. Updated yield response functions based on:
    - **Water Supply** that includes spring soil moisture, growing season precipitation based on long term probabilities, and irrigation level;
    - **Nitrogen Supply** that includes soil test nitrate, estimated nitrogen release from soil organic matter, nitrogen from previous crop residue, manure nitrogen and fertilizer nitrogen.

12. **Whole farm optimization**
    The whole farm optimization has been enhanced to include Nutrient Stewardship options for fertilizer product, timing and placement along with fertilizer economics to recommend nutrient application for all fields included in the analysis.

C. Components of AFFIRM v3

AFFIRM v3 is comprised of 4 separate but connected modules to identify crop nutrient deficiencies and generate corrective nutrient recommendations. A module is a set of mathematical equations that describe the relationship between variables (eg. crop available moisture and nutrient supply) that determine an outcome (eg. crop yield and fertilizer requirements).

1. Nutrient recommendation module

AFFIRM v3 is a full spectrum recommendation system for macronutrients (N, P_2O_5, K_2O and S) and micronutrients (B, Cu, Fe, Mn, Zn and Cl). This module provides fertilizer recommendations for nutrient deficiency corrections for only those nutrients that are limiting crop production and other soil limitations (moisture, soil texture and/or soil chemistry).

Fertilizer recommendations are formulated using crop specific nutrient calibration curves, combined with field information and laboratory soil test data. It utilizes a series of adjustments specific to the crop, field and nutrient (Figure 1). With field information, laboratory soil test data and sampling information, a basic recommendation is formulated. Recommendations are then adjusted for location, soil characteristics, fertilizer and/or manure management options and moisture conditions to produce final recommendations for N. P_2O_5, K_2O, S and micronutrients.

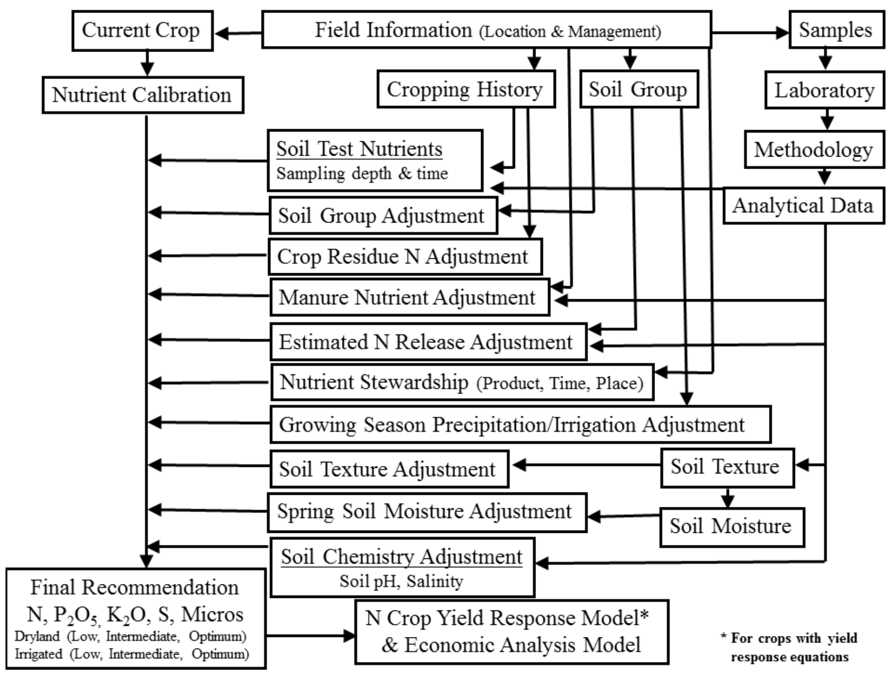

Figure 1. Schematic of the nutrient recommendation module of AFFIRM v3.

For those crops with yield response equations, AFFIRM v3 utilizes an economic analysis to determine a rate of N associated with economic optimization.

2. **Crop yield response module**

The relationship between nitrogen supply and available water to produce crop yield is described by crop yield response equations. Understanding this relationship requires intensive and extensive field research and advanced statistical analysis. The ability to predict yield from N supply allows one to calculate the total revenue produced (yield) from a quantity of fertilizer applied.

The crop yield response model for AFFIRM v3 (Figure 2) predicts crop yield response based on nitrogen supply (Ns) and water supply (Ws).

The nitrogen supply includes:

- soil test nitrate to a depth of 60 cm (24 inches);
- estimated nitrogen release from soil organic matter;
- previous crop residue nitrogen;
- manure nitrogen (current and past application);
- fertilizer nitrogen (source, time, and placement)

The water supply includes:

- spring soil moisture level,
- growing season precipitation level,
- irrigation level

Using the nitrogen supplied by the soil, crop residue, and manure with expected spring soil moisture conditions, the crop yield response model predicts crop yield at increasing levels of nitrogen fertilizer for low, intermediate and optimum levels of anticipated precipitation or irrigation. Generally speaking, yield increases with additional N fertilizer application. However, there is a point when additional N applied to a crop results in smaller and smaller yield increases. This is referred to as the principle of diminishing returns. The model stops when added yield increases are below a significant research level (i.e. less than one bushel). Model equations are regression-based non-linear functions and yield is predicted at 10 lbs increments of nitrogen.

Crop yield response equations are specific to the crop, soil group and fertilizer management (product, time and placement). Model equations are available for those annual crops with yield response data. The module assumes P, K, S and micronutrients are in adequate supply.

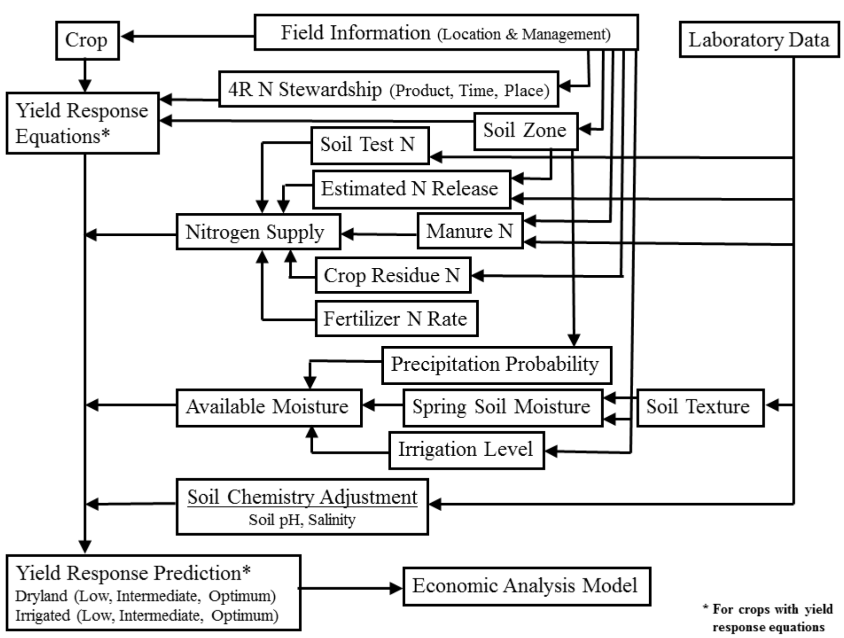

Figure 2. Schematic of the crop response module for AFFIRM v3.

3. **Nitrogen economic analysis module**

The goal to achieve the potential maximum yield may not always be economic (i.e. the dollar spent for extra fertilizer returns less than a dollar revenue from extra yield). Rather, producers should aim at those yields that will optimize economic returns. For crops with yield response equations, AFFIRM v3 formulates N recommendations on a marginal economic analysis (see Figure 3). The incorporation of crop price, N fertilizer cost and yield response data allows AFFIRM v3 to analyze how increasing the rate of N will influence yields, costs and economic returns. Derived from the yield response equations, increasing N supply will increase yield, but eventually at a decreasing rate. Following the principle of diminishing returns, AFFIRM v3 expresses this concept in the economic analysis as a ratio called the investment ratio:

- Investment ratio (IR) = Marginal return (MR) / Marginal cost (MC)

Where:

- Marginal return = expected yield increase (bu/10 lb N) X crop price ($/bu)
  = ($/10 lb N)
- Marginal cost = fertilizer nitrogen cost ($/10 lb N)

An IR greater than 1 indicates an economic return greater than zero (i.e. the additional yield produced from the extra fertilizer applied was greater than the extra fertilizer cost). An IR less than 1 indicates an economic loss and although it may increase yield, it is not enough to cover the cost of the extra fertilizer. Maximum economic return is achieved when MR equal MC.

The AFFIRM v3 nitrogen economic analysis module compares the incremental cost (10 lbs) of N fertilizer with added return of the extra crop yield produced from the additional 10 lbs of N fertilizer. In a perfect world, it would make economic sense to keep applying fertilizer until the yield would just cover the fertilizer cost (i.e. IR = 1). However, in the uncertain world of crop production (weather and crop prices), a default IR of 2 has been chosen (i.e. additional revenue should be double the additional cost) as a starting point. The user can override this default and set the IR to reflect the user's comfort level of risk.

Based on estimated yield data from the crop response module (Figure 2), the nitrogen economic module (Figure 3) initiates by determining the additional yield gained (i.e. yield increase) from an additional 10 lbs of N (AFFIRM v3 stops calculating when yield increase is less than 1 bushel). Marginal returns are compared to marginal costs to determine the investment ratio. The economic rate of N reported reflects the set target investment ratio. Sample calculations of the model are included in the nitrogen economic analysis calculations section of this manual. For those crops without a yield response equation, the basic recommendation is reported and a nitrogen economic analysis cannot be conducted.

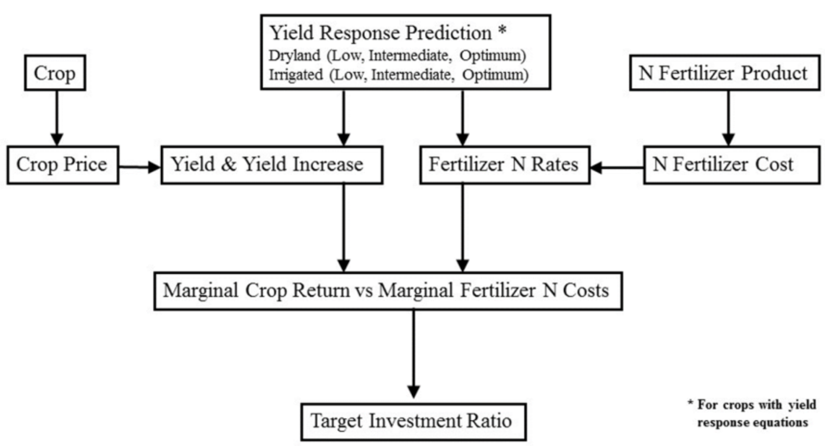

Figure 3. Schematic of the nitrogen economic analysis module for AFFIRM v3.

4. Farm optimization module

The farm optimization module will optimize the allocation of a fertilizer budget to those fields analyzed individually by AFFIRM v3 and provide a summarization of fertilizer requirements for the farm. Based on the available fertilizer budget, the optimization module integrates the resources of yield response data and economic analysis to allocate the budget to optimize economic return. Like the nitrogen economic analysis of individual fields, the farm optimization analysis is specific to the anticipated growing season precipitation or irrigation level (low, intermediate and optimum).

The farm optimization module (Figure 4) accesses the recommendation and economic analysis information from all analyzed fields. Before running the optimization analysis, the fertilizer budget is debited to fulfill the P_2O_5, K_2O, S and micronutrients recommendations of all fields and N recommendations of those fields without yield response equations. The remaining portion of the budget is then available to optimize N requirements of those fields with yield response equations.

Based on the target investment ratios, the optimization module systematically allocates N fertilizer (in 10 lb increments) to those fields that will provide the highest economic return as measured by the investment ratio (IR). It will continue to distribute N fertilizer until all target investment ratios are achieved or the budget is exhausted. When the budget is exhausted, AFFIRM v3 indicates the IR that was achieved. Sample calculations of the model are included in the farm optimization module calculation section.

This optimization component is particularly useful if the farm budget does not meet the individual field recommendations made by AFFIRM v3. This module will assist deciding where best to allocate limited fertilizer budget among all fields for the highest economic return. As well, it is an excellent summary tool to calculate total fertilizer costs and view recommendations for each field on the farm.

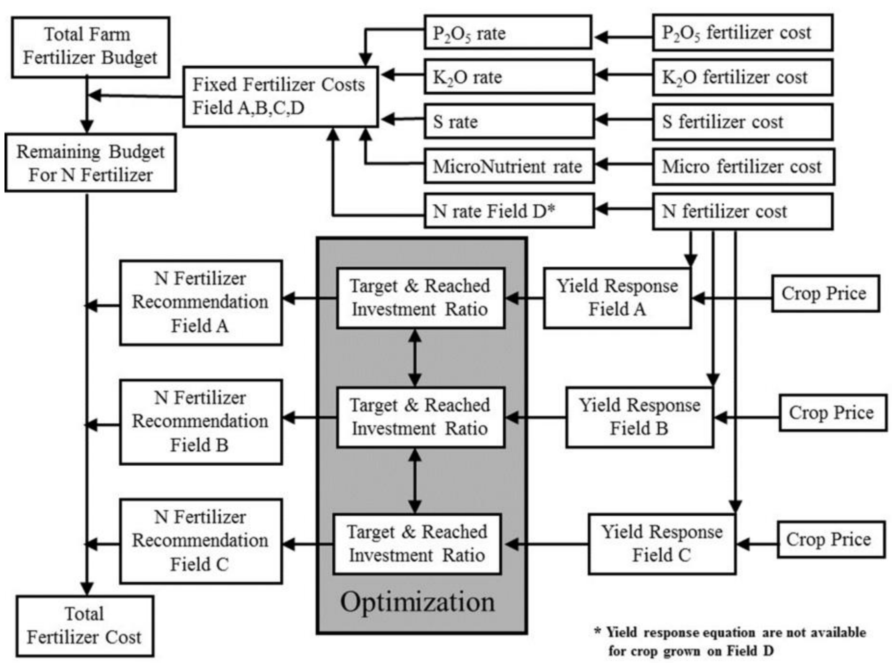

Figure 4. Schematic of the farm optimization module for AFFIRM v3.

D. AFFIRM v3 limitations

1. Current field research

This version of AFFIRM v3 is based on research conducted within the last 10 years. Agronomic practices are constantly evolving that includes new crops, new varieties, new fertilizers and new management options. Tillage, crop residue management and manure management can have a profound effect on crop nutrient requirements. AFFIRM v3 has been designed to incorporate new research as it becomes available.

2. Crop yield response model

To determine the yield increases from additional fertilizer, AFFIRM v3 has crop response equations specific to each crop, soil group and fertilizer management (source, time, placement) that incorporates nitrogen supply and available moisture. Due to the extensive research required, yield response equations have only been developed for 14 of the 160 possible crops within AFFIRM v3. Crops such as forages, pulses and specialty crops are not included in the economic analysis. Within the optimization module, all nutrient recommendations are static for these crops.

3. Farm optimization

Due to limited research data, the marginal analysis is currently restricted to nitrogen. Nitrogen yield response equations are developed on the assumption that all other nutrients are in adequate supply and therefore, P_2O_5, K2O, S and micronutrient costs are considered a fixed cost and removed from the budget in the first step of the module. This partial budget approach focuses on the nitrogen fertilizer requirements. These nutrient recommendations and incurred costs cannot be changed. AFFIRM v3, however, assumes the base yield produced without any nitrogen applied should be adequate to cover the costs of these nutrients.

E. Nutrient recommendation modules

From Alberta field and laboratory research data, the nutrient recommendation module utilizes a series of coefficients based on the information entered and a series of adjustments to formulate fertilizer requirements (Figure 1). To determine the nitrogen requirement, AFFIRM v3 will utilize the crop response module (Figure 2) and economic analysis module (Figure 3) to formulate an economic optimum nitrogen rate for each field. Once data input for all fields is completed, the user can proceed to the farm optimization module (Figure 4) to summarize nutrient recommendations and fertilizer costs and/or determine where best to allocate resources for N application amongst the fields to optimize economic returns with a limited budget.

1. Fertilizer recommendations

AFFIRM v3 formulates nutrient recommendations based on soil test results and numerous factors that will influence nutrient availability and crop yield potential (Figure 1).

a. Soil sample depth

Field research data indicates that approximately half of the available nitrogen and sulfur are present below 15 cm (6 inches). If only surface samples (0-6 or 0-12 inch) are used to measure nitrate-N and sulfate-S, then AFFIRM v3 will estimate the sub-soil nitrate-N and sulfate-S to 60 cm (24 inches). Estimates are dependent upon whether the field has been irrigated and the previous crop grown or fallow.

Recommendations for phosphate, potash and micronutrients (boron, copper, iron, manganese and zinc) are based on soil test results from 0-15 cm (0-6 inches). Recommendations for chloride are based on soil test results for soil samples to a depth of 60 cm (24 inches).

b. Soil sampling time

Basic fertilizer recommendations are based on spring soil sampling. For those samples not taken in the fall, AFFIRM v3 adjusts the soil test nitrogen to account for the mineralization (i.e. conversion of nitrogen to a plant available form) that would have occurred between the time of sampling and spring seeding. Adjustments are dependent upon the soil group of the field.

c. Soil test laboratory

Each soil test laboratory has specific set of techniques and methods to determine plant available nutrients. Based on the soil test laboratory selected, AFFIRM v3 will utilize a nutrient calibration appropriate for the laboratory method associated with the specific laboratory. In some cases, a laboratory may use more than one method to determine a nutrient soil test (such as soil test P). Please use Table 1 below for most appropriate for Alberta conditions.

Table 1. Soil test laboratories and associated soil test methods.

Laboratory	Laboratory Extraction or Procedure											
	NO_3-N	P	K	SO_4-S	pH	Salinity	B	Cl	Cu	Mn	Fe	Zn
A & L	K_2SO_4	Mehlich 3	Mehlich 3	Mehlich 3	1:1 Soil:Water	1:2 Soil:Water	Mehlich 3	K_2SO_4	Mehlich 3	Mehlich 3	Mehlich 3	Mehlich 3
AGAT	Mod Bray 1 Miller & Axley	Mod Bray 1 Miller & Axley	Ammonium Acetate	$CaCl_2$	1:2 Soil:Water	1:2 Soil:Water	Hot $CaCl_2$	$Ca(NO_3)_2$	DTPA	DTPA	DTPA	DTPA
AGVISE	KCl	Olsen	Ammonium Acetate	KCl	1:1 Soil:Water	1:1 Soil:Water	DTPA	$Ca(NO_3)_2$	DTPA	DTPA	DTPA	DTPA
ALS	$CaCl_2$	Mod Kelowna (SK)	Mod Kelowna (SK)	$CaCl_2$	1:2 Soil:Water	1:2 Soil:Water	Hot Water	$Ca(NO_3)_2$	DTPA	DTPA	DTPA	DTPA
Down to Earth	$CaCl_2$	Mod Kelowna (SK)	Ammonium Acetate	$CaCl_2$	1:1 Soil:Water	1:1 Soil:Water	Hot Water	$Ca(NO_3)_2$	DTPA	DTPA	DTPA	DTPA
Exova	Mod Kelowna (NW)	Mod Kelowna (NW)	Mod Kelowna (NW)	$CaCl_2$	1:2 Soil:Water	1:2 Soil:Water	Hot Water	$Ca(NO_3)_2$	DTPA-TEA	DTPA-TEA	DTPA-TEA	DTPA-TEA
Farmer's Edge	$CaCl_2$	Mod Kelowna (NW)	Mod Kelowna (NW)	$CaCl_2$	1:2 Soil:Water	1:2 Soil:Water	DTPA	$Ca(NO_3)_2$	DTPA	DTPA	DTPA	DTPA
Midwest	$CaCl_2$	Bray 1	Ammonium Acetate	Ammonium Acetate	1:1 Soil:Water	1:1 Soil:Water	Hot Water	$Ca(NO_3)_2$	DTPA	DTPA	DTPA	DTPA

d. Current crop and nutrient requirements

Crops vary in their nutrient requirements and tolerance to soil and environmental stresses. Fertilizer recommendations are dependent upon the crop to be grown for the year. Growing conditions and crop type will result in different nutrient removal rates and therefore different nutrient requirements. If a pure legume crop or legume with a non-legume crop mix is to be grown, then AFFIRM v3 factors in the microbial symbiotic nitrogen fixation to greatly reduce fertilizer nitrogen requirements. Under seeding a perennial legume crop in an annual grain crop, will alter fertilizer recommendation given for the annual grain crop. As the percent legume increases in the under seeded crop, the rate of nitrogen fertilizer can be decreased while the rate of phosphate, potash and sulfur should be increased to insure a healthy establishment.

2. Fertilizer recommendation adjustments

a. Soil test regions

Soil test regions within Alberta are reflective of the climatic differences (growing season precipitation and evapotranspiration) within the province, which influences crop yield potential. Alberta has eight different soil test regions of agricultural importance (Figure 5). AFFIRM v3 uses soil regions information to determine precipitation probabilities and will adjust all macronutrient recommendations accordingly, with the greatest reduction made in those portions of the province with the greatest potential moisture deficit (i.e. brown and dark brown soil groups). Soil test regions are defined by ecoregions, which are distinctive ecological groupings formed in response to climate. Within each ecoregion, there are ecodistricts, which are distinctive relief assemblages (drainage), geology, landforms, soils, vegetation, water and fauna.

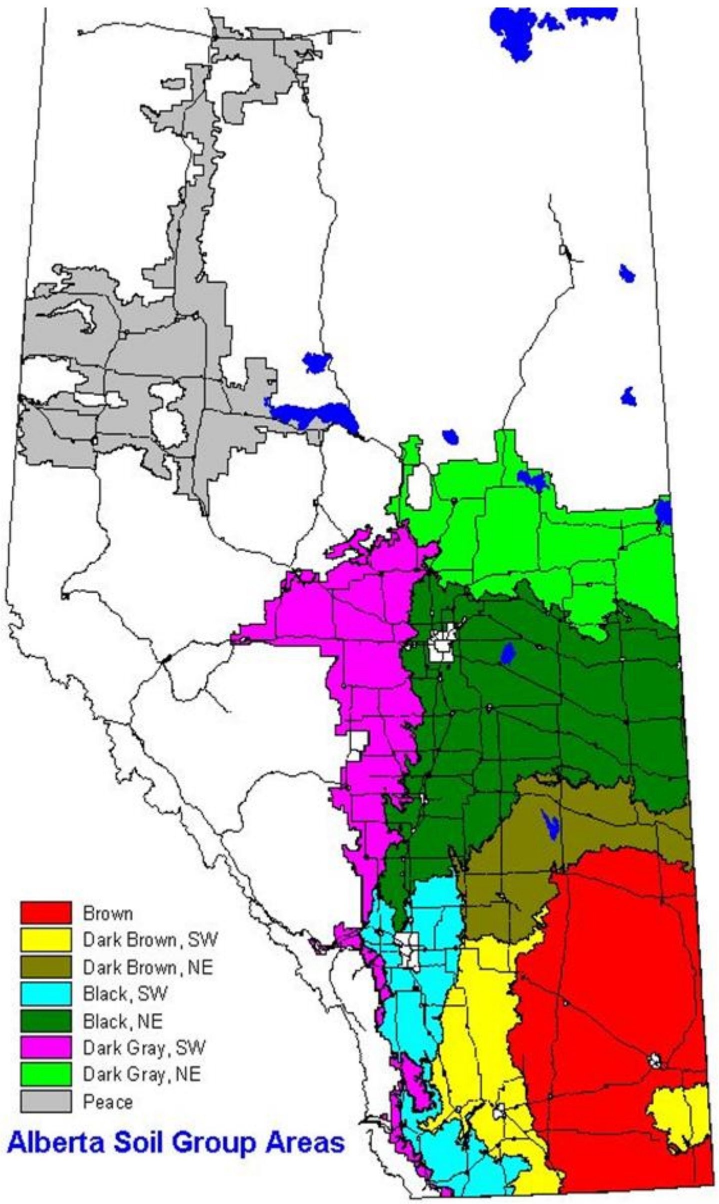

Figure 5. Soil test group areas for Alberta.

b. Soil texture

Soil texture is the relative proportions of sand, silt and clay in soil. Texture affects the water holding capacity and nutrient availability of the soil. Sandy textured soils have a lower water and nutrient retention capability than silt or clay, which can limit crop growth potential. As a result, AFFIRM v3 reduces nitrogen recommendations for those very coarse and coarse textured soils under irrigation. In organic soil conditions, P recommendations are increased for irrigated crops due to the limited supply of plant available P and larger yield potential.

Method to determine soil texture by hand

To determine soil texture, follow the hand method outlined in Figure 6. By feeling, squeezing and observing a handful of soil, the texture of the soil can be determined. If the relative proportions of sand and clay from laboratory analysis, then use Figure 7. Once the texture is determined, then the soil texture group can be identified in Table 2. AFFIRM v3 requires a soil texture group when entering soil information.

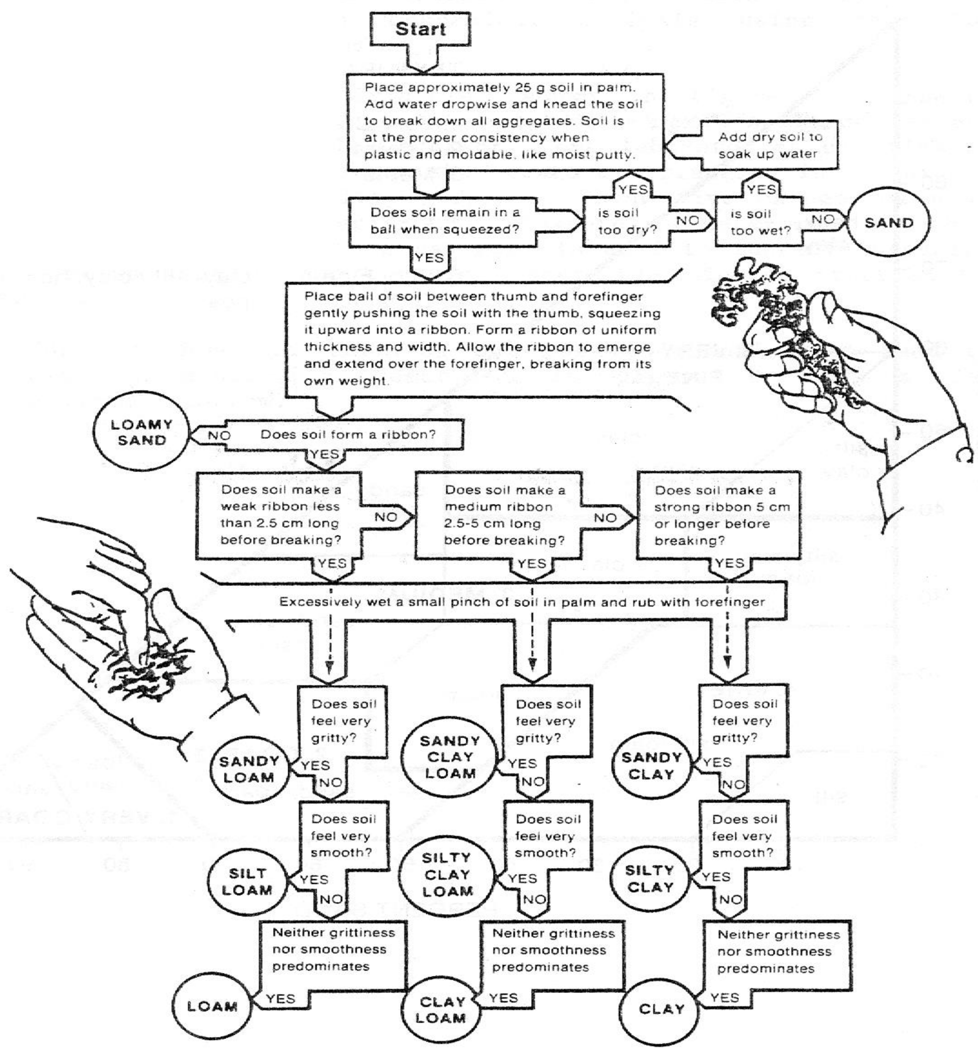

Figure 6. Determining soil texture by hand.
Source: Laverty, D.H. and A. Bollo-Kamara, 1988.

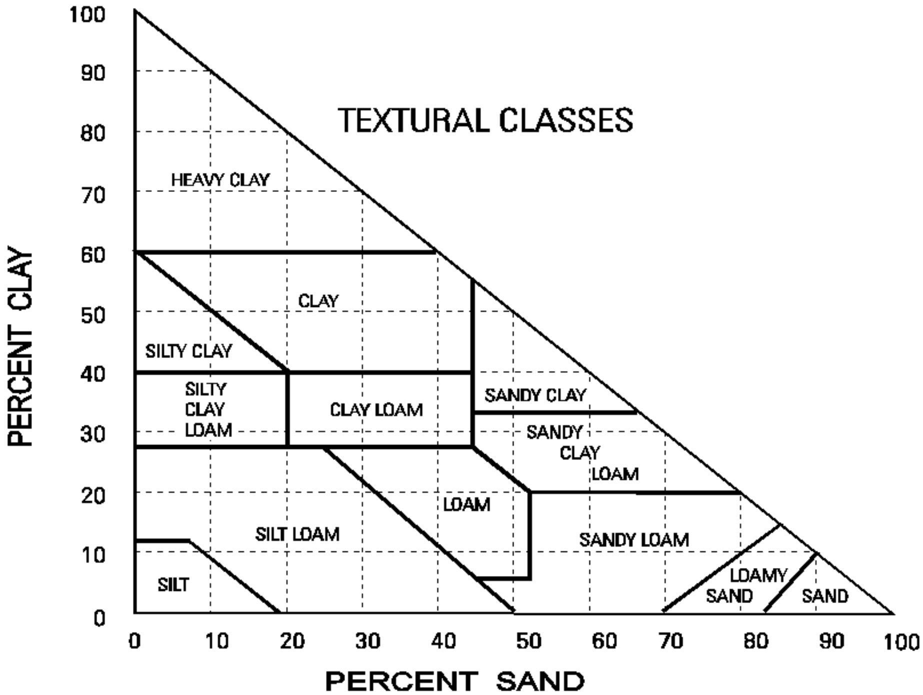

Figure 7. Soil textural classes.
Source: Canada Department of Agriculture, revised 1976.

Table 2. Determining soil texture group from soil textural class.

Soil Texture Group	Soil Texture Classes and Description
Very Coarse	Sand, Loamy Sand
Coarse	Sandy Loam, Fine Sandy Loam
Medium	Loam, Sandy Clay Loam, Sandy Clay, Clay Loam
Fine	Silt Loam, Silty Clay Loam, Silt
Very Fine	Clay, Silty Clay, Heavy Clay
Muck	30 – 45% Organic Matter
Peaty Muck	45 – 65% Organic Matter
Mucky Peat	65 – 85% Organic Matter
Peat	85 – 100% Organic Matter

Source: Kryzanowski, L., et al.1988.

c. Spring soil moisture

Spring soil moisture will affect nutrient availability and early plant growth potential. In combination with anticipated growing season precipitation, spring soil moisture plays an important in determining estimated yield response for the economic analysis. AFFIRM v3 will adjust crop requirements according to the amount of available moisture present early in the growing season. Soil moisture is highly dependent upon soil texture (Figure 8).

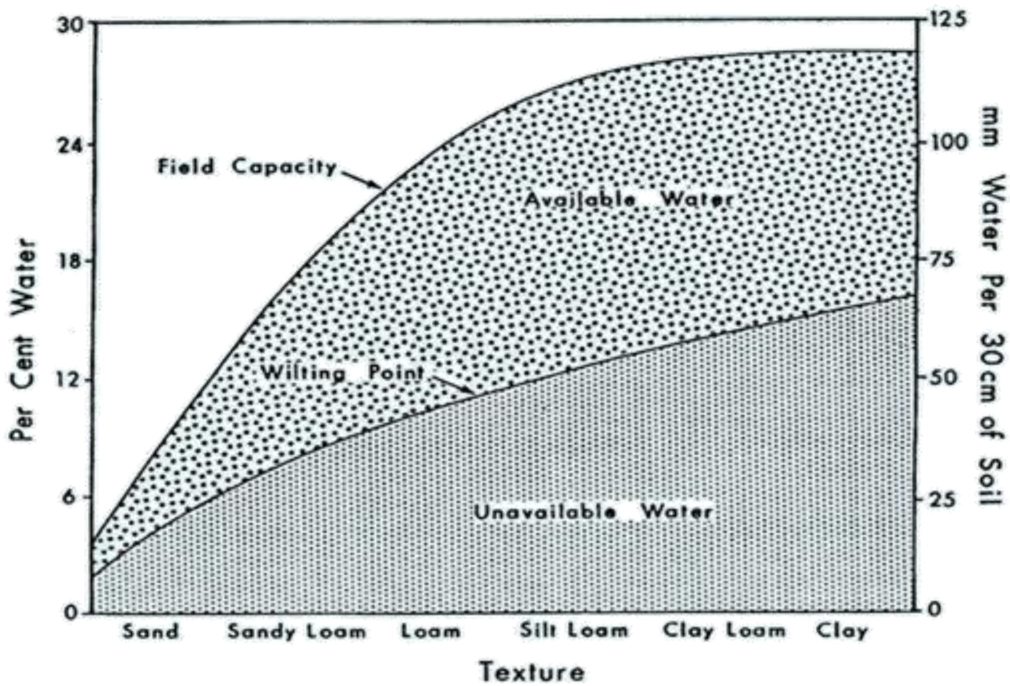

Figure 8. Relationship of soil texture and soil moisture.
Source: Buckman and Brady, 1969.

Method to determine available soil moisture

Based on the soil texture and depth of moist soil, the soil moisture status is simple to determine. The Brown Soil Probe (Figure 9) is an effective tool for determining the depth of moist soil (a soil moisture probe can be made by welding a 2 cm steel ball on one end of a 1 meter long 1.25 cm rod and welding a handle on the other end). By vigorously pushing the probe into the soil in one motion, without turning, the probe will penetrate the soil and will stop when dry soil is reached. Stones and frozen soil may stop the probe as well, but these can be easily detected. The Brown Soil Probe has a short section of a wood bit welded to the end of the probe so that a sample of soil can be withdrawn when the probe is twisted clockwise. This soil sample can be used to determine texture class and moisture by feel.

Figure 9. Soil sampler and Brown soil moisture probe.

Here are some tips when using the soil moisture probe to determine stored soil water content:

- Select a representative area of the field. Avoid saline areas, potholes, and other problem areas. Depression areas, slopes, and knolls can be measured separately for site-specific crop planning.
- Each field should be sampled separately. Rainfall amounts can vary over short distances, crops and varieties differ in water use and crops mature at different times due to varying seeding dates and days to maturity, etc.
- Sample a minimum of 15 to 20 sites per field and record the average depth of moist soil. Spring sampling may require more sites within a field because of increased variability caused by snow trapping, snow drifting, water runoff, moisture migration within the soil and variations in ground frost, etc.
- With the soil texture and depth of moist soil, use Table 3 to determine the spring soil moisture level (low, intermediate or optimum). For irrigated crops, an optimum soil condition can be assumed.

Table 3. Estimating plant available soil moisture based on depth of moist soil.

Texture Group	Plant available soil moisture (cm/m)	Depth of moist soil (cm)		
		Low	Intermediate	Optimum
Very Course	7-8	30-60	60-120	120 +
Course	10-14	30-50	50-100	100 +
Medium	15-18	15-30	30-60	60 +
Fine & Very Fine	16-19	15-30	30-60	60 +

Source: Derived from Buckman and Brady, 1969.

d. Soil pH

Soil pH or soil reaction indicates acidity or alkalinity of the soil. AFFIRM v3 considers a soil pH below 6.5 as acidic and a soil pH above 7.5 as alkaline. A soil pH of 7.0 is neutral. Soil pH will physically, chemically and biologically affect the availability of nutrients. Nutrients can be physically unavailable, tightly bound to soil colloids. Chemical structures of some nutrients, particularly P, can be changed under low pH, making them unavailable for plant uptake. Microbial survival and growth can be affected by pH, influencing N fixation, mineralization and the release of plant available nutrients.

Crops vary in their acidity tolerance (Table 4). Crop production in soils more acidic than the tolerance level of a crop will result in reduced yields. Under acidic conditions, AFFIRM v3 will adjust recommendations on the basis of crop type and pH level for anticipated reduced yield potential. To contend with soil acidity, options include growing a crop that is more acid tolerant or liming the soil to correct the acid condition. However, before making a substantial investment to lime, marl or wood ash, give consideration to the area of application and application rate. A specific lime requirement test should be requested from the laboratory.

Table 4. Crop tolerance to acid soils

Non-tolerant Crops: Alfalfa, sweet clover	Tolerate pH 5.5 to 6.0
Moderately Tolerant Crops: Barley, wheat, canola, alsike, red clover, trefoil	Tolerate pH 5.0 to 5.5
Tolerant Crops: Brome, timothy, creeping red fescue, flax, oats	Tolerate pH 4.5 to 5.0

Source: Alberta Agriculture, 2004

e. Soil salinity

Electrical conductivity (EC) is a measure of the total soluble salt concentration in a soil (i.e. salinity). Soluble salts are present in soils at all times, however, when the concentration of salts is high, the soil is considered "saline" and crop growth can be reduced (Table 5). Yield reduction is dependent upon the crop species and their level of salinity tolerance (Table 6). Generally, grass forages tend to have higher salinity tolerance than field crops. AFFIRM v3 will adjust recommendations according to the crop type and salt concentration.

Table 4. Effect of slat concentration on crop growth.

EC (dS/m)	Description
0-2.5	Negligible salt effects
2.5-4.9	Very sensitive crops affected
5.0-8.0	Yield of most crops are reduced
8.0+	Salinity level is very high and a serious limitation to most crops

Source: Kryzanowski, L. et al. 1988.

Table 5. Salt tolerance of common crops grown in Alberta.

Salt tolerance	EC (dS/m)	Field crops	Forages
Low	0-4	Field beans Peas	Timothy White Dutch clover Alsike clover Red clover
Moderate	4-8	Corn Potatoes Canola Flax Yellow mustard Oats	Meadow fescue Reed canary grass Intermediate wheatgrass Crested wheatgrass
High	8-16	Spring wheat Winter wheat Fall rye 2-row barley Sunflower Safflower 6-row barley Sugar beets	Bromegrass Alfalfa Sweet clover Birdsfoot trefoil Slender wheatgrass Russian wildrye Tall wheatgrass Altai wildrye
Very high	>20		Alkali sucatan Levonns alkaligrass Beardless wildrye

Source: Alberta Agriculture, 2001

3. Additional considerations

There are many other factors that can affect the level of nutrients available to the crop. Below is a list of factors that are considered when making fertilizer decisions.

a. Soil organic matter (SOM)

Soil organic matter measured as percent organic matter is the amount of plant and animal residue in the soil. Soil organic matter can range from recent crop residue to highly decomposed organic residues. The color of the soil is usually closely related to its organic matter content, with darker soils being higher in organic matter, while light coloured soils (brown or grey) have lower soil organic matter levels. Organic matter content of the soil will influence the water holding capacity and nutrient availability of the soil. Typical levels of Alberta soil group SOM (for cultivated soils) range from 2 – 10% (Table 7). Specific soil organic matter levels may vary based on management history (tillage, crop residue, native vegetation) and landscape position.

Table 6. Typical soil organic matter levels for soil zones in Alberta.

	Cultivated Soil		Native Soils	
Soil Zone	**Mean**	**Range**	**Mean**	**Range**
Brown Soil	2.4	1.9 – 2.9	5.0	3.1 – 6.9
Dark Brown	4.6	3.3 – 6.0	8.1	6.4 – 9.8
Black	7.2	4.8 – 9.6	12.0	7.4 – 16.7
Dark Grey (NE, SW)	5.7	5.3 – 6.0	6.5	5.3 – 7.7
Dark Grey (Peace)	5.2	3.4 – 6.9	14.3	4.8 – 23.7

Source: Adapted from Reinl, E. 1984.

b. Estimated nitrogen release (ENR) from soil organic matter

The organic matter serves as a reserve for many essential nutrients, especially nitrogen. Bacterial activity will release some of this reserve nitrogen, making it available for crop growth (a process known as mineralization). The ENR is an estimate of the amount of nitrogen that will be released over the growing season and is related to the soil organic matter level, plus soil moisture and temperature.

ENR provides valuable information about the soils ability to mineralize soil organic nitrogen. The nitrogen recommendation module and the crop yield response to nitrogen module of AFFIRM v3 both account for the average nitrogen release over the growing season (Table 8), based on average soil organic matter of each soil group. However, nitrogen release in a field may deviate from this average due to variation in soil organic matter levels, soil moisture and soil temperature during the growing season, residue management and landscape position. For example, soils with higher organic matter levels than the typical average for a particular soil group (Table 8) may have greater nitrogen release potential. Elevated measured ENR values would indicate greater than expected nitrogen from the soil for crop growth.

ENR can be determined from soil organic matter or specific laboratory tests. Lab calculated ENR values provide field specific estimates of nitrogen release that are more precise than AFFIRM v3 calculated ENR estimates, based on regional soil organic matter levels (Table 8). Potential nitrogen release (PNR) test determines the readily mineralizeable organic N present in the soil. Laboratories will typically use either a hot KCl or phosphate-borate test to determine the PNR. Once the concentration of the mineralizeable organic N pool is determined (i.e. PNR), ENR is calculated through a series of equations that factor in the effects of soil temperature and moisture over the growing season. There is a strong correlation between soil organic matter level and ENR.

Table 7. Typical estimated nitrogen release (ENR) values (lb/ac) for soil zones in Alberta.

	Cultivated Soil	
Soil Zone	**Mean**	**Range**
Brown Soil	45	40 - 51
Dark Brown (NE, SW)	70	56 – 83
Black (NE, SW)	95	71 – 117
Dark Grey (NE, SW)	70	76 – 83
Dark Grey (Peace)	75	56 – 92

Source: Derived from Campbell, C. A., et al. 1984, 1997 and Jalil, A., et al., 1996.

AFFIRM v3 takes this source of nitrogen into account when calculating N fertilizer requirements for the crop production. Consideration should be given to the difference between regional and field specific ENR values when making N fertilizer decisions.

c. Previous crop residue management

Above and below ground residues from previous crop in rotation can provide a source of N to the crop to be grown in the current cropping year. N mineralization from previous crop residues depends upon various factors like quantity of residues, microbial degradability of the residue (quality of residue), and soil and environmental conditions. Residues from field crops are usually very high in their C:N ratios. Therefore addition of residues from a previous field crop would immediately hasten immobilization of available soil N. But with subsequent microbial decomposition, N from these residues would eventually be re-mineralized. In contrast, residues from a previous pulse (legume) crop would contribute to larger N mineralization and hence higher N supply to the current crop for a given substrate quantity and soil and environmental condition (Miller et al., 2003; Przednowek et al., 2004; St. Luce, 2015). Again, N contribution of pulses may vary depending upon soil and environmental conditions, which affect the degree of biological N_2 fixation, legume grain yields, and the quantity and quality of crop residues (St. Luce, 2015). Plowing down a forage crop can increase plant available nitrogen in the soil for subsequent crop use. To determine the potential amount of nitrogen currently available to the crop, consider:

- The type of forage stand (percent legume)
- The time of year when the crop was plowed down, and
- Whether the crop was harvested before plow down.

If a stand has been harvested prior to plow down or the stand has as low percentage of legume, less nutrients will be available to the crop compared to an unharvested stand or a high legume content crop. The longer the period between plow down and subsequent cropping the longer the time for mineralization to occur and release useable forms of nutrients into the soil.

AFFIRM v3 uses the crop yield from the previous year and the residue management to calculate the nitrogen from the previous crop that would be available for the next crop.

d. Manure application

Manure is a valuable resource and a significant source of nutrients. One of the most critical tasks in manure nutrient management planning is determining the appropriate manure application rates to get the desired crop productivity. Manure nutrient content is highly variable and can vary depending upon livestock source and method of storage and handling. It is also necessary in certain scenarios to determine fertilizer application rates to meet any nutrient requirements not met through manure application. These activities involve using information including: available land base; soil nutrient profile; crop nutrient requirements; nutrient content of manure; application method and time, and soil and weather conditions.

Table 8. Manure ammonia nitrogen retention factors.

Application Strategy	Weather Conditions				
	Average	Cool-Wet	Cool-Dry	Warm-Wet	Warm-Dry
Surface applied, incorporated within 1 day	0.75	0.90	0.85	0.75	0.50
Surface applied, incorporated within 1 day	0.70	0.87	0.81	0.69	0.43
Surface applied, incorporated within 1 day	0.65	0.85	0.78	0.56	0.35
Surface applied, incorporated within 1 day	0.60	0.83	0.70	0.50	0.28
Surface applied, incorporated within 1 day	0.55	0.80	0.70	0.50	0.20
Surface applied, not incorporated	0.34	0.60	0.50	0.25	0.00
Injected	1.00	1.00	1.00	1.00	1.00
Cover crop	0.65	0.75	0.25	0.40	0.50

Source: Nutrient Management Planning Guide, Alberta Agriculture and Food, 2008

The current practice in Alberta is to base manure application on crop available N, which is the first limiting nutrient in most Alberta cropping scenarios. The impact this practice has on levels of other nutrients in the soil should be considered. By applying manure based on N, other nutrients including P and K will be simultaneously applied at rates that exceed crop removal. This is due to the typical nutrient content of most manure. This has three important implications:

- Applying nutrients above their agronomic requirement prevents the full economic value of manure to be realized.
- Research has clearly demonstrated that longterm application of P above agronomic rates is contributing to P build-up in surface soil layers to the point that the risk of runoff losses is increased. Loss of P to surface water is a significant environmental concern.
- High soil test levels of certain nutrients can impair the crop's ability to take up other essential nutrients (e.g., high soil test P can impair zinc uptake).

Phosphorus-based application of manure has the advantage of avoiding nutrient accumulation. Unfortunately, a major constraint is the current application technologies are not able to consistently apply manure at the low rates that would be required to meet agronomic P requirements. Also, the required land base to meet needs of phosphorus-based application of manure can 3 to 6 times greater than nitrogen-based application.

If eligible land base exceeds manure supply the issue then becomes how to prioritize fields for application to maximize economic benefit. Fields can be prioritized based on:

- distance to field from storage;
- fertility requirements (e.g., high nutrient use crops, high fertilizer recommendations);
- value of the crop to be grown;
- presence of degraded soils (e.g., eroded areas, low organic matter, poor tilth) that would benefit from manure application;
- desire to minimize nuisance to neighbours or environmental risk;
- accessibility or flexibility in crop management.

AFFIRM v3 calculates the nutrients available from manure application as a contributing source for crop production and determining fertilizer requirements. AFFIRM v3 utilizes specific laboratory manure analysis or book values for manure sources, combined with how the manure is applied, the weather conditions at the time of manure application and the rate of manure application to calculate the quantity nutrients available from manure sources for crop production. AFFIRM v3 also factors in the previous 2 years application of manure to gauge the nutrients available for crop production.

e. Fertilizer application

The effectiveness of fertilizer application can be influenced by fertilizer timing (season), placement and the fertilizer product.

Nitrogen fertilizer requirements for optimum economic returns on crops grown in Alberta cover a very wide range of application rates depending on the soil nitrogen level, soil nitrogen mineralization during the growing season, manure nitrogen, nitrogen from previous crop residue, spring soil moisture and growing season precipitation and or irrigation. Nitrogen fertilizers are very soluble and move readily in moist soil. Placement with or very near the seed is not necessary to ensure effective utilization. Placement options that can be considered: broadcast, pre-plant band, side-band or mid-row band at planting, seed row placement, in-season broadcast and in-season fertigation.

Table 9. Relative effectiveness of nitrogen fertilizer application for increasing crop yield.

Method and Time of Nitrogen Fertilizer Application	Soil-Climatic Categories			
	Dry	Intermediate	Optimum	Irrigated
Spring Broadcast and Incorporated	100	100	100	100
Spring Banded	120	110	105	110
Fall Broadcast and Incorporated	90	75	65	95
Fall Banded	120	110	85	110

Source: Alberta Fertilizer Guide, 2004

Enhanced efficiency fertilizer nitrogen (EEFN) products includes fertilizer N products with nitrification inhibitors or nitrification plus urease inhibitors or controlled release N products. The purpose of these enhanced efficiency products is to control the transformation of ammonium-N to nitrate-N, the dominate nitrogen form used by crops. The potential outcome of the use of these products is to synchronize available crop N with crop demand, reduce N losses, increase N uptake by the crop, increase crop yield or reduce fertilizer N requirements to achieve similar yields with non-EEFN products. It is also possible to blend EEFN and non-EEFN products to improve synchronized fertilizer N with crop demand. There can be a significant cost difference between EEFN and non-EEFN products which will influence the economic decision for products and rates of application.

For phosphate fertilizer application, available soil test phosphorus (P) levels tend to be characteristic of individual fields or soil types and do not vary widely from year to year owing to previous management. The rate of phosphate fertilizer required will depend on several aspects: available soil test phosphorus level of the field, phosphorus requirement of the crop to be grown and growing conditions. Phosphate fertilizers do not move readily in soil. Placing the band of phosphate near developing seedling roots of annual crops is most effective. Placement below the depth of seeding may improve availability under dry conditions because the fertilizer is in a moist part of the root zone for a longer time than with seed row placement. Broadcast-incorporated applications are less effective than when fertilizer is banded with or near the seed of annual crops. Broadcast application should be two to four times the recommended rates for banding or seed row application. On established forages, response to broadcast applications may be delayed owing to the slow movement of phosphorus into the root zone. A greater response may occur in the year following application than in the year of application. On soil very deficient in phosphorus, phosphate fertilizer should be banded or incorporated before seeding perennial forages.

Potassium (K) deficient soils are not common throughout Alberta, but do occur quite frequently in certain areas and soil types. Potassium deficiencies tend to occur on sandy, calcareous soils and soils with poor subsurface drainage adjacent to and on organic soils. Soils that test low in available potassium occur most frequently in west-central, northwestern (excluding the Peace region) and northeastern Alberta. Potassium will move in the soil more readily than phosphorus, but for annual crops, potassium fertilizers are more efficient when drilled with the seed or banded. Broadcast applications can be used at about twice the rate used for drill-in application. The maximum amount that may be safely placed with the seed of cereals is 35 lb/ac. For small-seed crops such as canola or flax, the maximum safe rate with the seed is 15 lb/ac. Broadcast or band applications can be made in either fall or spring.

Sulfur deficient soils include Gray Wooded and Dark Gray Wooded soils and well drained Black soils. Sulfur deficiency is not common on Brown and Dark Brown soils. Deficiencies seldom occur in crops grown on fallow, but legume crops, cereal and oilseed crops that have been wellfertilized with nitrogen fertilizer commonly require sulfur fertilization. Sulfur requirements of canola and legumes are greater than those of cereals. Sulfur in the sulfate form moves readily in moist soils. Therefore, soluble sulfate fertilizers provide an available sulfur source either as broadcast, drill-in or band applications. Elemental sulfur can also be used as a sulfur fertilizer, but is most effective as a broadcast fall application to allow for oxidation to the plant available sulfate form.

Micronutrients including boron, chloride, copper, iron, manganese, molybdenum, and zinc are required in small amounts by plants. For that reason, application rates of these fertilizer nutrients, if required, are very small, but the lasting effect can be for several growing seasons. Broadcast and incorporation is often the most effective to achieving an even distribution of the micronutrient fertilizer product.

When possible, AFFIRM v3 makes use of limited research to adjust fertilizer application rates based on product, time and placement.

f. Cation Exchange Capacity (CEC)

The cation exchange capacity (CEC) indicates the soil's capacity to hold cation nutrients expressed in milliequivalents per 100 grams of soil (meq/100g) or centimol per kg of soil (cmol/kg). Any element with a positive charge is called a cation and in this case, it refers to the basic cations, calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+1}) and sodium (Na^{+1}) and the acidic cations, hydrogen (H^{+1}) and aluminum (Al^{+3}).

CEC is a useful indicator of soil fertility, particularly the supply of three important plant nutrients: calcium, magnesium and potassium. CEC varies according to the type of soil and is highly dependent upon the soil texture and organic matter content (Table 9). Humus, the end product of decomposed organic matter, and clay have a great capacity to attract and hold cations due to their chemical structure. Both colloidal structures have a large number of negatively charged binding sites. Sandy soils with low organic matter have less capacity to exchange cations (due to the lack of negative charge) and therefore have very low CEC values. However, this can be improved by increasing soil organic matter content.

Table 10. Cation exchange capacity (CEC) values for soil textures.

Soil texture	CEC (meq/100g soil)
Sands	3-20
Loams and silt loams	10-25
Clay and clay loams	20-50
Organic soils	50-100

Source: Mengel D.B., 1993

CEC is also related to the age of a soil. As soils age, they become more weathered, physically and chemically. Older soils tend to have lower CEC than younger soils. Alberta soils are considered to be young, developed in the past 10,000 years after the last glaciation. As a result, CEC has little influence of fertilizer recommendations except for course textured soils high is sand content.

AFFIRM v3 provides fertilizer recommendations adjusted for soil texture that is based on the available water holding capacity of the soil.

g. Soil tillage system

Soil moisture conditions and soil fertility levels differ under conventional and direct tillage. Converting to a no-till, minimum tillage or reduced tillage operation can improve spring soil moisture conditions and nitrogen supplying power of the soil. Minimizing soil disturbance improves water infiltration, maintains existing soil moisture, increases soil organic matter and reduces the risk of erosion. These are all factors that increase yield potential. However, switching tillage methods changes the soil ecosystem, which can result in changes in nutrient availability and nutrient stratification.

With changing soil tillage systems, there may be a transition period that limits nitrogen availability. Limited tillage and reduced incorporation of crop residues result in slower nitrogen release rates due to less contact with soil microorganisms and reduced oxygen supply. Under direct seeding systems, soil temperatures are cooler and can limit the availability for P and K and additional nutrients may be required to take advantage of the higher yield potential.

F. Crop yield response to nitrogen and moisture module

In order to conduct the nitrogen economic analysis and optimization calculations, yield response equations are required. The crop yield response model within AFFIRM v3 incorporates available nitrogen and total plant soil moisture to predict crop yield (Figure 2). The current version of AFFIRM v3 has yield response equations for:

Wheat

- Wheat - Northern Hard Red (NHR)
- Wheat - Western Soft White Spring (WSWS)
- Wheat - Western Amber Durum (WAD)
- Wheat - Western Extra Strong (WES)
- Wheat - Western Red Spring (WRS)

Barley

- Barley (Feed and Food)
- Barley (Malt)
- Barley (Hulless)

Other Cereals

- Oats (Milling)
- Triticale (Spring)

Oilseeds

- Canola
- Canola (Argentine)
- Canola (Polish)
- Flax

1. Crop yield response model

The Harmsen-Mitscherlich equation is a biologically relevant model which recognizes the principle of diminishing returns for added nutrients, and assumes that crop yield is plateaued at a maximum or potential yield. This potential yield is limited by moisture availability, and increases linearly with increasing moisture availability. The model also assumes that crop nutrient availability increases curvilinearly with increasing moisture availability. Hence, predicted crop yields by this model are functions of yield based water and nutrient (e.g. nitrogen) use efficiencies that are agronomically relevant and quantifiable. Once yield based water and nitrogen use efficiencies are known, crop nitrogen requirements can be predicted for different moisture and nitrogen availability. The model uses two key variables, Nitrogen supply (Ns) and Water supply (Ws). Both of these variables are composed of additional sources of nitrogen and water as described below.

AFFIRM v3 utilizes a set of Harmsen-Mitscherlich yield response equations based on nitrogen fertilizer source, placement and time of application for each crop. The initial equations were developed using research data for HRS Wheat, Barley and Canola. These equations were expanded to other related crops utilizing regional variety testing data.

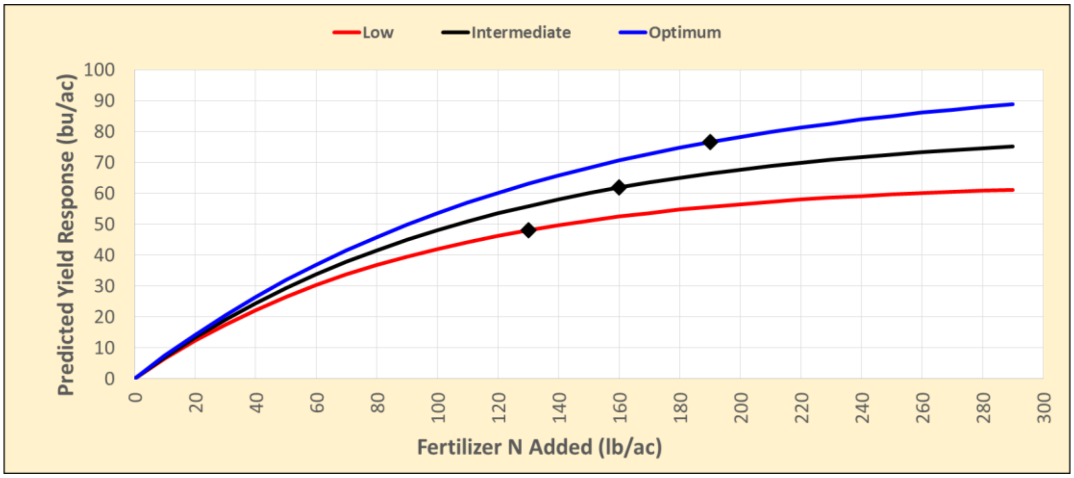

Figure 10. Harmsen-Mitscherlich equation yield response curves.

2. Nitrogen supply (Ns)

The total nitrogen available to the crop is the sum of the sources of nitrogen within the agriculture system and includes soil nitrogen (soil test nitrate, estimated nitrogen release) crop residue nitrogen, manure nitrogen and fertilizer nitrogen.

a. Available soil test nitrate

Soil test nitrate measured or estimated to a depth of 60 cm (24 inches). If subsurface soil test nitrate data is unavailable, AFFIRM v3 will estimate total available soil test nitrate in the soil profile based on the upper soil samples. Previous crop history and irrigation factor into these estimates. This estimate can result in a significant error, hence users are strongly encouraged to have subsoil samples analyzed for soil nitrate levels.

b. Estimated nitrogen release (ENR) from soil organic matter

The organic matter serves as a reserve for many essential nutrients, especially nitrogen. Bacterial activity will release some of this reserve nitrogen, making it available for crop growth (a process known as mineralization). The ENR is an estimate of the amount of nitrogen that will be released over the growing season and is related to the soil organic matter level, plus soil moisture and temperature. AFFIRM v3 can calculate the ENR based on regional soil organic matter levels, laboratory measured soil organic matter, or specific N mineralization soil tests.

c. Previous crop residue nitrogen

Above and below ground residues from previous crop in rotation can provide a source of N to the crop to be grown in the current cropping year. Addition of residues from a previous field crop would immediately hasten immobilization of available soil N. But with subsequent microbial decomposition, N from these residues would eventually be re-mineralized. In contrast, residues from a previous pulse (legume) crop would contribute to larger N mineralization and hence higher N supply to the current crop for a given substrate quantity and soil and environmental condition. AFFIRM v3 uses the crop yield from the previous year and the residue management to estimate the nitrogen available for the next crop.

d. Manure nitrogen

Manure is a valuable resource and a significant source of nutrients. One of the most critical tasks in manure nutrient management planning is determining the appropriate manure application rates to get the desired crop productivity. Manure nutrient content is highly variable and can vary depending upon livestock source and method of storage and handling. It is also necessary in certain scenarios to determine fertilizer application rates to meet any nutrient requirements not met through manure application. These activities involve using information including: available land base; soil nutrient profile; crop nutrient requirements; nutrient content of manure; application method and time, and soil and weather conditions.

AFFIRM v3 calculates the nitrogen available from manure application towards the nitrogen supply for crop production. AFFIRM v3 utilizes either specific laboratory manure analysis or book values for manure sources, combined with how the manure is applied, the weather conditions at the time of manure application and the rate of manure application to calculate the quantity nitrogen available from manure sources towards the nitrogen supply for crop production. AFFIRM v3 also factors in the previous 2 years application of manure to gauge the nutrients available for crop production.

e. Fertilizer nitrogen

To calculate optimum fertilizer nitrogen rates, AFFIRM v3 uses Nutrient Stewardship to compare nitrogen fertilizer sources, timing of fertilizer application, and fertilizer placement. The crop yield responses equations with AFFIRM v3 are limited by the data available from research studies. These equations will be augmented as more research becomes available. For the current crop yield response calculation, AFFIRM v3 is limited to urea, ESN and urea-ESN blend fertilizer nitrogen sources, fall or spring time of applications and banded or seed-placed fertilizer placement. Individual crop response equations were developed for combinations of source, time and placement for specific crops and soil test regions.

Future research is needed to address other fertilizer nitrogen sources including enhanced efficiency fertilizers (EEF) such as controlled release (CR) products, or products with nitrification inhibitors (NI) and/or urease inhibitors (UI), timing including fall, spring and in-season, and placement such as seed-placed, injection, banding, fertigation, broadcast, broadcast & incorporated

3. Water supply (Ws)

The available moisture is the sum of spring soil moisture plus growing season precipitation or irrigation.

a. Spring soil moisture

Spring soil moisture will affect nutrient availability and early plant growth potential. Soil moisture is a function of soil texture and depth of moist soil. AFFIRM v3 assigns soil moisture levels for Low, Intermediate and Optimum conditions.

b. Growing season precipitation

Growing season precipitation is defined by the long-term probability equations for each soil zone. AFFIRM v3 calculates growing season precipitation for Low, Intermediate and Optimum conditions based on these precipitation probability equations.

c. Irrigation

For irrigated crops, AFFIRM v3 assigns irrigation levels for Low, Intermediate and Optimum irrigation conditions based on Alberta research. (Bennett and Harms, 2011; Bennett, et al, 2014)

4. Further crop response adjustments

a. Soil pH

Crops vary in their acidity tolerance (Table 4). Production in soils more acidic than their tolerance level will result in reduced yields. Under acidic conditions, AFFIRM v3 will adjust the yield response to nitrogen on the basis of pH level.

b. Soil salinity

Electrical conductivity (EC) is a measure of the total soluble salt concentration in a soil. Soluble salts are present in soils at all times, however, when the concentration of salts is high, the soil is considered “saline” and crop growth can be reduced (Table 5). Yield reduction is dependent upon the crop species and their level of salinity tolerance (Table 6). Generally, grass forages tend to have higher salinity tolerance than field crops. AFFIRM v3 will adjust yield response to nitrogen according to salt concentration.

G. Nitrogen economic analysis module calculations

The marginal economic analysis module (Figure 3) is used to determine the economic optimizing rate of N by comparing the added costs of N (i.e. marginal cost) with the added returns from additional crop yield increases (i.e. marginal return). It is economically beneficial to increase yields by adding N as long as added returns exceed added costs (i.e. investment ratio > 1). However, in the uncertain industry of crop production, AFFIRM v3 suggests choosing an N rate that produces twice as much return (i.e. investment ratio = 2). Table 10 outlines the economic analysis module calculations for a field of Wheat - Northern Hard Red (NHR) for intermediate moisture conditions.

Table 11. N fertilizer economic analysis for Wheat - Northern Hard Red (NHR), Dark Brown (NE) soil group, intermediate moisture conditions.

Fertilizer Nitrogen Added (lb/ac)	Estimated Yield (bu/ac)	Predicted Yield Increase (bu/ac)	Added Yield Increase (bu/ac)	Estimated Revenue from Fertilizer Nitrogen ($/ac)	Marginal Return ($/ac)	Total Cost of Fertilizer Nitrogen ($/ac)	Marginal Cost of Fertilizer Nitrogen ($/ac)	Gross Margin Change ($/ac)	Investment Ratio
0	40.7	0.0							
10	44.1	3.4	3.4	20.57	20.57	5.70	5.70	14.87	3.61
20	47.0	6.4	3.0	38.60	18.03	11.40	5.70	27.20	3.16
30	49.6	9.0	2.6	54.39	15.79	17.10	5.70	37.29	2.77
40	51.9	11.3	2.3	68.30	13.91	22.80	5.70	45.50	2.44
50	54.0	13.3	2.0	80.53	12.23	28.50	5.70	52.03	2.15
60	55.7	15.1	1.8	91.29	10.76	34.20	5.70	57.09	1.89
70	57.3	16.6	1.6	100.67	9.38	39.90	5.70	60.77	1.65
80	58.7	18.0	1.4	108.96	8.29	45.60	5.70	63.36	1.45
90	59.9	19.2	1.2	116.22	7.26	51.30	5.70	64.92	1.27
100	60.9	20.3	1.1	122.63	6.41	57.00	5.70	65.63	1.12
110	61.9	21.2	0.9	128.26	5.63	62.70	5.70	65.56	0.99

N fertilizer cost = $0.57/lb N   Wheat - Northern Hard Red (NHR) price = $6.05/bu

Example calculations for 60 lbs of N applied:

Marginal Cost = N fertilizer cost ($/lb) X 10 lbs
= $0.57 X 10
= $5.70

Added Yield Increase = (Predicted Yield Increase @ 60 lbs N) – (Predicted Yield Increase @ 50 lbs N)
= 15.1 bu – 13.3 bu
= 1.8 bu*

Marginal Return = yield increase x crop price
= 1.8 bu X $6.05/bu
= $10.76

Investment Ratio = marginal return/marginal cost
= $10.76/$5.70
= 1.89

* Estimated yield values are rounded, therefore your own calculations may not be same as the table.

H. Farm optimization module calculations

When fertilizer decisions are made, most likely there is a need to consider the fertilizer requirements for the entire farm, rather than on an individual field basis. This module provides a summarization tool that will assist in allocating the farm fertilizer budget to optimize economic returns. Incorporating the cost of all recommended nutrients for the farm provides a more realistic assessment of the total fertilizer economics of the farm operation, rather than just nitrogen on an individual field basis. Using the optimization module, AFFIRM v3 will summarize farm fertilizer recommendations and assist in the economic decisions for the entire farm. AFFIRM v3 will determine how to best allocate funds to best fit a farm budget that is limiting. Due to the tremendous amount of data required for this module, AFFIRM v3 can only assess the N requirements of those crops that have yield response equations available.

The example below illustrates the steps involved in the optimization module. The fields, in this example, are located in the Black (Southwest) soil region. The yield response is for an Intermediate moisture condition and a target investment ratio of 2 for all fields is assumed. The fertilizer nitrogen used in this example is urea, applied in the spring banded.

Tables 11 and 12 outline the information required to make the calculations.

Table 12. Fertilizer nutrient costs.

Fertilizer cost ($/lb)			
N	**P_2O_5**	**K_2O**	**S**
0.57	0.40	0.34	0.46

Table 13. Field and crop information.

Field	Field size (acres)	Crop	Crop price	Yield response equations	Recommendations (lbs/ac) (Intermediate moisture level)			
					N	**P_2O5**	**K_2O**	**S**
A1	100	Mustard (Yellow)	$17.00/bu	Not available	50	10	0	5
A2	150	Peas (Feed)	$5.14/bu	Not available	0	20	0	0
A3	120	Canola	$10.45/bu	Available	100	15	0	10
A4	140	Malt Barley	$4.35/bu	Available	40	10	0	0
A5	100	Wheat - NHR	$6.05/bu	Available	40	15	0	0
A6	150	Wheat - WAD	$7.59/bu	Available	90	10	0	5

In this example, the total cost required to fulfill the recommendations of each field calculated (Table 13).

Table 14. Fertilizer and nutrient costs to meet AFFIRM v3 recommendation.

Field	Crop	Fertilizer Nutrient Requirements (lbs)				Fertilizer Nutrient Costs ($)			
		N	**P_2O_5**	**K_2O**	**S**	**N**	**P_2O_5**	**K_2O**	**S**
A1	Mustard (Yellow)	5,000	1,000	0	500	2,850	400	0	506
A2	Peas (Feed)	0	3,000	0	0	0	1,200	0	0
A3	Canola	12,000	1,800	0	1200	6,840	720	0	552
A4	Malt Barley	5,600	1,400	0	0	3,192	560	0	0
A5	Wheat - NHR	4,000	1,500	0	0	2,280	600	0	0
A6	Wheat - WAD	13,500	1,500	0	750	7,695	600	0	345
TOTAL		**40,100**	**10,200**	**0**	**2,450**	**22,857**	**4,080**	**0**	**1,403**

Example calculations for Field ‘A1’: Nitrogen:

Quantity required (lbs) = N recommendation (lbs/ac) X field size (ac)
= 50 lbs/ac x 100 ac
= 5,000 lbs N

Dollars required ($) = Quantity required x N fertilizer cost
= 5,000 lbs N X $0.57/lb N
= $2,850.00

Based on the recommendation, the farm will require **$28,340** for fertilizer application.
However for this example, the farm fertilizer budget is **$25,000**.
Therefore, a total of **$3,340** needs to be cut to meet the budget. **($25,000 minus $28,340 equals -$3,340**)
Where can costs cut be made to meet the budget?

Based on the recommendations, $ needed for PKS for all fields is **$5,483**.
The $ needed for N for those fields with crops without Yield Response data (fields A1 and A2) is **$2,850**.
This becomes a fixed cost of **$5,483 plus $2,850 equals $8,333**.

The optimization module allows for the opportunity to alter the N application for fields A3, A4, A5 and A6 to meet the budget using yield response to nitrogen fertilizer data.

The economic analyses are provided in Tables 14, 15, 16 1nd 17 for the 4 fields.

Table 15. Economic analysis for Canola for field A3.

Fertilizer Nitrogen Added (lb/ac)	Estimated Yield (bu/ac)	Predicted Yield Increase (bu/ac)	Added Yield Increase (bu/ac)	Estimated Revenue from Fertilizer Nitrogen ($/ac)	Marginal Return ($/ac)	Total Cost of Fertilizer Nitrogen ($/ac)	Marginal Cost of Fertilizer Nitrogen ($/ac)	Gross Margin Change ($/ac)	Investment Ratio
0	37.2	0.0							
10	39.2	2.1	2.1	21.53	21.53	5.70	5.70	15.83	3.78
20	41.2	4.0	1.9	41.49	19.96	11.40	5.70	30.09	3.50
30	42.9	5.8	1.8	60.19	18.70	17.10	5.70	43.09	3.28
40	44.6	7.4	1.7	77.54	17.35	22.80	5.70	54.74	3.04
50	46.1	9.0	1.5	93.63	16.09	28.50	5.70	65.13	2.82
60	47.6	10.4	1.4	108.68	15.05	34.20	5.70	74.48	2.64
70	48.9	11.7	1.3	122.68	14.00	39.90	5.70	82.78	2.46
80	50.2	13.0	1.2	135.64	12.96	45.60	5.70	90.04	2.27
90	51.3	14.1	1.2	147.76	12.12	51.30	5.70	96.46	2.13
100	52.4	15.2	1.1	159.05	11.29	57.00	5.70	102.05	1.98
110	53.4	16.2	1.0	169.50	10.45	62.70	5.70	106.80	1.83
120	54.3	17.2	0.9	179.32	9.82	68.40	5.70	110.92	1.72
130	55.2	18.0	0.9	188.41	9.09	74.10	5.70	114.31	1.59

Table 16. Economic analysis for Malt Barley for field A4.

Fertilizer Nitrogen Added (lb/ac)	Estimated Yield (bu/ac)	Predicted Yield Increase (bu/ac)	Added Yield Increase (bu/ac)	Estimated Revenue from Fertilizer Nitrogen ($/ac)	Marginal Return ($/ac)	Total Cost of Fertilizer Nitrogen ($/ac)	Marginal Cost of Fertilizer Nitrogen ($/ac)	Gross Margin Change ($/ac)	Investment Ratio
0	83.0	0.0							
10	86.7	3.7	3.7	15.88	15.88	5.70	5.70	10.18	2.79
20	89.9	6.9	3.2	29.84	13.96	11.40	5.70	18.44	2.45
30	92.7	9.7	2.8	42.20	12.36	17.10	5.70	25.10	2.17
40	95.2	12.2	2.5	53.07	10.87	22.80	5.70	30.27	1.91
50	97.4	14.4	2.2	62.68	9.61	28.50	5.70	34.18	1.69
60	99.4	16.4	2.0	71.17	8.49	34.20	5.70	36.97	1.49
70	101.1	18.1	1.7	78.60	7.43	39.90	5.70	38.70	1.30
80	102.6	19.6	1.5	85.22	6.62	45.60	5.70	39.62	1.16
90	104.0	20.9	1.3	91.00	5.78	51.30	5.70	39.70	1.01
100	105.1	22.1	1.2	96.14	5.14	57.00	5.70	39.14	0.90
110	106.2	23.1	1.0	100.66	4.52	62.70	5.70	37.96	0.79

Table 17. Economic analysis for Wheat - Northern Hard Red (NHR) for field A5.

Fertilizer Nitrogen Added (lb/ac)	Estimated Yield (bu/ac)	Predicted Yield Increase (bu/ac)	Added Yield Increase (bu/ac)	Estimated Revenue from Fertilizer Nitrogen ($/ac)	Marginal Return ($/ac)	Total Cost of Fertilizer Nitrogen ($/ac)	Marginal Cost of Fertilizer Nitrogen ($/ac)	Gross Margin Change ($/ac)	Investment Ratio
0	52.2	0.0							
10	54.7	2.5	2.5	15.19	15.19	5.70	5.70	9.49	2.66
20	56.9	4.8	2.2	28.74	13.55	11.40	5.70	17.34	2.38
30	59.0	6.8	2.0	40.90	12.16	17.10	5.70	23.80	2.13
40	60.7	8.6	1.8	51.73	10.83	22.80	5.70	28.93	1.90
50	62.4	10.2	1.6	61.47	9.74	28.50	5.70	32.97	1.71
60	63.8	11.6	1.4	70.12	8.65	34.20	5.70	35.92	1.52
70	65.1	12.9	1.3	77.86	7.74	39.90	5.70	37.96	1.36
80	66.2	14.0	1.1	84.82	6.96	45.60	5.70	39.22	1.22
90	67.2	15.0	1.0	90.99	6.17	51.30	5.70	39.69	1.08

Table 18. Economic analysis for Wheat - Western Amber Durum (WAD) for field A6.

Fertilizer Nitrogen Added (lb/ac)	Estimated Yield (bu/ac)	Predicted Yield Increase (bu/ac)	Added Yield Increase (bu/ac)	Estimated Revenue from Fertilizer Nitrogen ($/ac)	Marginal Return ($/ac)	Total Cost of Fertilizer Nitrogen ($/ac)	Marginal Cost of Fertilizer Nitrogen ($/ac)	Gross Margin Change ($/ac)	Investment Ratio
0	56.7	0.0							
10	59.8	3.1	3.1	23.53	23.53	5.70	5.70	17.83	4.13
20	62.7	5.9	2.8	45.01	21.48	11.40	5.70	33.61	3.77
30	65.2	8.5	2.6	64.51	19.50	17.10	5.70	47.41	3.42
40	67.6	10.9	2.4	82.35	17.84	22.80	5.70	59.55	3.13
50	69.7	13.0	2.1	98.67	16.32	28.50	5.70	70.17	2.86
60	71.7	15.0	2.0	113.47	14.80	34.20	5.70	79.27	2.60
70	73.5	16.7	1.8	126.98	13.51	39.90	5.70	87.08	2.37
80	75.1	18.4	1.6	139.28	12.30	45.60	5.70	93.68	2.16
90	76.6	19.8	1.5	150.51	11.23	51.30	5.70	99.21	1.97
100	77.9	21.2	1.4	160.76	10.25	57.00	5.70	103.76	1.80
110	79.2	22.4	1.2	170.09	9.33	62.70	5.70	107.39	1.64
120	80.3	23.5	1.1	178.59	8.50	68.40	5.70	110.19	1.49
130	81.3	24.6	1.0	186.33	7.74	74.10	5.70	112.23	1.36

Following the principles of economic optimization, AFFIRM v3 deducts the P_2O_5, K_2O, S, and micronutrient requirements of all fields and the N requirements of those crop without yield response equations from the budget. In this example, the farm budget available for allocation of nitrogen fertilizer for crops on fields A3, A4, A5 and A6 (crops with Yield Response data) is **$25,000** minus **$8,333** equals **$16,667**.

AFFIRM v3 will allocate the 35,100 lbs of available N fertilizer in 10 lbs/ac increments. Since each field a different size, the following outlines fertilizer requirements for each 10 lb application to each field:

- A3 - 1,200 lbs
- A4 - 1,400 lbs
- A5 - 1,000 lbs
- A6 - 1,500 lbs

Following the principle of allocating resources to optimize economic return (i.e. highest investment ratio), AFFIRM v3 will allocate N in the sequence displayed in Table 18 until the budget is exhausted or the target investment ratios are reached.

Table 19. Farm optimization - Allocation of 10lb increments of fertilizer N for fields A3, A4, A5 and A6.

Field	Crop	Field Size (ac)	Fertilizer Nitrogen Added (lb/ac)	Marginal Return ($/ac)	Investment Ratio	Fertilizer Nitrogen Allocated for this step (lb)	Cumulative Fertilizer Nitrogen Allocated (lb)	Total Budget Required ($)
A6	Wheat - WAD	150	**10**	23.53	4.13	1,500	1,500	855
A3	Canola	120	**10**	21.53	3.78	1,200	2,700	1,539
A6	Wheat - WAD	150	**20**	21.48	3.77	1,500	4,200	2,394
A3	Canola	120	**20**	19.96	3.50	1,200	5,400	3,078
A6	Wheat - WAD	150	**30**	19.50	3.42	1,500	6,900	3,933
A3	Canola	120	**30**	18.70	3.28	1,200	8,100	4,617
A6	Wheat - WAD	150	**40**	17.84	3.13	1,500	9,600	5,472
A3	Canola	120	**40**	17.35	3.04	1,200	10,800	6,156
A6	Wheat - WAD	150	**50**	16.32	2.86	1,500	12,300	7,011
A3	Canola	120	**50**	16.09	2.82	1,200	13,500	7,695
A4	Malt Barley	140	**10**	15.88	2.79	1,400	14,900	8,493
A5	Wheat - NHR	100	**10**	15.19	2.66	1,000	15,900	9,063
A3	Canola	120	**60**	15.05	2.64	1,200	17,100	9,747
A6	Wheat - WAD	150	**60**	14.80	2.60	1,500	18,600	10,602
A3	Canola	120	**70**	14.00	2.46	1,200	19,800	11,286
A4	Malt Barley	140	**20**	13.96	2.45	1,400	21,200	12,084
A5	Wheat - NHR	100	**20**	13.55	2.38	1,000	22,200	12,654
A6	Wheat - WAD	150	**70**	13.51	2.37	1,500	23,700	13,509
A3	Canola	120	**80**	12.96	2.27	1,200	24,900	14,193
A4	Malt Barley	140	**30**	12.36	2.17	1,400	26,300	14,991
A6	Wheat - WAD	150	**80**	12.30	2.16	1,500	27,800	15,846
A3	Canola	120	**90**	12.12	2.13	1,200	29,000	16,530
A5	Wheat - NHR	100	**30**	12.16	2.13	1,000	30,000	17,100
A3	Canola	120	**100**	11.29	1.98	1,200	31,200	17,784
A6	Wheat - WAD	150	**90**	11.23	1.97	1,500	32,700	18,639
A4	Malt Barley	140	**40**	10.87	1.91	1,400	34,100	19,437
A5	Wheat - NHR	100	**40**	10.83	1.90	1,000	35,100	20,007

In this example, the budget is not enough to meet the target investment ratio of 2 and AFFIRM v3 stops allocating fertilizer when the total capital required = **$16,530**. The total amount of Nitrogen fertilizer allocated to each field is:

Field A3	Canola	= 90 lbs/ac
Field A4	Malt Barley	= 30 lbs/ac
Field A5	Wheat - NHR	= 20 lbs/ac
Field A6	Wheat - WAD	= 80 lbs/ac

The investment ratios that were reached were in this example were:

Field A3	Canola	= 2.13
Field A4	Malt Barley	= 2.17
Field A5	Wheat - NHR	= 2.38
Field A6	Wheat - WAD	= 2.16

The final fertilizer nutrient requirements for this example are presented in Table 19. Note the final recommendations of nitrogen are reduced for fields A4, A5 and A6 compared to Table 12.

Table 20. Adjusted fertilizer nutrient recommendation.

Field	**Field size (acres)**	**Crop**	**Recommendations (lbs/ac) (Intermediate moisture level)**			
			N	**P_2O_5**	**K_2O**	**S**
A1	100	Mustard (Yellow)	50	10	0	5
A2	150	Peas (Feed)	0	20	0	0
A3	120	Canola	90	15	0	10
A4	140	Malt Barley	30	10	0	0
A5	100	Wheat - NHR	20	15	0	0
A6	150	Wheat - WAD	80	10	0	5

To achieve the target IR of 2, the $ required for N to crops with yield response data (i.e. A3, A4, A5 and A6) is **$20,044**. This would require an increase in the fertilizer budget to **$28,340.** This would allow for the full allocation of **35,165 lbs** of N.

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