Measuring Nutrient Removal, Calculating Nutrient Budgets

Summary

Nutrient removal is the quantity of nutrient removed from a specified area. Commonly, farmers and advisers use published removal rates (on a yield unit basis) to estimate such quantities. However, measurements may be taken on the farm to improve evaluations and provide opportunities to further examine and evaluate nutrient management practices. The measurements that are essential to calculating nutrient removal are:

- harvest area
- weight of moist plant material
- moisture content of harvested plant portions
- nutrient concentration.

Guidance is provided for using these measurements to calculate dry matter yield and nutrient removal. In addition, nutrient budgets are discussed, along with their evaluation using soil test data. In the last section, two examples are provided. The first considers a farming operation that produces forage for internal use. The second guides the reader through measurements and calculations used on a grain farm.

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Nutrient removal is the quantity of nutrients removed in plant material harvested from the field. All plant material contains quantities of the following elements: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). The first six elements, N, P, K, Ca, Mg, and S, are taken up in greater quantities by plants and are termed **macronutrients**. They are present in concentrations of percent (%). The remaining nutrients are present in smaller concentrations, parts per million (ppm), and are therefore referred to as **micronutrients**. Directly measuring nutrient removal requires measuring how much biomass is removed from the field as well as the concentrations of nutrients in that biomass.

Nutrient removal is commonly estimated from measured yields and published nutrient concentrations. For instance, the P removal rate of corn grain has been estimated by multiplying 0.37 lb P_2O_5 bu^{-1} by the yield in bushels per acre. However, there are inaccuracies involved with using average concentrations. For grains, much of this uncertainty comes from the use of a volumetric measurement (bushel) rather than a mass measurement. For forages, nutrient removal coefficients usually do not specify how much moisture is assumed to exist.

Nutrient removal estimates are most often used to calculate **partial nutrient budgets**, where total applications are compared with total removals. Such budgets are partial because losses from erosion, runoff, and leaching are not considered, nor are additions from atmospheric deposition, sediment deposition, or collection of runoff from other areas. Partial nutrient budgets have implications for soil test levels of immobile nutrients. Positive budgets result when application rates exceed those of removal, and under such conditions, soil test levels are expected to rise. Negative budgets result when application rates are less than removal

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and are expected to draw down soil test levels. Finally, balanced budgets, where applications equal removal, are expected to keep soil test levels of immobile nutrients fairly stable. Consequently, nutrient rates that balance nutrient budgets are referred to as **maintenance applications**.

Natural resource professionals can measure, rather than estimate, nutrient removals themselves on the farm. There are a couple of reasons for doing so. First, measured removals reflect variations in varieties, hybrids, and management practices used in a given area and are expected to be more accurate than generalized estimates. Second, collecting such information provides new ways for advisers and farmers to work together, increasing communication and providing new opportunities to improve management practices.

Periodically calculating nutrient budgets from locally collected information provides a check on whether or not implemented practices are meeting management objectives. Although nutrient budgets are most commonly used in operations where manure scheduling and distribution are the primary issues, they are useful in all production settings.

In this chapter, guidance is provided for accomplishing two tasks:

- measuring nutrient removal rates
- calculating nutrient budgets over time

We focus on approaches that can be used on the farm and we limit our discussion to forage and grain crops.

Measuring Components of Nutrient Removal

Measurements needed for calculate nutrient removal rates are:

- harvest area
- weight of moist plant material harvested from the area
- moisture content of plant material
- nutrient concentration of plant material

The first three measurements are used to determine how much total dry matter (DM) was harvested from a known area. Dry matter is plant material that contains 0% moisture. Its weight is termed **dry weight**. The amount of DM removed per acre is needed because nutrient concentrations determined by a laboratory are reported on a DM basis (Mills and Jones, 1996). At harvest, plant material contains some amount of moisture, so its weight is referred to as **wet weight**.

Determining the amount of moisture in the harvested plant material makes it possible to subtract the weight of water and find the DM yield per acre.

Measuring Harvest Area

Knowing the exact area harvested is crucial to accurately determining yield. A common approach to determining field size is to use the global positioning system (GPS). A vehicle equipped with a differentially corrected GPS receiver coupled with a computer running mapping software is driven around the border of the area to be measured. Geographic information system (GIS) software is then used to calculate the area within the border outlined by the vehicle. Another GIS-based method is to import aerial photographs into GIS software and outline the area using polygon drawing tools. Of the two, field measurements are expected to be more accurate, since driving the field border can reveal areas that cannot be farmed and that may not have been detectable from an aerial photograph, particularly if the photograph is not recent.

Measuring Wet Weight

To determine DM yield, wet weight of plant material must first be measured.

Equipment for Forage

Often, forage is not weighed. Many times, forage producers are not concerned with the weight of the harvested material but instead pay attention to the number of bales or the approximate volume of hay or silage. This is typically the case when forage is produced and used within the same farming operation. However, when forage is produced for markets off the farm, its price is determined by weight. A recent investigation into the accuracy of estimating the weight of a bale showed that estimates were off an average of 16% and tended to underestimate bale weights (Yohn et al., 2007). Therefore, to improve estimates of nutrient removal, accurate determinations of weight are needed.

Scales. The most accurate equipment for measuring forage wet weight is a scale, which should be properly calibrated. If a scale is not available on the farm, neighbors or grain elevators are possibilities. For measuring large bales or many small bales, a platform truck scale is a good option. If individual small bales are weighed, less expensive scales can be used, such as large animal scales.

Forage Wagons with No Scale. When no scale exists, weight can be approximated from volume (Wiersma and Holmes, 2000). The internal length and width of a wagon are measured and height marks made at half-foot intervals. When the wagon is filled, the height of forage is recorded, and forage volume calculated. Volume is converted to DM weight using a table of average DM density (pounds DM per cubic foot of forage). Average density values for the first cutting of alfalfa, second and subsequent cuttings of alfalfa, red clover, grass, oat, and corn are 5.7, 5.0, 5.5, 4.6, 5.0, and 5.0 lb DM ft^{-3}, respectively (Wiersma and Holmes, 2000). Considerable uncertainty exists with this method, and it should be noted that DM is **estimated weight**, rather than wet weight.

Tractor Hydraulics as Scales. This method was developed by Yohn et al. (2007). The approach calibrates hydraulic pressure to weight. First, gauges are installed in hydraulic lines to measure pressure. For instance, gauges can be placed in lines leading to the two cylinders of a front end loader. To calibrate, objects of a known weight, such as seed bags or tractor weights, are progressively added. Each time more weight is added, the pressure is recorded. This allows pressure to be related to weight. During calibration, the weight used should cover the range expected for the plant material to be weighed. As an example, for round bales, up to 1500 pounds may be needed in the calibration. Once calibrated, hydraulic pressure associated with lifting each bale to a specific height can be converted to weight.

Equipment for Grain

Grain yields can be measured with a platform truck scale, grain cart scale, or yield monitor.

Collecting Samples for Moisture Determination

Collecting representative samples is a critical step for accurately assessing plant moisture content. Samples for moisture analysis should be collected when the sample is weighed.

Forage Samples

Ideally, a separate sample should be taken from each weighed load, separated by lot. A lot is forage harvested within one day from one field and from a specific variety or hybrid. To collect a forage sample, a core sampler is recommended (Brusewitz et al., 1993; Undersander et al., 2005). Each sample should consist of 10 to 12 cores that are composited into a single sample from which a smaller portion is taken for moisture determination.

Grain Samples

Two primary approaches are used to collect grain samples (GIPSA, 2006, 2001). The first one is taking a sample from a moving stream of grain. The second approach is collecting samples from grain at rest, such as a truck, combine hopper, or bin. Taking a sample from flowing grain can be done with a large coffee can held to one side of the stream. A minimum of three such samples per load is suggested. For grain at rest, a hand probe is recommended, taken at specific locations and angles, depending on the length of the probe and the type of container being sampled. At least two probes should be used for a hopper trailer.

Measuring Moisture Content

Various methods exist for determining the moisture content of plant material. Different equipment and techniques exist for forage and grain.

Forage Moisture

For forages, moisture can be determined either by measuring the weight difference of a sample after drying or by using an electronic moisture meter.

In commercial laboratories, forage moisture is calculated directly by weighing the wet weight of the sample, drying the sample in a forced-air oven at 176°F until a stable weight is obtained (Mills and Jones, 1996), and calculating moisture content as follows:

$$\text{Moisture (\%)} = \frac{\text{wet weight (g)} - \text{dry weight (g)}}{\text{wet weight (g)}} \times 100\% \qquad [1]$$

On the farm, other options exist for drying samples. A microwave oven procedure was developed by Farmer and Brusewitz (1980) and has been made available online by Chamliss (2002). In this procedure, a 100-g sample (wet weight), cut into 1-inch pieces, is placed in a microwave oven, along with a 10- to 16-oz. glass of water. The microwave oven is then run on high setting for 5 minutes, the sample removed, and weighed again. The glass is then emptied and refilled with fresh water and placed back in the microwave. The sample is returned to the oven and the microwave run on high for 2 minutes. Changing water and running the microwave for 2 minutes is done repeatedly until the sample weight stabilizes.

Moisture can also be determined on-farm with a Koster forage moisture tester (Koster Crop Tester, Inc., Brunswick, OH). This tester is a self-contained electrical forced-air dryer. The sample is placed in the specimen container that comes with the dryer. The sample is then dried for 30 minutes and weighed again. Subsequently, the sample is dried in 10-minute increments until the weight stabilizes.

The electronic moisture meter is an indirect measurement of moisture. The instrument actually measures either electrical conductance or resistance and converts that information to moisture as a percent of wet weight.

Studies have been conducted to determine the accuracy of various on-farm approaches to measuring the moisture of forages. The Prairie Agricultural Machinery Institute tested the Koster forage moisture tester on alfalfa and corn silage and found it to have acceptable accuracy (3%) when compared with a standard oven-dry method (Prairie Agric. Machinery Inst., 1981). Oetzel et al. (1993) tested the microwave oven, the Koster forage moisture tester, and an electronic moisture meter on samples of alfalfa, corn silage, and high-moisture shelled corn. They found that all three of the measurements had good reproducibility. For alfalfa, all three underestimated moisture when compared with the standard oven-dry method but had an acceptable error rate of about 6.4%. For corn silage, the microwave oven and Koster forage moisture tester underestimated moisture content, with the Koster tester doing so significantly and with a nominally acceptable error rate of 9.4%. The electronic moisture tester gave inaccurate results, with a total error of 19.6%, and consistently overestimated corn silage moisture. It was thought by the authors that such inaccuracy may have been attributable to the heterogeneous nature of the corn silage material. For high-moisture shelled corn, a much more homogeneous material, the electronic moisture meter was the most accurate, with an error of 1.25%.

[1] Trade names are included for the benefit of the reader and do not imply endorsement of or preference for the product listed by the author or SSSA.

Both the microwave oven and the Koster tester underdried the corn, with the Koster tester not drying as much as the microwave oven, resulting in greater error. The error of the microwave was acceptable (2.1%), while that of the Koster tester was marginally so (9.7%). Brusewitz et al. (1993) reviewed the various methods and concluded that the microwave oven was almost as accurate as the reference oven and therefore recommended its use for drying samples. They determined that moisture meters for corn silage were inaccurate, in agreement with Oetzel et al. (1993), but could be accurate for hay if calibrated with results from a microwave oven.

Grain Moisture

For grains, moisture meters are the most common approach for determining moisture content. These meters work in principle like those described for forages.

The accuracy of the moisture meter should be checked periodically by comparing readings from the moisture meter with those from a meter used at a grain elevator (Hurburgh and Wilcke, 1995). If a moisture sensor is coupled to a yield monitor on the combine, calibration involves reading the average moisture of a load and comparing it with the average moisture of several samples taken from that load, measured with a separate moisture meter.

Calculating Dry Matter Yield

Harvest area, wet weight, and moisture are all used to calculate DM yield. First, DM weight is calculated as:

$$\text{DM weight (lb)} = \text{weight wet (lb)} - \left(\text{wet weight (lb)} \times \frac{\text{moisture (\%)}}{100\%}\right) \quad [2]$$

Second, DM yield is determined by dividing DM weight by the harvest area:

$$\text{DM yield (lb acre}^{-1}) = \frac{\text{DM weight (lb)}}{\text{area harvested (acres)}} \quad [3]$$

Measurements for Forage

Forage Removed from the Field. Each load hauled from the field should be sampled and weighed. The DM yield is calculated by adding up the DM weights of all loads and dividing by the area harvested, according to Eq. [3]. If partial loads from two different fields are combined into a single load, estimate the portion of the load attributable to each field.

Forage Stored in the Field. When bales are stored in the field, gather a few representative bales from each lot to create a load and divide the total DM weight of the load by the number of bales to get the average DM weight per bale, as shown in Eq. [4]. Multiply the average DM bale weight by the number of bales stored in the field.

$$\text{Avg. DM weight of a bale (lb bale}^{-1}) = \frac{\text{DM weight of a load (lb)}}{\text{number of bales in a load (bales)}} \quad [4]$$

Measurements for Grain

Yield Monitor. In cases where yield monitors are used, data are recorded by field and load within the field. This feature is available with or without a GPS receiver. When yield monitors have been properly calibrated, total wet weight of grain and moisture can be recorded for either individual loads or the field. Equation [2–3] can then be used to calculate DM yield.

Truck Trailer. The number of truck trailer loads leaving a field can be used to estimate total wet weight by weighing each load on a platform scale. When a load contains grain from more than one field, estimating the percent volume occupied by the grain from each field allows the load weight to be partitioned to each field.

Grain Cart with a Scale. Wet weight can also be measured with grain carts equipped with scales. Weights and moisture percentages of individual loads are recorded and separated by field.

Measuring Nutrient Concentration

Nutrient analyses of plant material need to be conducted by a reputable laboratory with good quality control procedures and participating in the North American Proficiency Testing Program (http://www.naptprogram.org/). Such laboratories will have instructions for storing samples before submission. Many also have protocols for collecting samples. Generally, plant samples should be placed in polyethylene freezer bags and stored in a freezer until they can be submitted.

The results provided by the laboratory will have different concentration units for different elements. For the macronutrients, N, P, K, Ca, Mg, and S, concentrations are reported as a percentage of the DM weight of the sample. For the remaining micronutrients, parts per million units are used.

Calculating Nutrient Removal

Nutrient removal calculations for elements will differ based on the units used to report their concentrations. Differences also exist for P and K because practitioners use the oxide forms of these elements, P_2O_5 and K_2O, rather than the elemental form reported by the laboratory. All calculations use the DM yield calculated in Eq. [3].

Concentrations Reported in Units of Percent

Nitrogen, Calcium, Magnesium, Sulfur

Calculating nutrient removal for these elements is performed by dividing the percent elemental nutrient concentration by 100 and multiplying the quotient by the DM :

$$\text{Nutrient removal (lb acre}^{-1}) = \text{DM yield (lb acre}^{-1}) \times \frac{\text{concentration (\%)}}{100\%} \qquad [5]$$

Phosphorus

This calculation is the same as Eq. [5], except that a conversion factor (2.29) has been included that transforms elemental P content to P_2O_5 content.

$$\text{Nutrient removal (lb } P_2O_5 \text{ acre}^{-1}) = \text{DM yield (lb acre}^{-1}) \times \frac{\text{P concentration (\%)}}{100\%} \times 2.29 \quad [6]$$

Potassium

Like P, this equation contains a factor (1.20) that converts elemental K to K_2O.

$$\text{Nutrient removal (lb } K_2O \text{ acre}^{-1}) = \text{DM yield (lb acre}^{-1}) \times \frac{\text{K concentration (\%)}}{100\%} \times 1.20 \quad [7]$$

Concentrations Reported in Units of Parts per Million

This calculation works for all the micronutrients: B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn.

$$\text{Nutrient removal (lb acre}^{-1}) = \text{DM yield (lb acre}^{-1}) \times \frac{\text{concentration (ppm)}}{1{,}000{,}000} \quad [8]$$

It should be noted that while Ni has recently been recognized as an essential element, it is not routinely analyzed in commercial soil testing laboratories. As an additional note, nutrient removal rates of all micronutrients are small.

Converting Published Removal Coefficients to a Dry Matter Basis

In some cases, DM yield may be known or estimated, but nutrient concentrations are not measured. In such cases, the only alternative is to use published nutrient removal rates. Published estimates are in pounds of nutrient per yield unit of the crop considered.

Forage

Published coefficients for forages are in units of pounds per ton. Many published coefficients do not specify the moisture content. Table 1 provides values that can be used in such cases (Koelsch et al., 2004).

Table 1. Dry matter content used to report nutrient removal per ton (Koelsch et al., 2004).

Crop	DM content per ton
	%
All hay	85
Alfalfa silage, mid-bloom	40
Barley straw	90
Corn silage	35
Corn stover	85
Oat straw	90
Rye straw	90
Small grain silage, dough stage	35
Sorghum silage	30
Sorghum-sudan silage	30
Sorghum stover	80
Wheat straw	90

To convert published removal coefficients from a moist basis to a DM basis, the following equation is used. The published nutrient removal rate is divided by the DM content estimated in Table 1, and the quotient then multiplied by 100. The result will be a larger number because a ton of DM will contain more nutrients than a ton of moist plant material where some of the weight is water.

$$\text{Nutrient removal rate}\left[\text{lb (ton DM)}^{-1}\right] = \left(\frac{\text{nutrient removal rate}\left[\text{lb (moist ton)}^{-1}\right]}{\text{DM content}\left[\text{\% (moist ton)}^{-1}\right]}\right)\times 100\%\ \text{DM (ton DM)}^{-1} \quad [9]$$

For example, if a published removal coefficient is 3.1 lb P_2O_5 (moist ton)$^{-1}$ for corn silage at 65% moisture, this is equivalent to:

$$P_2O_5\ \text{removal rate}\left[\text{lb (ton DM)}^{-1}\right] = \left[\frac{3.1\ \text{lb}\ P_2O_5\ \text{(moist ton)}^{-1}}{35\ \text{\% DM (moist ton)}^{-1}}\right]\times 100\%\ \text{DM (ton DM)}^{-1} = 8.9\ \text{lb}\ P_2O_5\ \text{(ton DM)}^{-1}$$

This value can then be multiplied by the DM yield to estimate nutrient removal.

Grain

Published coefficients for grain are in units of pounds per bushel. When the only information available on farm is pounds DM harvested, these coefficients must be converted from volumetric to gravimetric measurements, corrected for moisture. This is accomplished by dividing the published nutrient removal rate by the amount of DM in a bushel, estimated in Table 2 (Hirning et al., 1987):

$$\text{Nutrient removal rate}\left[\text{lb (lb DM)}^{-1}\right] = \left\{\frac{\text{nutrient removal rate}\left[\text{lb (moist bu)}^{-1}\right]}{\text{DM weight}\left[\text{lb DM (moist bu)}^{-1}\right]}\right\} \qquad [10]$$

Table 2. Commonly used test weights and moisture percentages of various grains (Hirning et al., 1987).

Crop	Test weight	Moisture	Dry matter
	lb bu^{-1}	%	lb bu^{-1}
Barley	48.00	14.50	41.04
Corn	56.00	15.50	47.32
Flax	56.00	9.00	50.96
Oats	32.00	14.00	27.52
Rye	56.00	14.00	48.16
Sorghum	55.00	14.00	47.30
Soybean	60.00	13.00	52.20
Sunflower	100.00	10.00	90.00
Wheat	60.00	13.50	51.90

For instance, a nutrient removal rate of 0.38 lb P_2O_5 bu^{-1} corn grain at 15.5% moisture is equivalent to:

$$P_2O_5 \text{ removal rate}\left[\text{lb (lb DM)}^{-1}\right] = \left[\frac{0.38\ \text{lb}\ P_2O_5\ \text{(moist bu)}^{-1}}{47.32\ \text{lb DM (moist bu)}^{-1}}\right] = 0.0080\ \text{lb}\ P_2O_5\ \text{(lb DM)}^{-1}$$

Once this value has been calculated, it can be multiplied by DM yield to estimate nutrient removal.

Comparing On-Farm Nutrient Removal Rates with Published Values

It is always a good idea to compare the values generated on the farm to published estimates (Table 3). Often, it is difficult to find published estimates for both macro- and micronutrients. Some sources that have such information are Jacobsen et al. (2005), Mitchell (1999), and Zublena (1991). Such a comparison helps ensure that the numbers being generated on the farm are reasonable. If large discrepancies are found, a check may be needed of the calculations, equipment, or procedures.

Table 3. Nutrient removal coefficients for various crops (Murrell, 2005).

Crop	Unit	Nutrient removal		
		N	P_2O_5	K_2O
		lb unit^{-1}		
Alfalfa	ton	51	12	49
Alsike clover	ton	41	11	54
Barley grain	bu	0.99	0.4	0.32
Barley straw	bu	0.4	0.16	1.2
Barley straw	ton	13	5.1	39
Beans, dry	bu	3	0.79	0.92
Birdsfoot trefoil	ton	45	11	42
Bluegrass	ton	30	12	46
Bromegrass	ton	32	10	46
Buckwheat	bu	0.83	0.25	0.22
Canola	bu	1.9	1.2	2.0
Corn grain	bu	0.90	0.38	0.27
Corn stover	bu	0.45	0.16	1.1
Corn stover	ton	16	5.8	40
Corn silage	bu	1.6	0.51	1.2
Corn silage	ton	9.7	3.1	7.3
Fescue	ton	37	12	54
Flax grain	bu	2.5	0.7	0.6
Flax straw	bu	0.7	0.16	2.2
Millet	bu	1.4	0.4	0.4
Mint	lb oil	1.9	1.1	4.5
Oat grain	bu	0.77	0.28	0.19
Oat straw	bu	0.31	0.16	0.94
Oat straw	ton	12	6.3	37
Oat silage	ton	9.0	11	45
Orchardgrass	ton	36	13	54
Potato tuber	cwt	0.32	0.12	0.55
Potato vine	cwt	0.2	0.05	0.3
Red clover	ton	45	12	42
Reed canarygrass	ton	28	9.7	44
Rye grain	bu	1.4	0.46	0.31
Rye straw	bu	0.8	0.21	1.5
Rye straw	ton	12	3.0	22
Ryegrass	ton	43	12	43
Sorghum grain	bu	0.66	0.39	0.27
Sorghum stover	bu	0.56	0.16	0.83
Sorghum stover	ton	28	8.3	42
Sorghum-sudan	ton	30	9.5	34
Soybean grain	bu	3.8	0.84	1.3
Soybean stover	bu	1.1	0.24	1.0
Soybean stover	ton	40	8.8	37
Soybean hay	ton	45	11	25

Sugarbeet root	ton	3.7	2.2	7.3
Sugarbeet top	ton	7.4	4.0	20
Sunflower grain	cwt	2.7	0.97	0.90
Sunflower stover	cwt	2.8	0.24	4.1
Sunflower stover	ton	23	2.0	34
Switchgrass	ton	22	12	58
Timothy	ton	25	11	42
Tobacco (leaves)	cwt	3.6	0.90	5.7
Vetch	ton	57	15	49
Wheat grain	bu	1.5	0.60	0.34
Wheat straw	bu	0.7	0.16	1.2
Wheat straw	ton	14	3.3	24

Forage

Concentrations Reported in Units of Percent

Nitrogen, Ca, Mg, S. The concentrations of these nutrients are converted to removal rates per ton of DM using Eq. [11].

$$\text{Nutrient removal rate } \left[\text{lb (ton DM)}^{-1}\right] = \left(\frac{\text{concentration (\%)}}{100\%}\right) \times 2000 \text{ lb (ton DM)}^{-1} \quad [11]$$

Phosphorus. This calculation is the same as Eq. [11] except that an additional factor (2.29) has been included to convert elemental P content to P_2O_5.

$$\text{Nutrient removal rate } \left[\text{lb } P_2O_5 \text{ (ton DM)}^{-1}\right] = \left(\frac{\text{P concentration (\%)}}{100\%}\right) \times 2000 \text{ lb (ton DM)}^{-1} \times 2.29 \quad [12]$$

Potassium. This equation contains a factor (1.20) that converts elemental K to K_2O.

$$\text{Nutrient removal rate } \left[\text{lb } K_2O \text{ (ton DM)}^{-1}\right] = \left(\frac{\text{K concentration (\%)}}{100\%}\right) \times 2000 \text{ lb (ton DM)}^{-1} \times 1.20 \quad [13]$$

Concentrations Reported in Units of Parts per Million

This calculation works for all the micronutrients: B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn.

$$\text{Nutrient removal rate}\left[\text{lb (ton DM)}^{-1}\right] = \left(\frac{\text{concentration (ppm)}}{1{,}000{,}000}\right)\times 2000\ \text{lb (ton DM)}^{-1} \qquad [14]$$

It is important to remember that the results of Eq. [11–14] are for a ton of DM and may be higher than published estimates that assume some moisture is in the ton of harvested forage (less than 100% DM in a ton). To adjust the removal rates in Eq. [11–14] for the assumed DM contents in Table 1, use the following equation. The results from this equation can be compared with published estimates of nutrient removal.

$$\text{Nutrient removal rate}\left[\text{lb (ton at a specified DM \%)}^{-1}\right] = \text{nutrient removal rate}\left[\text{lb (ton DM)}^{-1}\right]\times\frac{\text{DM content (\%)}}{100\%} \qquad [15]$$

Grain

Published coefficients for grain are in units of pounds per bushel. Since bushel is a volumetric measure, the weight of DM in a bushel must be calculated from test weight and moisture measurements. Test weight is the pounds of grain per Winchester bushel (2150.42 in^3).

There are many instruments that measure test weight. Test weight is normally recorded to the nearest half-pound per bushel (0.5 lb bu^{-1}). Some meters are capable of measuring test weight as well as moisture. Other instruments simply measure test weight and must be used in combination with a separate moisture meter.

Grain elevators will also take grain samples and analyze them for moisture and test weight. To ensure the most accurate measurements, take the samples to the elevator soon after harvest. Both moisture and test weight can change over time.

In cases where test weight and moisture are not measured, commonly accepted values can be used (Table 2).

The DM content of a bushel of grain is found using:

$$\text{Bushel DM weight (lb DM bu}^{-1}\text{)} = \text{test weight (lb bu}^{-1}\text{)} - \left[\text{test weight (lb bu}^{-1}\text{)} \times \left(\frac{\text{grain moisture (\%)}}{100\%}\right)\right] \quad [16]$$

Concentrations Reported in Units of Percent

Nitrogen, Ca, Mg, S. The concentrations of these nutrients are converted to nutrient removal rates per bushel using Eq. [17].

$$\text{Nutrient removal rate (lb bu}^{-1}\text{)} = \left(\frac{\text{concentration (\%)}}{100\%}\right) \times \text{bushel DM weight (lb DM bu}^{-1}\text{)} \quad [17]$$

Phosphorus. This equation includes the factor needed (2.29) to elemental P content to P_2O_5.

$$\text{Nutrient removal rate (lb P}_2\text{O}_5\text{ bu}^{-1}\text{)} = \left(\frac{\text{P concentration (\%)}}{100\%}\right) \times \text{bushel DM weight (lb DM bu}^{-1}\text{)} \times 2.29 \quad [18]$$

Potassium. This equation uses the factor 1.20 to convert elemental K to K_2O.

$$\text{Nutrient removal rate (lb K}_2\text{O bu}^{-1}\text{)} = \left(\frac{\text{K concentration (\%)}}{100\%}\right) \times \text{bushel DM weight (lb DM bu}^{-1}\text{)} \times 1.20 \quad [19]$$

Concentrations Reported in Units of Parts per Million

This calculation works for all the micronutrients: B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn.

$$\text{Nutrient removal rate (lb bu}^{-1}\text{)} = \left[\frac{\text{conentration (ppm)}}{1{,}000{,}000}\right] \times \text{ bushel DM weight (lb DM bu}^{-1}\text{)} \quad [20]$$

Calculating Partial Nutrient Budgets of Immobile Nutrients

A partial nutrient budget compares nutrient additions to nutrient removals within a specified time period. Many nutrient recommendation systems use nutrient removal as the first approximation of the application rate needed to maintain soil test levels of immobile nutrients, like P and K, over time.

The general formula for calculating a budget is given below. The minimum interval should include nutrient applications and the removal of those nutrients by all of the crops for which the applications were intended. Figure 1 illustrates this concept. For instance, in a corn–soybean rotation, producers often apply P and K once every 2 years. Such an application would be denoted "nutrient applications for Crops 1 and 2" or "nutrient applications for Crops 3 and 4" in Fig. 1. All applications are included, such as small rates of seed-placed fertilizer. To calculate the

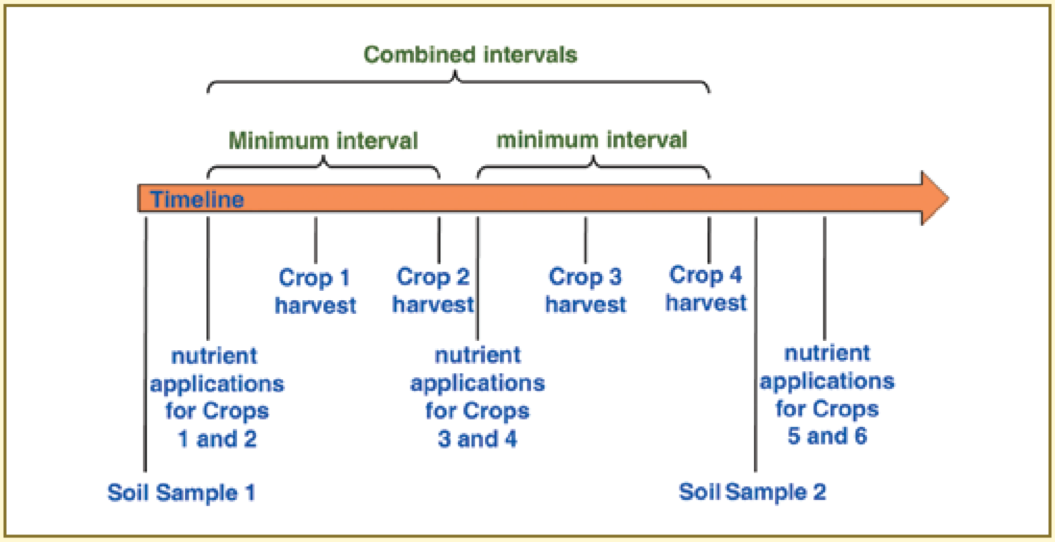


Fig. 1. Time line demonstrating the minimum and combined intervals suggested for calculating nutrient budgets.

nutrient budget, the P and K removed by the corn–soybean rotation is subtracted from the total P and K applied:

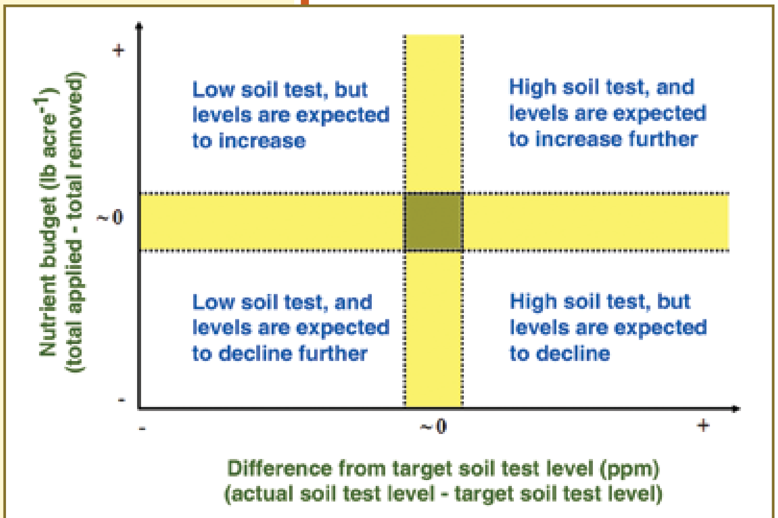
$$\text{Nutrient budget (lb acre}^{-1}\text{)} = \text{sum of all nutrient additions (lb acre}^{-1}\text{)} - \text{sum of all nutrient removals (lb acre}^{-1}\text{)} \quad [21]$$

Once the budget for the minimum interval is known, it can be evaluated with soil test information. Using soil test data may change the time frame considered in the budget. The most recent soil test should be identified. All minimum intervals completed since the soil test was taken should be considered. Keeping with the corn–soybean rotation, Fig. 2 indicates that there have been two minimum intervals completed since the first soil sample was taken. In cases where the most recent soil test has no completed minimum intervals after it, the previous soil test should be used or future nutrient removal estimates made that allow the interval to be completed.

The appropriate soil test is compared with target levels (Fig. 2). Such a comparison is made simply by subtracting target levels from soil test measurements. A positive difference indicates that current levels exceed target levels, while a negative difference indicates the opposite. A difference approximately equal to zero indicates that levels have reached targets. Some margin for error needs to be considered, indicated by the gray areas in Fig. 2.

Once soil test levels have been compared with targets, they are used to evaluate nutrient budgets. Such a comparison produces the quadrants in Fig. 2. Starting in the upper left-hand corner of this figure, if a positive nutrient budget exists when soil test levels are below target levels, the budget is in the appropriate direction, since it is expected that soil test levels will increase with time. Conversely, a positive budget would not be appropriate for the upper right-hand corner of Fig. 2. In this case, soil test levels are already too high and are likely to increase in the future, unless the soil has a high fixation capacity. Moving to the lower left-hand corner, an unsuitable situation is identified where soil test levels are lower than desired, but nutrient removals exceed nutrient applications. Such a situation would be expected to further deplete nutrients from the soil. If soil tests are already very low, depletion may not be reflected by further reductions in soil test levels. Finally, in the lower right-hand corner, the negative budget depicted is appropriate for a soil testing higher than desired. The negative budget is expected to draw down soil nutrients over time, bringing soil test levels back into the desired range. In the center of the diagram is a shaded box. This may be considered a nutrient management target, where soil test levels are in the desired range and budgets are approximately balanced.

Fig. 2. A diagram showing how nutrient budgets and soil test information can be used together to evaluate nutrient management programs.



« Sample Calculation 1

Example Calculations

Forage Example

A college student has come back to the family dairy farm during the summer. She wants to take the knowledge she has gained to improve the operation wherever it is needed. Her father has always spent most of his time with the livestock, but she is more interested in the crop side of the business. They have a few hundred cows and a few hundred acres. To manage needed feed and manure applications, alfalfa is grown for three years, followed by two years of corn grown for silage. The typical practice on these fields is to apply 25 tons of dairy manure per acre before alfalfa seeding. After the third year of alfalfa, the first year of corn is grown and receives P with the seed at planting. After this corn is harvested, another 25 tons of dairy manure per acre are applied, and corn is grown again a second year. Phosphorus is again applied with the seed. Each application of P with the seed is 40 lb P_2O_5 acre^{-1}. Applications of P and K with each 25 ton acre^{-1} manure application are 130 lb P_2O_5 and 270 lb K_2O acre^{-1}. The student calculates that over the 5-year period, total applications are typically 340 lb P_2O_5 and 540 lb K_2O acre^{-1}.

In the past, her father didn't keep track of the number of tons of forage removed from a field. Instead, he knew about how many acres needed to be planted to each crop to keep enough feed available for the operation as it changed size over time. Consequently, published removal values in units of pounds per ton weren't particularly useful for keeping track of nutrient removal, so he never did it. The family doesn't have a scale on the farm that's big enough to weigh forage boxes (wagons). The student decides that the next time forage is removed from a field, she will keep track of the number and volume of each load. She creates marks near the top of each forage box at half foot intervals and measures the internal dimensions. These measurements allow her to estimate volume (cubic feet) of forage loads at various heights in the boxes. She also decides that initially, she'll use the rough estimate of 5.0 lb DM ft^{-3} provided by Wiersma and Holmes (2000).

When harvest time arrives, the student decides to record data from two fields: one grown to alfalfa and one grown to corn silage. In the alfalfa field, she counts and adds up all of the volumes of alfalfa taken from each field by each box, then multiplies the total volume by 5.0 lb DM ft^{-3}. She does this for each of three cuttings of alfalfa during the season. She estimates that the total DM removed from the 50-acre field during the season was 450,000 lb. Using Eq. [3], she converts the total DM production to DM yield:

$$\text{DM yield (lb acre}^{-1}) = \frac{450{,}000 \text{ lb}}{50 \text{ acres}} = 9{,}000 \text{ lb acre}^{-1}\text{, or } 4.5 \text{ tons acre}^{-1}$$

On the field grown to corn silage, she followed the same procedure during harvest, counting the number of forage boxes and estimating their volume, then converting the results to estimates of DM yield. For the 60-acre field, she estimated that 315,000 lb of DM was harvested, which amounted to 5250 lb DM acre^{-1}, or 2.63 tons acre^{-1}.

Now that she has some yield estimates, she wants to use some of the published removal rates to estimate the nutrient removal by alfalfa and corn silage. The removal rates she finds are 12 lb P_2O_5 and 50 lb K_2O ton^{-1} for alfalfa and 3.1 lb P_2O_5 and 7.3 lb K_2O ton^{-1} for corn silage. The moisture of plant material for these estimates is not given, so she assumes, using Table 1, that corn silage is 35% DM and that alfalfa is 85%. With these assumptions, she converts the published coefficients from a moist to a DM basis, using Eq. [9]. For alfalfa, she finds for P that:

$$P_2O_5 \text{ removal rate } \left[\text{lb (ton DM)}^{-1}\right] =$$

$$\left[\frac{12 \text{ lb } P_2O_5 \text{ (moist ton)}^{-1})}{85\% \text{ (moist ton)}^{-1}}\right] \times 100\% \text{ DM (ton DM)}^{-1} =$$

$$14 \text{ lb } P_2O_5 \text{ (ton DM)}^{-1}$$

Using the same method, she calculates that the K_2O removal for alfalfa is 59 lb K_2O ton^{-1}. Similarly, she finds that for a DM ton of corn silage, 8.9 lb P_2O_5 and 21 lb K_2O are removed.

Next she estimates nutrient removal for the alfalfa and corn silage crops just harvested. She does this by multiplying the removal rates by the DM yield. For instance, for alfalfa P removal, she calculates:

$$P_2O_5 \text{ removal (lb } P_2O_5 \text{ acre}^{-1}) = \left[14 \text{ lb } P_2O_5 \text{ (ton DM)}^{-1}\right]\left(4.5 \text{ tons DM acre}^{-1}\right) = 63 \text{ lb } P_2O_5 \text{ acre}^{-1}$$

Similarly, she calculates that alfalfa has also removed 266 lb K_2O acre^{-1}. She estimates that the corn silage removed 23 lb P_2O_5 and 55 lb K_2O acre^{-1}.

She then decides to do some further estimating. Using the values she just calculated, she examines a five-year nutrient budget that considers the manure applications they typically make and the nutrients removed. Since she doesn't have yield information for past crops, she uses the information she has and substitutes it for the missing years in her budget. She assumes that the 63 lb P_2O_5 and 266 lb K_2O acre^{-1} estimated for this year's alfalfa crop is removed in each of the three years it is grown. This gives a total estimated removal rate for alfalfa in the crop rotation of 189 lb P_2O_5 and 798 lb K_2O acre^{-1}. In the same manner, she estimates that the two years of corn silage removes a total of 46 lb P_2O_5 and 110 lb K_2O acre^{-1}. Summing these together for the five-year period, she gets 235 lb P_2O_5 and 908 lb K_2O acre^{-1}. When she uses Eq. [21] to compare these removals to the total nutrient application rates during this period (340 lb P_2O_5 and 540 lb K_2O), she finds that the P budget is positive (105 lb P_2O_5 acre^{-1}) and the K budget is negative (−368 lb K_2O acre^{-1}). Examining the last soil test that was taken, she sees that soil test P levels on some fields are approaching levels where different P management strategies may need to be employed. She also notices that soil test K levels were not as high as they should be, and with negative budgets, they aren't expected to get any higher unless supplemental K is added.

Using the information she has gained, she intends to do some tissue sampling in the future, rather than rely solely on estimated removal rates. She also feels that the farming operation may want to devise some system for keeping better track of DM removal from the fields, so that better plans can be put in place to manage nutrients.

Sample Calculation 2 »

Grain Example

A farmer is using a grain moisture meter, a portable grain scale used for measuring test weight, and a grain cart fitted with a scale. In the last load harvested, the scale reads 35,101 lb. After taking the reading, the farmer begins to transfer grain from the cart to the truck hopper. During the transfer, he takes three flow samples and dumps each one into a separate bucket. He then mixes the grain in each bucket and takes representative samples. On each sample, he measures moisture and test weight and then averages the three readings together. He finds the average moisture to be 21.3% and the test weight to be 60.5 lb bu^{-1}. Using Eq. [2], he calculates his DM weight in the load to be:

$$\text{DM weight (lb)} = 35{,}101\ \text{lb} - \left(35{,}101\ \text{lb} \times \frac{21.3\%}{100\%}\right) = 27{,}624\ \text{lb}$$

When he adds this to the DM weights from the other 11 grain cart loads from the field, he gets a total of 342,000 lb. Using Eq. [3] he finds the DM yield:

$$\text{DM yield (lb acre}^{-1}) = \frac{342{,}000\ \text{lb}}{40\ \text{acres}} = 8550\ \text{lb acre}^{-1}$$

Last, he uses the moisture and test weight data to calculate the amount of DM in a bushel of his grain, according to Eq. [16]:

$$\text{Bushel DM weight (lb DM bu}^{-1}) =$$
$$60.5\ \text{lb bu}^{-1} - \left[60.5\ \text{lb bu}^{-1} \times \left(\frac{21.3\%}{100\%}\right)\right] = 47.6\ \text{lb DM bu}^{-1}$$

The farmer then combines the grain in all three buckets, takes a representative sample, and sends it off to the laboratory.

A few days later, he receives analytical results. He is particularly interested in the results for N (1.89%), P (0.29%), K (0.40%), and Zn (17 ppm). To calculate the removal of these nutrients from the DM yield, the farmer uses Eq. [5–8]:

$$\text{N removal (lb acre}^{-1}) =$$

$$8550 \text{ lb acre}^{-1} \times \frac{1.89\%}{100\%} = 162 \text{ lb N acre}^{-1}$$

$$P_2O_5 \text{ removal (lb } P_2O_5 \text{ acre}^{-1}) =$$

$$8550 \text{ lb acre}^{-1} \times \frac{0.29\%}{100\%} \times 2.29 = 57 \text{ lb } P_2O_5 \text{ acre}^{-1}$$

$$K_2O \text{ removal (lb } K_2O \text{ acre}^{-1}) =$$

$$8550 \text{ lb acre}^{-1} \times \frac{0.40\%}{100\%} \times 1.20 = 41 \text{ lb } K_2O \text{ acre}^{-1}$$

$$\text{Zn removal (lb acre}^{-1}) =$$

$$8550 \text{ lb acre}^{-1} \times \frac{17 \text{ ppm}}{1{,}000{,}000} = 0.14 \text{ lb Zn acre}^{-1}$$

The farmer wants to compare his rates of removal with those published by others, just to see how different his are. Using Eq. [17–20] he calculates:

$$\text{N removal rate (lb bu}^{-1}) =$$

$$\left(\frac{1.89\%}{100\%}\right) \times 47.6 \text{ lb DM bu}^{-1} = 0.900 \text{ lb N bu}^{-1}$$

$$P_2O_5 \text{ removal rate (lb } P_2O_5 \text{ bu}^{-1}) =$$

$$\left(\frac{0.29\%}{100\%}\right) \times 47.6 \text{ lb DM bu}^{-1} \times 2.29 = 0.32 \text{ lb } P_2O_5 \text{ bu}^{-1}$$

$$K_2O \text{ removal rate (lb } K_2O \text{ bu}^{-1}) =$$

$$\left(\frac{0.40\%}{100\%}\right) \times 47.6 \text{ lb DM bu}^{-1} \times 1.20 = 0.23 \text{ lb } K_2O \text{ bu}^{-1}$$

$$\text{Zn removal rate (lb bu}^{-1}) =$$

$$\left(\frac{17 \text{ ppm}}{1{,}000{,}000}\right) \times 47.6 \text{ lb DM bu}^{-1} = 0.0008 \text{ lb Zn bu}^{-1}$$

He finds that his values for N and Zn are close to published estimates, but his values for P and K are a bit lower, but reasonable.

Finally, the farmer wants to examine the P and K nutrient budgets for the field. He uses a corn–soybean rotation. The last sample he took was three years ago. Since that time, he has grown two corn crops and one soybean crop.

He plans to do soil sampling again next year after soybean harvest. He knows that the budget won't be complete until he factors in the removal for next year's soybean crop. Even so, he wants to see where the field is now and predict where it might be after next year.

Since the farmer already measured the nutrient removal for this year's corn crop, he needs only to calculate removal for the soybean and corn crops from the previous two years. Because this was the first year he took grain samples, he doesn't have his own nutrient removal rates to use. Consequently, he uses standard estimates from the Cooperative Extension Service in his state. For corn grain, he uses removal rates of 0.38 lb P_2O_5 bu^{-1} and 0.27 lb K_2O bu^{-1}. For soybean grain, he uses 0.84 lb P_2O_5 bu^{-1} and 1.3 lb K_2O bu^{-1}. His records on the field show that corn grain yield two years ago was 200 bu $acre^{-1}$ and that soybean yield last year was 60 bu $acre^{-1}$. Multiplying the standard removal coefficients by these grain yields estimates P_2O_5 and K_2O removal by the corn two years ago to have been 76 lb P_2O_5 and 54 lb K_2O $acre^{-1}$. The soybean crop last year removed 50 lb P_2O_5 acre and 78 lb lb K_2O $acre^{-1}$. So for the last three years, the amount of P_2O_5 removed is 183 lb P_2O_5 $acre^{-1}$, found by summing 76 lb P_2O_5 $acre^{-1}$ (corn 2 yr ago) + 50 lb P_2O_5 $acre^{-1}$ (soybean last year) + 57 lb P_2O_5 $acre^{-1}$ (corn this year). Similarly, K_2O removal has been 173 lb K_2O $acre^{-1}$.

The farmer next examines the amount of nutrients he applied. Two and a half years ago, in the fall before the corn crop was grown, he had his fertilizer dealer apply 200 lb $acre^{-1}$ of 10–52–0 (104 lb P_2O_5 $acre^{-1}$) and 200 lb 0–0-60 (120 lb K_2O $acre^{-1}$). Last year, he had the same amount applied again after soybean harvest. So, the total for the two applications is 208 lb P_2O_5 and 240 lb K_2O $acre^{-1}$.

To evaluate his current nutrient budget, he subtracts the total amount of nutrients removed from the total applied. For P_2O_5 this is 208 lb P_2O_5 $acre^{-1}$ − 183 lb P_2O_5 $acre^{-1}$ = 25 lb P_2O_5 $acre^{-1}$. For K_2O, the budget is 240 lb K_2O $acre^{-1}$ − 173 lb K_2O $acre^{-1}$ = 67 lb K_2O $acre^{-1}$. So right now, budgets for both nutrients are positive. Because no more nutrient applications are planned before next year's soybean crop, the farmer wants to predict what the budgets will be after that crop is harvested. Again using standard estimates and a predicted yield of 60 bu $acre^{-1}$ (the same as the last soybean crop harvested), the predicted removal is 50 lb P_2O_5 $acre^{-1}$

and 78 lb K_2O acre^{-1} for next year. When these values are added to the current nutrient budget, the results are −25 lb P_2O_5 acre^{-1} and −11 lb K_2O acre^{-1}.

The farmer also looks at the soil test results from samples taken three years ago. According to the laboratory report, P levels were lower than the farmer and the adviser felt they should be, but K levels were about right. While the budgets for both nutrients are negative, the one for K is not far from being balanced. The farmer feels that the budget for K is probably within error of being balanced. However, the negative P budget is of concern, because it will not build soil tests to desired levels.

General Comments

It is advisable to take several samples to get an estimate of the average nutrient removal rates under the management practices encountered. Don't put too much weight on just a few samples. If you are unsure of your analyses, standard, published removal rates may always be used. Always keep good records, and be sure to retain laboratory analysis sheets, as well as moisture and test weights if available. The more analyses you collect, the better your average estimate of local nutrient removal rates will become.

Supplemental information about the samples may also prove useful when interpreting analysis results. If possible, gather information about manure application history, cropping history, soil test levels, hybrid/variety, planting date, and any other information you think may impact nutrient removal rates in your area.

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