

Nutrient Uptake Timing by Crops

to assist with
fertilizing decisions

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EXTENSION

Timing the application of nutrients so that they are available before peak crop nutrient demand is critical. Adequate nutrients early in the growing season are necessary to maximize yield and ensure that especially nitrogen (N) and phosphorus (P) are available for good grain or seed fill. A large portion of N and P used for grain and seed fill comes from the stem, leaves, and head, rather than directly from the soil. If these nutrients are not available for early plant growth, then yield and efficiency of fertilizer use are reduced. Maximum nutrient uptake varies among crops, and generally occurs prior to maximum growth rates. The objective of this document is to present nutrient uptake curves for selected Montana crops (small grains, oilseeds, corn and sugar beet) to help growers and their advisers optimally time fertilizer applications. The focus is on N because it is more commonly topdressed than P or potassium (K).

INTRODUCTION

All plants require the same mineral elements; however, the quantity, rate and timing of uptake vary with crop, variety, climate, soil characteristics and management. These combined factors influence the nutritional need, nutrient content, and overall yield of a crop. When fertilizer prices represent a large portion of a producer's costs, it is very important to maximize fertilizer nutrient use efficiency (the percentage of applied nutrient removed by the crop). Timing fertilizer applications so that nutrients are available when plants need them should increase nutrient use efficiency and reduce potential adverse environmental effects.

Plants require a balanced supply of nutrients throughout their development. Generally, they have accumulated most of their nutrients by sometime between flowering and ripening stages. Approximately 50 to 90 percent of N and P in the plant at flowering moves from the leaves and stem to the developing seed (1). Therefore, low nutrient uptake early in a plant's growth lowers nutrient quantity for the seed, affecting both yield and quality.

Knowing how nutrient needs change during the growing season is essential for matching nutrient supply with plant needs, especially for producers who can apply nutrients in-season or for those considering controlled- and slow-release fertilizers. Because nutrient uptake varies among regions and growing seasons, the results presented in this guide should be considered as general guidelines only.

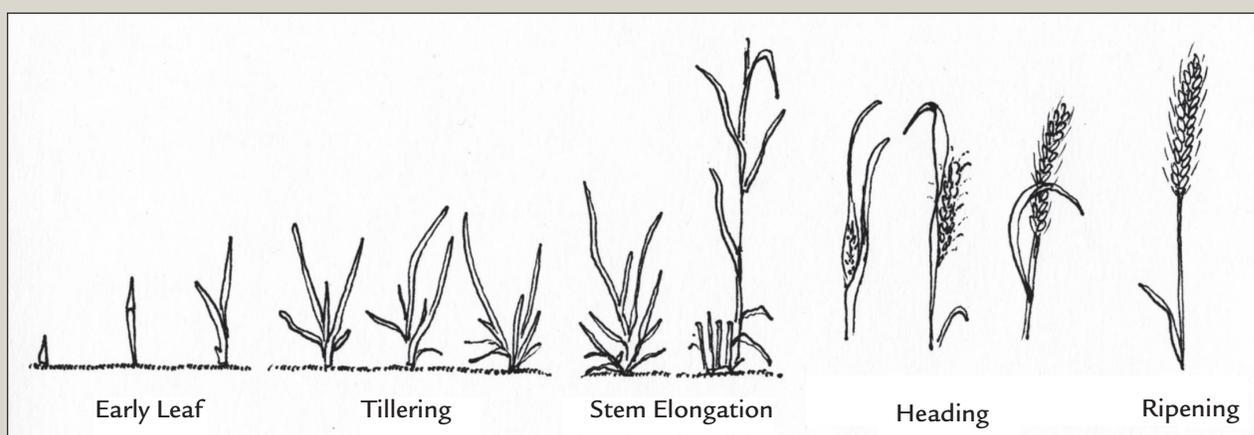


FIGURE 1. Approximate cereal grain growth stages. Flowering may occur before or after head emergence, depending on crop and variety. This figure was modified from its original (2).

CROP GROWTH

GROWTH STAGES Crop nutrient uptake rates are different at each growth stage, and crop growth rates vary with crop, variety, and growing conditions. Therefore, we encourage producers to base their in-season fertilizer management decisions on crop growth stage rather than time of year or an index of crop growth such as ‘Days After Emergence’.

For the purposes of this document, cereal grain plant growth is divided into five basic growth stages (early leaf, tillering, stem elongation, heading and ripening; Figure 1). Tillering refers to the development of small shoots coming from buds at the base of the plant. Heads begin to develop on each tiller even before the stem becomes visible between leaves (stem elongation). However, ‘heading’ begins when the seed head is pushed up through the last leaf and becomes visible. During ripening, lower leaves may die because nutrients stored in the lower leaves are moved to the grain.

Oilseed crop growth stages are divided into branching, bud formation, flowering and ripening. As an example, canola growth stages are illustrated and defined by the Canola Council of Canada (3). Corn growth stages are defined by leaf, tassel, silk and kernel development. They are illustrated and defined in a North Dakota State University publication (4).

NUTRIENT FUNCTIONS The three nutrients N, P, and K are classified as the ‘primary’ macronutrients because deficiencies of N, P and K are most common. Small amounts of N are important early for seedling vigor. However, high rates of N may damage seedlings and over-stimulate vegetative growth early in the season depleting soil moisture and depressing yields. Also, excess N may delay crop maturity. Phosphorus is necessary for energy storage and transfer and is essential for vigorous growth and seed development. It enhances crop maturity and quality, especially in grain crops. Potassium maintains water balance and therefore stalk strength. In addition, K promotes energy generation which is required for moving nutrients in the plant, N uptake and protein synthesis. Crops that are K deficient can have low total N uptake, yield, and protein.

For more information on plant nutrients, refer to MSU Extension’s *Nutrient Management Module 2* (#4449-2). See “Extension Materials” at the back of this publication for information on how to acquire referenced Extension publications.

NUTRIENT UPTAKE CURVES

Understanding nutrient uptake patterns of crops can help producers and their advisers determine the optimal timing of fertilizer applications. Our focus is on N because it is more commonly topdressed than other nutrients (see text box, below). The P and K accumulation and uptake curves illustrate the translocation of P and K into developing seed and importance of early availability of these nutrients.

HOW WOULD I USE AN N UPTAKE CURVE TO DETERMINE WHEN TO FERTILIZE?

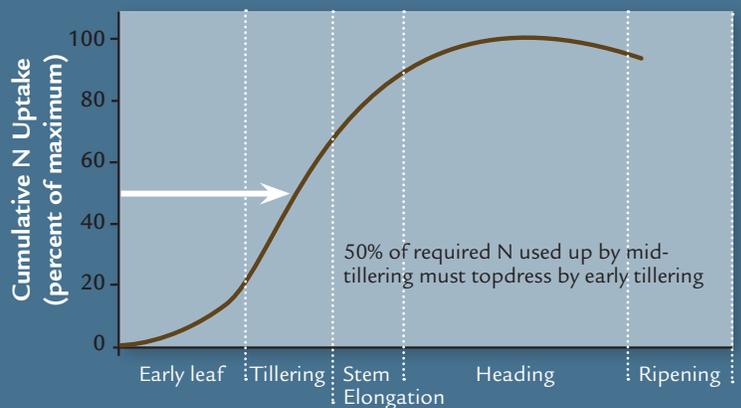
1. You first need to know crop N need and soil nitrate-N (preferably sampled in spring) to find the fertilizer N need.

Example with spring wheat

- ♦ expected N needed for 60 bu/acre yield \approx 200 lb N/acre (see *Fertilizer Guidelines for Montana Crops*, EB0161, for crop requirements)
- ♦ soil nitrate-N (from soil test) = 40 lb N/acre
- ♦ assume 60 lb N/acre preplant
- ♦ available at germination $40 + 60 = 100$ lb N/acre

2. Determine latest time that you could topdress:

- ♦ The soil and preplant fertilizer supply ($100/200 \times 100\%$) = 50% of the total N required.
- ♦ From Figure 3a, this amount only meets the requirements of wheat into mid- to late-tillering.
- ♦ Additional N needs to be applied at the beginning of tillering to allow time for fertilizer to become available and prevent N deficiency.



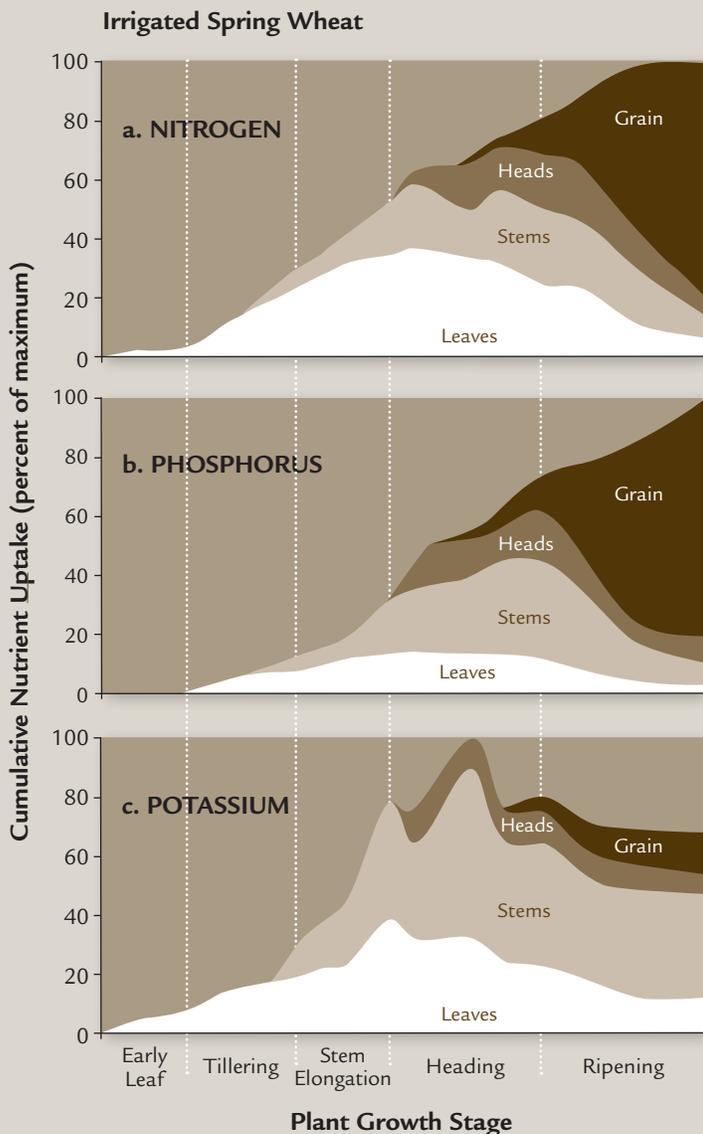


FIGURE 2. Nutrient accumulation in leaves, stem, head and grain of irrigated hard red spring wheat as a percent of each nutrient's maximum; a) nitrogen, b) phosphorus, and c) potassium. This figure was modified from its original (5).

SMALL GRAINS Nutrient uptake patterns are similar among barley, oat and wheat. We use wheat as the example. It has a high N uptake rate early in its development, with the maximum measured at tillering (steepest slope in curves on Figures 2a and 3a).

The rate of P and K uptake peaked between stem elongation and the beginning of heading in Montana (steepest slope in curves on Figures 2b and c). In Saskatchewan, the uptake rate of P and K was consistently high from tillering to stem elongation (Figure 3b).

In the Montana study, more than 70 percent of the total above ground N and P had been accumulated by the beginning of grain fill (Figures 2a and b). More than 55 percent of grain N and P came from redistribution of these nutrients accumulated by the leaves, stems, and head; the rest came from the soil. In the Saskatchewan study, wheat also accumulated most of its P by the peak of heading and beginning of grain fill (Figure 3b). In contrast, maximum N accumulation was reached during early heading. This was from full flowering to the end of flowering (Figure 3a) and earlier than in the Montana wheat.

In a nutrient uptake study on dryland spring wheat in Mandan, North Dakota, the time of maximum N accumulation depended on nutrient availability. The stands that received both N and P peaked in N accumulation by heading; those stands fertilized with only N reached peak accumulation during ripening; and those that were not fertilized were still taking up N at maturity (8). Maximum P accumulation occurred by heading, independent of available N levels. Regardless of when maximum accumulation is reached, sufficient N and P early in the growing season are critical to meet the demands of grain fill.

Maximum K accumulation occurred just after flowering, or mid heading, in the Montana study (Figure 2c). In the Saskatchewan study, maximum K accumulation was reached slightly earlier, during flowering and early heading (Figure 3b). Unlike N and P, very little of the accumulated K is used for grain fill (less than 20 percent, Figure 2c). Yet, K deficiency early in the growing season would limit N uptake and compromise yield and protein.

OILSEEDS Maximum N uptake rates for oilseeds are during branching and early bud formation, as illustrated by canola (Figure 4). Although the time when nutrients are accumulated most rapidly will vary with yearly growing conditions (Figure 4), it always comes before maximum accumulation and early in the crop's growth. Total N accumulation has been found to peak during the flowering stage. The uptake pattern for P and K are very similar to that of N, emphasizing the importance of early P and K availability for high seed production (9).

CORN AND SUGAR BEET Since corn and sugar beet are usually irrigated and can be fertigated (adding nutrients in irrigation water), N fertilization can be timed to match their N needs. In a Manitoba study, maximum N uptake rates in corn occurred between the 8-leaf to tassel emerging stage and again from silking to the dent stage (Figure 5). By the 10-leaf stage, 40 percent of the plant's N had been accumulated. At maturity, 73 percent of the total plant N was located in the grain (10). Over half the N required for grain fill came from the leaves and stalk. Therefore, insufficient N early in corn growth could greatly limit grain yield.

In sugar beet production, the N demand of seedlings is relatively small but critical for the plants to attain canopy closure as quickly as possible (13). As these early leaves mature there is very high demand for N, because they supply much of the N needed for root growth (Figure 5; 11). However, applying N after canopy closure or the onset of bolting causes increased top growth at the expense of sucrose quality and accumulation in the roots (12). After mid to late summer there should be no additional N uptake and the leaves begin to die as nutrients move into the growing roots.

LEGUMES Legumes fix their own N if the proper inoculants and sufficient amounts of P, K, sulfur (S) and micronutrients are present (*Growing Dry Pea in Montana, MT200502AG*). Maximum N uptake occurs during branching and early bud formation (14). Therefore early growing season availability of P and K is critical not only for direct incorporation into plant biomass but to ensure early N fixation.

CLIMATE Regional or yearly climatic differences will alter the rate and duration of nutrient uptake. The longer period of N, P, and K uptake by wheat in the Montana than the Saskatchewan study is likely because irrigation and rainfall (20 inches total during the study) allowed for continued water and nutrient uptake into maturity. The Saskatchewan study was on a dryland site (6 inches May to August rainfall in 1998 and 9 inches in 1999) where water and nutrient uptake would have been dramatically limited as plants approached maturity.

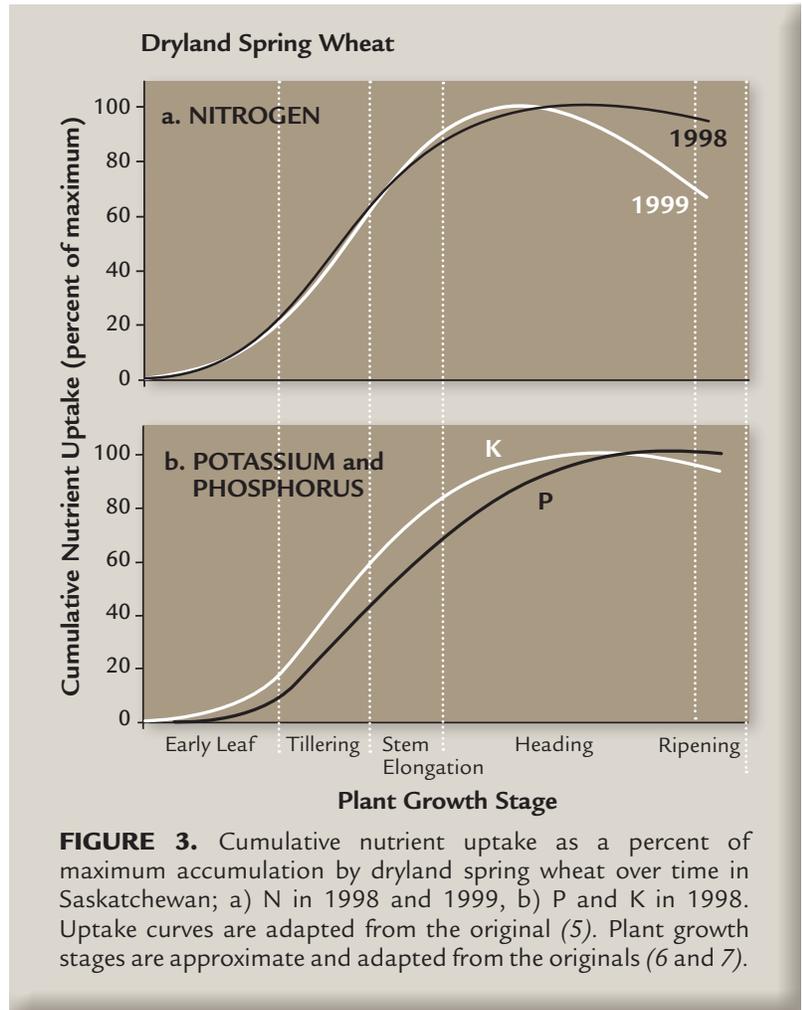


FIGURE 3. Cumulative nutrient uptake as a percent of maximum accumulation by dryland spring wheat over time in Saskatchewan; a) N in 1998 and 1999, b) P and K in 1998. Uptake curves are adapted from the original (5). Plant growth stages are approximate and adapted from the originals (6 and 7).

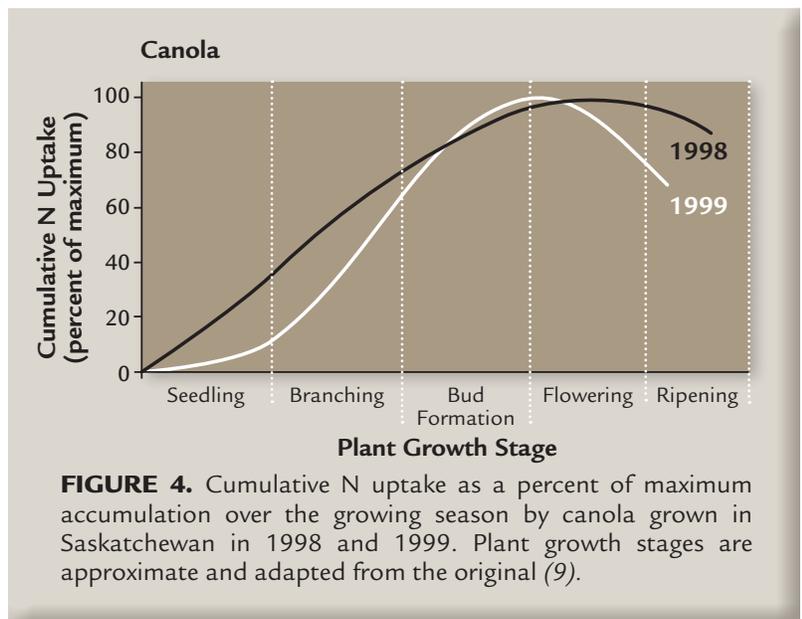


FIGURE 4. Cumulative N uptake as a percent of maximum accumulation over the growing season by canola grown in Saskatchewan in 1998 and 1999. Plant growth stages are approximate and adapted from the original (9).

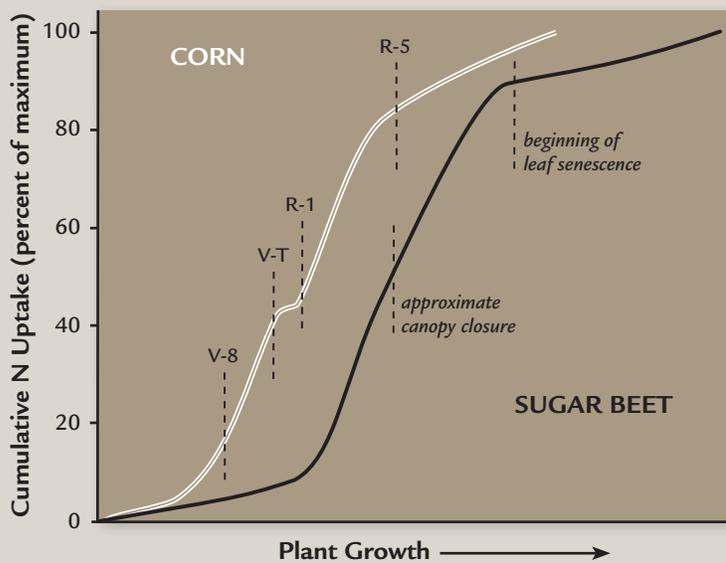


FIGURE 5. Cumulative N uptake as a percent of maximum accumulation by corn in Manitoba (V-8 = 8 leaf, V-T = tassel emergence, R-1 = silking, R-5 = dent) and sugar beet in Idaho. Adapted from originals (10, 11, 12).

The differences between the 1998 and 1999 uptake curves (Figures 3a, 4) were also likely caused by yearly climate variations which influenced the crops' growth and development. Optimal moisture and temperatures in 1999 promoted rapid growth, which required substantial nutrients early in the growing season. However, cold weather during ripening in 1999 apparently decreased N movement to the grain and resulted in N leaching or volatilization from the crop. Volatilization loss from plant tissue can be substantial. For example, winter wheat in Nebraska lost 20 to 40 percent of the soil applied N through volatilization from the plant tissue after anthesis (15). In the Saskatchewan wheat study, the actual N uptake was very different between 1998 and 1999, yet the N uptake pattern was very similar between the two years until mid-heading (Figure 3a). In canola, both the actual N uptake and the pattern of uptake over time (Figure 4) differed between years.

MANAGEMENT

Overall nutrient use efficiency and yield should increase if the correct balance of nutrients is available prior to maximum nutrient uptake. Maximum rate of uptake comes before maximum nutrient accumulation, which precedes maximum biomass. Therefore it is critical to apply fertilizer before maximum nutrient demands. This will ensure balanced nutrition for the crop and reduce the risk of nutrient deficiencies and decreased crop yield. It should also reduce fertilizer loss, increase nutrient use efficiency and is an environmentally sensitive management strategy (see *Crop and Fertilizer Management Practices to Minimize Nitrate Leaching*, MT201103AG).

In-crop fertilizer adjustments should be timed based on growth stage, when possible, rather than time of year. Nitrogen top-dressed at tillering increased both yield and protein of winter wheat grown in Montana, especially at low soil N levels (16). Waiting and applying N near the time of heading may help obtain optimum protein levels though it is generally too late to have an effect on yield (17). Since N is very mobile and a portion can be absorbed through the leaf, strategic timing would be particularly beneficial for producers that apply in-crop liquid N solutions.

Ideally, P and K fertilizer would be applied continuously to the root zone during early to mid-plant growth stages when P and K uptake are high. However, because P is very immobile and K is relatively immobile in the soil, this is not practical. In-season applications will likely not work their way into the root zone and foliar applications are not very effective since little P or K is taken up directly through the leaf. Therefore, P and K are best applied by subsurface banding at seeding, although K can also be broadcast at or near the time of seeding.

Using soil tests combined with nutrient uptake curves, producers and their advisers should be able to optimize both rate and timing of fertilizer application. For more information on soil testing and developing yield goals and/or fertilizer calculations, please see *Interpretation of Soil Test Reports for Agriculture* (MT200702AG) and *Developing Fertilizer Recommendations for Agriculture* (MT200703AG).

ENHANCED EFFICIENCY FERTILIZERS

Enhanced efficiency fertilizers (EEFs) have the potential to match nutrient availability with crop demand to provide a relatively predictable nutrient supply. EEFs slow the conversion of fertilizer to plant available forms, reduce fertilizer losses to leaching and volatilization, and reduce seedling damage when fertilizer is seed-placed (*Enhanced Efficiency Fertilizers*, [EB0188](#)). Controlled and slow release N fertilizers are coated or otherwise treated to slow the release of nutrients into the soil. An example is polymer coated urea. Stabilized fertilizers, such as urease and nitrification inhibitors have additives that alter or inhibit soil enzymatic and microbial processes to reduce fertilizer losses.

Ideally, the release of nutrients from EEFs would match the desired crop's nutrient uptake curve. Because EEFs delay the availability of applied nutrients, they must be applied sufficiently before peak crop demands. Currently, blends of EEFs with conventional fertilizers and future improved EEF technology should enable a close match between fertilizer nutrient availability and crop uptake. Please see *Enhanced Efficiency Fertilizers* for more information.

CONCLUSIONS

Matching fertilizer applications with crop nutrient uptake can optimize nutrient use efficiency and crop yield. This will become increasingly important if fertilizer prices rise, and air and water quality concerns continue to increase. Regardless of fertilizer costs, sufficient levels of nutrients should be provided so that plants have the nutrients they need throughout the growing season. Nitrogen should be applied no later than early tillering or branching, shortly before N uptake rate is the highest and likely most or much of the residual soil nitrate is used up. Optimal timing for in-season split applications of N can be determined using the provided crop nutrient uptake curves. Although maximum uptake rates of P and K come at a later growth stage than N, these nutrients need to be available to the young plants in the root zone. Therefore they are best supplied at or near seeding.

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EXTENSION MATERIALS

The following Extension publications can be found at <http://landresources.montana.edu/soilfertility/publications.html>

Crop and Fertilizer Practices to Minimize Nitrate Leaching (MT201103AG)

Developing Fertilizer Recommendations for Agriculture (MT200703AG)

Enhanced Efficiency Fertilizers (EB0188)

Fertilizer Guidelines for Montana Crops (EB0161)

Growing Dry Pea in Montana (MT200502AG)

Interpretation of Soil Test Reports (MT200702AG)

Nutrient Management Modules (#4449-1 to 4449-15)
<http://landresources.montana.edu/nm>

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