Estimating Nutrient Removal of Hay Production in Arkansas

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Arkansas forage production accounts for about 5.3 million acres of the state's land use as recorded by the 2017 census (USDA-NASS, 2017). Of this, pasture usage accounts for roughly 4 million acres and the remaining 1.3 million acres are used solely for hay production. Despite the similarities of these two production systems, their management requirements can be quite different, especially regarding soil fertility, nutrient management and fertilizer applications. Considering the amount of agricultural land occupied by these two systems, understanding the differences between these production systems and their respective nutrient management is vital to maximize production and profitability and minimize environmental and financial risks.

Harvesting of hay and grazing by livestock are the two primary pathways for nutrient removal by forage crops and pastures. Effective nutrient management strategies should aim to increase the productivity of each of these systems while reducing the unnecessary removal of nutrients from the field. These strategies should be based on sound research focused on validating the estimates of nutrient removal specific to regional production practices. Grazed production systems typically result in a level of nutrient cycling that returns at least a portion of the nutrients contained in the aboveground forage biomass to the soil through manure deposition, whereas a hay production system typically results in the removal of all nutrients contained in the aboveground biomass with each harvest.

Although nutrient removal varies from field to field, seasonally and among plant species, estimating nutrient removal is a useful tool for managing and budgeting nutrients when used properly. However, nutrient removal does not provide all the necessary information needed to develop fertilization management plans and should not be used as the sole basis for management. Using nutrient removal as the sole basis for fertilizer management is not suggested because some nutrients are immobile in the soil such as phosphorus (P), potassium (K), and zinc (Zn). These immobile nutrients are retained in the soil in larger quantities and supplied to the plant based upon availability and for these nutrients, soil testing allows for better estimation of fertilizer needs and long-term nutrient management. Nutrient removal rates used in conjunction with soil test levels can develop and improve nutrient management programs.

Hay Production vs. Pasture Grazing

Hay and pasture systems will typically require similar management throughout most of the season with the goal of increasing forage biomass. While the goal of hay and pasture production may be similar the nutrient cycling of the two systems is vastly different. In grazing systems, nutrients taken up by the plant are consumed by grazing animals and digested. Undigested nutrients and nutrients not retained for bodily function, growth, or milk production are redistributed to the field through urination and defecation. This process results in a lower total nutrient removal from the system relative to haying. Nutrient management is still a major concern for pasture systems, especially for nitrogen (N) with urinary (N) having a greater risk of loss from the system than fecal (N). Although the grazing system recycles nutrients, both redistribution of these nutrients in the field and susceptibility for N losses justify regular monitoring through soil and forage sampling and analysis. The lack of a uniform distribution of soil nutrients across the landscape in grazed forage systems may be exacerbated by hay and supplement feeding locations, water locations, and areas of shelter or shade. The land area represented by these sites should be considered when sampling soil and plants for nutrient analysis to ensure they don't bias the results. Hay production has a greater nutrient removal rate than grazing as the nutrients are taken up by the plant biomass, that biomass is harvested at a higher level of uniformity and efficiency, and the harvested product is typically removed from the field. In contrast to the re-distribution of nutrients in a pasture, hay production can lead to nutrient deficits if not monitored. The nutrients taken up by the hay that was removed from the field must be replaced to prevent yield-limiting nutrient-deficient conditions. Soil-test values, forage yield, and hay production profitability can change significantly in a few years if fertilization is not managed properly. Recent research in Arkansas has identified trends of reduced yields and nutrient removal as soil test nutrient levels decrease over time (Drescher et al., 2022, 2023; Mengez et al., 2024). While both systems result in some nutrient removal, this fact sheet will be focused on discussing the nutrient removal of hay production systems as these often create the largest concern due to the high rate of total nutrient removal.

Nutrient Uptake vs. Nutrient Removal

Nutrient uptake is defined as the total amount of nutrients taken up by the crop throughout a growing season. Total nutrient uptake is typically quantified from the aboveground portion of the plant, in most crop production systems. In many other crop production systems, a portion of the nutrients taken up are returned to the soil by crop residues such as stalks, stubble, or leaves. Nutrient removal refers to the amount of nutrients that are removed from the field during the harvest process such as in the grain, fiber crops, or hay that is then sold or used elsewhere. Compared to grain, fiber crops, and oil seed production, hay production will observe a greater relationship between the total nutrient uptake and nutrient removal due to a greater amount of plant material that is removed with each harvest, with less residue returned to the soil. Another aspect to consider regarding nutrient removal in hay production systems is the number of harvests per year. If a hay crop is harvested multiple times during the season this can lead to very large nutrient removal rates if biomass production is moderate to high.

Estimating Nutrient Removal

Nutrient removal by forage crops can be estimated in many ways, with the most common method being the use of standard nutrient concentrations and crop yield or biomass production. Nutrient concentrations are available through many sources such as the International Plant Nutrition Institute (IPNI). Nutrient concentration estimates presented by these sources are typically developed over broad geographic regions and crop production practices. Estimates of nutrient removal for forage species common to Arkansas forage and pasture production systems are listed in Table 1. Other resources are available for nutrient removal estimates, in addition to the ones provided here, such as smartphone applications, web-based calculators, and reference tables developed by companies and universities. One example is the Interactive Feed Composition Library by Dairy One (https://apps.dairyone.com/feedcomposition/), a database of forage analysis results providing average measurements for a range of parameters.

Table 1. Nutrient removal estimates for common forage crops in Arkansas.

CROP	NUTRIENT REMOVAL† (LB PER TON OF DRY MATTER)		
	N	P_2O_5	K_2O
Grass Species			
Bahiagrass	43	12	35
Bermudagrass	46	12	50
Fescue	37	12	54
Orchardgrass	36	13	54
Annual ryegrass	43	12	43
Sorghum-Sudan	30	9.5	34
Timothy	25	11	42
Legume Species			
Alfalfa	51	12	49
Red Clover	45	12	42
Soybean Hay	45	11	25
Vetch	57	15	49

†Data for nutrient removal obtained from the International Plant Nutrition Institute (IPNI).

While these tools simplify the process of estimating nutrient removal, compared to hand calculation, it is important to remember these are only estimations and can only be as good as the data in which they are based. The best way to determine nutrient removal is to collect a biomass sample of the forage and have it analyzed through a diagnostic laboratory. Many labs can provide this service including the University of Arkansas Fayetteville Agricultural Diagnostic Lab located in Fayetteville, AR. One aspect of forage production that is different from grain crop production is the high variability that can exist in forage nutrient concentrations based on cultural and fertilization management practices. Grain nutrient concentrations are typically very similar and consistent across production systems and cultural management practices; however, forage nutrient concentrations can vary greatly depending on soil nutrient availability, fertilization practices, and overall forage biomass production, especially for nutrients that are luxury consumed (plants take up more of a nutrient than needed for functioning if availability is high) such as N and K.

Nutrient removal is often reported as a percentage or concentration on a dry matter basis (mg nutrient/kg biomass, ppm, or percentage). While hay is often field dried, and moisture is low, moisture is still an important factor to consider when estimating nutrient removal. Yield can be determined by multiplying the average weight of the bales by the number of bales produced per acre. The following example provides the steps for estimating dry matter yield based on the moisture content of the hay, the number of bales produced, and the average weight of the hay bales.

Example 1. Estimating dry matter hay yield in pounds per acre.

$$\frac{100\ bales}{(40\ acres)} \times \frac{(800\ lb)}{(1\ bale)} \times \frac{(100 - 13.3\%\ moisture)}{(100)}$$
$$= 1{,}734\ lb\ Dry\ Matter/acre$$

Based on this example, the dry matter yield of this 40-acre hay field is 1,743 pounds of dry matter per acre using the moisture content from the forage analysis report and the number and weight of bales produced.

Once dry matter yield has been calculated, nutrient removal estimates can be calculated based on the dry matter yield and forage nutrient analysis. Nitrogen concentration in plant tissue and grain is measured as total N but may or may not be reported depending on the lab used or the analysis requested. When requesting forage analysis, most labs will provide crude protein. Crude protein is referred to as "crude" because it is calculated from N, and protein is generally made up of 16% N. Percentage N can therefore be backward calculated from percentage crude protein by dividing percentage crude protein by 6.25 (100 ÷ 16 = 6.25). Example 2 shows how to calculate N removal by forage on a dry matter basis using the conversion factor for crude protein.

Example 2. Estimating N removal in forage based on crude protein on a dry matter basis.

$$\frac{12.9\ \%\ Crude\ Protein}{(6.25 \times 100)} \times \frac{1{,}734\ lb\ Dry\ Matter}{(1\ acre)}$$
$$= 35.79\ lb\ N\,/\,acre$$

Crude protein measures are values based on total N taken up by the plant, including both organic and inorganic forms of N. Crude protein content and nitrate-nitrogen (NO_3-N) are separate measurements, nitrate-nitrogen is used for toxicity evaluation and does not represent all forms of N contained in the biomass. More information on nitrate toxicity can be found in the *Nitrate Poisoning in Cattle* factsheet (Gadberry & Jennings; FSA3024).

Unlike N measurements, P and K concentrations are reported in the amount of the elemental nutrient measured in the biomass. Therefore, no transformation is needed to determine the elemental nutrient removals of P and K. Example 3 shows the method for calculating the amount of P and K removed by the produced hay.

Example 3. Estimating P and K removal in forage on a dry matter basis.

Example 3.1 Estimating P removal in forage dry matter.

$$\frac{0.27\ \%\ P}{100\%\ Dry\ Matter} \times \frac{1{,}734\ lb\ Dry\ Matter}{(1\ acre)}$$
$$= 4.68\ lb\ P\,/\,acre$$

Example 3.2 Estimating K removal in forage dry matter.

$$\frac{3.1\ \%\ \mathrm{K}}{100\%\ Dry\ Matter} \times \frac{1{,}734\ lb\ Dry\ Matter}{(1\ acre)}$$
$$= 53.75\ lb\ \mathrm{K\ /\ acre}$$

Based on this example, the nutrient removal on a dry matter basis is 4.68 lb P/acre (elemental P) and 53.75 lb K/acre (elemental K) using the nutrient concentrations on a "Dry Matter Basis" from the forage analysis report and yield calculated in Example 1. If N is reported in the elemental form rather than crude protein, the equation in Example 3 can also be used to calculate N removal.

The expression P and K in a forage analysis report are the elemental concentrations. For nutrient management purposes, it is important to understand the difference between the elemental (P and K) and oxide (P_2O_5 and K_2O) expressions.

Laboratory analysis of grain and forage samples express nutrient concentration in the percentage of a given element, while fertilizers and fertilizer rate recommendations are expressed in the oxide nutrient form (e.g., 13-13-13, N-P_2O_5-K_2O). For nutrient management based on removal estimations a conversion from elemental P and K concentration to the oxide forms (P_2O_5 and K_2O) is necessary (Example 4).

Example 4. Conversion of elemental P and K to Oxide form.

Example 4.1 For conversion of elemental P to P_2O_5

$$\% \text{ P} \times 2.29 = \% \text{ P}_2\text{O}_5 \text{ or } lb \text{ P} \times 2.29 = lb \text{ P}_2\text{O}_5$$
$$4.68\ lb\ P/acre \times 2.29 = 10.72 \text{ lb } \text{P}_2\text{O}_5/acre$$

Example 4.2 For conversion of elemental K to K_2O

$$\% \text{ K} \times 1.205 = \% \text{ K}_2\text{O or lb K} \times 1.205 = \text{lb K}_2\text{O}$$
$$53.75\ lb\ K/acre \times 1.205 = 64.77\ lb\ \text{K}_2\text{O}/acre$$

If you are unable to determine the exact nutrient content of hay using a forage analysis, reliable sources can be used for estimate calculations. Example 5 uses values from Table 1 for Fescue to estimate the removal of P_2O_5 from the same 40-acre field that produced 100 bales weighing 800 lb per bale as is.

Example 5. Estimating P_2O_5 removal using removal estimates.

$$\frac{12\ lb\ \text{P}_2\text{O}_5}{2{,}000\ lb\ Dry\ Matter} \times \frac{1{,}734\ lb\ Dry\ Matter}{(1\ acre)}$$
$$= (10.4\ lb\ \ \text{P}_2\text{O}_5)/\text{acre}$$

Summary

Nutrient removal can be a useful tool to aid the management of nutrients and this publication outlines procedures for estimating nutrient removal of forages. However, nutrient management planning should not be solely based on the estimated removal of nutrients. Regular soil testing should be conducted to ensure soil fertility levels do not drastically change over time and create nutrient-limiting conditions. Nutrient balances (fertilization – crop removal) are based solely on managed inputs and measured outputs, not accounting for the natural inputs and outputs that occur in the field. Estimated nutrient removal supported by routine soil testing can become a useful tool for guiding nutrient management and fertilization and reducing the potential for over-fertilization and environmental loss.

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