Agronomy for dairy systems: Managing crops, nutrients, and whole‑farm interactions

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This article kicks off our new series, “ Agronomy for Dairy Systems.” Modern dairy agronomy must take a whole-farm, systems-based approach because crop production, forage quality, manure nutrients, feed rations, storage, and regulatory constraints are tightly interconnected. Optimizing dairy systems requires balancing yield with forage digestibility and managing manure as both a nutrient and soil-health resource, all while coordinating decisions across advisers to avoid unintended ripple effects. Earn 1.5 CEUs in Crop Management by reading the article and taking the quiz.

U.S. dairy farms operate across a wide continuum of scales and management systems, but industry consolidation has increasingly shifted production toward fewer, larger operations. As herd sizes and operational complexity grow, the interactions among cropping systems, feed needs, nutrient flows, and regulatory constraints become more tightly linked. For agronomists, this evolution increases the importance of system-wide thinking when supporting dairy clients.

In contrast to grain-only operations, crop production on dairy farms is embedded in a continuous feedback loop that integrates livestock nutrition, feed inventories, manure handling, storage constraints, and regulatory expectations. These linkages shape agronomic choices in ways that extend well beyond the field, requiring recommendations that account for the constant flow of feed and nutrients through the farm. The points below highlight what makes dairy agronomy distinct and why a systems-based approach is essential for effective decision-making.

- **Interdisciplinary support:** Dairies rely on advisory teams that may include nutritionists, veterinarians, environmental planners, financial advisers, and agronomists. Most farms also remain family managed with key decisions made by owner-operators.

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- **Year-round feed demand:** Because cows eat every day, cropping plans must align with harvest timing, storage capacity, and feed removal rates, not just field conditions.

- **Crop quality is co-equal with yield:** Crop production is an input to milk production, so digestibility and nutrient density matter alongside tons per acre.

- **Nutrient planning is system-based:** Nutrient management is shaped by manure generation, storage, land base, and permitting requirements. Fertilizer decisions sit within that larger system.

- **Ripple effects are real:** Changes in forage quality can influence intake and milk performance, which in turn, can affect nutrient excretion, manure composition, and application strategy.

Effective dairy agronomy requires whole-farm thinking and coordinated communication across advisers. **This article outlines three key agronomic considerations when working with dairy farms and highlights tools that support decision-making in integrated dairy systems.**

Key Point 1: Optimizing forage by aligning yield, quality, and storage

In grain systems, yield per acre is often the primary measure of success. In dairy forage systems, however, yield must be evaluated alongside forage digestibility and quality, both at harvest and after storage.

Role of forages in the ration

A dairy ration is typically a formulated mixture of forages, concentrates, minerals, and often by-product feeds. Each ingredient is analyzed, and a nutritionist balances the ration based on animal requirements, ingredient availability, and cost. In high-producing herds, forage commonly accounts for 45 to 65% of the ration's dry matter. It supplies most of the ration's fiber, a substantial portion of its protein, and, particularly in corn silage systems, a significant share of starch and energy.

Defining forage quality

Forage quality has two dimensions: measured nutrient composition and functional feed value at feedout.

- **Laboratory analysis** quantifies crude protein, starch, neutral detergent fiber (NDF), acid detergent fiber (ADF), fiber digestibility (NDFd), and energy concentration.

These parameters influence potential animal performance and ration flexibility.

- **Feed value** reflects how well those nutrients are preserved and remain available during storage and feeding. Aerobic stability, dry matter shrink, fermentation profile, and the presence of molds or mycotoxins all influence whether harvested nutrients are fully realized in the bunk. Forage with strong laboratory values can still underperform if fermentation is inconsistent or oxygen exposure leads to spoilage.

Impact of forage quality on cost of production and milk production

Forage quality is one of the strongest drivers of biological and economic performance on dairy farms because it governs how much digestible energy and effective fiber the cow can consume and convert into milk. Even relatively small shifts in digestibility or starch availability can create meaningful herd-level changes in intake, milk response, and purchased feed needs.

Fiber digestibility is a good example of how “small” changes scale. In a classic analysis, each 1 percentage-unit increase in NDF digestibility was associated with about 0.17 kg/day higher dry matter intake and 0.25 kg/day higher 4% fat-corrected milk (Oba & Allen, 1999). Those are per-cow effects; multiplied across hundreds or thousands of cows, improvements in NDFd translate into substantial additional milk and often better feed efficiency—without changing the acreage base.

Forage quality also strongly affects ration economics because it determines how much supplemental energy and protein must be purchased to hit production targets. Feed is typically the largest cost category on dairies; multiple sources place feed costs in the **~40–60%** range of the total cost of production (Penn State Extension, 2023). When forage digestibility and starch utilization are suboptimal—often due to delayed harvest maturity, high whole-plant dry matter, or inadequate kernel processing—rations may need to be adjusted to incorporate more higher-cost concentrates to maintain milk production and components.

Tips for improving forage quality

Forage quality is shaped long before it reaches the feed bunk. Decisions made at harvest—followed by the effectiveness of storage practices—determine how much digestible energy, fiber, and starch actually make it to the cow. Since losses can occur at every step, attention to detail is essential.

Harvest management

Harvesting forage at the optimal stage helps preserve nutrient levels and supports animal performance. Photo courtesy of Alexandra Wright.

- **Plant maturity:** Stage of maturity at harvest has a major impact on forage quality. Harvesting at the optimal stage helps preserve nutrient levels and supports animal performance. Harvesting too early or too late can reduce feed value.

- **Plant moisture:** Moisture content at harvest is critical for successful fermentation. Appropriate moisture supports efficient fermentation and reduces the risk of spoilage and nutrient loss. Excess moisture can contribute to effluent runoff while insufficient moisture can inhibit fermentation.

- **Processing of forage:** Length of cut and kernel processing influence storability and digestibility. Proper chop length supports packing and fermentation while effective kernel processing, especially for corn silage, improves starch availability and overall feed value.

Storage management

- **Density:** Adequate compaction creates the anaerobic conditions needed for proper fermentation. A well-packed bunker limits oxygen exposure and reduces spoilage. Improving packing density remains a common opportunity on many farms, especially those using horizontal silos.

A well-packed bunker limits oxygen exposure and reduces spoilage of forage. Photo courtesy of Adobe Stock/Lost_in_the_Midwest.

- **Fermentation and inoculants:** Inoculants can improve the speed and consistency of fermentation, helping preserve nutritional value and reduce spoilage. Uniform distribution is important for consistent results.

- **Excluding oxygen and water:** Oxygen and water are major contributors to forage spoilage. Effective compaction and the use of oxygen-limiting, waterproof covers help protect forage quality throughout storage.

- **Storage size:** Matching storage size to herd needs helps reduce feed waste and improve feedout management. Oversized bunks can contribute to underutilization, safety concerns, and spoilage.

Learn more

- Feed centers
- High quality silage management

Key takeaway: agronomic perspective

For agronomists working with dairy producers, the focus shifts from maximizing tons per acre to optimizing the nutritive quality of the ration as fed to the herd. When agronomy and nutrition are aligned, forage systems can improve economic efficiency, nutrient utilization and overall farm performance.

Key Point 2: Manure nutrient management in dairy systems

Dairy manure can be both an asset and a challenge. It supplies nitrogen (N), phosphorus (P), potassium (K), sulfur, micronutrients, and organic carbon, yet it is produced daily, must be stored safely, and must be land-applied within agronomic, weather, and regulatory limits. Below is an overview of the benefits and nuances agronomists may encounter when working with dairy manure.

Dairy manure nutrient content and composition

Dairy manure contains a mix of plant nutrients and organic matter with nitrogen present in both ammonium-N (immediately plant available but prone to loss if left on the surface) and organic-N (released gradually through mineralization). It also supplies phosphorus and potassium, often at levels that can meet or exceed crop needs depending on application rate as well as sulfur and micronutrients such as calcium and magnesium.

***Did you know?* Manure nutrient variability is the rule, not the exception**

The nutrient content of dairy manure can vary substantially within a farm and across farms because it reflects how manure is generated, handled, and stored. Key drivers include ration formulation, bedding material (e.g., sand vs. organic bedding), dilution with wash water or milkhouse waste, collection method (scrape vs. flush), storage type (pit, tank, lagoon), and time in storage. Because of this variability, nutrient management plans that rely on "book values" alone are prone to error. Regular manure testing and good sampling protocols are essential for credible nutrient budgets and for setting realistic crop-available N credits.

Learn more about manure nutrient concentration and variability at Manure DB.

Dairy manure can be solid (<75% moisture), slurry (75–90% moisture), or liquid (>90% moisture), depending on the region and management practices. Liquid and slurry manure contain much more water compared with other livestock manures, which increases hauling and application costs per unit of nutrient. Nutrient concentrations per gallon or ton can be modest and highly variable, so manure testing and good sampling are essential for setting reliable crop-available nutrient credits.

Manure and soil health benefits

Beyond its fertilizer value, dairy manure can measurably improve soil health by increasing organic carbon inputs that support soil structure and biology. A large meta-analysis found that manure application increased soil organic carbon (SOC) stocks by **~35.4% on average**, compared with soils not receiving manure though responses vary with climate and tillage (Glaser, 2021). As SOC rises, soils often show improved aggregation, porosity, infiltration, and plant-available water holding capacity—benefits that are frequently reported in long-term trials and reviews of manure-amended systems.

Manure also tends to increase soil microbial biomass and activity by supplying readily usable carbon substrates and nutrients. This can strengthen nutrient cycling and residue decomposition and meta-analyses, and field studies commonly report increases in microbial biomass under manure relative to mineral fertilizer alone (Ren et al., 2019).

Manure nutrient management complications

Managing dairy manure effectively requires understanding how its nutrients behave, how losses occur, and how farm logistics and regulations influence application choices. The following nuances help explain why manure planning must be both site specific and grounded in realistic operational constraints.

- **Nitrogen availability spans immediate and multi-year pools:** Manure N includes ammonium-N (immediately plant-available) and organic-N (released through mineralization over multiple seasons). In dairy manure, total nitrogen is commonly partitioned between ammonium-N and organic-N with organic-N often accounting for ~55% (liquid/slurry) to ~80%+ (solid) of total N, depending on storage and handling. The organic-N acts as a slow-release fertilizer with mineralization rates varying based on temperature, moisture, aeration, and manure C:N. Therefore, in practice, manure N crediting should be based on application history and expected mineralization, not a single-year snapshot.

- **Ammonia volatilization strongly depends on management:** Surface applications can generate substantial NH_3 losses while incorporation or injection can sharply reduce them. This matters because NH_3 loss lowers effective N supply and shifts the manure's realized N:P ratio, increasing the risk of P buildup when manure is applied to meet N needs.

Incorporation or injection of manure can sharply reduce ammonia losses through volatilization. Photo by Sarah Brickman.

- **N:P imbalance is often the binding constraint:** Manure planning is frequently constrained by phosphorus, not nitrogen. Because many manures have a lower N:P ratio than crop removal, N-based manure rates often overapply P, increasing soil test P and off-field loss risk over time. As a result, manure management can become a land-based and P-threshold challenge rather than a straightforward fertilizer replacement strategy.

- **Logistics and regulation shape what is feasible:** Even well-designed nutrient plans must operate within storage limits and field conditions. Storage capacity, setbacks, seasonal restrictions, incorporation requirements, and soil P thresholds can all constrain where and when manure is applied. These realities influence rotations, tillage choices, and sometimes the need for additional land access or alternative manure pathways.

Technology can improve nutrient use efficiency, but it changes the system

Manure processing and improved application methods can increase flexibility, reduce losses, and improve nutrient placement, but benefits are highly site-specific.

- **Solid–liquid separation** can reduce solids loading and create fractions with different nutrient profiles. Coarse separation (e.g., screw press) typically captures a limited share of total P because most P is associated with finer particles; systems that target finer solids (e.g., centrifugation, sometimes with chemical addition) can remove a substantially larger share of P but at higher capital and operating cost.

Learn more

- Manure subsurface drip Irrigation
- Nutrient management: accounting for nitrogen credits from legumes and manure
- Nutrient management: Apply nutrients to meet realistic yield goals
- Nutrient management: Manure injection
- Nutrient management: Split manure and fertilizer application

- **Injection and rapid incorporation** reduce ammonia loss and improve N recovery relative to surface application, with the tradeoff that placement may affect N_2O emissions depending on soil conditions. As an example, Yan et al. (2024) found that shallow injection of manure for field application reduces NH_3 emission by 62–70%.

- **Low-disturbance delivery systems** (e.g., dragline/umbilical with booster pumps) can reduce road hauling and improve distribution to nearby fields; practical distance and feasibility vary by terrain, right-of-way, and system design.

Key Point 3: Connecting manure, crops, and whole-farm decisions

Manure is both a fertilizer and a carbon amendment, but it behaves differently from bagged products. Its value depends on measurement, timing, placement, and the farm's storage and regulatory constraints. The most consistent technical opportunities are: (1) improve testing and crediting to avoid chronic over-application, (2) reduce ammonia loss through incorporation/injection where feasible, and (3) manage P intentionally through rate strategy, land access, rotation, or separation/exports when soil test P is high.

Because dairy farms function as integrated biological and operational systems, agronomic decisions influence far more than field-level performance. Changes in cropping systems often affect ration formulation, nutrient excretion patterns, storage requirements, and overall farm logistics. For example, shifting acreage from corn silage to triticale or other small grains may improve soil structure, reduce erosion risk, and create double-cropping opportunities. At the same time, it can alter fiber digestibility, shift protein concentrations in the ration, and change manure nutrient composition, potentially requiring adjustments in feed storage infrastructure and nutrient management plans.

Similarly, efforts to improve nutrient efficiency at the herd level—such as reducing crude protein concentrations in rations—may lower nitrogen excretion but also alter manure nutrient ratios, affecting fertilizer crediting and land application strategies. Changes in crop mix influence silage bunker capacity, hauling distances, manure storage volume, and labor allocation. As a result, agronomic optimization in dairy systems cannot occur independently; it must be coordinated with nutritionists, environmental planners, and farm managers to ensure that improvements in one area do not create unintended constraints elsewhere in the system.

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Tools and resources to dive deeper

Because dairy systems integrate crops, cows, manure, and storage logistics, advisers often need references that are **dairy specific**—not just general crop production guidance. Over the last few years, the U.S. dairy community has invested in tools that consolidate peer-reviewed science, practical implementation details, and decision-support resources in one place with an explicit focus on farm advisers.

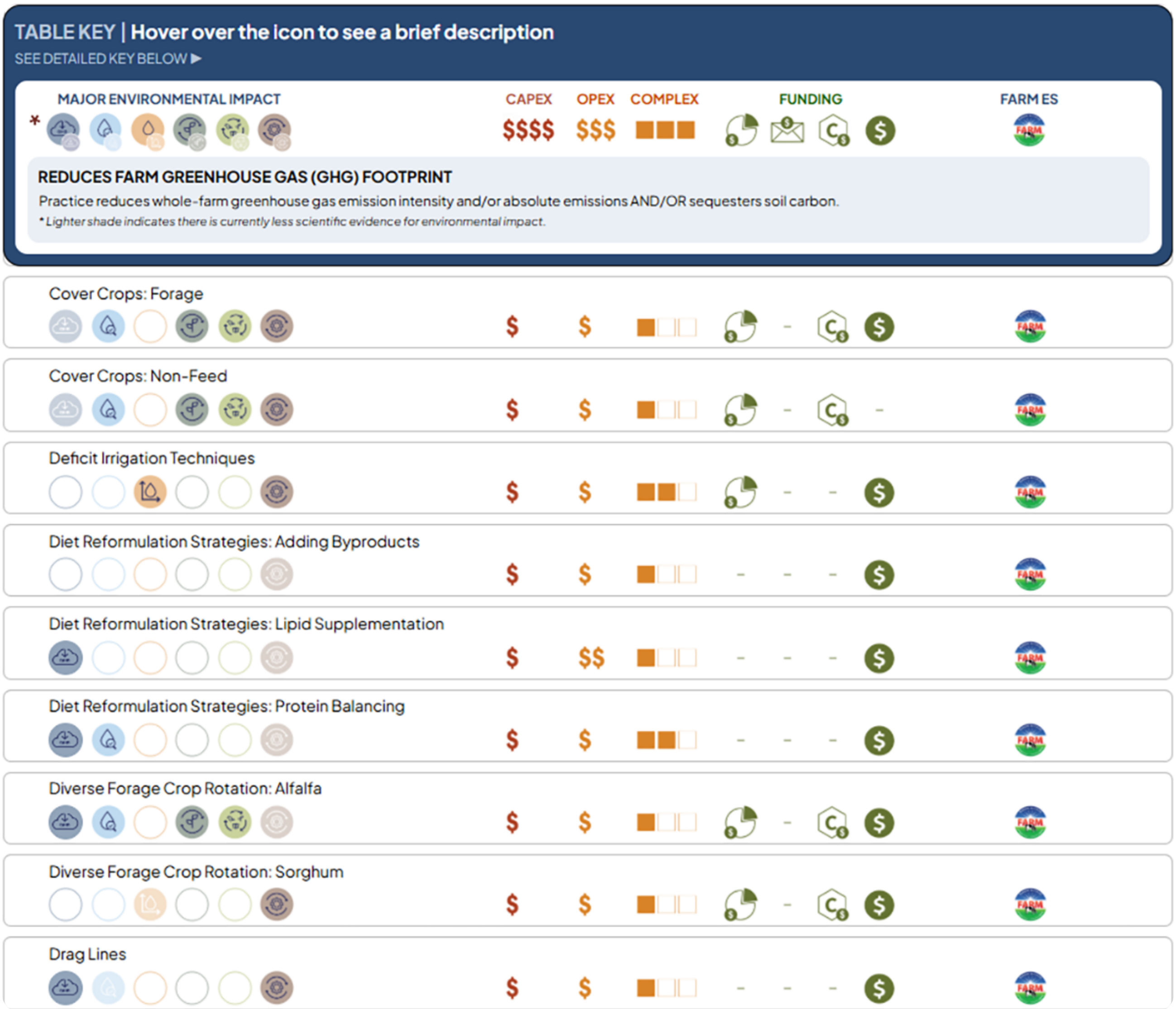
Dairy Conservation Navigator

The Dairy Conservation Navigator is a free, public platform created by the U.S. dairy checkoff that organizes science‑based information on conservation practices, technologies, and sustainability topics relevant to dairy farms. It is designed to help agronomists and other advisers quickly move from *"What is this practice?"* to *"When does it fit, what does it require, what does it cost, and what are the tradeoffs?"*

Learning Hub: Provides science‑based educational materials—including slides, handouts, and videos—covering key dairy sustainability topics such as greenhouse gas emissions, environmental modeling, and carbon markets.

Screenshot from the Learning Hub section of the Dairy Conservation Navigator website.

Practices and Technologies: A searchable library of more than 80 sustainable dairy-farming practices that helps farmers and advisers identify practical options for various farm sizes and regions. Users can filter by geography, costs, benefits, and other parameters; view photos and videos; and access details on capital and operating costs, implementation considerations, funding opportunities, and farmer-reported benefits.



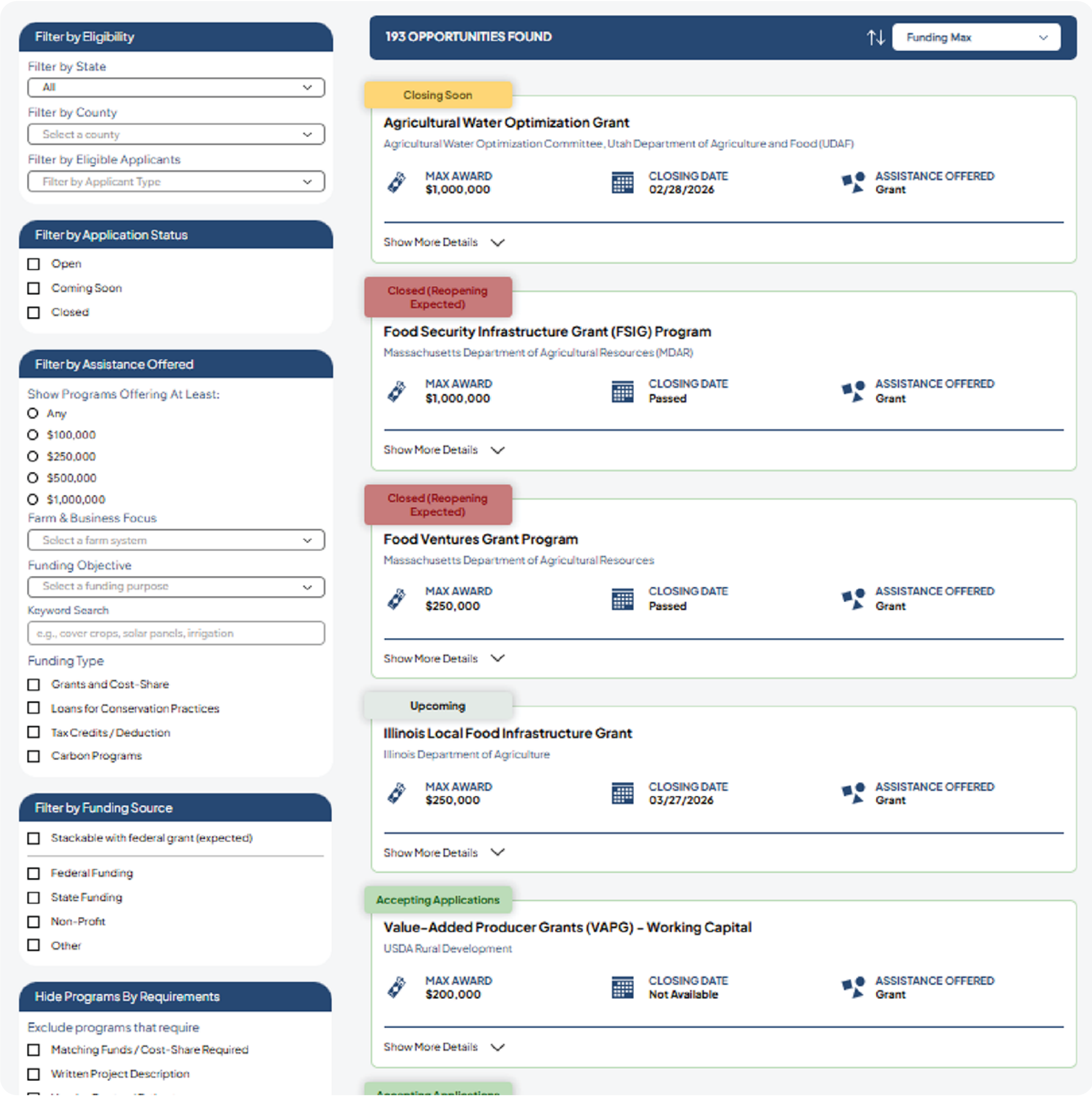
Screenshot from the Practices and Technologies section of the Dairy Conservation Navigator website.

Models and Tools: A suite of tools designed to support technical decision-making, including:

- Manure Subsurface Drip Irrigation Economic Analysis
- SuMMIT (Sustainable Manure Management Impacts Tool): A user-friendly life cycle assessment mode that estimates potential greenhouse gas reductions from manure collection, storage, and treatment systems.

Funding Opportunities Database: A consolidated database of federal-, state-, and private-funding programs relevant to dairy conservation and business investments. Updated daily using AI-assisted tools, it allows users to:

- Search by state or county for local opportunities
- Filter by focus areas (e.g., manure management, energy, cropland, water quality)
- Sort by project type (implementation, research, planning)
- Screen by eligibility, funding type, or maximum award amount
- View programs that are open, opening soon, or recently closed to support long-term planning



Screenshot from the Funding Opportunities section of the Dairy Conservation Navigator website.

Want to learn more about dairy?

Where this article series goes next: This article introduces how dairy systems differ from traditional cropping systems in terms of forage production and nutrient management. Future articles in this series will explore specific agronomic decisions—such as forage harvest timing, manure nutrient strategies, and field-level risk management—and the tools agronomists can use to support efficient dairy production.

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Self-Study CEU Quiz

Earn 1.5 CEUs in Crop Management by taking the quiz for the article. For your convenience, the quiz is printed below. The CEU can be purchased individually, or you can access as part of your Online Classroom Subscription.

1. What is a key difference between dairy cropping systems and grain-only systems?

a. Dairy systems focus mainly on producing crops for export markets.

b. Dairy systems generally require less coordination between management areas.

c. Dairy systems typically use fewer agronomic and nutrient inputs.

d. Dairy systems are integrated with livestock nutrition and manure management.

2. Why is year-round feed demand important in dairy agronomy?

a. Crops are harvested continuously throughout the growing season.

b. Feed must align with storage capacity and continuous animal intake.

c. It significantly reduces the need for fertilizer applications.

d. It removes most of the need for detailed cropping and feed planning.

3. In high-producing dairy herds, forage typically accounts for approximately what percentage of ration dry matter?

a. 20–30%.

b. 30–45%.

c. 45–65%.

d. 65–85%.

4. A dairy farm improves fiber digestibility in its silage without increasing acreage. According to the article, what is the most likely outcome?

a. Higher dry matter intake and increased milk production per cow.

b. Lower manure production and reduced storage needs.

c. Shorter harvest windows with less emphasis on timing.

d. Reduced need for forage testing and ration adjustments.

5. According to research cited in the article, a 1 percentage-unit increase in NDF digestibility (NDFd) is associated with approximately how much increase in milk production?

a. 0.10 kg/day.

b. 0.25 kg/day.

c. 0.50 kg/day.

d. 1.00 kg/day.

6. Feed costs on dairy farms typically represent approximately what percentage of total production costs?

a. 10–20%.

b. 20–30%.

c. 40–60%.

d. 60–80%.

7. Which harvest factor is most critical for ensuring proper fermentation of forage?

a. Soil pH.

b. Moisture content at harvest.

c. Fertilizer timing.

d. Plant population.

8. What is the primary purpose of achieving high packing density in silage storage?

a. Create an anaerobic environment to reduce spoilage.

b. Increase moisture content.

c. Improve nutrient concentration.

d. Reduce harvest time.

9. Forage quality has minimal impact on dairy farm economics.

a. True.

b. False.

10. Which form of nitrogen in manure is immediately plant available but prone to loss?

a. Organic nitrogen.

b. Nitrate nitrogen.

c. Urea nitrogen.

d. Ammonium nitrogen.

11. What is a key reason manure nutrient content is highly variable?

a. Uniform feeding practices.

b. Standardized storage systems.

c. Differences in ration, bedding, and handling methods.

d. Fixed nutrient composition.

12. What is often the primary limiting factor in manure nutrient management?

a. Nitrogen deficiency.

b. Potassium imbalance.

c. Phosphorus accumulation.

d. Sulfur loss.

13. Which management practice can significantly reduce ammonia (NH_3) loss from manure?

a. Injection or incorporation.

b. Surface application.

c. Delayed application.

d. Increased irrigation.

14. Agronomic decisions on dairy farms only affect field-level crop performance.

a. True.

b. False.

15. What is the primary purpose of the Dairy Conservation Navigator?

a. Provide up-to-date fertilizer pricing and commodity market information for farms.

b. Fully replace agronomists and other advisers with automated decision tools.

c. Track individual farm milk production, herd performance, and daily output trends.

d. Organize science-based information on dairy conservation practices and decision-support tools.

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