

SIGNIFICANT TECHNOLOGIES FOR IMPROVING FORAGE PRODUCTION: A REVIEW

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Abstract

As the expansion of arable land reduces natural pastures and their productivity, the need to use new technologies in the production of fodder crops has arisen. The production of fodder plants is the most important and most expensive input in sustainable livestock breeding. The main limitations in the production of green fodder are the unavailability of land for fodder, greater need for labor, longer growing time. Also, the unavailability of fodder of the same quality throughout the year, uncertain rainfall, the need for manure and lack of water are one of the limiting factors for the development of fodder plant production. The application of new technologies in the production of fodder plants is considered a necessary approach that can ensure stable production. Seed technology, system approach, hi-tech farming, and mechanization in fodder production are the four categories under which improved fodder production techniques can be categorized. Technological innovations in preparation hay and silage, including quality-enhancing additives, balaging, haylage preservation, and the creation of dehydrated goods like pellets and cubes, are examples of improved preservation techniques.

Key words: Fodder crops, sustainable production, new technologies, innovations.

Introduction

The production of fodder plants represents a significant and most expensive input in sustainable livestock breeding. Increasing the productivity and resilience of forage systems is essential to meet future food security and environmental sustainability goals. Modern technologies are transforming traditional practices, enabling better resource use and higher efficiency (Mba et al., 2025). That is why it is necessary to consider and evaluate all potential sources of food for livestock production (Ghasemi-Mobtaker et al., 2022). In livestock areas, the most important food and fodder resources are pastures and plant species (Krätli, 2019). The expansion of arable land has led to the reduction of natural pastures and reduced pasture productivity (Mutimura et al, 2012), while plant

waste has a high fiber content, but shows low digestibility and intake, which makes it inadequate for optimal animal productivity (Duncan et al., 2016). One of the main approaches to solving the problem of food shortages is the use of improved and cultured animal feed in combination with genetically improved animals (Ayele et al., 2021; Notenbaert et al., 2021). Increased livestock productivity and reduced emissions can lead to increased feed conversion efficiency (Demlew et al., 2019). According to Naik et al. (2015), the main limitations in the production of green fodder are the unavailability of land for fodder, greater need for labor, longer growing time. Also, the unavailability of fodder of the same quality throughout the year, uncertain rainfall, the need for manure and the lack of water are one of the limiting factors for the development of fodder production. According to Kishore et al. (2023), rising costs of packaged animal feed increase the cost of milk production. The non-commercial status of fodder crops and an unorganized small market without any policy support makes fodder production a low-priority activity. The continued sourcing of fresh food and forage will be essential to help ruminant agriculture begin to adapt to the world's rising temperatures (Baynah, 2023).

Because of the long forage breeding programs (up to 15 years to create a new variety), research projects and innovative techniques are necessary (Thomas et al., 2019). In this way, it will be possible for livestock production on grasslands to be sustainable, for food to be reliable and affordable. An agricultural technique known as "sustainable farming" reduces the use of non-renewable resources, preserves the environment, and uses more natural compost. Fairness in social and economic interactions, environmental protection, and economic viability are some of the most crucial objectives of sustainable agriculture. Along with many other advantages, it also seeks to enhance the quality of life for consumers. Sustainable agricultural types are shown in figure 1.



Figure 1. Sustainable agriculture types

A collection of methods known as "sustainable farming" aim to improve sustainability, productivity, and profitability by adhering to norms for the preservation of biological, physical, and cultural resources. Seven Sustainable agricultural practices are shown in figure 2.



Figure 2. Sustainable agricultural practices

Intercropping crops and trees to improve soil quality and other associated factors is known as agroforestry. It means cultivating crops where trees can provide shade.

Crop rotation: Because some crops are so vulnerable to pests and diseases, farmers might attempt to lessen their effects by rotating their crops. By reducing plant pests and diseases, this sustainable farming method will help to increase agricultural production.

Using Cover Crops: To preserve, nourish, and revitalise soil, farmers also advise growing cover crops. Typically, these crops are planted in the autumn or winter. This lessens the effect of wind and snow, which cause vulnerable soil types to erode. Soil discussion is aided by this approach.

Organic Farming: Eco-friendly farming is another name for organic farming. Farmers use biological fertilisers and pesticides made from plant or animal waste in this process.

Waste material recycling and composting are particularly crucial practices since they allow one to turn organic waste into compost that may be used. This method reduces waste, improves the soil, and lessens the demand for synthetic fertilisers.

Using Integrated Pest Management Techniques: Using micro-pests, Integrated Pest Management (IPM) primarily decreases the use of chemical pest control. Along with saving lives, these techniques also save money.

Urban agriculture is the practice of raising enough food to feed the expanding population by farming in urban areas. As a result, transportation's impact and greenhouse gas emissions will both be lessened.

Advanced techniques in forage plant production

Cost-effective forage production is essential for dairy farmers who want to improve their bottom line. Overall profitability can be improved by focusing on strategies to reduce input costs and improve activity. Some of the techniques that deserve attention and can improve the production of forage plants, and can be applicable in a wider context (Thomas, S.L. et al, 2019): 1. Seed technology; 2. System Approach; 3. Hi-tech Farming; 4. Mechanization

Seed technology

Seed technology is a multidisciplinary field that combines knowledge from botany, agriculture, genetics, and other related science to improve the quality and performance of seeds, ultimately contributing to global food security and sustainable agricultural practices (Feistritzer, 1975). It includes activities such as variety development, evaluation and release, seed production, processing, storage and certification. The main goal of seed technology is to improve agricultural production through the dissemination of high-quality seeds of high-yielding varieties.

Seed technology in forage production aims to enhance the quality, yield, and management of forage crops to improve livestock feed. Key components include the development of seed varieties, production methods, processing, storage, and quality assurance. Effective seed technology is essential for ensuring a consistent supply of high-quality forage seeds, which supports sustainable livestock production and pasture management (Kalsa et al., 2022).

Key aspects of seed technology in forage production:

1. Seed production and management:

Breeding programs: Creating novel forage varieties that exhibit enhanced traits such as increased yield, superior nutritional quality, resistance to diseases, and adaptability to particular environments (Steiner et al., 2020).

Variety selection: Adopting suitable agronomic practices, such as land preparation, sowing techniques, fertilization, and weed management, is crucial for optimizing seed yield and quality (Al-Shammmary et al., 2024).

Harvesting and Post-Harvest Management: Meticulous harvesting, threshing, cleaning, and drying processes are required to reduce seed damage and preserve viability (Yousaf et al., 2016).

Storage and Packaging: Proper storage conditions (temperature, humidity) and packaging (moisture-resistant, with clear labeling) are vital to avert seed deterioration and guarantee long-term viability (Corbineau, 2024).

2. Seed Quality and Testing:

Germplasm Collection and Evaluation: Identifying and assessing current forage germplasm (genetic resources) to discover appropriate varieties for various regions and agricultural systems (Mirr et al., 2021).

Purity and Health: Ensuring high seed purity, which includes the absence of weed seeds and inert materials, as well as being free from seed-borne diseases, is essential for both forage production and the health of animals (Malaviya et al, 2013; Tonapi et al., 2015; Rao et al., 2024).

Seed Testing: Consistent seed testing for germination, purity, and health is vital to assess seed quality and detect any possible problems (Elias, 2024; Prasad, 2023).

3. Dissemination and Utilization:

Seed Classes: It is vital to comprehend the various categories of seed (such as pre-basic, basic, and certified) along with their specific functions in the seed multiplication process (Rao et al., 2024; Gowda et al., 2017).

Seed Delivery and Distribution: Effective systems for seed delivery and ensuring access to high-quality seed are essential for the broad acceptance of enhanced forage varieties (Smith et al., 1987).

Extension Services: It is crucial to offer farmers information and training regarding appropriate seed handling, planting methods, and forage management techniques (Oscar and Kibet, 2021).

4. The Role of Technology and Innovation:

Developing New Varieties: The ongoing research and development of new forage varieties aims to enhance yield, nutritional value, and disease resistance (Humphreys, 2005; Chand et al., 2022).

Precision Agriculture Techniques: The application of technologies such as GPS and sensors can optimize forage production and enhance resource use efficiency (Ahmad et al., 2020; Getahun et al., 2024).

Breeding Programs: It is essential to concentrate on breeding programs that enhance seed production traits, including seed yield, seed quality, and resistance to diseases and pests (Tester et al., 2010).

System approach

A systems perspective in forage production entails perceiving the complete process as a complex, interrelated system instead of separate components. This comprehensive approach takes into account the interactions among various elements such as soil, climate, plant species, livestock, and management practices to maximize forage production and resource efficiency.

By comprehending these interconnections, farmers are able to make well-informed decisions that boost productivity, enhance sustainability, and reduce environmental impact.

1. Understanding Interconnected Components:

Soil Health: Healthy soils are crucial for forage production, influencing nutrient availability, water retention, and overall plant health (Omer et al., 2024).

Climate: Weather patterns, temperature, and rainfall significantly impact forage growth and quality (Giridhar et al., 2015).

Plant Species: Selecting appropriate forage species and varieties based on soil type, climate, and intended use (grazing, hay, silage) is essential (Guyader et al., 2016).

Livestock Management: Grazing strategies, stocking density, and animal health directly affect forage utilization and pasture recovery (Rouquette Jr., 2015).

Management Practices: Fertilizer application, pest and disease control, and harvesting techniques all play a role in forage production and quality (Capstaff et al., 2018).

2. Integrated Management Strategies:

Rotational Grazing: Moving livestock between different paddocks to allow for forage regrowth and prevent overgrazing (Steffens et al., 2013).

Intercropping and Cover Cropping: Integrating different forage species or using cover crops to improve soil health, suppress weeds, and extend the grazing season (Teague, 2018).

Precision Agriculture: Using technology to monitor forage growth, soil conditions, and animal performance to optimize resource allocation and management decisions (Ali et al., 2025).

Nutrient Management: Balancing nutrient inputs (fertilizer, manure) with plant requirements to maximize forage production and minimize environmental losses (Guyader et al., 2016).

3. Benefits of a Systems Approach:

Increased Productivity: Optimizing resource use and management practices leads to higher forage yields and improved livestock performance.

Enhanced Sustainability: Reducing reliance on external inputs (fertilizers, pesticides), minimizing environmental impacts, and promoting soil health.

Improved Profitability: Increased forage production, reduced costs, and improved animal performance can lead to greater economic returns.

Resilience to Climate Change: Diversifying forage species, improving soil health, and implementing sustainable management practices can enhance the resilience of forage systems to climate variability.

Hi-tech farming

Modern technology are used in high-tech agriculture to improve fodder productivity, quality, and resource efficiency. In order to create more efficient and sustainable forage production systems, this includes data-informed decision-making, precision farming techniques, and controlled environment agriculture. Grassland fertilisation and irrigation practices, as well as the frequency of use (cuts), are directly impacted by monitoring biomass yield and quality attributes (Figure 3, Ali & Kaul, 2025).

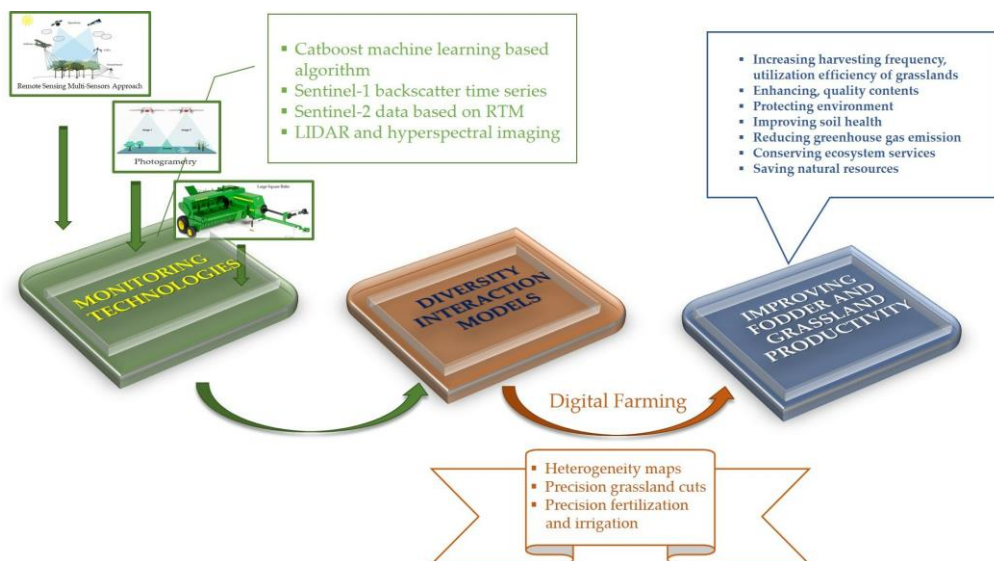


Figure 3. Monitoring biomass yield and quality traits grasslands

Here is an overview of the application of advanced technology in forage production:

1. Precision Agriculture for Forage:

GPS and Sensors: Employing GPS-guided equipment and sensors to accurately map forage fields, assess crop health, and pinpoint areas that need specific treatments. This facilitates the variable-rate application of fertilizers and pesticides, enhancing resource efficiency and reducing environmental impact (Bhamini et al., 2025).

Data Analysis and Modeling: Gathering and analyzing information on soil conditions, weather trends, and crop development to create predictive models for forage yield and quality. This empowers farmers to make well-informed choices regarding planting, harvesting, and irrigation methods (Velmurugan, 2024; Rautenhaus, 2017).

Automated Machinery: Utilizing automated tractors, combines, and other equipment for planting, harvesting, and hay production, thereby increasing efficiency and lowering labor expenses (Jensen et al., 2025).

2. Controlled Environment Agriculture for Forage:

Hydroponics and Aquaponics: Cultivating forages such as barley and alfalfa in hydroponic or aquaponic systems, which involve growing plants in nutrient-rich water solutions. This approach allows for regulated environmental conditions, year-round production, and effective water usage (Chisela Kaite, 2022).

Greenhouses and Vertical Farms: Employing greenhouses and vertical farming techniques to enhance environmental conditions for forage cultivation, including temperature, humidity, and light. This results in higher yields and better forage quality, particularly in areas with difficult climates (Vatistas, 2022).

3. Data-Driven Decision Making:

Real-time Monitoring: Utilizing sensors and internet-connected devices to track various parameters such as soil moisture, temperature, and plant health in real-time. This information offers valuable insights for optimizing irrigation, fertilization, and other management practices (Ayaz et al., 2019).

Decision Support Systems: Adopting decision support systems that consolidate data from multiple sources to provide farmers with actionable recommendations for enhancing forage production (Baldin et al., 2021).

Robotics and Automation: Employing robots for activities such as weeding, harvesting, and feeding livestock, which lowers labor expenses and enhances efficiency (Bloss, 2014).

Mechanization

Correct and timely applied cultivation technology greatly improves plants production (Popović et al., 2012; 2013; 2015; 2016; 2020a; 2020b; 2024; 2025a; 2025b; Jovanović Todorović et al., 2020; Vasileva et al., 2023). Automation greatly improves forage production by boosting efficiency, lessening labor needs, and improving yield and quality. It allows for prompt harvesting, which is essential for maintaining forage quality and maximizing productivity. Automation also facilitates larger-scale forage production and can reduce waste, leading to cost savings and amplified profitability.

Enhanced Productivity and Decreased Labor: By greatly accelerating the harvesting and handling of forage crops, mechanized tools like mowers, balers, and forage harvesters can cut down on the amount of manual labor required. This is especially crucial in places where labor costs are high or there is a labor shortage (Ah et al., 2020).

Enhanced Quality of Forage: Timely harvesting is essential to maintaining the nutritious value of forages, and mechanization can guarantee this. For instance, the quality of the finished product can be greatly increased by collecting hay at the ideal maturity level and reducing leaf loss (Capstaff et al., 2018).

Greater Production Scale: Farmers can grow and collect forage crops across greater regions thanks to mechanized equipment, which boosts output overall and may result in economies of scale (Sims et al., 2017).

Decreased Waste and Financial Savings: Farmers can reduce waste during harvesting and storage by using machinery for jobs like chopping and baling. This can result in a more economical use of resources and possibly cheaper production costs (Mishra et al., 2021).

Timeliness: Timely field activities are made possible by agricultural mechanization. Increased yield and cropping intensity can result from speedier completion of tasks including seedbed preparation, planting, and harvesting (Kumari et al., 2023).

Reducing Hazards: Mechanization can assist reduce the hazards of inadequate or delayed harvesting because of labor shortages or poor weather in areas that are prone to unfavorable weather conditions. Combine harvesters, for instance, can be used to swiftly

harvest crops during dry spells, lowering the possibility of spoiling or rain-related loss (Kumari et al., 2023).

Conclusion

The integration of seed technology, a systems approach, hi-tech farming, and mechanization is transforming forage production into a more efficient, sustainable, and productive agricultural sector. Advanced seed technologies ensure high-yielding, disease-resistant, and climate-resilient forage varieties, which form the foundation for improved livestock nutrition. A system approach enables holistic planning by integrating soil, water, crop, and livestock management to optimize resource use and long-term productivity.

Hi-tech farming-involving precision agriculture, sensors, GIS, and data analytics-enhances decision-making, reduces input costs, and ensures timely operations. Meanwhile, mechanization of land preparation, sowing, harvesting, and post-harvest handling reduces labor dependency, improves timeliness, and increases efficiency.

Together, these elements contribute to higher forage yield and quality, cost-effectiveness, and sustainability, ultimately supporting livestock health, productivity, and profitability in modern agricultural systems.

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