INTEGRATED NUTRIENT MANAGEMENT FOR ENHANCED FODDER PRODUCTION

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I. INTRODUCTION

Agriculture forms the cornerstone of India's economy, contributing significantly to the country's GDP and providing livelihoods to a substantial portion of the population. Among the various components of agriculture, livestock production holds a pivotal role, contributing both to the agricultural and national GDPs while supporting the livelihoods of a substantial rural populace. However, the productivity of livestock remains constrained by various factors, with inadequate supply of nutritive fodder being a critical limitation. As the demand for food crops takes precedence over cultivated forage crops, it becomes essential to optimize forage production on a per-unit-area and per-unit-time basis. For sustainable livestock production, the availability of high-quality forage is of paramount importance.

With the increasing pressure on arable land for food crops, the scope for expanding the area under cultivated forage crops is limited. However, the demand for quality fodder remains high due to its critical role in sustainable livestock production. India, being an agrarian economy with a significant dependence on livestock, faces a persistent challenge of inadequate forage supply. Integrated Nutrient Management (INM) offers a solution to this dilemma by optimizing nutrient utilization in forage crops. This chapter explores the impact of INM on soil health, nutrient availability, and forage productivity, highlighting its potential to bridge the gap in feed and forage supply.

1. **Background and Rationale:** The demand for feed and fodder in India continues to outpace supply, resulting in a substantial gap. With projections indicating even higher demand in the future, it is imperative to adopt innovative strategies to bridge this gap sustainably. The nutrient requirements of forage crops are particularly high, with nitrogen being a crucial constituent for protein synthesis. Unfortunately, the indiscriminate and continuous use of chemical fertilizers has led to detrimental effects on soil health and crop productivity. The use of integrated nutrient management, which entails the careful integration of mineral fertilisers and organic resources, offers a feasible approach to improve forage production while simultaneously preserving soil health.

2. **Integrated Nutrient Management: A Conceptual Overview:** Integrated nutrient management entails the synergistic use of mineral fertilizers and organic resources such as cattle manure, crop residues, composts, and biofertilizers. This approach aims to

optimize nutrient availability for plant uptake, enhance soil fertility, and promote sustainable crop growth. INM recognizes the complementary nature of organic and inorganic nutrient sources, and its adoption can lead to increased forage yield, improved nutrient content, and enhanced soil properties.

3. **Objectives of the Chapter:** This chapter reviews the existing literature on integrated nutrient management practices in forage crops with the primary objective of elucidating its impact on soil health, forage productivity, and quality. Specific focus is placed on assessing the effects of INM on soil properties, forage yield, and forage quality parameters. The chapter also explores case studies and experimental findings to provide insights into the practical application of integrated nutrient management in different agro-climatic regions.

II. SOIL PROPERTIES AND INTEGRATED NUTRIENT MANAGEMENT

The implementation of integrated nutrient management is of significant importance in enhancing the various qualities of soil, encompassing its physical, chemical, and biological characteristics. The judicious combination of organic and inorganic nutrient sources contributes to enhanced soil fertility, organic matter content, and nutrient availability for plant uptake. The interaction between nutrient sources leads to synergistic effects that influence soil structure, cation exchange capacity, and microbial activity.

1. **Improvements in Soil Physical Properties:** The application of integrated nutrient management practices has been shown to positively influence soil physical properties. The addition of organic matter through sources like farmyard manure (FYM) improves soil structure, water-holding capacity, and aeration. Additionally, the combination of organic and inorganic nutrients contributes to enhanced aggregate stability and reduced soil compaction, ultimately fostering better root growth and nutrient uptake by forage crops.

2. **Enhancement of Soil Chemical Properties:** Balanced nutrient application through integrated nutrient management results in improved soil chemical properties. Organic sources of nutrients, such as FYM and vermicompost, enrich the soil with essential macronutrients (N, P, K) and micronutrients. The synergistic action of organic and inorganic nutrients enhances nutrient availability, promotes ion exchange, and maintains optimal pH levels, thereby facilitating the growth and development of forage crops.

3. **Microbial Activity and Soil Health:** Integrated nutrient management practices stimulate microbial activity in the soil, fostering a conducive environment for nutrient mineralization and plant growth. Microorganisms play a vital role in nutrient cycling, organic matter decomposition, and soil aggregation. The use of organic manures promotes the augmentation of microbial variety and activity, hence leading to enhanced soil health and increased availability of nutrients.

4. **Build-up of Soil Nutrient Reserves:** The judicious combination of organic and inorganic nutrient sources leads to a build-up of soil nutrient reserves, ensuring a sustained supply of nutrients to forage crops. This build-up is particularly evident in secondary and micronutrients, which are critical for optimal forage production. The use of organic

resources helps prevent nutrient imbalances, thereby promoting the long-term sustainability of forage cropping systems.

5. **Case Studies and Experimental Evidence:** Numerous studies conducted across different agro-climatic regions highlight the positive influence of integrated nutrient management on soil properties. These case studies provide insights into the tangible benefits of adopting INM practices, such as increased soil organic carbon, enhanced nutrient availability, and improved soil health indices.

The incorporation of both organic and inorganic nutrients has been found to result in enhanced soil physical, chemical, and biological qualities. The application of farmyard manure (FYM) is connected with several favourable benefits, namely the accumulation of secondary and micronutrients, mitigation of the negative impact of soil acidity, salinity, and alkalinity, and the maintenance of soil health. Nitrogen is generally taken up by the plant in the form of nitrate NO_3 form under aerobic and as NH_4 ions under anaerobic condition of plant growth.The use efficiency of nitrogen fertilizers is improved in the presence of FYM. Substitution of 50 per cent mineral fertilizer-N by FYM under tropical conditions in various cropping system has been found to sustain the soil heath. Application of 50 % N each through urea and FYM obtained significant improvement in soil fertility in terms of available NPK which were comparatively higher than rest of the treatments (Kumar et al. 2007).

Many workers reported that integrated nutrient management practices significantly improved macro and micronutrient status of soils. Kemal and Abera (2015) found that the utilisation of a balanced combination of NPK fertilisers with farmyard manure (FYM) or other agricultural wastes resulted in enhanced soil fertility levels, leading to an improvement in maize crop output. The application of FYM in conjunction with chemical fertilisers has been found to enhance soil physical, chemical, and biological characteristics, leading to increased sorghum productivity (Sharma et al., 2007). The significant improvement in soil organic carbon and available N, P and K status to the extent of 17.8, 6.0, 13.9 and 7.98 per cent, respectively over no sheep manure application which could be attributed to addition of organic matter and increased activity of micro-organisms leading to higher mineralization of applied and inherent plant nutrients in soil (Sharma 2009). Application of 100 per cent RDN through FYM recorded significantly highest value of soil organic carbon as compared to all other treatments of integrated nitrogen management with highest values of residual nitrogen, phosphorous and potassium. The residual status of nutrients is thus, a function of nutrients supplied and their removal (Singh et al. 2013). The FYM also increases cation exchange capacity and microbial activity in soil besides supplying macro and micro plant nutrients. It helps in minimizing leaching losses, improving buffering capacity and influencing the redox conditions in the soil. Hence, proper blending of chemical fertilisers with organic manures which are locally available not only improves soil health but also helps to maximize the sustainable production.

The study of Kumar et al. (2016) at Hisar, Haryana observed that 100 per cent N through FYM, 100 per cent RDF through inorganic fertilizer and 75% RDF+25% N through FYM+*Azotobacter* resulted in build up of the residual status of nitrogen, phosphorus and potassium after the crop harvest than before sowing. The extent of decrease was less when nutrient supply was made practically through inorganic sources in combination with organic sources as compared to chemical fertilizers alone. Balanced application of NPK fertilizers with FYM or agricultural wastes improved the soil fertility status in addition to increase in maize yield (Kemal and Abera, 2015).

Soil fertility status after post-harvest of cenchrus: cowpea in alternate paired rows showed that physical and chemical properties of the soil (Bulk density, soil organic carbon, available N and P) had improved remarkably with application of 40 kg N/ha + 60 kg P_2O_5/ha + bacterial inoculation (Rhizobium, Azotobacter and PSB) as it is compared with other treatments combinations (control, bacterial inoculation, 40 kg N/ha, 60 kg P_2O_5 and 40 kg N + 60 kg P_2O_5) in sandy loam soils of Avikanagr, Rajasthan (Meena et al. 2018).

Similarly, 80 kg N ha^{-1} and 40 kg P ha^{-1} (100 % RDF) along with *Azotobacter*+PSB resulted in increased organic carbon and available N and P followed by 75 % RDF+*Azotobacter*+PSB in loamy sand soils of Gujarat (Patel et al. 2018). The microbial population might have increased in this treatment, resulted in soil aggregation and decomposition and increased organic carbon content in soil. The solubility of native phosphates was enhanced by the organic acids generated during microbial breakdown of organic waste, leading to an increase in the availability of phosphorus content.

The use of 50 per cent (40 kg N/ha) N through urea and 50 per cent N through FYM obtained significant improvement in soil fertility after the harvest of pearlmillet crop in terms of available N (174 kg/ha), phosphorus (48 kg/ha) and potash (204.8 kg/ha) which were comparatively higher than rest of the treatments in loamy sand soils of Gujarat (Ram et al. 2015). Application of FYM also increases cation exchange capacity and microbial activity in soil besides supplying macro and micro plant nutrients. It helps in minimizing leaching losses, improving buffering capacity and influencing the redox conditions in the soil (Gaur et al. 1971).

Singh et al. (2013) studied the effect of INM on soil fertility status under rainfed conditions in pearlmillet crop and found that 100 per cent RDN through FYM recorded highest value of soil organic carbon (0.30%) and showed the highest residual nitrogen (146.1 kg/ha), phosphorus (18.9 kg/ha) and potassium (237.8 kg/ha) followed by those receiving 80 per cent RDN through vermicompost + 20 per cent through urea. It is quite established that only a part of FYM is mineralized in one season and the rest has carry over effect. The residual status of nutrient is thus, a function of nutrients supplied and their loss/removal.Wailare and Kesarwani (2017) studied the effect of INM on physico-chemical properties of soil and reported that application of 5 t/ha poultry manure and 100 per cent RDF (120:60:40:: N:P:K) significantly improved the soil organic carbon and available N whereas, soil available phosphorous was recorded maximum under 5 t ha^{-1} poultry manure+100 % RDF.

Pathan and Kamble (2014) reported that RDF (20:80:40 kg NPK ha^{-1}), elemental sulphur (30 kg ha^{-1}), sodium molybdenum (1 kg ha^{-1}) and borax (4 kg ha^{-1}) along with FYM (10 t ha^{-1}) to perennial lucerne crop recorded significantly higher values organic carbon and soil available nutrients *viz.* nitrogen, phosphorous, potassium, sulphu, molybdenum and boron in clayey soils of Rahuri, Maharashtra. The increase in organic carbon content was partly due to the direct addition of organic manure (FYM) and partly through better root growth and also due to better activity of microorganisms. Also, the addition of FYM along with S, Mo and B was found beneficial in improving the status of soil micronutrients. Incorporation of such materials produces the organic acids, organic constituents and ultimately fermentation of humus, which in turn act as chelating agent for micronutrients. Therefore, addition of FYM increases the micronutrient status of soil.

III. FORAGE YIELD ENHANCEMENT THROUGH INTEGRATED NUTRIENT MANAGEMENT

Integrated nutrient management significantly contributes to enhanced forage yield, thereby addressing the pressing need for increased fodder availability. By ensuring an adequate and balanced supply of nutrients, INM practices promote vigorous vegetative growth, optimal tillering, and increased biomass accumulation.

1. **Promotion of Vegetative Growth:** Vegetative growth is a key determinant of forage yield and quality. Integrated nutrient management, through its synergistic effects on nutrient availability, promotes robust vegetative growth in forage crops. Adequate nitrogen supply, facilitated by organic sources, results in increased shoot and leaf development, ultimately contributing to higher biomass production.

2. **Tillering and Tiller Development:** Tillering, the process by which new shoots (tillers) develop from the base of the plant, significantly influences the overall structure and yield of forage crops. Integrated nutrient management encourages tiller initiation and development, leading to a greater number of productive tillers per plant. This intricate interplay between nutrient availability and tiller dynamics contributes to improved forage yield.

3. **Enhanced Biomass Accumulation:** Biomass accumulation, the net result of photosynthesis and nutrient assimilation, is a critical factor in determining forage yield. Integrated nutrient management practices ensure an abundant supply of essential nutrients, which fuels photosynthesis and biomass production. Consequently, forage crops exhibit increased biomass accumulation, translating to higher overall fodder yield.

4. **Nutrient Composition and Forage Quality:** While the primary objective of integrated nutrient management is to enhance forage yield, it also exerts a positive influence on nutrient composition and forage quality. The balanced nutrient supply, particularly nitrogen, phosphorus, and potassium, contributes to improved crude protein content, higher energy values, and enhanced nutritional quality of the forage.

5. **Case Studies and Experimental Evidence:** The efficacy of integrated nutrient management in enhancing forage yield has been demonstrated through numerous case studies and experiments. These studies underscore the role of INM in achieving substantial increases in biomass production and overall forage yield, thereby substantiating its practical applicability in diverse agroecological settings.

Nutrients from different sources have played a significant role in increasing forage productivity. However, their use in forage crops is very limited due to preferential need for food and cash crops on one hand and on the other, nutrients removal from the soil pool by forage crops specially multi cuts and perennial ones is much higher. Such high removal of nutrient, if not replenished, would widen the gap between addition and removal.

According to a study conducted by Puri and Tiwana (2008) in Ludhiana, it was found that the application of 25 metric tonnes of farmyard manure per hectare and 100 kilogrammes of nitrogen per hectare resulted in the production of abundant and high-quality feed from maize crops.

A study carried out by Duhan (2013), the utilisation of 100% prescribed nitrogen through farmyard manure (FYM) resulted in a significant increase in the fodder yield of sorghum. The output rose from 41.11 to 56.97 q/ha when compared to the absolute control group.

In a study conducted by Choudhary and Gautam (2007) in New Delhi, it was observed that the incorporation of farmyard manure (FYM) at a rate of 10 tonnes per hectare resulted in an increase in the total green forage and dry matter yield of pearl millet. Kumar and Shivadhar (2006) suggests that in order to achieve improved, sustainable, and high-quality fodder production from single cut oat under irrigated circumstances at Jhansi, it is recommended to apply 50 percent of the necessary NPK, along with vermicompost at a rate of 5 tonnes per hectare and farmyard manure (FYM) at a rate of 5 tonnes per hectare. In a study conducted by Pal (2015), it was noted that the application of 10 t ha-1 of farmyard manure (FYM) in combination with sulphur (30 kg/ha), boron (4 kg/ha), and molybdenum (1 kg/ha) resulted in significantly better green and dry forage production of berseem compared to two other treatments: 100 percent recommended dose of fertiliser (RDF) and RDF with 5 t/ha of FYM together with sulphur, molybdenum, and boron.

In a study conducted by Yadav et al. (2010) in the middle Gujarat agro-climatic conditions, it was observed that the application of 75 kg N ha-1 (chemical fertiliser) combined with 25 kg N ha-1 through FYM or castor cake, along with the simultaneous inoculation of Azotobacter chroococcum (ABA-1) and Azospirillum lipoferum (ASA-1), resulted in a significantly higher yield of green forage in sandy loam soils. Moreover, the application of FYM in conjunction with biofertilizer, specifically Azospirillum and PSB, resulted in a noteworthy enhancement in the production of green fodder in both hybrids and composites of pearl millet, as demonstrated by the study conducted by Basanti et al. (2012). In a study conducted by Jayanthi et al. (2002), it was shown that the application of 150 kg N ha-1, in combination with 40 kg P ha-1, and the dual inoculation of seed with Azotobacter chroococcum (a nitrogen-fixing bacterium) and Pseudomonas striata (a phosphate-solubilizing bacterium), resulted in enhanced vegetative development in multi-cut fodder oat. Application of 20 kg N + 60 kg P plus mixture of *Rhizobium trifolii*and phosphate solubilizing bacteria (PSB) recorded highest green fodder (65.45 t/ha) of berseem (Meena and Mann, 2006).Rawat and Agrawal (2010) at Jabalpur (Madhya Pradesh) revealed thatvermicompost 5 t ha^{-1} along with *Azotobacter* @ 2 kg ha^{-1} gave the highest green fodder yield and daily fodder supply of 3.76 q ha^{-1}. Basanthiet al. (2012) recordedmaximum fresh forage yield with FYM,*Rhizobium*, phosphate solubilizing bacteria and *Azospirillium.* In their study, Godara et al. (2012) found that incorporating either vermicompost at a rate of 5 t ha-1 or FYM at a rate of 10 t ha-1, together with the addition of Azotobacter and 75% recommended dose of fertiliser (100% RDF-80 kg N/ha, 40 kg P/ha), led to increased green herbage production in oat. Furthermore, this integrated approach resulted in a 25% reduction in fertiliser usage. In a study conducted by Devi et al. (2014) in Hisar, it was shown that the inoculation of Azotobacter led to a notable increase in the production of green forage, resulting in a greater overall yield compared to the inoculation of nobiofertilizer. Additionally, the researchers noted that the combination of 100 percent recommended dose of fertiliser (RDF) with biofertilizers (specifically Azotobacter and PSB) resulted in the highest yields of both green fodder and dry fodder.

The balanced use of NPK fertilizers with lime and FYM helped in improving the crop productivity and growth of maize (Dutta et al. 2013). In the research conducted by Shekhara et al. (2009), it was found that the utilisation of 50 percent inorganic fertiliser and 50 percent farmyard manure (FYM) resulted in a notable increase in both the yield of green fodder and the efficiency of nutrient utilisation in multicut fodder sorghum.In a study conducted by Karkiet et al. (2005) in New Delhi, an experiment was conducted on maize. The researchers reported that the application of 120 kg N+10 t FYM ha-1 resulted in a considerable increase in plant height and dry matter output per plant. In a study conducted by Kumar et al. (2005) in New Delhi, it was noted that the application of 120 kg N+26.2 kg P2O5+33.2 kg K2O ha-1, combined with 10 t FYM ha-1, resulted in increased plant height and leaf area index of maize. In a study conducted by Sathish et al. (2011) in Kathalagere, India, it was observed that the application of 50 percent nitrogen (N) through farmyard manure (FYM) and 50 percent through nitrogen-phosphorus-potassium (NPK) resulted in increased maize yields. The utilisation of a combination consisting of 75 percent NPK, 4.5 tonnes per hectare of farmyard manure (FYM), and biofertilizer containing Azotobacter and PSB demonstrated superior results in terms of enhancing both fodder output and green biomass yield, as compared to alternative combinations and an unfertilized control (Rasoolet al., 2015).

The effect of inorganic and biofertiliser on Napier bajra hybrid grass at Coimbatore revealed that highest green and dry fodder yields were obtained with biofertiliser mixture (*Azospirillium*+ *Phosphobacterium*) along with 100% recommended dose of N and P fertilizer together (Chellamuthu*et al.,* 2000).The study conducted by Sharma et al. 2004 at Jorhat, Assam found that 50 % RDF along with vermicompost (2.5 t/ha) and FYM (2.5 t/ha) recorded the highest green forage and dry matter yields in oat crop. In a similar manner, the combination of 50% recommended dose of fertiliser (RDF) with vermicompost at a rate of 5 tonnes per hectare (t/ha) and farmyard manure (FYM) at a rate of 5 t/ha resulted in considerably greater yields of green fodder and dry matter compared to the other treatments, except for the combination of 50% RDF with either vermicompost or FYM at a rate of 5 t/ha in oats. The study conducted by Sheoran et al. (2004) found that the yield achieved with 100% recommended dose of fertiliser (RDF) was comparable to the yield obtained using 50% RDF combined with either vermicompost or farmyard manure (FYM) at a rate of 5 tonnes per hectare. The study provides evidence that the utilisation of organic fertilisers not only contributes to cost savings compared to inorganic fertilisers, but also promotes soil health.

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IV. IMPROVING FORAGE QUALITY THROUGH INTEGRATED NUTRIENT MANAGEMENT

The nutritional quality of forage plays a pivotal role in determining its suitability for livestock consumption and overall animal health. Integrated nutrient management improves multiple quality metrics in addition to increasing forage yield. By ensuring an optimal nutrient supply, INM practices contribute to improved protein content, enhanced energy values, and overall nutritional superiority. This chapter comprehensively explores the impact of integrated nutrient management on forage quality and its implications for livestock production.

1. **Augmented Protein Content:** Protein is a crucial component of livestock feed, and its availability in forage is of paramount importance for meeting the dietary requirements of animals. Integrated nutrient management practices, particularly those involving organic sources, result in higher nitrogen availability. This, in turn, leads to increased protein synthesis in forage crops, consequently improving the protein content of the harvested fodder.

2. **Enhanced Energy and Nutrient Density:** The energy value of forage, determined by factors such as fiber content and digestibility, directly influences its nutritional quality. Integrated nutrient management promotes optimal nutrient availability and balanced plant growth, leading to improved energy values and enhanced nutrient density in forage. This nutritional richness contributes to better feed efficiency and overall animal productivity.

3. **Micronutrient Enrichment:** Micronutrients play a pivotal role in animal nutrition, as their deficiency can have adverse effects on livestock health and productivity. INM practices, which involve the application of organic amendments, contribute to increased micronutrient availability in forage. This enrichment enhances the overall micronutrient content of the fodder, ensuring that animals receive a well-rounded and nutritionally adequate diet.

4. **Palatability and Digestibility:** Palatability, the appeal of forage to livestock, and digestibility, the ease with which animals can extract nutrients from feed, are critical determinants of livestock consumption patterns. Integrated nutrient management practices influence the physical and chemical characteristics of forage, rendering it more palatable and digestible. This, in turn, leads to greater feed intake and improved utilization of nutrients by livestock.

5. **Case Studies and Experimental Evidence:** Numerous studies have demonstrated the positive impact of integrated nutrient management on forage quality. By augmenting protein content, improving energy values, and enhancing nutrient density, INM practices contribute to superior forage quality that meets the nutritional requirements of livestock. These case studies provide empirical evidence of the efficacy of INM in enhancing forage quality and, consequently, livestock productivity.

   Nitrogen, being an essential component of protein, plays a crucial role in the enhancement of protein content in fodder. This can be achieved by increasing the rate of nitrogen application through the utilisation of organic manures, inorganic fertilisers, and

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biofertilizers, hence leading to an augmented availability of nitrogen. Patel et al. (2018) observed significantly highest crude protein and lowest crude fibre content in sandy loam soils of Gujarat with 80 kg N ha^{-1} and 40 kg P ha^{-1} along with *Azotobacter* + PSB which in turn resulted in better succulence and palatability.

In a study conducted by Yadav et al. (2007) in Anand, Gujarat, it was discovered that the application of 75 kg N (urea) plus 25 kilogramme N ha-1 (FYM) resulted in an increase of 18.6% in dry matter yield and 20% in crude protein yield of sorghum, compared to the application of 100 kg N ha-1 (urea). Singh et al. (2015) observed that the use of a combination of 75% prescribed dose of nitrogen from inorganic sources and 25% from vermin-compost resulted in improved fodder quality indices, including juice percentage, dry matter content, digestibility, and neutral detergent fibre content.

Also, the highest crude protein content of forage sorghum was found 75 kg N/ha through chemical fertilizer+25 kg Nha^{-1} through FYM or castor cake along with the combined inoculation with *Azotobacterchroococcum*(ABA-1)+*Azospirillumlipoferum*(ASA-1) by Yadav et al. (2010). The maximum dry matter and protein yields were obtained by applying vermicompost at a rate of 5 metric tonnes per hectare, together with the inoculation of Azotobacter at a rate of 2 kilogrammes per hectare (Rawat and Agrawal, 2010). Biofertilizer inoculation recorded higher dry matter and protein yields resulting in higher realization compared to no biofertilizer inoculation (Devi et al. 2014, Patel et al. 2010).

Protein and digestibility dry matter (DDM) yields increased by 14.9 and 1.9 %, respectively due to *Azospirillum*inoculation over no inoculation (Gupta et al. 2007). The *Azospirillum*culture recorded 7.7 % higher crude protein yield over un-inoculated control (Agrawal et al. 2005). The maximum dry matter and crude-protein yields were recorded when forage sorghum is inoculated with *Azotobacter*+*Azospirillum*as compared to their individual or no inoculation (Yadav et al. 2007).Godara et al. (2012) at Ajmer, Rajasthan found that application of N (80 kg/ha) and P (40 kg/ha) along with vermicompost (5 t/ha) recorded maximum dry matter and crude protein yields in oat crop. The increased crude protein yield was due to added supply of nutrients and well developed root system under balanced nutrient application.

FYM and inorganic fertilizer are known to have synergistic effect. Sometimes the FYM has supplementary and complimentary effect with inorganic fertilizer. Kalra and Sharma (2015) at Ludhiana, Punjab reported that 40 kg N ha^{-1} in conjunction with FYM (12.5 t/ha) produced equivalent crude protein in fodder maize compared to 120 kg N ha^{-1} alone. FYM (25 t/ha) alone produced crude protein equivalent to 12.5 t ha^{-1}FYM in combination with 80 kg N ha^{-1}. They further observed significantly higher IVDMD with application of FYM @ 25 t ha^{-1} than all the levels of nitrogen alone but at par with 80 kg N ha^{-1} in the presence of FYM @ 12.5 tha^{-1}.

The study conducted by Meena et al. (2018) at Avikanagar, Rajasthan found that 40 kg N ha^{-1}+60 kg $P_2O_5ha^{-1}$ along with bacterial inoculation (*Rhizobium, Azospirillium*and PSB) in cenchrus:cowpea in alternate paired rows had brought significant improvement in dry matter as well as crude protein content. Sharma (2009) at Bikaner, Rajasthan found that N levels increased the dry matter and crude protein yield significantly at each levels of sheep manure. He further reported that dry matter yield with 150 kg N ha^{-1}+10 t ha^{-1} sheep manure was at par with 150 kg N ha^{-1} alone and 100 kg N ha^{-1}+10 t ha^{-1} sheep manure, but was significantly higher over rest of the N levels with or without sheep manure. Whereas, the difference in yields of crude protein at 100 or 150 kg N ha^{-1} along with 10 t/ha sheep manure were statistically at par but significantly greater than rest of the N levels with or without sheep manure application.

According to Kumar and Sharma (2002), when the dose of FYM and nitrogen was increased, crude protein either increased significantly or tended to increase. Application of 50 % recommended dose of N:P (40:20) along with vermicompost (5 t /ha) and FYM (5 t/ha) gave significantly higher dry matter and crude protein yields of sorghum (Kumar et al. 2004). Furthermore, it was shown that the highest levels of crude protein (4.59 q/ha) and dry matter (60.6 q/ha) yields were achieved by applying 50% recommended dose of fertiliser (RDF) in combination with 10 metric tonnes per hectare of farmyard manure (FYM), and 100% RDF alone, respectively. Similarly, crude protein and dry matter yields increased by 14.9 and 1.9 per cent, respectively, due to *Azospirillum* inoculation over no inoculation (Gupta et al. 2007). In the study conducted by Kumar et al. (2008), it was shown that the application of a combination of 25 per cent nitrogen through farmyard manure (FYM), 75 per cent recommended dose of fertiliser (RDF), and Azotobacter inoculation resulted in significantly higher dry matter production in sorghum compared to other combinations of organic and inorganic fertilisers. In a study conducted by Patel et al. (2007), it was demonstrated that the utilisation of 100 percent RDF (recommended dose of fertiliser) in combination with FYM (farmyard manure) at a rate of 10 tonnes per hectare resulted in a considerable improvement in both the dry matter and crude protein yields of fodder maize. This finding was observed to be superior to the other fertility levels that were examined under the specific environmental conditions prevalent in middle Gujarat. Additionally, the treatment exhibited elevated levels of dry matter and crude protein content compared to the exclusive use of 100% recommended dose of fertiliser (RDF).

V. ADOPTION AND EXTENSION OF INTEGRATED NUTRIENT MANAGEMENT PRACTICES

The successful adoption of integrated nutrient management practices requires concerted efforts from various stakeholders, including farmers, agricultural extension services, policymakers, and researchers. The dissemination of knowledge, training, and technical support are essential components of promoting the widespread adoption of INM.

1. **Farmer Awareness and Education:** Raising awareness among farmers about the benefits of integrated nutrient management is a critical step in fostering its adoption. Educational programs, workshops, and training sessions can be organized to disseminate knowledge about INM practices, their impact on forage production, and the associated economic and environmental advantages. By empowering farmers with information, they can make informed decisions and actively participate in the adoption process.

2. **Capacity Building through Extension Services:** Agricultural extension services play a pivotal role in providing farmers with the necessary guidance and technical expertise to implement INM practices effectively. Extension agents can offer personalized

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recommendations, conduct soil tests, and assist in developing customized nutrient management plans based on specific agro-climatic conditions and farm requirements.

3. **Policy Support and Incentive Mechanisms:** Government policies and incentive mechanisms can significantly influence the adoption of integrated nutrient management practices. Subsidies on organic inputs, financial support for soil testing, and the provision of extension services can incentivize farmers to transition towards sustainable INM practices. Policy frameworks that promote the judicious use of chemical fertilizers while emphasizing organic amendments can contribute to the widespread adoption of INM.

4. **Research and Innovation:** Continued research and innovation are essential for refining integrated nutrient management practices and tailoring them to diverse agroecological contexts. Research institutions can conduct field trials, analyze the impact of different nutrient combinations, and develop region-specific nutrient management recommendations. By staying abreast of the latest scientific advancements, farmers can benefit from cutting-edge practices that maximize forage yield and quality.

5. **Knowledge Sharing and Networking:** Facilitating knowledge sharing and networking among farmers, researchers, extension services, and policymakers can create a conducive environment for the exchange of ideas and experiences related to integrated nutrient management. Platforms such as farmer cooperatives, agricultural forums, and online communities can serve as channels for disseminating success stories, best practices, and lessons learned, thereby accelerating the widespread adoption of INM.

VI. CONCLUSION

Integrated nutrient management holds immense potential for revolutionizing forage production in India. By harnessing the synergistic effects of organic and inorganic nutrient sources, INM practices can enhance soil health, promote sustainable forage yield, and improve overall nutritional quality. The successful adoption of INM requires a multi-dimensional approach encompassing farmer education, extension services, policy support, and research-driven innovation. As India strives to meet the growing demand for livestock products, integrated nutrient management emerges as a promising pathway towards ensuring food security, enhancing rural livelihoods, and advancing agricultural sustainability.

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