Indian Journal of Ecology (2022) 49(6): 2431-2435
DOI: https://doi.org/10.55362/IJE/2022/3843

Manuscript Number: 3843
NAAS Rating: 5.79

Fodder Quality Assessment Through Remote Sensing: A Review

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Abstract: This paper reviews the approach and techniques of remote sensing based fodder quality estimation. Timely knowledge of the fodder quality is important to meet the demands in the animal feeding. Remote sensing (RS) is a promising technology for assessing farm level fodder quality as compared to conventional methods. Various studies have been conducted on RS based fodder quality assessment at the farm level in the last two decades. In most of the studies handheld spectroscopy has been used for the small farm area, and aircraft or an unmanned aircraft vehicle (UAV)-based Hyperspectral imagery (HSI) or spectroscopy for the large area. In most of the studies, spectroscopy has been commonly used for fodder quality assessment to extract crude protein (CP), neutral detergent fibre (NDF), dry matter (DM) and acid detergent fibre (ADF) parameters for limited areas. While aircraft or UAV-based spectroscopy is being used for the large areas. These studies also suggest that multi-spectral imagery (MSI) data can be captured using UAVs and the Sentinel-2A/B satellite, while HSI data can be acquired by handheld or UAV-based hyperspectral cameras.

Keywords: Acid detergent fibre, Crude protein, Dry Matter (DM), Fodder quality, Hyperspectral, Neutral Detergent Fibre (NDF), Unmanned Aerial Vehicle (UAV)

Livestock has long been a symbol of wealth and power in all civilizations and India is blessed with a wide variety of livestock, such as “56.7% of world's buffaloes, 12.5% cattle, 20.4% small ruminants, 2.4% camel, 1.4% equine, 1.5% pigs and 3.1% poultry (Report of Animal Husbandry & Dairying 12th Five Year Plan, 2012-17)”. The significance of livestock in India is well recognized for agriculture sector (ICAR-IGFRI, Vision 2050, 2013). As per the 19^{th} livestock census report, India has the world's largest livestock population (512.06 million). Despite having the world's largest livestock population and highest milk production (176.35 million tonnes in 2018-19), the productivity of Indian livestock is lower than the global average and even lower than that of European countries (Rajendran and Mohanty 2004, Pratap and Jha 2005).

This largest population of livestock in the world plays a variety of roles in ensuring food security by supply of milk and meat and also eliminating unemployment in India. Accurate pasture management and feed planning are important aspects in increasing the profitability of livestock production. Updated information on concurrent field conditions such as harvest time, fertilizer rates and fodder procurement will help farmers to manage their feed for livestock (Schellberg et al 2008). Because, the agriculture sector is the backbone of India and plays a vital role in providing livelihood to more than half of India's population despite its declining contribution to India's GDP (Sasmal 2016). Livestock is the most important of the various enterprises under the vast umbrella of the agriculture sector.

In 2050, people will need about 400 million tonnes of milk and 14 million tonnes of meat. While in 2011, about 122 million tonnes of milk and 5 million tonnes of meat production were made only (IGFRI, vision 2050). Supplying nutritious fodder is an essential part of the dairy industries, while reducing the cost of quality livestock products requires a feed-based cost-effective feeding approach as feed alone accounts for 60-70% of the milk production cost. Therefore, any effort to increase fodder availability and reduce fodder costs will helpful in increasing profit margins for livestock owners as well. Presently, the country is facing a shortage of 35.6% green forage, 10.95% dried crop residue and 44% concentrated feed material (IGFRI vision 2050). In India, only 4.2 to 4.4% of crop land is devoted for fodder cultivation and there is a rare chance to expand the fodder growing area due to intensive use of agricultural land for food and other crops. Due to the scarcity of cropland for food production and the adverse effects of climate change, increased attention has been paid to forage production in controlled environmental settings in the recent years (Ahamed et al 2023).

Low production of quality and quantity of green fodder is one of the major reasons to prevent high production of dairy animals in India (Gupta et al 2019). This problem can be prevented by adopting proper agricultural practices in producing high quality fodder such as maize, oats and berseem. Maize is one of the most popular fodder crop in India as well as in the world. It has a higher growth rate and yield and is more adaptable, digestible, and palatable (Chaudhary et al 2014). "On the dry weight basis, average nutritional content in fodder maize is 20.5-24.7% dry matter (DM), 5.5-8.7% crude protein (CP), 23.1-30.2% crude fibre (CF), 64. 1-72.8% neutral detergent fibre (NDF), 38.3-46.8% acid detergent fibre (ADF) and 6.0-8.0% ash (Chaudhary et al 2011)".

Although, the optimum quality and quantity of maize forage production depends on several factors. such as planting date, adequate availability of moisture and important micronutrients (Fales and Fritz 2007). Some highlights of the findings from the different researchers in this field are depicted as under with their citations for assessment of quality of fodders.

Remote sensing technology based fodder quality assessment: In the past two decades, remote sensing satellite-based forage quality assessment approaches have emerged as a viable method for large-scale mapping (Jennewein et al 2021). Because remote sensing has potential to provide pasture quality information, which is of great interest for researchers. However, there is a need for further refinement in tools like spectral, spatial and temporal resolution of remote sensing satellites for better prediction accuracy of forage quality (crude protein, fibre etc.). Optical remote sensing sensors are using reflected light from the visible (0.4 - 0.7 µm) to shortwave infrared (1.4-2.5 µm) region to detect variations in foliar chemistry (Jennewein et al *2021*). Youngentob et al (2012) have carried out research for the extraction of digestible protein (DP) and digestible dry matter (DDM) using hyperspectral remote sensing from leaf to canopy-level. Which is reflected light in very narrow (3-10 nm) spectral bands (Jennewein et al *2021*). Some recent works suggested that DDM can also be estimated using multispectral imagery obtained from unmanned aerial vehicles (Insua et al 2019, Michez et al 2020). Although, this technology is best suited to provide accurate solutions at low cost and high temporal coverage (Pullanagari et al 2012).

Several methods exist to evaluate the quantity, quality and acreage of forage (Kumar et al 2022, Karwariya et al 2022). It is important to have precise and up-to-date information about the quality of fodder to meet the demand of livestock (Singh et al 2020). Conventionally, farmers use visual criteria, such as plant phenological stage and leaf color, to evaluate forage quality. Moreover, agronomists and nutritionists evaluate the quality of fodder through laboratory-based chemical analysis and NIR (near-infrared reflectance) spectroscopy. Methods that take place in a lab are used to figure out the chemical composition of fodder and how well it can be digested.

Acid detergent fibre (ADF) represents cellulose, lignin, and silica, which is essential parameters that is negatively correlated with fodder crop's digestibility. The amount of protein in fodder is another important factor that needs to be taken into account when making rations with good quality fodder.

Protein comprises amino acids, which are key elements of all cells and tissues. Protein is an important part of ruminants' diets because it gives them nitrogen, which is needed for their metabolism and the making of milk and meat. Many studies on grassland are based on field spectroscopy. Handheld spectrometers are sensitive in the wavelength range of approximately 350 nm to 2500 nm, with high spectral and radiometric resolution. This instrument is being used by agronomists to predict fodder yield and quality parameters such as CP, ADF, NDF, CF within a limited spatial area (Safari et al 2016, Zhou et al 2019).

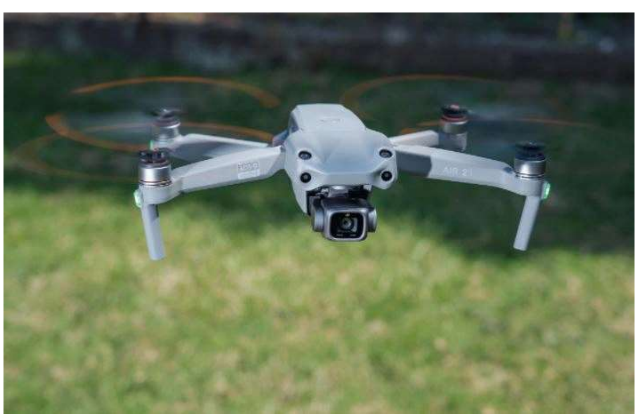
Although, Remote sensing satellite is a cost-effective approach to assess forage yield and quality. In which, optical

Satellite based fodder quality estimation

and microwave remote sensing sensors can be used for monitoring and mapping forage yield and quality. Nowadays, spectroscopy is being used more commonly for quality evaluation using CP, NDF and ADF parameters, but it has some limitations for point level observations over large areas. Aircraft or drone-based applications of spectroscopy can reduce these limitations. In addition to point level observation, it is also proving 2D image with spectral reflectance value of pixels' in numerous bands. Airborne imaging spectroscopy is being used worldwide for forage quality assessment. But manned aerial-based observations require extensive pre-planning. On the other hand, UAVs allow observation from low altitude for large areas with relatively low cost. Which is globally adopted for vegetation mapping and biomass estimation using multispectral sensors.

Use of Hyperspectral and Unmanned Aerial Vehicle (UAV)

Hyperspectral imaging is a technique used to capture and analyze the spectral signature of an object or scene. It involves collecting and analyzing the electromagnetic spectrum over a wide range of wavelengths, typically in the visible and near-infrared range. Nowadays, UAVs and a hyperspectral imaging approach are being utilized to capture canopy reflections of fodder in the range of 450 nm to 800 nm for robust fodder quality and yield estimation by Geipel et al 2021 and observed that the maximum accuracies of estimation were achieved by general models based on the pooled data and by means of PPLSR model for estimation of fresh (FM) and dry matter (DM) yields, as well as crude protein (CP), dry matter digestibility (DMD), neutral detergent fibre (NDF), and indigestible neutral detergent fibre (iNDF) content. Wijesingha et al 2020 were used five predictive modelling regression algorithms (Partial least squares, Gaussian process, Random forest, Support vector machine, and Cubist) to develop quality estimation models. UAV with a hyperspectral sensor has been used to capture the spectral imageries from the grasslands, and crude protein (CP) and acid detergent fibre (ADF) concentration of the fodder was evaluated.



Drone-based Hyperspectral Data Capture and Processing

Nasi et al 2018 used Integrated spectral and 3D features using airborne miniaturized multispectral, hyperspectral and colour (RGB) cameras to estimate crop biomass and nitrogen content. In which excellent results were achieved by integrating hyperspectral and 3D features. Askari et al 2019 were utilised Hyperspectral imageries (HSI) and multi-spectral imagery (MSI) for the development of forage quality evaluation. Wherein, The MSI datasets were acquired using UAV sensors and the remote sensing satellites such as Landsat, LISS-III and Sentinel-2 etc. But the HSI datasets were acquired using a handheld hyperspectral sensor.

Some recent work has suggested that the use of push-sweep hyperspectral instruments mounted on manned aircraft has highest potential to estimate the fodder quality (Pullanagari et al 2018). This method needs a fully equipped aircraft, which is expensive and not easily available everywhere. Which is a major limitation of the use of UAVs for the assessment of fodder quality.

Application of Different Prediction Models for Assessment of Fodder Quality

Normalized difference vegetation index (NDVI), soil-adjusted vegetation index (SAVI), Partial least squares regression (PLSR), random forest regression (RFR), normalized-difference sand index (NDSI), Spectral ratios (SRs), Leaf area index (LAI), and artificial neural network (ANN) are well known predictive model for fodder quality assessment using high resolution satellite data. Apart from these predictive models, random forest, Gaussian processing regression (GPR), Support vector machine (SVM), Classification and regression tree (CART), and naïve Bayes (NB), and cubist regression (CBR), that have not been analysed with remote sensing satellite data for the estimation of fodder quality. Recently, a study has conduct by Wijesingha et al 2020 to estimate CP and ADF of fodder crop using UAV-borne imaging spectroscopy data and found that the resulting models can precisely estimate CP and ADF. The accuracy of that model are almost similar to obtained accuracy with the use of field spectroscopy. Punalekar et al 2018 were used integrated optical remote sensing (RS) satellite datasets (hyperspectral and Sentinel-2) with a radiative transfer model (PROSAIL) to estimate leaf Area Index and biomass for dairy industry. The hyperspectral and remote sensing spectral datasets has been utilized to achieve LAI through PROSAIL approach, which is compared with field based observations of LAI. Lugassi et al 2019 examined the relationship between CP, NDF, and reflectance in the visible–near-infrared–shortwave infrared (VIS–NIR–SWIR) spectral range using lab, field based measurement, and RS data and developed a statistical models using various calibration and validation data. Furthermore, they have utilized NDVI, SAVI and WDRVI indices as substitutes to estimate CP and NDF.

In addition, Machine learning techniques can be used to estimate the quantity and quality of fodder cropland using UAVs imaging spectrometry and spectral imaging. In this process, RS data can be obtained at least 4-times during the primary growth period and 3-times in re-growth season. Reference measurements can be included fresh and dry biomass and several quality parameters, such as DM, NDF, indigestible NDF, and nitrogen uptake. Various Machine learning algorithms were trained using reference measurements using training data. Recently Oliveira et al 2020 conducted a study for estimation of biomass, nitrogen content and digestibility using hyperspectral and 3D datasets and found that the results are better with a combined dataset of hyperspectral and 3D data than with multispectral and 3D data. Raab et al 2020 conducted a study to evaluate the potentials of combining Sentinel-1 and 2 datasets to estimate the quantity and quality of fodder crops. In which, study showed that sentinel-2 satellite datasets-based obtained parameters were adequate for predicting Organic ADF and CP concentration from field observations. A slight improvement in accuracy was found by adding the Sentinel-1 radar dataset to estimate ADF and CP. However, the combined Sentinel-1 and Sentinel-2 datasets did not improve well for dry matter estimation. Therefore, the Optical Remote Sensing Sensor (Sentinel-2) dataset may be sufficient to accurately estimate fodder quality.

CONCLUSION

The Crude Protein, Dry Matter, Neutral Detergent Fibre and Acid Detergent Fibre can be estimated for rapid and robust forage yield and quality estimation from grasslands and at different cutting regimes with combining of UAV-borne hyperspectral imaging spectroscopy (HSI), Radar Sentinel-1 and Multispectral imagery (MSI) of Sentinel-2 satellite. The MSI dataset will be obtained using UAV and Sentinel-2A/B satellite, while the HSI dataset can be acquired by handheld hyperspectral camera. Prediction models can be developed using PLSR statistical method and machine learning algorithms. In addition to this, vegetation indices NDVI, SAVI and WDRVI can be used for better results in fodder quality estimation.

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Received 27 July, 2022; Accepted 27 November, 2022