Chapter

Remote Sensing: Useful Approach for Crop Nitrogen Management and Sustainable Agriculture

Salima Yousfi, José Fernando Marin Peira, Gregorio Rincón De La Horra and Pedro V. Mauri Ablanque

Abstract

Soil fertility is among the most important criteria that affect crop yield and quality. Nitrogen stress due to the low soil fertility and the lack of nitrogen availability is a major factor limiting the crop productivity in arid and semiarid environments, where fertilization is not optimized in terms of timing and quantity. Managing nitrogen fertilization is one of the most important criteria in the precision agriculture, which helps to improve crop production, environment conditions, and farmer's economy. It is very important to apply N fertilizers with efficient methods allowing to the nutrient use efficiency and avoiding nitrogen losses and environment contamination. Nowadays, remote sensing methods using spectral and thermal approaches have been proposed as potential indicators to rapid identification of crop nitrogen status by providing information about vegetation canopy properties across large areas. The use of remote sensing methods to schedule nitrogen fertilization can help farmers to practice a more sustainable agriculture, minimizing risks of losing the harvest by providing an adequate rate of nitrogen when the crops' needs and at a specific location.

Keywords: nitrogen fertilization, remote sensing, smart N management, farmer's decisions, precision agriculture, sustainable agriculture

1. Introduction

Soil nitrogen amount is among the most important criteria that affect crop yields and quality. Plant growth and development need nitrogen in greater quantity, since it is involved in various physiological processes. Nitrogen is a part of many components of plant cells, including amino acids, nucleic acids [1], proteins, and chlorophyll in plant leaves. Likewise, nitrogen availability produces rapid and early crops' growth, increases protein content of crops, facilitates the uptake and utilization of other nutrients as potassium and phosphorous, improves fruit quality, and controls overall growth of plant [2, 3]. However, nitrogen deficiency rapidly inhibits the growth of plants and alters many metabolic processes. The lack of nitrogen decreases photosynthesis [4], causes appearances of chlorosis [5], reduces chloroplast size [6], and provokes a high decrease in crop quality and yields.

Consequently, analyzing nitrogen amount in soil and crops and the application of N fertilizer in the event of a deficit are essential to improve crop production. A key factor in the efficiency of nitrogen application is to adjust N input to N crop demand [7]. The addition of N fertilizer when crops' needs, with the right dose, may increase yields and reduce the farmer's input costs. In this way, precision agriculture permits the distribution of the correct quantity of agricultural inputs (fertilization and water irrigation) in real time and at a specific location. Mulla and Schepers [8] reported that precision agriculture aims to improve site-specific agricultural decision-making through collection and analysis of data, formulation of site-specific management recommendations, and implementation of management practices to correct the factors that limit crop growth, productivity, and quality. Moreover, Gebbers and Adamchuk [9] described the precision agriculture as a key to optimize the use of available resources to increase the profitability and sustainability of agricultural operations, to reduce negative environmental impact, and to improve the quality of the work environment and the social aspects of farming.

Therefore, monitoring nitrogen fertilization with a high coverture of crop, high spatial variability, and right timing of applications are very important to improve crop's production and to help farmers to take decisions. Nowadays, crop water and nitrogen managements use many indices acquired by remote sensing techniques. Mulla and Miao [10] informed that proximal sensing of crops is currently the primary tool used to detect nutrient deficiencies for variable rate application of fertilizer. This is based on researches that showed nitrogen deficiencies could be detected using spectral reflectance in the green, red, red edge, and near-infrared portions of the spectrum.

In this chapter, we explain the usefulness of the use of remote sensing techniques in precision agriculture in managing nitrogen fertilization. Remote sensing methods are rapid and nondestructive ways of permitting multiple optical measurement indicators of plant greenness and crop nitrogen status. Fox and Walthall and Hunt et al. [11, 12] showed that the greenness of plants is strongly related to leaf chlorophyll content and to N status, and so it has been used as an indicator of N availability. Moreover, remote sensing techniques can be generally defined as doing the right management practices at the right location, in the right rate, and at the right time [10]. This would reduce surplus N in the crop production system without reducing crop yield, which would in turn reduce N losses to surface and groundwaters [13].

2. Remote sensing systems and smart nitrogen fertilization

Remote sensing methods using spectral and thermal approaches have been proposed as potential indicators to allow rapid identification of crop nitrogen status by providing information about vegetation canopy properties. Guérif et al. [14] reported that reflective sensors represent a new approach showing great potential to provide quick and easy, nondestructive estimates of plant nitrogen status. Remote sensing observations in the visible and near-infrared spectral may provide information of leaf chlorophyll content, and such information permit the early detection of plant nutrient deficiency. Guérif et al. [14] have demonstrated that the canopy chlorophyll content is more strongly related to the canopy nitrogen content. This provides the necessary link between remote sensing observations and the canopy state variables used as indicators of nitrogen status. Moreover, nitrogen stress decreases canopy reflectance in near-infrared [15, 16] and increases canopy reflectance over all visible wavelengths, because of a shortage of chlorophyll and other light-absorbing pigments [15]. Therefore, vegetation indexes combining information from visible and near-infrared regions may maximize sensitivity to N stress and are used as tools in nitrogen fertilization.

2.1 Ground remote sensing to detect nitrogen deficiency

The use of low-cost ground remote sensing methods to schedule nitrogen fertilization may contribute to more sustainable agriculture [17]. Ground remote sensing instruments are very useful for small-scale operational field monitoring of biotic and abiotic stress agents. This technology has better temporal, spectral, and spatial resolutions than satellite remote sensing [18]. In this category, the effective and easy-to-measure Trimble GreenSeeker is the most used; it is equipped with an active sensor and emits its own light to measure canopy reflectance corresponding to the red and near-infrared. GreenSeeker measures the normalized difference vegetation index (NDVI), which is formulated using the following equation: (NIR − R)/(NIR + R), where R is the reflectance in the red band and NIR is the reflectance in the near-infrared band. In addition, Hunt et al. [12] informed that NDVI value varies with absorption of red light by plant chlorophyll and the reflection of NIR radiation by water-filled leaf cells.

NDVI is one of the most well-known vegetation indices used in precision agriculture in managing crops' fertilization. NDVI values indicate N uptake, plant health, and yield prediction [19] and correlate positively with intercepted photosynthetically active radiation and also correlate well with N content [20]. In this regard, NDVI readings are used to assess the effect of nitrogen fertilization [21, 22], since its values depend on two factors, nitrogen content and total biomass [23].

In the last decades, several companies offer equipment with N-sensor for proximal sensing of crop nitrogen and nutrient deficiencies as Trimble's GreenSeeker, Ag Leader's OptRx, and Yara's N-sensor. Farmers can use these services to analyze the level of nitrogen in their crops and make decisions before providing nitrogen fertilization. All these companies and many others help the farmer to analyze the levels of nitrogen deficiency in crops and to calculate the exact amount of N fertilizer for each crop.

2.2 Nitrogen management by airborne and satellite imagery

One of the most active applications in the nitrogen fertilization managing is the use of aerial remote sensing services. Multispectral, hyperspectral, and thermal aerial imagery obtained by unmanned aerial vehicle (UAV) flights is a useful tool to detect nitrogen N crop needs. According to Ref. [24], there are various categories of imaging systems derived from remote sensing and used in fertilization application. Among them we cited the RGB/CIR cameras, which combine infrared (CIR), red, green, and blue light imagery (visible or RGB) and enable to estimate green biomass [24] and N status (NDVI type of information). The multispectral cameras, which can acquire a limited number of spectral bands at once in the VIS-NIR regions, are widely used for evaluating green biomass, nutrient status, pigment degradation, and photosynthetic efficiency [24]. The infrared cameras or thermal imaging cameras have a potential use in predicting nutrients stress in crops.

Nowadays, various companies provide farmers aerial remote sensing services through multispectral and hyperspectral or thermal aerial imagery, which is used for the diagnostics of crop nutrient deficiency in different crops (wheat, rice, cotton, horticultures, and other crops). Several models of nitrogen applications are developed by the use of aerial platform imagery, permitting to improve farm nitrogen management. Nitrogen algorithm models, developed by the information obtained through N-sensor, can help farmers to calculate the correct dose of N supply needs by crops and location and thus increase crops' production and decrease environmental contamination due to excessive N fertilization.

Additionally, multispectral and hyperspectral satellite imagery also has a major role in managing crop growth. Data of satellite imagery (sometimes with free access) are frequently used in fertilization management and soil analyses on large spatial and temporal scale. Söderström et al. [25] explained that the advantage of using satellite data for N management within fields compared with handheld or vehicle-mounted sensors is that the data collected cover huge areas and can be used on a multitude of scales, from watersheds and landscapes to fields. New low-cost or publicly available satellite systems such as Sentinel-2 with high temporal resolution and with additional wavebands targeted for assessment of crop properties open up exciting possibilities for improved N management and nutrient use efficiency for more efficient food chains.

The CropSAT, Sentinel, and Fertisat are some satellites that offer farmers the possibility to improve the efficiency of nitrogen fertilization, using variable rate application (VRA) technologies. In addition, nitrogen maps created by satellite imagery can be used for site-specific adjustment of N fertilizer in the fields and are often adapted to specific requirements of crops, since each species has a different phenology and thus a different quantity and critical time for nitrogen application. Nevertheless, sometimes the climatic conditions are the main problems using satellite imagery to crop managements. In addition, weather conditions also influence the absorption of nitrogen by plants; hence, information derived from remote sensing imagery consider all these elements when defining precise doses of nutrient fertilizer.

3. Smart nitrogen fertilization for sustainable agriculture

In the recent years, remote sensing techniques are being considered as a key factor in the sustainability of agriculture. Information managed through NDVI and thermal and multispectral imageries are the most used in the precision agriculture for vegetation monitoring, since it permits to correct in real time problems found in the fields as the lack of nutrients or overfertilization; thus, avoiding losses of production and environment damages.

3.1 Timing of fertilization and plant needs

Both deficit and excess of N fertilizer have negative effects on plant growth. Guérif et al. [14] informed that too much nitrogen is not good either, as nitrogen toxicity can occur in overfertilized plants, leading to stunted growth and a poor-quality plant. In addition, Rubio et al. [26] showed that an excessive amount of N in ammonium form may adversely affect plant growth, causing a rapid development of the crop, with rapid stem elongation that makes plants too soft and blocks the absorption of Ca^{2+}. Moreover, Dynarski [27] added that overfertilized crops permit to take up more nitrogen than they need, which disrupts the balance of nutrients in plant tissue, and the result is that crops will be deficient in other necessary nutrients, such as sulfur and zinc, reducing in this way crop quality. Other authors added that inadequate quantity of N fertilizer could decrease fruit production [28, 29], increase susceptibility to insect pests [11, 30] and pathogens [28, 30, 31], and reduce nutritional quality of harvested products [28, 32].

However, the efficiency of N fertilization does not only depend on the contribution of the appropriate amount but also on providing this amount to crops at the right time, since each species has critical points in the cycle of growth where nitrogen input is primordial. For example, wheat cultivars need N supply in the spring and early summer, while corn absorbs most nitrogen fertilizer in midsummer, and other crops need N fertilizer just after crop emergence or at seedling. In this regard, nitrogen fertilizer should be applied when the crop needs and with adequate quantity.

In this regard, many researches showed that leaf spectral reflectance properties are closely related to growth environments (water and nutrients' availability), but it is also strongly associated to crop needs at different growth stages. In recent years, remote sensing methods are frequently used in managing N fertilizer in various farms; these techniques can help farmers to calculate the exact dose of N fertilizer necessary for crops and most importantly apply it at the right period. Many researchers have developed several models and algorithms using remote sensing information (through NDVI, drones, and satellite imagery) to determine N rates for different species and locations.

3.2 Remote sensing and soil fertility

The excess of N fertilizer causes negative effect on soil, since it affects composition and fertility of soils. The long-term use of fertilizers has become a significant source of soil and water pollution [33, 34]. The application of nitrogen above the appropriate levels may cause nitrate accumulation in lower parts of the root expansion, and consequently there is a risk for soil nitrogen leaching [35, 36]. In addition, [37] affirmed that soil acidity is developed in response to nitrogen fertilizer addition when addition of N exceeds the assimilation or N storage by biotic components or soil organic matter, respectively. The same authors added that excessive N fertilizer input could affect soil chemical and biological health, as well as the soil organic matter.

Hence, it is important first to know the current soil nutrient levels before any supplement of N fertilizer. In this way, soil parameter reflectance can provide information on the compositions and properties of soil. The study of spectral reflectance of soils has the ability to provide nondestructive and rapid prediction of soil physical, chemical, and biological properties [38]; soil texture, structure, and moisture [39]; and soil mineralogy and organic matter [40]. Therefore, potential information acquired through remote sensing technologies can help avoid soil degradation due to overfertilization. Moreover, mapping and analysis of soil fertility using remote sensing imagery or N-sensors before N supply can diminish soil compaction and increase N efficiency and absorption.

3.3 Environment protection

Another important effect of remote sensing techniques in nitrogen management is the protection of the environment. Excessive and long period of nitrogen fertilization accumulates contaminants in the soil and provoked environment damages. Guérif et al. [14] informed that overfertilizing can be a source of unnecessary extra costs as well as an environmental hazard in the case of nutrient runoff. Moreover, Saggar et al. and Vistoso et al. [41, 42] indicated that N fertilizer application at levels exceeding plant requirements leads to significant environmental consequences in many parts of the world due to N losses, such as nitrate NO_3 leaching, NH_3 volatilization, and nitrous oxide (N_2O) emission. Deterioration of water quality is also one of the most serious global environmental problems derived from the excessive crop nitrogen fertilization. Groundwater or surface water is being polluted mainly by nitrates when crop overfertilization occurs. Riley et al. [43] showed that the transport of N from agricultural soils to surface waters has been linked to eutrophication of freshwater and estuaries. High fertilization rates lead to N losses with negative impacts not only on atmospheric greenhouse gas (GHG) concentrations but also on water quality [44].

The excess of nitrogen fertilizer can be leached downward into groundwater, be mixed with surface waters, or be released into the atmosphere as gases, causing a high rate of environmental pollution. In addition, matching N application and crop requirements decrease deleterious environmental effects of excessive fertilization, either by nitrate pollution of water [45] or by gaseous emissions [46].

Consequently, all these negative consequences for the environment, associated with excessive nitrogen fertilizer, need new technological approaches to improve nutrient management. The use of remote sensing data to control dose and timing of nitrogen fertilizer can protect environment and permit best management of crops to more sustainable agriculture.

3.4 Impact of the intelligent fertilization in farmer's economy

In addition, excessive application of fertilizers also affects the farmer economy negatively. Efficiency of nitrogen fertilization can help farmers to improve control of incomes and reduce costs, avoiding unnecessary supply of N fertilizer. The application of the right dose of fertilizer (and sometimes no fertilization) helps farmers for best crop management, since the application of N does not always increase performance. The estimation of N plant and soil status prior to fertilization is important, particularly when fertilizer rates are above the optimal farmer's economic level and crop needs; in this case, farmers can reduce the unnecessary N fertilization and maintain yield at a lower cost. At many times, the minimum fertilization can optimize the yield and income of farms and permit the sustainability of agriculture. At present, the number of farmers who accept the use of new technologies in their crop management has increased. Farmers have realized that the better use of fertilizer through remote sensing information can greatly improve their income, protect their crops, and develop the rural environment.

4. Farmer's decisions to sustainable agriculture

In the past, farmers were not customary to the applications of new technologies in their farms. The farmers used classical methods to manage their crops and frequently applied irrigation and fertilized without having information on plant needs and soil composition. Traditional crop management leads to harvest loss, particularly when the different types of stresses are detected very late. In addition, the excessive use of fertilizers by farmers provokes often soil degradation and environmental pollution. Rosea et al. [47] indicated that as a response to the environmentally and socially destructive practices of postwar mechanization and intensification, the concept of sustainable agriculture has become prominent in research, policy, and practice. Sustainable agriculture aims to balance the economic, environmental, and social aspects of farming, creating a resilient farming system in the long term.

However, in recent years, remote sensing techniques to the sustainable agriculture are applied successfully by numerous farmers and in different category of crops including cereals, viticulture, horticulture, and grassland. Farmers using remote sensing information in their crop management can increase the efficiency of resource use and reduce the uncertainty of decisions required in the field.

At present, smart devices and intelligent systems interact flexibly with the precision agriculture. Remote sensing platforms that provide data storage and interpretation permit the intelligent analysis of crop status and accurate farmer's decisions. Cambra Baseca et al. [48] informed that systems for precision agriculture can be based on satellite navigation systems or terrestrial systems for geographic information and sensors located in the plot. These systems collect information to be used to make decisions with greater precision and to optimize crop yields.

Smart strategies, used by farmers to the sustainable nitrogen management, can help farmers to take the right decisions to reduce nutrient loss in the environment, maximize uptake of N by crops, reduce fertilizer costs, and protect environmental conditions. These strategies can be as simple as applying the right fertilizers in the right period and with the exact quantity at a precise location. Fertilization decision system is commonly designed for soil nutrient evaluation, management, and crop fertilization by integrating modern information technology, with soil quality evaluation and crop fertilization theory [49]. Consequently, precision agriculture using new technologies has powerful to improved farmer's decisions (appropriate use of fertilizer). Therefore, decisions taken by farmers afterward remote sensing diagnostics have significant effect in the sustainability of agriculture, the high crop productivity and quality, the prevention of environmental degradation, the farmer's economy (costs and income), and the rural improvement.

5. Conclusions

Nitrogen fertilization with the correct dose and timing is essential for successful crop production. Sustainable nutrient management strategies have been highly successful in various farms through the world. Monitoring fertilization has become a valuable tool in farm crop management, helping farmers to improve crop productions and to increase incomes.

Smart fertilization based on remote sensing techniques has shown various advantages, such as improvement of crop productivity and quality and agroecosystem protection. In the latest years, the costs of remote sensing application in nitrogen management have decreased and have become more common in agricultural sectors.

However, the economy of small farmers or farmers from developing countries is limited and doesnot permit the use of remote sensing services. For these reasons, the use of new technologies in monitoring nitrogen fertilization should be reinforced by the assistance and grants of the state in many regions of the world. Technical and economic support to improve the level of knowledge of the new technologies between farmers permits the sustainability of agriculture, the improvement of the global production, and environment protection.

Author details

Salima Yousfi[1]*, José Fernando Marin Peira[2], Gregorio Rincón De La Horra[2] and Pedro V. Mauri Ablanque[1]

1 Agro-Environmental Research Department, Madrid Institute for Rural, Agrarian and Food Research and Development (IMIDRA), Madrid, Spain

2 Area Verde MG Projects S.L., Madrid, Spain

*Address all correspondence to: salima.yousfi@madrid.org

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