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Precision Nitrogen Management for Cotton Using (GreenSeeker) Handheld Crop Sensors †

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Abstract: The precise monitoring of nitrogen (N) is an effective strategy for enhancing the crop yield per unit of land, but it involves field-level soil and crop data. The two years of experimental study were conducted during the cotton growing seasons of 2018 and 2019 at the Agriculture Research Farm of the Department of Agricultural Engineering, Bahauddin Zakariya University, Multan. The Nitrogen Fertilizer Optimization Algorithm (NFOA) was formulated based on the observed data for cotton lint yield (CLY) and GreenSeeker Normalized Difference Vegetation Index (GSNDVI) during the growing stages of cotton. The precision nitrogen application rate-based green seeker (PNAR) G.S for cotton was identified as 150-165 kg/ha. A linear relationship was observed between CLY (R2 = 0.80) for cotton with the GSNDVI. The average nitrogen requirement (N_{req}) using (PNAR) G.S was determined through the nitrogen fertilizer optimization algorithm (NFOA). The N_{req} was found to be 0.013 kg/kg for cotton. Precision N management originating from handheld crop sensors (GreenSeeker) may be helpful in decision-making for site-specific in-season N fertilizer management to enhance crop yield.

Keywords: Green-Seeker; cotton; NDVI; PNAR; NUE; NFOA

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1. Introduction

Precision N-management approaches are sustainable agricultural development practices. They have promoted overcoming the growing food demands and preventing declining natural food resources. Small landholders need to focus on these development approaches to maximize per unit land productivity. Hence, precision agriculture approaches are a fruitful method for upholding declining natural resources by applying inputs only at the right time when needed [1]. Additionally, Variable rate application (VRA) can calculate the N-fertilizer to resist the intra-field variabilities and to minimize the leaching of N-fertilizer because of over-application in the field. It has been reported that precision agriculture techniques, in combination with VRA, are the most effective way to make an N-management strategy based on spatial variability [2]. Moreover, N-management strategies can also be developed using a handheld sensor (Green-Seeker), providing real-time variable fertilizer rates over the field. These sensors are key tools for boosting crop yield per unit of land on less fertile soils. However, crop N sensors never provide the actual amount of required fertilizer; rather, the actual N status of plants is analyzed through vegetation indices through these crop N sensors. One of the most common and effective indices is the normalized difference vegetation indices (NDVI) that assist in generating in-season N requirement algorithms [3]. Depending upon the developed nitrogen fertilizer optimization algorithm (NFOA), plant N needs can be calculated easily to meet the requirement of the crop nutrient levels in the entire field [4]. Many researchers have reported the application of active crop sensors and handheld sensors (Green-Seeker) to determine the in-season nitrogen (N) application rates [5,6]. Therefore, the present research was conducted to develop the nitrogen fertilizer optimization algorithm (NFOA) and to adopt sensor-based algorithm approaches to formulate the precision input management strategy for cotton to achieve maximum productivity per unit of land.

2. Materials and Methods

The experimental field for the study was selected at the Agriculture Research Farm of the Department of Agricultural Engineering, Bahauddin Zakariya University, Multan (Figure 1). The research area was selected based on the easiness and timeliness of the soil collection, plant, and yield data, to ensure the proper analysis. The accessibility of all the field inputs (water, implements, and fertilizer) and laborers was ensured before site selection. The climatic conditions of Multan are arid, with sweltering summers and cold winters. Cotton seeds were sown using the "Chogga" method, which is adopted traditionally due to the unavailability of cotton planters. Cotton seeds sown at a rate of 2.02 kg/ha were applied to the field, and the variety of the seeds used in this experiment was "IUB-13". The nitrogen fertilizer optimization algorithm (NFOA) for the N-management strategy was formed with the help of the observed data of cotton crops during the 2018 and 2019 growing seasons. The Green-Seeker sensor was used to collect the NDVI data for wheat during its growing stages. The stages decided for the collection of the NDVI values were 3-feekes, 5-feekes, booting, and before the harvest of the crop. Moreover, the data for the observed cotton lint yield (CLY) were also used to determine their relationship with the GSNDVI. The relationship of CLY with GSNDVI for each of the growing stages of wheat was analyzed in MS Excel. The relationship that represents satisfactory performance was selected for the nitrogen fertilizer optimization algorithm (NFOA) to predict the in-season CLY. Moreover, these selected equations were used to determine the Final Precision Nitrogen Uptake (FPNU) and Early Season Precision Nitrogen Uptake (EPNU).

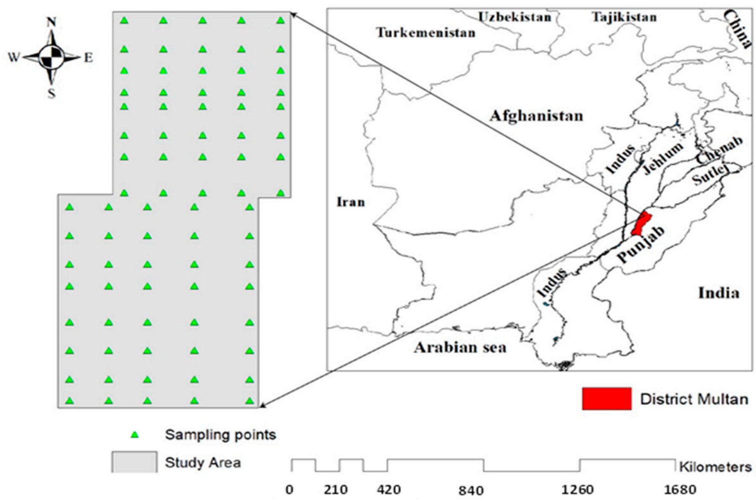


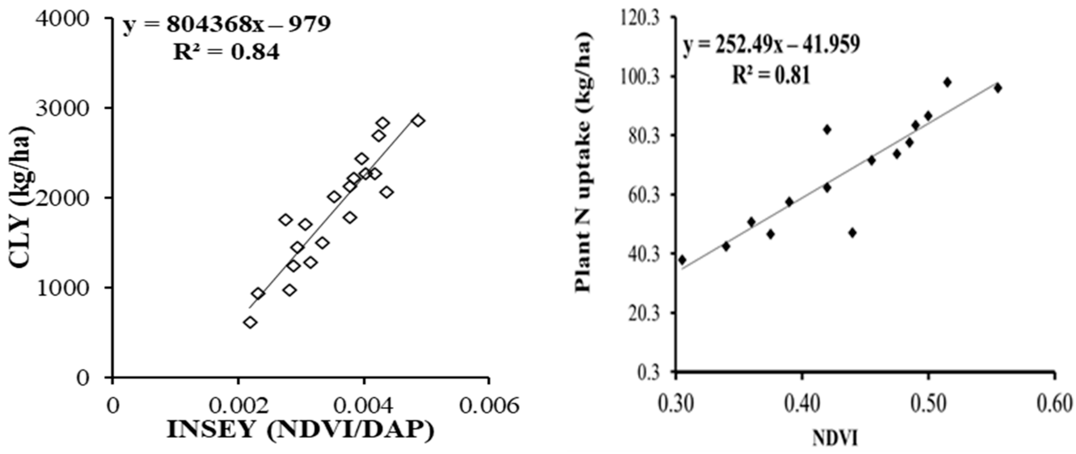
Figure 1. Location of the study area with a sampling position.

3. Results and Discussion

The data on the cotton lint yield (CLY) were plotted against the Green-Seaker-based in-season estimated yield (GSINSEY) (Figure 2a). This relationship provides a measure of the final plant N uptake (FPNU) by the crop for achieving a certain yield level and can prove to be useful in developing a nitrogen fertilizer optimization algorithm (NFOA) for precision N management. The relationship of INSEY vs. CLY performed better compared to other (days after planting) DAP days due to a higher coefficient of determination (R^2 = 0.84). Therefore, this relationship (CLY (kg/ha) = 804368 $\times$ GSINSEY $-$ 979) was used to calculate the FPNU in NFOA development. It has been studied that final plant N uptake requires the accurate measurement of crop yield to establish a relationship of N requirement before generating a nitrogen fertilizer optimization algorithm (NFOA). The inaccurate estimation of yield may result in the over- or under-recommendation of N fertilizers [7]. The relationship between NDVI and in-season N requirement was developed for cotton crops and is shown in Figure 2. It analyzed that the coefficient of determination R^2 between the NDVI and N requirement was 0.82. The relationship between the NDVI and N requirement indicates a clear exponential regression to measure the in-season N application rate using Equation (1) as follows:

$$\mathbf{y = 141.09e^{-2.389x}} \quad (1)$$

where, y = total N (kg/ha) and x = in season NDVI value measured from sensor.



(**a**) (**b**)

Figure 2. (**a**) Relationship of cotton lint yield (CLY) with INSEY (NDVI/DAP) data collected at different time intervals (**b**) plant N uptake and NDVI.

The relationship between sensor NDVI and cotton plant N uptake in the year 2018 is reported in Figure 2b. As crop plant N uptake is defined by the product of plant dry biomass and N content, it should be related to NDVI [5]. Therefore, the N application should be based on the relationship between sensor NDVI and N uptake by the plant. When the total N uptake by the cotton plant regressed against the NDVI readings, a strong linear model with a coefficient of determination (R^2 = 0.81) was observed. The EPA was determined using the following relationship of (EPNU (kg/ha) = 252.49 × GSNDVI − 41.95), which was analyzed between actual plant N uptake and the sensor NDVI values.

GreenSeeker-Based Topdressing N recommendation Algorithm for Cotton

Based on the above result determined in Figure 2a, the relationship of INSEY and CLY with higher (R^2) values was used to determine the final plant N uptake (FPNU). In the present study, FPNU was determined using the N requirement (N_{req}) and predicted CLY. N_{req} is defined as the amount of N needed to produce 1 kg of cotton. Therefore, the FPNU includes the N uptake by the cotton plant, and the N_{req} at different yield ranges was based on the results reported by [8]. According to the NFOA developed by [9], a precise in-season N application rate can be determined by taking the difference between the predicted EPNU and FPNU before topdressing divided by nitrogen use efficiency (NUE).

The following GreenSeeker (GS) nitrogen fertilizer optimization algorithm (NFOA) was proposed to determine the topdressing N fertilizer application rate for cotton crops:

- Predicting cotton yield using GS INSEY (NDVI-DAP) before topdressing N fertilizer application
    - Cotton lint yield CLY (kg/ha) = 804368 × (GSINSEY) − 979.

    - The average N requirement (Nreq) of 0.013 kg/kg for cotton lint yield (CLY) of 2355 kg/ha was found based on the (GS) N application rate.
    - Similarly, the average N requirement (Nreq) of 0.011 kg/kg for cotton lint yield (CLY) of 2335kg/ha was found based on the precision N application rate of soil analysis.
- Calculating final plant N uptake (FPNU) using predicted cotton yield and N_{req}, i.e.,
    - FPNU (kg N/ha) = CLY × N_{req}.
- Predicting early season plant N uptake (EPNU) using GSNDVI before topdressing
    - EPNU (kg N/ha) = 252.49 × GSNDVI − 41.95
- Determination of in-season topdressing N fertilizer requirement (NR)
    - NR (kg N/ha) = (FPNU − EPNU)/Nitrogen use efficiency (NUE)
    - NUE value was set to 40%.

4. Conclusions

The two years analysis of data for cotton indicated that a Green-Seeker handheld sensor could be used to determine the optimum N rate. The precision nitrogen management rate-based Green-Seeker $(PNAR)_{G.S}$ for cotton was identified as 150–165 kg/ha. A linear relation was also observed between CLY (R^2 = 0.80) for cotton with the GSNDVI. The average N requirement for cotton lint yield based on the nitrogen fertilizer optimization algorithm (NFOA) was 0.013 kg/kg, indicating the instant application of N fertilizer precisely by using handheld crop sensors. The performance evaluation of NFOA indicated satisfactory results based on their NSE, RMSE, NRMSE, and MAPE. Overall, the results showed that Green-Seeker-based N management strategies might increase crop yield.

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