#7619 QUANTIFICATION OF OPTIMAL FERTILIZERS DEMAND FOR WHEAT AND CORN FIELDS IN MOROCCO USING VERY HIGH RESOLUTION REMOTE SENSED IMAGERY AND HYBRID COMPUTATIONAL APPROACHES

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ABSTRACT

Demand on agricultural products is increasing as population continues to grow. Data driven management of macronutrients (i.e., nitrogen (N), phosphorus (P) and potassium (K)) and crops are of critical prominence to get the most out of soil in terms of crop yield while preserving environment. This study aims to establish a quantitative framework for macronutrient (i.e., nitrogen, phosphorus, and potassium) status (i.e., excess, deficiency) for winter wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) crops, in order to establish variable rate and optimal fertilization at a field scale. To do so, we will collect soil inputs over experimental plots of wheat and corn with a fertility gradient variability, located in two Moroccan regions with different agroclimatic conditions (Mediterranean to semi-arid areas). We will proceed *in situ* soil and crop sampling at significant growing stages and dates for lab chemical analysis. The collected field data (soil and crops samples) will be analyzed against remote sensing multi sensors onboard drone-based platforms datasets (i.e., hyperspectral, multispectral, and thermal wavelengths). In parallel, the collected datasets will serve for training, validation and testing of computational models that will be developed in this study. For instance, this study will investigate the performance of a hybrid approach that incorporates empirical methods of regression (e.g., random forest, principal component analysis, support vector regression least squares, partial and artificial neural networks) during the major growth stages for wheat assimilated N, P, and K content estimation, with physical methods based on radiative transfer models. If successful, this study is expected to show correlations between major nutrients nitrogen (N), phosphorus (P) and potassium (K) content in soil obtained in laboratory and corresponding reflectance generated from processed hyperspectral and thermal remote sensing datasets. To this end, we will evaluate the development of a general-purpose model for estimating the respective macronutrients content from these images. The performance of the model will be assessed using descriptive statistical indices and analysis of variance. We expect therefore that this project will demonstrate the potential of precision agriculture suitability, especially in sub-Saharan African countries.

Keywords: Airborne remote sensing, Drone-based platforms (also known as Unmanned Aerial Vehicle (UAV)); Agricultural soils and crops; variable rate fertilization, soil fertility, precision agriculture, machine learning, multi-modeling approaches

INTRODUCTION

Demand on agricultural products is increasing as population continues to grow (Godfray et al., 2010). Data driven management of macronutrients (i.e., nitrogen (N), phosphorus (P) and potassium (K)) and crops are of critical prominence to get the most out of soil in terms of crop yield while preserving environment. Thus, it is important to know the quantity of soil uptake-ready macronutrients to bring deficient rate through manure or inorganic fertilizers, avoiding therefore yield loss and potential environmental consequences, usually due to extra dosage of it. Nitrogen (N) presence is critical at physiological scale and constitutes just about 0.2 percent of a plant's dry weight. It increases the leaf area index (LAI), chlorophyll content and the activity some enzymes (e.g. phosphoenolpyruvate carboxylase) (Boussadia et al., 2010; Zhu et al., 2014). Nitrogen cycle in soil and air is quite complex and seems to rapidly enter into volatilization process, and crops remove an excessive amount of it from soil which turns the reactive part extremely scarce (Naeem et al., 2017). Phosphorus (P) is also ubiquitous in major crops biochemical processes such as photosynthesis and takes part in some biomolecules such as nucleic acids, adenosine di- and tri-phosphates (ADP and ATP, respectively) (Wang et al., 2020). Similarly to N and P, Potassium (K) is involved notably in photosynthesis and enzyme activation, which are eventual activities to sustain crop development (Wang et al., 2020).

Soil fertility is a proxy for crop yield, hence laboratory-based soil and yield mapping techniques can help into getting information about fertility status of soil and to come out with the appropriate recommendation (Patel et al., 2020). However, these methods prove to be costly and very restricted in time and space, especially if we plan to apply variable rate fertilization over large fields. During the last decade, multispectral and hyperspectral remote sensing has been employed for the identification and determination of plant uptake as well as soil nutrient properties through processing of spectral absorption features (Diacono et al., 2014). Various studies on the estimation of important macronutrients of soil through the application of remote sensing were conducted. For instance, in a recent study, Patel et al. (2020) used Derivative Analysis for Spectral Unmixing (DASU) approach on hyperspectral signatures of different types of soils and found that endmember features of NPK compost and soil have respectively diagnostic spectral absorption bands around 989.3 nm and 2195.1 nm , respectively. Reda et al. (2020) conducted a research in Morocco to assess performance of empirical regression models combined with variable selection algorithms to predict total P and Olsen P -the one in soil solution available for crops- under soil texture variation. The study showed that Olsen P prediction with Support Vector Machine regression coupled with Genetic Algorithm exhibited the best performance, with an $R^2 = 0.77$ and RMSE = 20.09 mg kg^{-1}, and noticed a wide variation in regression accuracy between the different combinations of algorithms and soil textures under investigation. Nonetheless, variable rate application technology relies basically on soil and yield mapping to achieve decent fertilizers recommendation not only for soil calibration but also for in-season correction whenever a kind of macronutrients deficiency occurs. For cereal crops, Fu et al. (2020) exhibited that crop reflectance variability along different growing stages is explained up to 68% by the variation in LAI and Chlorophyll a and b contents, which are eventual proxies of crop Nitrogen status. Liang (2005) mentioned that we can assess crop N uptake either through data driven empirical methods or leaf and canopy radiative transfer models or both. Other studies in fact have tried to estimate leaf N content through hybrid methods (i.e. the inversion of PROSAIL model with fitting algorithms) based on aerial hyperspectral data (Li et al., 2019; Liang et al., 2015).

The choice made by each of the previous studies have shown a potential of remote sensing datasets to hold information about crop yield and nutrition status, nevertheless these studies featured that this information is actually hidden under layers governed most of the time by eventual spatial and genotypical variability. To our knowledge, no research had previously assessed high resolution remote sensing-based models that fall within optimization of fertilizers in arid and semi-arid region in Africa on any kind of crops whatsoever. This study aims to tack this question by establish a quantitative framework for optimal macronutrient application for winter wheat and corn crops, which will ultimately lead to the development of regional framework and a crop specific variable rate nutrition model at a field scale.

MATERIALS AND METHODS

Study Area and Field Data Collection

This study will be conducted initially in Morocco, with a focus on regions with variability in both agroclimatic conditions (Mediterranean, semi-arid) and soil types (clay-marl, reddish siliceous, humus). To do so, we will establish an experimental design with an artificial fertility gradient experiment using experimental plots that have variability in terms of N, P and K concentration in soil. Similar protocol was used in previous studies (i.e., Mahajan et al., 2014) to assess nutrients uptake in wheat crops. In terms of the investigate crops, this study will focus on winter wheat and corn crops as there are the dominant annual cereal crops that exists in Morocco and in other countries in Africa.

To acquire a holistic overview regarding our prospective experimental plots, it will be necessary to get the most possible amount of data from soil and crops across our experimental plots, according to a tight schedule of sampling extended over the crop cycle. For soil testing, data corresponding to soil status before fertility gradient being established to assess the initial amount of solution NPK and crop uptake ready. We will also sample our plots a short period next to fertility gradient design and sowing, but the most important will be required subsequently after harvest to be able to establish our balance sheet in respect to crop yield, soil NPK uptake and total removal by crops. Soil and crop samples will be sent to laboratory for chemical testing to get eventual responses regarding to NPK in soil solution, crop fresh and dry weight, NPK uptake and concentration in leaves, stalk and grains.

Remote Sensing Data Acquisition and Processing

Multi sensors UAV (Hyperspectral, multispectral, and thermal) data will be collected over the investigated the area. This study will gather spectral information over many high-resolution bands over our experimental fields. The UAV-derived data will be collected on the same day as ground samples observations (e.g., of soil and crop samples) which will, among other reasons, highlight growth stages in which distinct spectral responses occur. This decision will help us identify in which physiological stage and spectral wavelength we have significant response related to the quantity of macronutrients absorbed by our respective crops. In fact, several studies tried to find out for some crop species, notably for wheat the most effective physiological stages to be remotely sensed exploited for the estimation of crop yield and nutrition. For instance, Barzin et al. (2020) tried to develop a yield prediction model for corn using UAV remote sensing and exhibited that during vegetative stages of the plant (i.e. V3-4-5), Soil Adjusted Vegetation Index and Canopy Chlorophyll Content Index were the head estimators in yield predicting models, while Green Leaf Index and Visible Atmospherically Resistant Index were dominating at tasselling stage (VT) in assessing accurately corn grain yield (R2=0.93). Li et al. (2010) also found that Red edge and NIR bands turn to be good estimator for wheat N concentration at Feekes 4–7 growth stages (F. Li et al., 2010). Raw data will be geometrically and atmospherically calibrated and converted to reflectance images using ENVI Software (L3Harris Geospatial, USA).

Statistical Analysis and Modeling

We expect to develop and investigate the performance of a hybrid multi-approach that will incorporate empirical methods of regression (e.g., random forest, principal component analysis, support vector machine, regression, partial least squares, and artificial neural networks) during the major growth stages for wheat assimilated N, P, and K content estimation.

This method will be combined with other physical methods based on inversion of radiative transfer models (e.g., PROSPECT, LIBERTY.) and regression based on distinct published Red-Edge, IR wavelengths, as well as hyperspectral vegetation indices. For this, we will use Python based libraries (Pandas, NumPy, Scikit-Learn, TensorFlow) for training our models, as being commonly used in a wide community of scientists operating in machine learning and data science. The various modelling methods will be applied using different packages in R as well as the assessment of the performance of models.

EXPECTED RESULTS AND PERSPECTIVES

We hypothesize that this study will reveal significance between solution soil nutrient availability, crops nutrients uptake rate, photosynthesis, physiological events (seedling...), growth stages and spectral responses, mostly around distinguished Red-Edge and IR wavelengths. Furthermore, we expect to identify diagnostic spectral bands or/and regions that could remotely translate nutrient deficiencies which may occur at different growing stages. This would accordingly reduce yield loss caused by in-season deficiency through eventual crop nutrients calibration in a preventive manner. Although it has been mentioned in anterior studies that, the empirical relationships are “growth stage site-specific”, and may consequently give rise to some sort of outliers or inaccurate predictions, we believe that their application in other sites with different conditions (i.e., radiation incidence angle, soil texture and moisture, crop health status and respective canopy and leaf distribution) can lead to different outcomes (Hatfield et al., 2008). To avoid such constraints, we have considered incorporating hybrid computational approaches by trying to fit our models in respect to canopy and leaf radiative transfer models, through which we expect to determine crops physical and physiological features associated with crop nutrition status.

This study will take advantage of the increased availability of lightweight hyperspectral sensors onboard UAVs to acquire high-spatial-resolution imagery (i.e., hyperspectral). Hence, using cost-effective remote sensing tools to optimize the process of fertilization and water consumption will enhance the extension of precision agriculture efficiency. It will also help to have efficiency controlling farming inputs with higher accuracy regarding the specific need in nutriments in Morocco and Africa. Moreover, the temporal and spectral resolutions that airborne imagery is offering in this research, will drastically reduce the cost of soil analysis and field research, and will ultimately contribute to maximize crop yields with remaining sustainable, an accessible matter to all size of farms, especially smallholder farms. This will strongly commit not only to Moroccan practices of agriculture and food security but will also impact the African environmental and social development.

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