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Evaluation of Citrus Gummosis disease dynamics and predictions with weather and inversion based leaf optical model

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ABSTRACT

One of the major threats for crops around the world due to pest and diseases, which can impact the health, economy, environment, and society at large. In general, several issues related to crop yield improvement arises due to insufficient and inadequate knowledge. Therefore, there is a need to develop viable models that incorporate various weather-soil-plant factors, which can give better understanding of the crop and enable timely interventions for yield improvement. To overcome Citrus Gummosis disease related issues and increase the Citrus productivity, seven different datasets Temperature (T), Humidity (R_h), Rainfall (R), Soil Moisture (SM), Soil Temperature (ST), Leaf Area Index (LAI) and Chlorophyll (C_{ab}) were used. Considering various plant, soil and environmental factors, the Citrus Gummosis prediction model has been developed with the multi-source datasets from June 2014 to November 2016 using Support vector regression (SVR) and multilinear regression (MLR). The research is carried out for healthy (5–10 Yrs. and 11–15 Yrs.) and unhealthy (5–10 Yrs. and 11–15 Yrs.) age group of plants. Inverse PROSAIL model has been simulated for retrieving citrus C_{ab} and LAI values. These values were validated with the actual field data. Both the weather and soils based disease prediction models has been developed and validated with MLR and SVR. Further, the influence of Gummosis disease on plant parameters was also studies with the new contribution of Biophysical variables (LAI and C_{ab}) based statistical prediction model. The SVR model gave fairly good performance as compared to MLR. In addition to the separate models a the combined scenario approach (Integrated Gummosis Disease Forecast Model: IGDFM) is designed to understand the interconnectivity of the parametric conditions (weather-soil- plant parameters) with disease physiology with respect to different age group of the plants. The RMSE of proposed approach for higher age group plants (i.e. 11–15 years) in the combined scenario was 0.9061 and 0.8518 for SVR and MLR methods, respectively. It is envisaged that this study could enable farmers to recognize and predict the timing and severity of the Gummosis disease in Citrus and thereby achieve yield improvement.

1. Introduction

Agriculture is the backbone of the Indian economy as more than 50 percent of the Indian population directly or indirectly depends on agriculture for their livelihood (Naqvi and Singh, 1999; Choudhari et al., 2018). The Indian agricultural sector is immensely large and productive owing to its diversity in agro-climatic conditions. Though agriculture is the strongest source of economy the farmer's community is however encountering tremendous hurdles in maximizing crop productivity. Various attempts have been made to understand the prime issues behind the lower crop yields. Accordingly, pest and disease modeling using different techniques (Patel et al., 2004; Matthews and Woolhouse, 2005; Cooke et al., 2006; Duveiller et al., 2012; Cunniffe et al., 2015; Kim et al., 2014) is one of the important direction to reduce the impact on crop yield (Donatelli et al., 2017). Recently, agricultural forecasting (including pest and diseases) techniques were developed using neural networks, fuzzy neural networks, support vector regression, time series, RBF networks and Fuzzy Support Vector Regression (FSVR) (Leksakul et al., 2015; Shi, 2011). Further, internet-based forecasting system and decision support systems were implemented using various multi-source data to predict fruit crop diseases (Pavan et al., 2011; Small et al., 2015). The dispersal modeling and forecasted meteorology approaches were also developed for disease warnings (Garrett et al., 2006; Skelsey et al., 2009; Luo et al., 2012). The specific focus of this work is on Citrus (Mandarin Orange), and is discussed in more details below:

1. The Citrus (Mandarin Orange) is an important fruit crop in the

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world (NBH, 2012, 2013). It is regarded as the second largest global fruit industry. In fact, more than 50 countries are growing citrus commercially in different agro-climatic regions (Naqvi and Singh, 1999, 2002; Naqvi, 2004; Timmer et al., 2004). Citrus occupies an important place in the horticulture wealth and economy of India (Naqvi, 2004). It is the third largest fruit industry after Mango and Banana (Naqvi and Singh, 1999; Naqvi, 2004) and India ranks amongst the top citrus producing countries in the world (Das, 2009; Badnakhe et al., 2015). In spite of its commercial value, the citrus producing farmers in India face severe economic losses due to the vulnerability of citrus to diseases (Naqvi and Singh, 1999, 2002). This is especially true for the 'Vidarbha' region of eastern Maharashtra; which is susceptible to diseases like Gummosis caused by 'Phytophthora' pathogen. It causes serious losses in production (Kerr, 1966; Naqvi and Singh, 1999, 2002). Phytophthora is a soil born and water-loving fungus. It is the most destructive plant pathogen (Naqvi and Singh, 1999, 2002; Naqvi, 2004; Timmer et al., 2004). Severe losses can also occur in groves subjected to flood irrigation if trees are planted on susceptible rootstocks (Naqvi and Singh, 1999, 2002; Olsen et al., 2000). It has been recorded as a primary constraint to sustaining optimum production and causes a partial reduction in the annual yield (Naqvi and Singh, 2002). The pathogen spreads rapidly, which is difficult to manage and control. The soil-borne nature of Phytophthora makes it extremely difficult to eradicate it. In fact, once Phytophthora enters and gets established in an orchard, it becomes an endemic problem. Such species are measured in terms of propagule count. It was recorded up to or as much as 250 to 350/cc in the soil of highly infested orchards. Usual practices such as water stress (during December-January) and flood irrigation (during May-June) disturb the balance of water intake of plants. It causes decayed feeder roots and water demand for an excessive bearing, which results in a sudden decline of such plants. In most of the citrus orchards the population ranged from 1 to 20 propagules/cc in soil, but occasionally it may be 100–200 propagules/cc in the soil. It is difficult to decide the threshold level in this case. However, the population greater than 10 propagules/cc in soil significantly affects the fibrous root density when treated with fungicides (Naqvi and Singh, 2002).

2. By understanding the economic value of Citrus, many research work has also initiated on citrus fruit and leaves diseases, use of technology in citrus farming, use of spectral analysis for feature identification in citrus disease or production management (Carrer et al., 2017; Choi et al., 2016; Maldonado and Barbosa, 2016; Sharif et al., 2018; Diaz et al., 2017)
3. There is another case about the effect of lack of transpiration and photosynthesis activity due to the presence of pathogen on plant physiology (Fig. 1). Plant physiology is affected by the change in the photosynthesis processes due to lack of nutrients (Isaac, 1992; Gifford, 1995; Cannell and Thornley, 2000; Das, 2005). Photosynthetically Active Radiation (PAR) absorption and leaf C_{ab} content were also measured in order to understand plant growth (Iglesias et al., 2002; Russell et al., 1989). Plant leaves and stem symptoms may be an indicative parameter of disease prediction (Das, 2008). Phytophthora affects the root system and shows yellowing symptoms of leaves, which affect the plant's physiological processes. Leaf Area Index, Cab can be considered as pre-stress detectors for diseases. PROSAIL (PROSPECT + SAIL) model is developed from PROSPECT (a model of leaf optical spectra which works on plate model) (Jacquemoud and Baret, 1990) and SAIL model (Scattering by Arbitrary Inclined Leaves). A leaf based Inverse PROSAIL model is used to extract C_{ab} and LAI content (Jacquemoud et al., 2009; Badnakhe et al., 2015).
4. There are different techniques used for inversion of (Radiative Transfer Model) RTM such as: Iterative optimization techniques, Look-up tables (LUTs) and Neural networks (NNs), Support Vector Regression (Jacquemoud et al., 1995; Bacour et al., 2006; Kaundal et al., 2006; Durbha et al., 2007; LaDeau et al., 2011; Darvishzadeh et al., 2012). The LUT based approach has been implemented for the citrus disease study with multiple solutions based on the prior knowledge of input parameters (Darvishzadeh et al., 2008).
5. It has been found that the Gummosis will occur, and spreads with some specific conditions such as an external environment above the soil, the internal environment within the soil, plant internal environment. The external environmental above soil condition includes (Temperature) T, (Humidity) $R_{h,}$ and (Rainfall) R. The soil parameters such as (Soil Moisture) SM and (Soil Temperature) ST are related to the internal environment of the soil. The biophysical parameters (Leaf Area Index) LAI and (Chlorophyll Content) C_{ab} are related to the plant internal environmental condition. Insufficient knowledge about the factors affecting plant disease progress is one of the most pivotal problems in addressing the issue of disease management (Kerr and Keane, 2013). Individual research and case studies have been done on a citrus leaf, fruit, etc., with respect to several diseases for different regions (Pydipati et al., 2006; Deng et al., 2016; Afonso et al., 2017; Ali et al., 2017; Dorj et al., 2017). For the successful monitoring of agro-meteorological parameters, an interoperable sensing system was also deployed and used (Sawant et al., 2017). However, there is still a need to find the correlations between different biotic factors and also a functionally viable model for Citrus Gummosis forecast for efficient and effective disease management.

Considering the pest and disease modeling literature and Citrus Gummosis disease cycle, the specific objective of this paper are:

- To study and understand the Citrus Gummosis disease dynamics through severity and incidence
- To simulate and perform Inversion of PROSAIL model to retrieve the Citrus leaf C_{ab} and LAI parameters. To develop and validate Citrus Gummosis disease forecast model by considering a combination of weather, soil, and plant parameters.

This paper is organized into various sections: Section 2 describes the design and plan of an experiment for Citrus Gummosis monitoring. Different modeling approaches also include in the same section with multi-source data. A Section 3 presents results and discussions on the modeling and validation for Gummosis. A Section 4 concludes with a comparison of different models, the best suitable model for disease and a description of the future work.

2. Materials and methods

While studying the interaction between crop-weather-soil-plant-disease parameters, a test bed for Citrus Gummosis disease prediction experiment was chosen at Warud, Amravati District of Maharashtra. This district is categorized as a semi-arid tropic zone. The section includes test bed information for conducting experiments with a standard set up surveillance data (leaf spectra, leaf Cab and LAI, SM and ST, disease gradation with Oozing Scale and soil analysis for Phytophthora colony count) and other all sensory parameters (T, R_h, R). The Gummosis severity and incidence evaluation method is illustrated (Eqs. (1) and (2)) and the different parametric models are designed and evaluated for Gummosis disease severity predictions with statistical regression techniques.

2.1. Test bed

A test site was selected in Warud, which is located in the eastern region of Maharashtra in order to study crop-weather-disease interactions. The test bed was situated at approximately 21°25′25″ to 21°30′00″ N latitude and 78°7′12″ to 78°16′42″ E longitude. It is comprised citrus orchards from Benoda (BN), Bargaon (BRN), Nagziri (NZ) (Fig. 1(b))