ESTIMATING SAFETY FACTOR AGAINST ROOT LODGING USING SENTINEL-1 DATA

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ABSTRACT

Lodging in wheat is one of the main constraints limiting yield and grain quality. Accurate information about crop lodging susceptibility during the growing season is critical for improving yield estimates and for targeting the expenditure on lodging control. In this context, this study aims to estimate safety factor against root lodging (SF_A) as a measure of lodging susceptibility by exploiting Sentinel-1 data using Extreme Gradient Boosting Regression. Through extensive field experiments during a crop season, several crop variables were collected from several plots in multiple visits, and the corresponding metrics were extracted from the Sentinel-1 images. Our results show that the field measured SF_A correlated well with the field lodging and the cross-validated regression model could estimate SF_A with an R^2_{CV} = 0.73 and $RMSE_{CV}$ = 0.59. Thus, the SF_A measure constitutes a state-of-the-art approach in the remote sensing community for the assessment of root lodging susceptibility.

Index Terms— Lodging susceptibility, wheat, remote sensing, Sentinel-1, safety factor, SAR

1. INTRODUCTION

Crop lodging, which is the permanent bending of the crop stem from its vertical position (stem lodging) or displacement of root anchorage (root lodging) [1], is a major yield-reducing factor in cereal crops such as wheat. Lodging can cause severe yield reductions by up to 75% [2], delay the harvest, increase the drying costs and deteriorate the grain quality in cereal crops [3]. The in-season assessment of lodging susceptibility is essential to develop appropriate crop management strategies (e.g., nitrogen fertilizer application) and mitigate yield losses [4]. Remote sensing (RS) data, responsive to rapidly changing plant physiology, can provide near-/real-time information about lodging susceptibility in real field conditions on a large scale [5].

This work provides a novel demonstration of estimating safety factors against root lodging (SF_A) as an indicator of lodging susceptibility in wheat using synthetic aperture radar (SAR) data. SF_A quantifies a plant's ability to bear the self-weight moment produced by the aerial parts of the plant (stems, leaves, and heads). The study focuses on an agricultural region situated in Jolanda di Savoia, Italy, where 11 Sentinel-1 images were acquired synchronously with field measurements (e.g., biomass, height, safety factor) made in an area of 600 ha 2018.

2. METHODOLOGY

A set of 61 plots (size 60×60m) were identified using stratified random sampling from six information strata (sowing date, soil pH, soil type, elevation, seed density, and crop variety). Three subplots (2×2m) were selected within each plot, and the readings were averaged. In each plot, temporal crop measurements were made in three visits between 14 March – 30 June, covering four major crop phenological stages – stem elongation, booting, flowering, and milking. Several cultivars: PR22D66 (LSS: 1.5), Marco Aurelio (2.5), Rebelde (3), Massmio Meridio (3), Claudio (4), Monastir (5), Odisseo (6.5), Giorgione (7) and Senatore Capelli (9) with a wide range of lodging susceptibility scores (LSS) were sown in the study area. The LSS (ranging from 0,9) indicates a cultivar's susceptibility to lodging, with a LSS of 9 depicting maximum lodging susceptibility.

In each subplot, crop height (HP), fresh biomass (FBP), and height at the center of gravity (hP) were first measured using an inch tape. The plants were then subjected to simulated lodging using a custom-built handheld lodging meter (reading up to 6 Nm with 0.001 Nm intervals; Mecmesin Ltd., UK) similar to the one used by van Delden et al.

(2010). The anchorage strength (SA) reading was noted from the lodging meter. The plant self-weight moment (MP) and safety factor against root lodging (SFA) were measured using equation 1 and equation 2, respectively (van Delden et al., 2010).

$$M_P(Nm) = sin\theta \times h_P \times FB_P \times g \quad (1)$$

Where

$\theta = 10^o, 20^o, 30^o, 40^o, 45^o, 60^o$ from the vertical

g (N/kg) = acceleration due to gravity, which is 9.8

$$SF_A = \frac{S_A}{M_P} \quad (2)$$

To better understand the field measured parameters, we first analyzed and interpreted their temporal variations across different growth stages.

We downloaded ten Sentinel-1 (in Interferometric Wide swath mode) images in ascending mode between March 14 and June 30, 2018 via the Copernicus Open Access Hub. The Sentinel-1 data was processed in SARScape to extract backscattering coefficients and coherence, while SNAP was used to extract polarimetric parameters. The approach described in detail in [6] was used to extract backscattering coefficients.

We used the phase processing coherence module in SARScape to generate coherence maps. To achieve the lowest temporal baseline (six days), we estimated coherence between every adjacent image pair (e.g. between date 1 and date 2; between date 2 and date 3; and so on). The processing steps for coherence estimation include i) Orbit file and orientation angle correction, (ii) interferogram generation, iii) interferogram flattening and topographic phase removal, iv) adaptive phase filtering, and v) geocoding. We also applied a dual-pol H/α/A polarimetric decomposition on the Sentinel-1 images. The processing chain consisted of six steps: i) orbit file correction, ii) TOPS Split to extract the sub-swath, iii) radiometric calibration, iv) TOPS Deburst, v) Refined Lee polarimetric speckle filter, and vi) H/α/A decomposition to produce entropy (H), alpha angle (α) and anisotropy (A) parameters.

We also performed a Pearson correlation analysis between SFA and satellite-derived metrics to understand the correlation between the variables. Finally, SF_A was estimated and mapped using Extreme Gradient Boosting (XGB) tree regression models. The flow chart of the methodology is presented in Fig. 1.

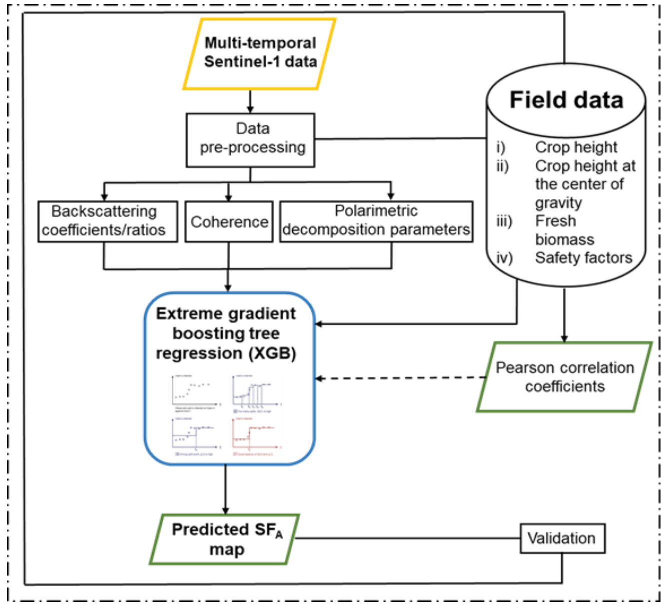

Fig. 1. Flowchart of SF_A estimation methodology. The inputs are colour-coded in the yellow, model is in blue, and the primary/intermediate outputs are in green. The dashed line represents signifies that the output is used for interpretation.

3. CENTRAL CONCLUSIONS

Our results showed that SF_A decreased progressively with crop growth and correlated well with observed lodging in the field. The lowest SF_A values were observed during the flowering and grain filling periods when the lodging risk is the highest. A strong and significant correlation ($r>0.60$, p-value <0.05) was observed between SF_A and VV coherence. The cross-validated XGB model using the metrics from Sentinel-1 data could explain 73% of the SF_A variability in the study site, with some degree of underestimation at high SF_A (>2) values (Fig. 2a).

Fig. 2b illustrates the predicted SF_A map derived from Sentinel-1 (26 March 2020) image over the wheat fields during the stem elongation stage. The spatial distribution of predicted SF_A in the maps shows that $SF_A \leq 1$ shows that the gravitational forces due to crop M_P alone could cause lodging. On the other hand, $SF_A>1$ indicates that M_P alone may or may not cause lodging. These maps can serve as a valuable baseline for assessing SAR data's capability for mapping SF_A in wheat and consequently can be used as an indicator of root lodging susceptibility early in the season. This information can be used to develop optimum in season-crop management practices, for instance, by altering the nitrogen fertilizer rate, applying plant growth regulators, etc. In conclusion, this is the first study demonstrating the use of RS data in lodging susceptibility assessment using a simple SF_A-based method, which can provide more robust estimates when combined with other crop biophysical/environmental parameters.

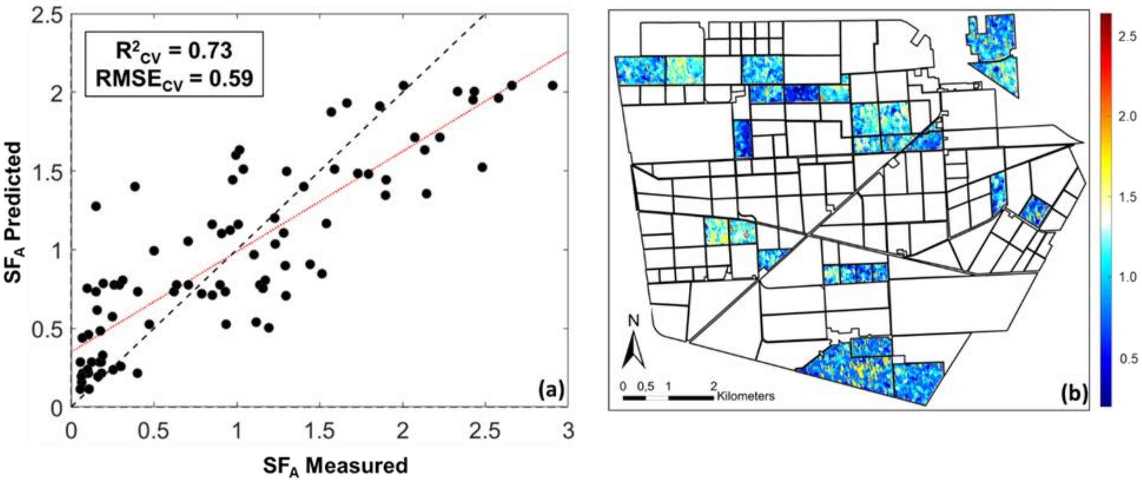

Fig. 2. (a) Scatterplot between measured and predicted SFA values using Sentinel-1 derived metrics. The diagonal black dashed line is the 1:1 line, while the red dashed line is the modelled regression line. (b) Sentinel-1 (26 March 2018) SFA map predicted using the cross-validated XGB regression models. Wheat was in the stem elongation growth stage. The farm boundaries are also overlaid on the map, and the non-wheat fields are masked out.

4. REFERENCES

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