Detecting Crop Lodging Stage using SAR-derived Crop Angle of Inclination

INTRODUCTION

Crop lodging is the permanent bending of stems from the vertical or displacement of the root anchorage, causing destruction of canopy structure, degradation of grain quality and severe yield reductions. It is caused by the complex interaction between crop's genetic, environmental and management factors, and is widespread in cereal crops like wheat. Assessments of the lodged area and severity of lodging are challenging and time consuming due to the heterogeneous distribution of lodging within a field and the absence of a standard scale to represent it. The few remote sensing-based studies of lodging have focused on detecting lodging, but lodging stage (and severity) measured by crop angle of inclination has not been looked at. The crop angle of inclination (CAI), defined, as the angle made by the crop stem with respect to the zenith direction, is an important metric to describe the physical structure of a lodged crop or the lodging stage (moderate, severe or very severe). To the best of our knowledge, there is no research evidence on the use of remote sensing for CAI estimation. The main objective of this study was to compare the performance of Sentinel-1 and multi-incidence angle (FQ8-27° and FQ21-41°) RADARSAT-2 data for estimating crop angle of inclination (CAI), a strong indicator of lodging severity.

MATERIALS AND METHODS

The study was carried out in the Bonifiche Ferraresi farm (Fig.1), situated in Jolanda di Savoia (central coordinates 44°52'59''N, 11°58'48''E), a commune in the province of Ferrara, Italy.

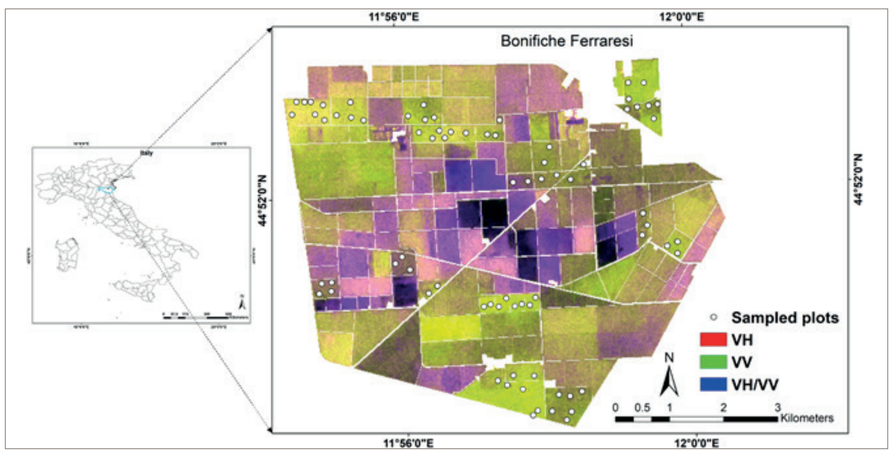

Fig. 1. The study area (left) and RGB composite of Sentinel-1 image acquired on 6 June 2018 with 76 sampled plots overlaid on it (right)

A set of 5 single look complex (SLC) RADARSAT-2 fine Quad-pol (FQ) and 11 SLC/GRD (ground range detected) Sentinel-1A/B images were used in this study. The RADARSAT-2 images were acquired in 2 beam modes: FQ8 (2 images) and FQ21 (3 images). The field measurements were made between May 1(flowering stage)-June 30 (ripening stage) in two rounds. The number of subplots ranged between 3 (for healthy plots)-8 (for lodged plots). For each subplot, CAI was measured indirectly using a plumb bob, an inch tape and some trigonometric calculations (Fig. 2). Support vector regression models were calibrated and cross-validated to estimate (and map) CAI using satellite-derived metrics from Sentinel-1, RADARSAT-2 FQ8 (~27o) and RADARSAT-2 FQ21 (~41°).

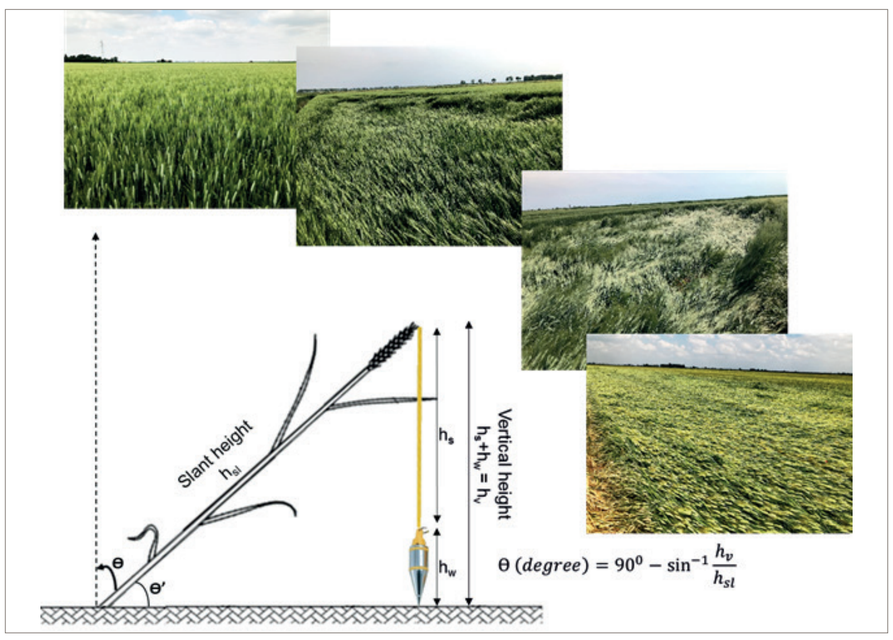

Fig. 2. Measurement and calculation of crop angle of inclination. The photographs depict different angles of lodging in wheat fields.

RESULTS

We examined the correlation of the 48 satellite metrics (43 from RADARSAT-2 and 5 from Sentinel-1 data) with CAI, using Pearson correlation coefficients (r) (Fig.3). We then calibrated and cross- validated the SVR models for the three datasets and the accuracy statistics are displayed in Fig. 3. To map the spatial variability of CAI, the developed SVR models were applied on the Sentinel-1 and RADARSAT-2 images. An example map derived from the Sentinel-1 is shown in Fig. 4.

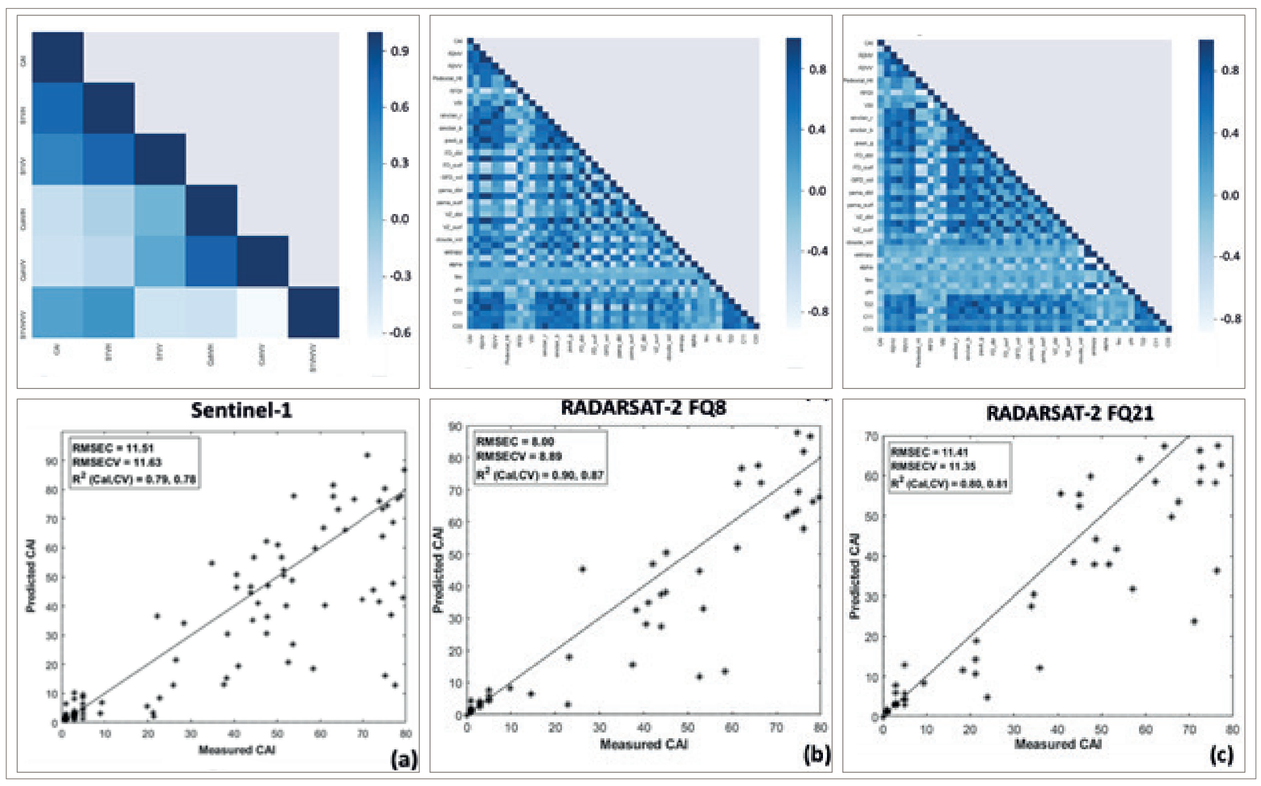

Fig. 3. Correlation matrix between CAI and the satellite-derived metrics (left) and predicted versus measured crop angle of inclination (CAI) (right) for (a) Sentinel-1 *(n=118)*, (b) RADARSAT-2 FQ8 *(n=57)* and (c) RADARSAT-2 FQ21 *(n=61)*.

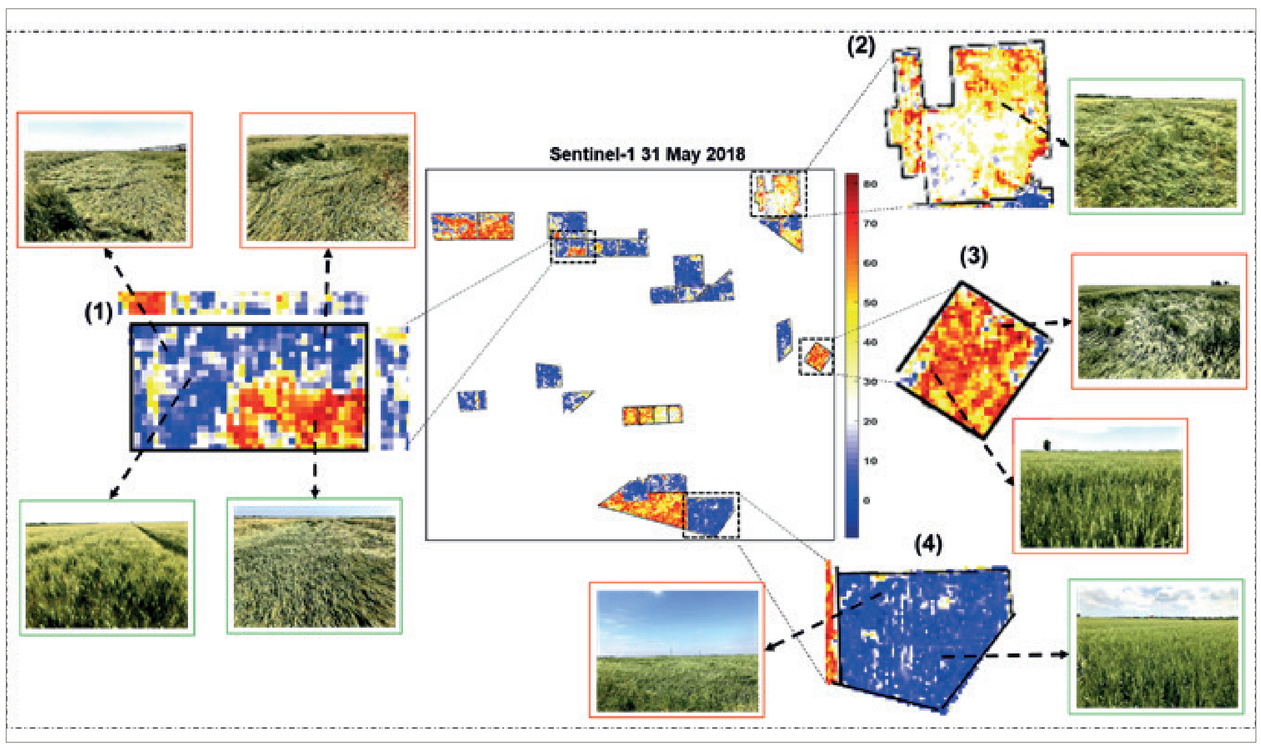

Fig.4. CAI map generated from Sentinel-1 data acquired on 31st May 2018. Blue corresponds to healthy crops (0<CAI<5°) and red corresponds to very severe lodging (61°<CAI <90°)

CONCLUSIONS

1 The low incidence angle RADARSAT-2 data (FQ8) estimated CAI with the maximum accuracy (R^2CV of 0.87) while the performance of high incidence angle RADARSAT-2 (FQ21) and Sentinel-1 data (R2CV of 0.81 and 0.78) was comparable. It can be concluded that the differences in sensor configuration (mainly the incidence angle) had a primary influence on the model performance while the increased dimensionality of RADARSAT-2 data played a secondary role. However, the combination of the two can improve our ability to monitor CAI throughout the crop growth cycle.

2 The low incidence angle data was found to be particularly sensitive to high CAI (>60°) while high incidence angle predicted the lower CAI values more accurately.

3 In summary, this study provides a theoretical basis of the potential of moderate to high-resolution SAR remote sensing data in estimating CAI as a measure of lodging stage.

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