THE USE OF A GROUND BASED REMOTE SENSOR FOR WINTER WHEAT GRAIN YIELD PREDICTION IN NORTHERN POLAND

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ABSTRACT

Crop canopy sensors, besides being mostly used for N status determination and variable N application, give the opportunity to apply them to grain yield forecasting on production fields. Algorithms for yield prediction were based on GNDVI measurements accomplished with a Crop Circle sensor at three winter wheat growth stages (GS 31, GS 39 and GS 71) in the years 2008 and 2009. The algorithms for the two years did not differ significantly only for the latest GNDVI measurement data. This was probably due to a definitely different distribution of rainfall at the time of intensive wheat growth in the two seasons. The later the reflectance data were collected the higher the relationship between GNDVI and grain yield. Grain yields predicted in 2009 on the commercial field, on the basis of the algorithm from year 2008 were on the average overestimated by 33%. But when GNDVI was first normalized for the year-to-year differences ($GNDNI_{2008}/GNDNI_{2009}$), then regressed against actual grain yield, the overestimation error was reduced to 10%. The % differences between actual and predicted grain yields were in both cases higher in the southern part of the field, surrounded by a forest. Such results indicate that the grain yield predictions in a field with parts close to surrounding forest or windbreak could be overestimated as the yielding potential of the crop, expressed in GNDVI values, can not be realized due to the terrain position and the negative effect of trees.

Keywords: GNDVI, Crop Circle, winter wheat, yield prediction

INTRODUCTION

Tractor-mounted crop canopy sensors have been mostly used for plant nitrogen (N) status estimation and its variable application. Gathering the information on a canopy reflectance gives also the opportunity to calculate different vegetation indices (VI's), of which some e.g. GNDVI are closely related to grain yield (Shanahan et al., 2001). This is because remote sensing data integrates the effects of the conditions on crop growth, and hence can provide immense potential for the use in grain yield forecasting (Reyniers et al., 2006). The successful use of the VI's, created at the research stage, for yield prediction on a commercial field seems to be strongly dependent on similarity of the temporally and spatially variable crop growth conditions in which the algorithms are developed and validated. The field surroundings, such as windbreaks or forest, may affect crops negatively in direct neighborhood (negative influence up to a distance equal to the height *h* of the trees, and positively for distances between 1 and 10-15 *h* if the field is located on the leeward in relation to the predominant wind direction (Jakubczak and Wołk, 1977; Baldwin and Johnston, 1984; Baldwin, 1988; both mentioned by David et al., 1994;). This influence of field surroundings on yield results mainly from changes in microclimatic conditions, such as shadowing, wind velocity, transpiration and temperatures (David et al., 1994; Jakubczak and Wołk, 1977) but for now it is not clear if they modify VI's. The objective of the research was to investigate the robustness of the GNDVI data of winter wheat for grain yield predictions on a commercial field partially surrounded by a forest.

MATERIALS AND METHODS

The research was conducted in 2008 and 2009 in northern Poland (54° 31' N 17° 18' E) on fields cropped with winter wheat (*Triticum aestivum L.*, cv. *Trend*) and farmed by Farm Frites Poland Dwa Sp. z o.o. The fields under study are dominated by Dystric Cambisols (WRB 1998) with predominantly sandy loam as texture and less frequent loamy sand. They developed from glacial moraine depositions of the last glaciation. The amount of monthly rainfall for the period from March to July were 94, 41, 20, 68, and 70 mm in 2008 and 47, 5, 69, 72, and 139 mm in 2009, respectively.

A strip-trial design (Griffin et al., 2006) was used to compare the effect of 6 N treatments: 0, 50, 100, 150, 200 and 250 kg ha^{-1} on grain yield variation. Fertilizer was applied at once at the beginning of the vegetation period. A light sensor Crop Circle^{TM} ACS-210 (Holland Scientific, Lincoln, NE) was used to collect reflectance data at 590 and 880 nm, which were then used to calculate the Green Normalized Difference Vegetation Index (GNDVI) (Dellinger et al., 2008), at the following growth stages: GS 31, GS 39 and GS 71 (Zadoks et al., 1974). At harvest time (GS 92) plants from the area of 1m^2 were hand cut and used to determine grain yield at 15% of moisture. Data of GNDVI and grain yield were then regressed and used to develop algorithms for grain yield prediction for the two years.

To perform a validation of the algorithm from the first year (2008), GNDVI was measured on 04.06.2009 (GS 59) also on a field of 21.9 ha on the same farm, sown with the same winter wheat cultivar. Reflection data was logged with geographical coordinates. Grain yield was measured at harvest time by yield monitors with DGPS data logging, mounted on two Claas Lexion 560 harvesters on 15th of August 2009.

Relationships between grain yields and GNDVI were evaluated using linear regression. Statistical comparison between slopes of regression for the years was based on results of multiple regression analysis (year was treated as binomial independent variable). To assess the effect of tree shade on the quality of grain yield forecasting, the shortest distance between the forest border and each raster cell of the interpolated yield map was calculated. Relationships between 'distance to forest' and 'difference between observed and predicted yield' were examined.

RESULTS

Comparison of slopes of the relationship grain yield vs. GNDVI for the same measurement dates, indicated significant differences between years at the two earlier growth stages (GS 31 and GS 39). This was probably due to definitely different distribution of rainfall at the time of intensive wheat growth. As the plants developed throughout the growing season the differences between N treatments with respect to GNDVI values increased. The later the reflectance data were collected the higher the relationship between GNDVI and grain yield. Respectively, for the last measurement date (GS 71) in 2008 and 2009, R^2 equaled 88.6 and 77.9% (Fig 1).

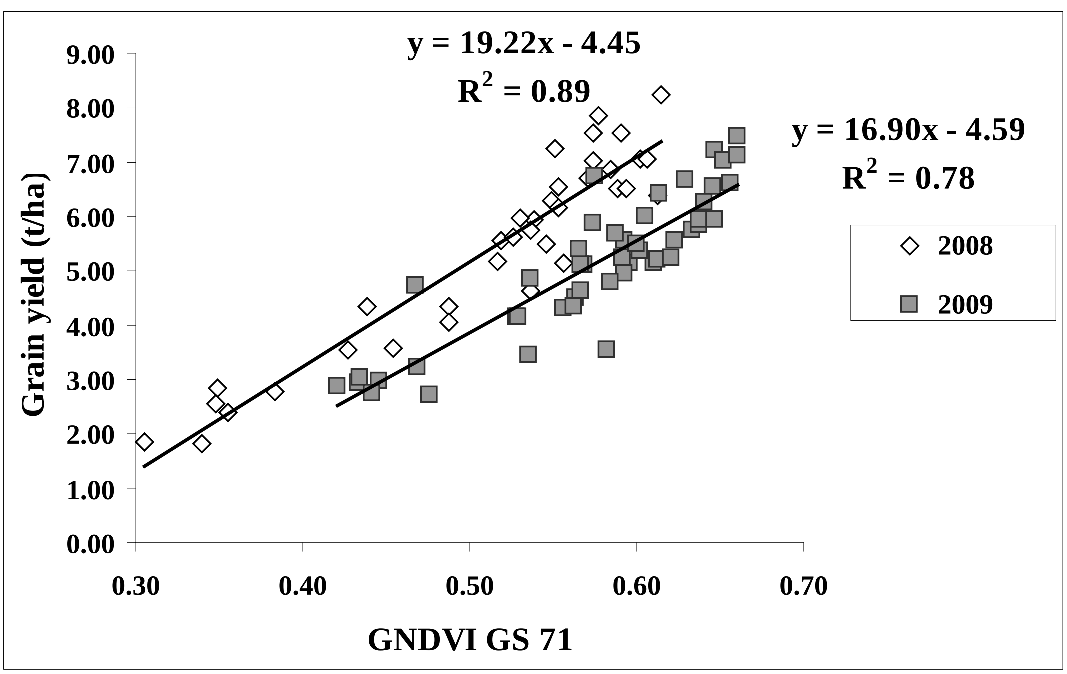

Fig. 1. Relation between grain yield and GNDVI in years 2008 and 2009

Grain yields predicted in 2009 on the production field on the basis of the algorithm from year 2008 (grain yield vs. GNDVI, GS 71), were on the average overestimated by 33% (Fig 2a).

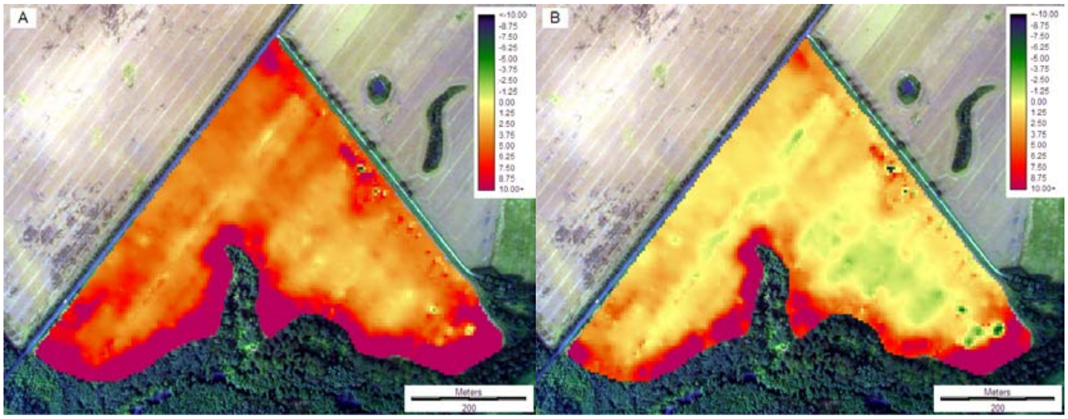

Fig. 2. Map of differences between actual and predicted grain yield (a) no normalization of GNDVI earlier applied (b) GNDVI normalized for year to year differences

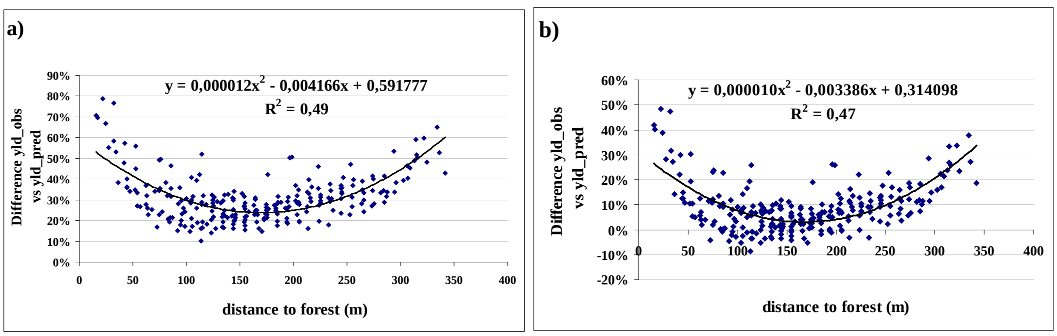

Fig. 3. Relation between the yield differences in Fig 2 and distance to the forest (a) no normalization of GNDVI earlier applied (b) GNDVI normalized for year to year differences

However, if GNDVI was first normalized for the year to year differences ($GNDNI_{2008}/GNDNI_{2009}$) then regressed against actual grain yield the overestimation error was reduced to 10% (Fig. 2b). The relative differences between actual and predicted grain yields were in both cases higher in the southern part of the field surrounded by a forest.

The relative yield differences were quite well related to the distance from the forest with R^2 of 0.49 and 0.47, respectively, for non-normalized and the normalized prediction algorithms. We observed that the relationship between distance to the forest and relative yield difference was weakened for distance values higher than 150-200m (Fig. 3). This may indicate some spatial effects of the northern field borders on the yield differences as well.

CONCLUSIONS

More robust algorithms for grain yield forecasting could be achieved based on multi-year yield and GNDVI data measured at different growth stages. The best prediction of yield was usually done at later crop growth stages when the time between measurement and harvest is relatively short and yield components are almost fully developed. Such late yield predictions have the advantage that the preceding weather conditions are already known and thus allow one to choose the algorithm developed in the previous years with the best fit to the weather pattern in the year of yield prediction. Normalizing the GNDVI for the year-to-year differences, eg. when GNDVI values from previous years and the current year are already known, may also significantly improve yield prediction. Applying the algorithms to predict yields of wheat cultivars which were not used for the algorithm's development may increase the yield prediction error. Forecasting of grain yields were most successful with increasing distance to the forest at the southern field border of the field. Ground truthing (performed at time of GNDVI measurement of the whole field) indicated on a greener canopy close the forest which agreed with the higher GNDVI values. GNDVI values reflect the actual yielding potential of the crop, which can be achieved if all growing conditions, such as light, water and nutrient status, temperature and pests are not limiting yield development in the period remaining to the harvest. All factors affecting the above mentioned growing conditions, for example the terrain position (accumulation, excess of water), headlands (compaction) and shadowing by the nearby trees (David et al. 1994; Jakubczak and Wołk 1977) may not permit to achieve this maximum potential yield. Such results indicate that the grain yield predictions in a field with parts close to forest stands (at southern position) or windbreak could be overestimated, as the yielding potential of the crop, expressed in GNDVI values, can not be realized due to the terrain position and the negative effect of trees.

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