# 9B.5 DURUM WHEAT YIELD AND PROTEIN CONTENT RESPONSES TO METEOROLOGICAL CONDITIONS: IMPROVEMENT OF CERES-WHEAT ROUTINE WITH A SIMPLIFIED FORECASTING INDEX FOR EARLY ASSESSMENT

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## 1. INTRODUCTION

Durum wheat (*Triticum turgidum* L. var. *durum*) grain protein content (GPC) plays a key role in determining the technological and rheological properties of flour for making high quality pasta. For this reason, a premium price is commonly paid to the farmer for wheat with a high grain protein content.

The sensitiveness of durum wheat to weather conditions and the uncertainty of the Mediterranean environment affect both harvest quantity and quality (Cossani et al., 2012; Rharrabti et al., 2003a, 2003b), making it difficult to warrant the standard quality. Moreover, the inverse relation between GPC with grain yield (Rharrabti et al., 2001), which are both important agronomic targets, makes the field management decision-making process even more complicated.

In fact, in the years when high yield can lead to low GPC, the farmers have the opportunity to minimize the climate impact on the grain quality through late nitrogen fertilization, close to anthesis.

In this context, an operational tool for durum wheat production estimation becomes necessary not only to forecast the final crop production, but also to better identify the driving climate variables in the specific productive area.

Crop models are recognized to be useful tools able to capture and describe the interactions between environmental variables and crops, helpful for the interpretation and

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extrapolation of experimental results and the identification of the weather driving variables.

Unfortunately, few studies on durum wheat modeling were carried out, especially in the Mediterranean and particularly for GPC simulation, therefore the modeling of the durum wheat responsiveness needs further investigations. In most wheat simulation models (CERES-Wheat, SWHEAT, AFRCWHEAT2, APSIM-N-wheat) the GPC is determined by the soil N availability and the plant N demand, the latter being positively related to the leaf area expansion, and thus to the leaf biomass able to store N. Therefore, the models assume the "source-limited" nature of the grain protein deposition, and the LAI is the main descriptor of the source of N available for the translocation. However, while wheat crop models show high performances in the yield assessment, poor results are commonly obtained for GPC estimation, also because the majority of simulation models have been developed for soft wheat where GPC has much less importance. Therefore, current algorithms must be revisited, and GPC modeling is still a challenge.

Our goals were: to evaluate the suitability of a mechanistic and deterministic model (CERES-Wheat) to identify the forcing and status variables affecting the GPC of durum wheat; to improve the model performance, through the assessment of a new routine for GPC simulation; to develop and test a simplified forecasting index (SFI).

## 2. MATERIALS AND METHODS

The research was carried out in Val d'Orcia (Lat. 43.03 N, Long. 11.66 E, 250-450 a.s.l.), a rural area of Tuscany (Central Italy). Meteorological, productive and phenological data for durum wheat cv. Claudio were used for calibration (data-set from wheat variety trials carried out, from 1997 to 2009, by Regional Agency for Development and Innovation in the Agro-forestry Sector, one field per year) and validation (data-set from the field monitoring carried out by Department of Agrifood Production and Environmental Sciences of the University of Florence and Siena Provincial Agrarian Consortium; 9 fields in 2009, 7 fields in 2010, 4 fields in 2011) of CERES-Wheat (DSSAT-CSM 4) (years 1998-2011), and for a long-term analysis (LTA) (years 1955-2011).

The model performance was assessed by means of a correlation analysis ($R^2$) between measured and simulated data, and quantified by the computation of Relative Root-Mean-Squared Error (RRMSE) (Jørgensen et al., 1986), Modelling Efficiency (EF) (Nash and

Sutcliffe, 1970), Coefficient of Residual Mass (CRM) (Loague and Green, 1991).

A new routine for GPC simulation was developed: GPC = {(TN/NS*100)+ 0.5}*5.7. Where: TN = total N available for the translocation from aerial biomass into the grain; NS = grain nitrogen sink; 0.5 = additional factor due to the genetic difference between durum and soft; 5.7 = conversion factor for grain N to protein.

In the long-term study, the fertilization was entered accordingly to the protocol most widespread in the study area: a total amount of N ranging from 95 to 200 kg/ha, split into one fertilization at sowing, and two applications during the crop cycle, at tillering and stem elongation stages, was adopted. Sowing and harvest dates were simulated automatically, within the period 10 Nov. - 30 Dec., when optimum soil conditions occur and at grain maturity, respectively. Monthly meteorological indices were computed for the main crop development stages: March (tillering), April (stem elongation, booting and ear emergence) and May (anthesis and grain filling).

To identify the main environmental and crop variables affecting production, a linear regression analysis between the harvest components (yield and GPC), the meteorological indices, and the maximum LAI simulated by the model at the end of growth stage was performed. Furthermore, a multiple linear regression analysis was performed (with SPSS.18 software) to develop the simplified index for harvest forecast (SFI).

Field measurements were carried out during two growing seasons (2010 and 2011 harvests) and the data collected (LAI, plants density, yield, grain humidity after drying, GPC and grain gluten concentration, timing of phenological stage) were used to validate the SFI and the CERES performance in determining the variables affecting the GPC.

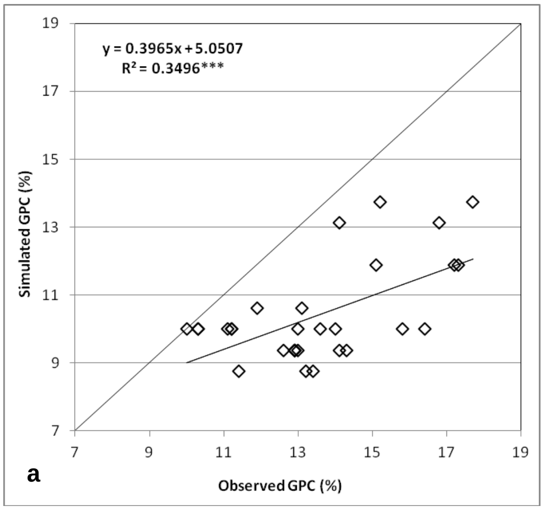
## 3. RESULTS AND DISCUSSION

A highly significant correlation ($P \leq 0.001$) was always found between CERES estimates and observed yield data. On the contrary, a poor relationship was found between the GPC observed and simulated ($P \leq 0.01$) by both CERES and CERES modified with the new routine, even though in the latter case performance indices improved (Fig. 1).

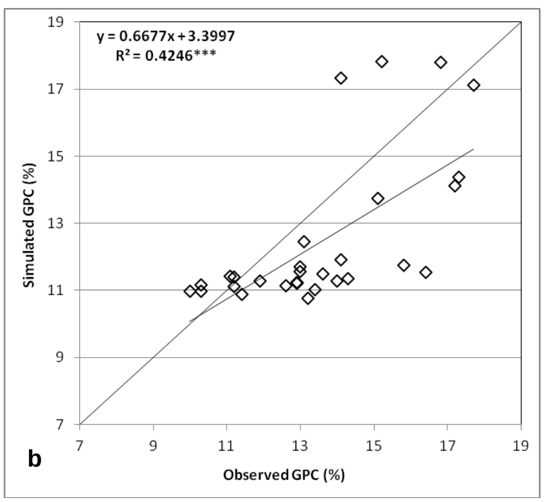
The LTA confirmed the well-established inverse relationship between yield and GPC; in general, weather conditions that adversely affect the yield are able to enhance the GPC (Tab. 2).

LTA highlighted the relevance of water availability during the early growth stage for the crop yield (Tab. 2).

Fig. 1 Comparison between simulated and observed GPC: CERES performance (a) and CERES improvement (b).




$R^2$ = 0.35 *** ; RRMSE = 26 % ;
EF = 0.93 ; CRM = 0.23




R2 = 0.42 *** ; RRMSE = 16 % ;
EF = 0.98 ; CRM = 0.08

During this period the leaf grow, the tillers increase, and the final density is reached (Miller, 1992). The number of potential spikelets per spike are also set (Miller, 1992). Therefore, since the survival of numerical components of wheat grain per $m^2$, such as tillers and spikelets, is positively related with the final yield (Fischer, 2011), a favorable water supply at tillering stage can promote the harvest quantity. The warm and water deficit conditions during the grain filling stage promote GPC (Tab. 2), since affect the starch accumulation in the grain more than that of the protein, and reduce the kernel size and weight (Zhao et al., 2009; Orlandini et al., 2011). The results of LTA also confirmed the positive role of LAI at heading stage on harvest quantity and quality (Tab. 2).

Rainfall distribution at tillering and LAI at heading stage were then included in the SFI as a main status and forcing variables that affect yield (Eq. 1) and GPC (Eq. 2).

(Eq. 1) $YIELD = 8622.546 – 200.57 * DD_{march} + 1221.299 * LAI_{april}$

(Eq. 2) $GPC = -90.64 + LAI_{april} * DDmarch * 0.607$

SFI was validated in two conditions; the first validation was made over 56 years and SFI failed in the prediction of GPC variability (no correspondence between simulated and forecasted data). The second validation was made using data observed during 2010 and 2011 growing seasons. Therefore, fields were distinguished on the base of LAI value at the heading stage in intermediate (1≤LAI≤2) and extreme (2<LAI<1). SFI was able to forecast the GPC variability at intermediate LAI and failed for extreme LAI, suggesting that the relationship between LAI and GPC is not linear. In fact, the assumption of "source-limited" nature of the protein deposition, adopted by CERES, was valid only at intermediate range of LAI. On the contrary, CERES was unable to capture the dilution dynamics of grain protein, described by the inverse relationship between yield and GPC, which occurred at extreme values of LAI.

SFI could be integrated with remote sensing technologies to improve the spatial and temporal coverage of the predictions, opening interesting opportunities for operational applications at different scales (from farm to regional). LAI values could be retrieved by remote sensing data and used to develop a prescription maps for nitrogen fertilization

The realization of an automated data acquisition system from satellite data sources will be a realistic possibility for site-specific agriculture applications.

Tab.2 Correlations between harvest (grain yield and GPC) and meteorological indices and plant LAI.

| ***Weather variable*** | ***Yield*** | | | ***GPC*** | | |
|---|---|---|---|---|---|---|
| | *March* | *April* | *May* | *March* | *April* | *May* |
| MTMAX (°C) | ns | ns | ns | n.s. | n.s. | +* |
| MTMIN (°C) | ns | ns | − * | − ** | − * | n.s. |
| TP (mm) | + *** | ns | + * | − *** | − * | −* |
| WD (warm days) | ns | ns | − * | n.s. | n.s. | + * |
| DD (drought days) | − *** | ns | − * | + *** | + * | +** |
| ***Crop variable*** | | *April* | | | *April* | |
| LAI | | + *** | | | + *** | |

MTMAX=Mean Maximum Temperatures; MTMIN=Mean Minimum Temperatures; TP=Total Precipitation; WD=Warm Days; NR=Non-Rainy Days; positive (+), negative (−), no significant (n.s.), significant at P ≤ 0.05 (*), significant at P ≤ 0.01 (**), significant at P ≤ 0.001 (***).

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