Photosynthetic capacity of field-grown durum wheat under different N availabilities: a comparative study from leaf to canopy

presented by
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(CNR-ISAFOM)
Human resources:

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Rossella Albrizio

Master students of IAMB

Technicians and field workers
Planned activities

➢ Field experiment site: IAMB

➢ Crop: durum wheat (“Quadrato”)

➢ 5 intensive measurement days: 4 – 8 May 2007 (2 weeks after flowering)

➢ Join instruments, resources and energy .....
Objectives

- To characterize the photosynthetic capacity, growth and yield of field-grown durum wheat in response to N availability.
- To compare measurements performed at different hierarchical scales (canopy & leaf) in order to determine whether the analysis of photosynthetic activity at the flag leaf can be representative of the whole plant and can be used as an indirect way to assess differences in yield caused by differences in N fertilization.
Experimental design

IRR=100% ETc
IRR=50% ETc
Rainfed

B_0 – barley no fertilized
B_1 – fertilized barley (120kg/ha of N)
W_0 – wheat no fertilized
W_1 – fertilized wheat (120 kg/ha of N)
Studied parameters

- **Agronomical parameters**
  - LAI, SLA
  - Above-ground biomass, radiation interception
  - Yield, HI, & sink related traits

- **Plant Water status**
  - LWP at pre-dawn and midday (Scholander chamber)

- **Nitrogen status**
  - N & protein content analysis
  - NDVI (GreenSeeker)
  - Chlorophyll content (SPAD)
Studied parameters

- **Gas exchange**
  - Leaf scale (2 LICORS-6400)
  - Canopy scale (Canopy chambers)

- **Stable isotopes**
  - $\delta^{13}C$
  - $\delta^{15}N$
Gas exchange parameters (leaf scale)

- $A/C_i$ curves + Chlorophyll fluorescence (& all related parameters)
- A/PAR curves (& all related parameters)
Gas exchange parameters (canopy scale)

- Carbon Exchange rate (in terms of assimilation and dark respiration)
- Transpiration rate
The increase in GY observed in HN treatment can be explained on the basis of the increase in biomass leading to a larger number of spikes per plant, nr of grains per spike and nr of grains per m², without changes in grain growth.

<table>
<thead>
<tr>
<th></th>
<th>Low N</th>
<th>High N</th>
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</thead>
<tbody>
<tr>
<td>$GY$ (Mg ha⁻¹)</td>
<td>4.0 (4.3) ± 0.5 (0.1)</td>
<td>5.8 (5.7) ± 0.3* (0.2*)</td>
</tr>
<tr>
<td>$HI$</td>
<td>0.45 (0.48) ± 0.02 (0.01)</td>
<td>0.48 (0.46) ± 0.02 (0.02)</td>
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<tr>
<td>$TKW$ (g)</td>
<td>56.6 (57.5) ± 0.9 (0.7)</td>
<td>57.3 (57.0) ± 1.0 (1.4)</td>
</tr>
<tr>
<td>$KWP$ (g)</td>
<td>3.2 (3.4) ± 0.4 (0.3)</td>
<td>5.2 (5.0) ± 0.5* (0.3*)</td>
</tr>
<tr>
<td>Grains spike⁻¹</td>
<td>30.2 (28.4) ± 2.2 (1.3)</td>
<td>37.5 (33.2) ± 3.0* (1.3*)</td>
</tr>
<tr>
<td>Spikes plant⁻¹</td>
<td>1.9 (2.1) ± 0.2 (0.1)</td>
<td>2.5 (2.6) ± 0.2* (0.3*)</td>
</tr>
<tr>
<td>$AB$ (Kg m⁻²)</td>
<td>1.0 (1.2) ± 0.1 (0.04)</td>
<td>1.3 (1.4) ± 0.1* (0.08*)</td>
</tr>
<tr>
<td>$LAI$ (m² m⁻²)</td>
<td>0.6 (0.5) ± 0.3 (0.1)</td>
<td>2.2 (2.2) ± 0.4* (0.6*)</td>
</tr>
<tr>
<td>$\Psi_p$ (MPa)</td>
<td>-0.38 (-0.39) ± 0.05 (0.06)</td>
<td>-0.48 (-0.50) ± 0.08 (0.08)</td>
</tr>
<tr>
<td>$\Psi_m$ (MPa)</td>
<td>-1.85 (-1.97) ± 0.11 (0.06)</td>
<td>-1.88 (-2.0) ± 0.11 (0.08)</td>
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</table>
A strong positive relationship was found between GY and biomass and between GY and LAI, 2 weeks after anthesis. These results confirm that both the LAI and biomass values reached 2 weeks after anthesis are key factors determining wheat yield, as it is largely reported in the literature (e.g. Villegas et., 2001).
Plant nitrogen & chlorophyll content

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<tbody>
<tr>
<td>Grain N (%)</td>
<td>1.5 ± 0.1</td>
<td>2.2 ± 0.1*</td>
</tr>
<tr>
<td>Flag leaf N (%)</td>
<td>1.5 ± 0.2</td>
<td>2.8 ± 0.3*</td>
</tr>
<tr>
<td>SLN (g m⁻²)</td>
<td>1.3 ± 0.1</td>
<td>2.8 ± 0.1*</td>
</tr>
<tr>
<td>SPAD</td>
<td>30.2 ± 1.8</td>
<td>51.3 ± 1.8*</td>
</tr>
<tr>
<td>NDVI</td>
<td>0.51 ± 0.05</td>
<td>0.74 ± 0.02*</td>
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N supply significantly increased the N content in the grains (≈ 45%)

Leaf N content doubled in the fertilized plants on both dry matter and leaf area basis (SLN)
Due to the effect of N supply on both the Chl contents and grain yield a strong positive relationship was found between SPAD and GY and between NDVI and GY.
Leaf level: gas exchange

$A_{\text{sat}}$ was 24% significantly higher in HN treatments.

Chl fluorescence showed a significant increase in $\Phi_{\text{PSII}}$.
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<tr>
<td>$A_{sat}$ (µmol m$^{-2}$ s$^{-1}$)</td>
<td>16.9 ± 0.5</td>
<td>20.9 ± 0.7*</td>
</tr>
<tr>
<td>$R_d$ (µmol m$^{-2}$ s$^{-1}$)</td>
<td>-0.83 ± 0.1</td>
<td>-1.10 ± 0.1</td>
</tr>
<tr>
<td>$R_d/A_{sat}$ (%)</td>
<td>4.9 ± 0.2</td>
<td>5.3 ± 0.2</td>
</tr>
<tr>
<td>$E$ (mmol m$^{-2}$ s$^{-1}$)</td>
<td>2.8 ± 0.5</td>
<td>2.9 ± 0.2</td>
</tr>
<tr>
<td>$g_s$ (mmol m$^{-2}$ s$^{-1}$)</td>
<td>270.1 ± 14.2</td>
<td>258.0 ± 13.4</td>
</tr>
<tr>
<td>$V_{c,\text{max}}$ (µmol m$^{-2}$ s$^{-1}$)</td>
<td>80.9 ± 10.3</td>
<td>133.3 ± 11.0*</td>
</tr>
<tr>
<td>$J$ (µmol m$^{-2}$ s$^{-1}$)</td>
<td>128.9 ± 9.2</td>
<td>167.0 ± 11.1*</td>
</tr>
<tr>
<td>$I$ (%)</td>
<td>12.9 ± 2.6</td>
<td>16.3 ± 3.2</td>
</tr>
<tr>
<td>$C_i/C_a$</td>
<td>0.70 ± 0.01</td>
<td>0.62 ± 0.03*</td>
</tr>
<tr>
<td>$PNUE$ (µmol CO$_2$ mol N$^{-1}$ s$^{-1}$)</td>
<td>193.3 ± 2.2</td>
<td>112.1 ± 1.7*</td>
</tr>
</tbody>
</table>

$A_{sat}$, $V_{c,\text{max}}$ and $J$ were significantly higher in HN treatment, while $g_s$, $E$ and $I$ were not affected. This means that a non-stomatal effect was responsible for differences in CO$_2$ assimilation.

Hence, the decrease in photosynthetic capacity of flag leaves in LN treatment is explained on the basis of a reduction in the carboxylation efficiency by Rubisco together with a decrease in the ability to regenerate RuBP.
Canopy level: gas exchange
In HN treatment was found a significant increase of about 30% in both the daily and the maximum canopy assimilation rates.

The similar increase in in $R_{\text{canopy}}$ and $A_{\text{canopy}}$ and in $R/A$ ratio of about 40% found in both N treatments suggest that the increase in photosynthesis cause a proportional increase in whole-plant respiration.

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<tr>
<td>$A_{\text{canopy}}$ (mmol m$^{-2}$ day$^{-1}$)</td>
<td>364.6 ± 3.4</td>
<td></td>
<td>472.8 ± 6.2*</td>
<td></td>
</tr>
<tr>
<td>$A_{\text{canopy, max}}$ (μmol m$^{-2}$ s$^{-1}$)</td>
<td>10.4 ± 0.2</td>
<td></td>
<td>13.4 ± 0.1*</td>
<td></td>
</tr>
<tr>
<td>$R_{\text{canopy}}$ (mmol m$^{-2}$ day$^{-1}$)</td>
<td>-164.0 ± 3.1</td>
<td></td>
<td>-192.1 ± 4.4</td>
<td></td>
</tr>
<tr>
<td>$Canopy R/A$ (%)</td>
<td>44 ± 4.3</td>
<td></td>
<td>40 ± 1.7</td>
<td></td>
</tr>
<tr>
<td>$E_{\text{canopy, (mm day}^{-1})}$</td>
<td>2.5 ± 0.1</td>
<td></td>
<td>2.7 ± 0.1</td>
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</table>
The observed decrease in $A_{\text{sat}}$ was proportional to the decrease of GY.
HYPOTHESES OF PHOTOSYNTHESIS REDUCTION

↓ \( A_{sat} \)

↓ Carboxilation efficiency of Rubisco (\( V_{c,\max} \))

↓ RuBP regeneration (\( J_{\max} \))

Can be limited by

Reductant and ATP supply from e- transport

↓ Leaf N content

↓ \( \Phi_{PSII} \)

Loss/inactivity of Calvin cycle enzymes further than Rubisco
Conclusions

- The observed increase of about 40% in GY in the HN treatments was attributable to the increased photosynthetic capacity of the canopy. This increase can be explained by a combination of different factors, such as an increase in above ground biomass, leading to a higher LAI with the consequent increase in overall canopy carbon assimilation.

- Leaves from HN treatments showed higher SLN values (and therefore more N per unit leaf area) resulting in higher assimilation rates per unit leaf area. Hence differences in N fertilisation affected not just carbon assimilation on a leaf area basis, but also the development and the duration of leaf expansion, which resulted in canopies with a larger green leaf area and higher carbon assimilation rates.
Conclusions

- These results allowed us to explain that in spite the fact productivity depends by the whole-canopy photosynthesis rather than to the activity of single organs, differences in flag leaf photosynthesis during grain filling reflected photosynthetic changes at the canopy level.

- Therefore, photosynthetic measurements at the leaf level may provide a simpler and less expensive (but realistic) characterisation of canopy photosynthesis and the grain yield attained by the crop.
Conclusions

- A similar response in photosynthetic gas-exchange parameters at both levels of organisation was observed.

- Gas exchange measurements performed at the leaf level during grain filling provided a realistic characterisation of the photosynthetic performance of the crop, giving an idea about the impact of N availability. Therefore, photosynthetic changes at the leaf level seem to mirror changes in canopy photosynthesis.

- The close relationship found between flag leaf photosynthesis and yield can be also explained because at the time when gas-exchange measurements were performed (2 weeks after anthesis), the potential differences in yield, and therefore the available sinks (i.e. number of grains per spike) were already established, and probably the only photosynthetic organs providing assimilates to growing grains were the flag leaf and the ear.
Photosynthetic capacity of field-grown durum wheat under different N availabilities: A comparative study from leaf to canopy

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ABSTRACT

The effect of N availability on photosynthetic capacity, growth parameters and yield was studied in field-grown durum wheat plants at both the leaf and canopy levels. Two contrasting nitrogen levels (150 and 0 kg N/ha) were assigned in a randomized block design with nine replicates each. Total biomass was measured at the anthesis and yield and its nongrowth components at maturity. Photosynthetic measurements were performed 2 weeks after application of nitrogen treatments (at anthesis). Flag leaves were measured using a LiCOR 6400 with the chlorophyll fluorescence meter, and the whole canopy by measuring CO2 and H2O fluxes in an auto controversial chambers system. We showed a clear decrease in photosynthetic gas exchange and chlorophyll content with N fertilization at both canopy and leaf level. As a consequence, the increase in yield or response to N fertilization comes as a result of a larger green leaf area combined with a higher photosynthetic capacity, the latter attributable to an increase in the maximum carboxylation velocity of Rubisco. Moreover, gas exchange measurements of the flag leaf during grain filling provide a realistic characterization, not just the photosynthetic performance of the crop, but also about the quantum yield of photosynthesis. Thus, measurements performed on the flag leaf matched those at the canopy level with proportional increases in terms of gas exchange and chlorophyll content, providing a fast, cheap and reliable estimation of canopy photosynthetic and the grain yield attained by the crop.

1. Introduction

Durum wheat is the most widely cultivated cereal in the south and East Mediterranean basin in terms of area, Italy and Spain being the major producers (Raya, 2005). Despite water limitation, nitrogen (N) availability is the main constraint limiting yield in these environments (Buscaglia, 2003). Moreover, it is an essential plant nutrient that is required for high yield in wheat (Raza et al., 2008), and could even limit yield more than poor water conditions (Zalata et al., 2008). Worldwide food production doubled in the last four decades with a 4-fold increase in fertilization (Mickelbart, 2002; Pixel et al., 2007). However, the indiscriminate use of N fertilization has led to agricultural, socio-economic and environmentally negative impacts such as global warming (from increasing atmospheric N2O), nitrate contamination of aquifers, eutrophication of surface waters (Cebol, 2005), and soil acidification (from de-esterified NH4+). Further reasons concern about agricultural and environmental sustainability have stimulated attempts to maximize crop yields while decreasing N input (Good et al., 2010; Moon et al., 2009; Lica and Alvarado, 2009; 2007 and references therein).

Gas exchange in C3 crops such as wheat is usually measured by assimilates coming from three sources: (a) leaf photosynthesis, (b) pre-anthesis reserves stored in the leaf and (c) canopy photosynthesis. Moreover, during this period between sowing and anthesis occurs, increasing the importance of the youngest photosynthetic organs such as flag leaf and ears. While the relative photosynthetic contribution of the ear to grain filling has been recognized (mainly under drought, Almas et al., 1999; Albal et al., 2004, flag