Project title:	Targeted CO_2 enrichment management for long season tomato crop production in the UK
Project number:	PE 021
Project leader:	Dr Barry Mulholland, ADAS Boxworth
Report:	Final report, 31 March 2015
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Location of project:	Cornerways Nursery, Norfolk
Industry Representatives:	Phil Morley, Tomato Growers Association, Philip Pearson, APS Salads Ltd, Paul Simmonds, British Sugar, Nigel Bartle, R M Sayer, Paul Howlett, Wight Salads, Dr Paul Challinor, May Barn Consultancy
Date project commenced:	1 July 2014
Date project completed (or expected completion date):	31 March 2015

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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- A preliminary study has developed a methodology and a model of photosynthesis which, when combined, is designed to estimate canopy photosynthesis and CO_2 offtake (kg/ha) by UK grown long-season tomato crops.
- Diurnal rates of photosynthesis were observationally higher (but not statistically consistent) in Roterno compared with Piccolo.
- Photosynthetic efficiency declined markedly from August-October and in particular when the growing point was removed (7 October). Over the course of the project (123 days), the data tentatively suggests that there was a stronger photosynthetic response (net CO_2 uptake) to CO_2 enrichment in the morning period (up to 12:00 h) compared with the afternoon (post 12:00 h).
- Piccolo exhibited a relatively flat yield response compared with Roterno and Dometica, which showed strong linear yield responses to an increase in accumulated light receipt.

Background

Project objectives:

The overarching objective of the work was to develop a robust sampling protocol to identify photosynthetic response and net uptake of CO_2 enriched crops of selected commercial types of glasshouse grown long season tomato. More specifically, the work evaluated the following objectives:

1. To establish representative leaf photosynthesis and leaf growth measurements for selected tomato cultivars at a single grower site under standard CO_2 enrichment conditions.

2. To extrapolate single leaf measurements of gas exchange to whole plant diurnal photosynthesis.

3. To select cultivars with contrasting leaf area to fruit load source sink ratios to identify any end product inhibition or stomatal closure limitations to photosynthesis.

4. To compare current irrigation strategies to shoot photosynthetic performance and explore links with any limitations to optimum performance identified in **Obj 3**.

5. To integrate the findings from **Objs 1-4** and develop a robust sampling protocol to evaluate the daily photosynthetic response under standard CO_2 enrichment of current UK glasshouse grown commercial cultivars of tomato.

6. Use data from **Objs 1-5** to develop preliminary key crop parameter response surfaces to CO_2 enrichment using selected modelling approaches.

Summary

Key points:

- Under UK conditions, a linear model of photosynthesis can be used to predict growing season photosynthesis (March-November).
- Photosynthesis was highest under the brightest periods of the day between 10:00–15:00 h. However, the duration of peak photosynthesis was broader during July and August compared with a peak around midday in September and October.
- There are significant differences between the level of radiation received and yield. e.g. Piccolo produces a “flat” yield response whereas Roterno and Dometica exhibited strong positive responses to solar radiation. This suggests that shoot density could be manipulated to increase the number of stems in Piccolo to scavenge available resource, as light does not appear to be a limiting factor.

Approach and results

Data was collected from Cornerways commercial tomato production nursery in Norfolk from 10 July to 23 October 2014. Three cultivars; Dometica, Piccolo and Roterno were used in the trial, and one crop row was used for each cultivar. To calculate CO_2 uptake on a canopy level, a methodology had to be developed to i) estimate the net CO_2 uptake of single leaves (**Figure i**);

Figure i. Terminal leaflet gas exchange measurement on a commercial tomato cultivar, Cornerways Nursery, Norfolk.

ii) calculate the most relevant leaf to make the measurements on; iii) non-destructively estimate leaf area from single leaves to per unit area e.g. hectare; iv) scale gas exchange up from single leaves to canopy and area e.g. hectare;

Allometric estimates of leaf area were calculated from length x breadth and projected leaf area measurements. An example plot for Piccolo is enclosed which shows the goodness of fit for projected leaf area against allometric estimates for top, middle and bottom segregated leaves (**Figure ii**).

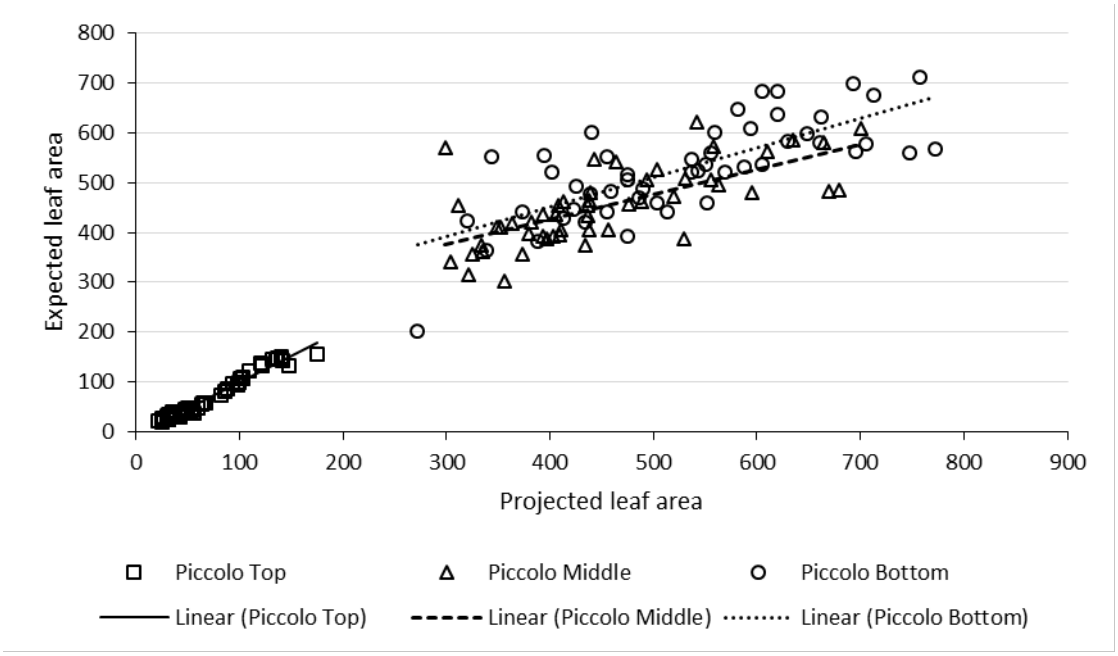


Figure ii. Goodness of fit for measured projected leaf area against calculated leaf area (L x B x constant) for Piccolo top, middle and bottom segregated leaves (Significant predictive fits were found for all leaf positions; P<0.001).

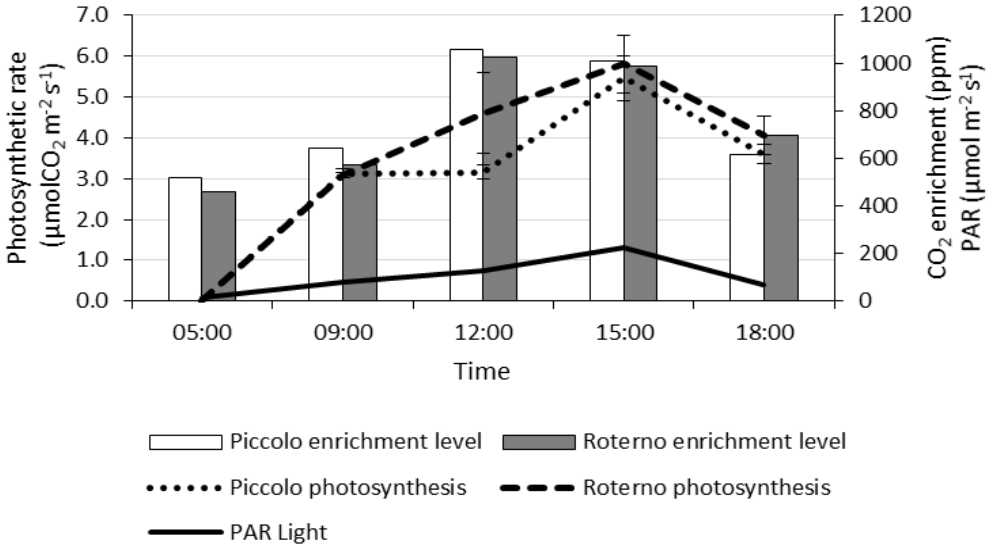
There was a need to separate the canopy into top, middle and bottom zones, as smaller leaves in the top areas were less variable compared with larger leaves lower down in the canopy. Nevertheless, the technique produced significant predictive fits ($P<0.001$) across all cultivars and sampling times conducted throughout the experiment. From this data, total leaf areas per m^2 (at a density of 4 shoots per m^2) were calculated which were contemporaneous with gas exchange measurements (**Table i**).

Table i. Total plant leaf areas per m^2.

Foliage density (cm^2/m^2)	Piccolo	Roterno
July	28148	36680
August	24203	32735
September	24385	32917
October	29952	38484

Typical daily gas exchange measurements exhibited peak photosynthesis occurring between 12:00-15:00 h between July and October (**Figure iii**).

July



October

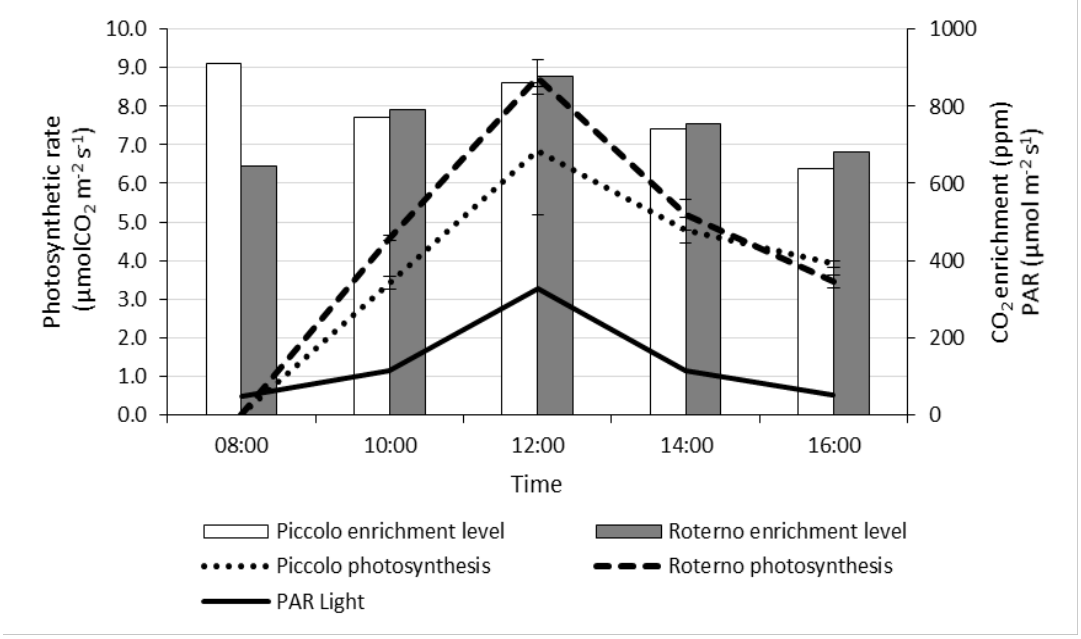


Figure iii. Rate of photosynthesis for Piccolo and Roterno against CO_2 enrichment levels and photosynthetically active radiation (PAR) in July and October 2014.

Modelling canopy photosynthesis and net CO_2 uptake

Solar radiation was recorded as hourly averages throughout the study period (123 days). There were only 28 hours of solar radiation that exceeded 750 Wm^{-2} representing typical UK summer / early autumn conditions (**Table ii**).

Table ii. Short wave radiation receipts at Cornerways Nursery, Norfolk, UK, June to October 2014.

Radiation level (W/m^2)	Number of hourly recordings
radiation = 0	1316
0 < radiation < 40	291
40< radiation < 650	1248
650 < radiation < 750	69
radiation > 750	28
Total	**2952**

Photosynthesis was effectively represented by a linear model for the crop types Piccolo and Roterno (**Figure iv**).

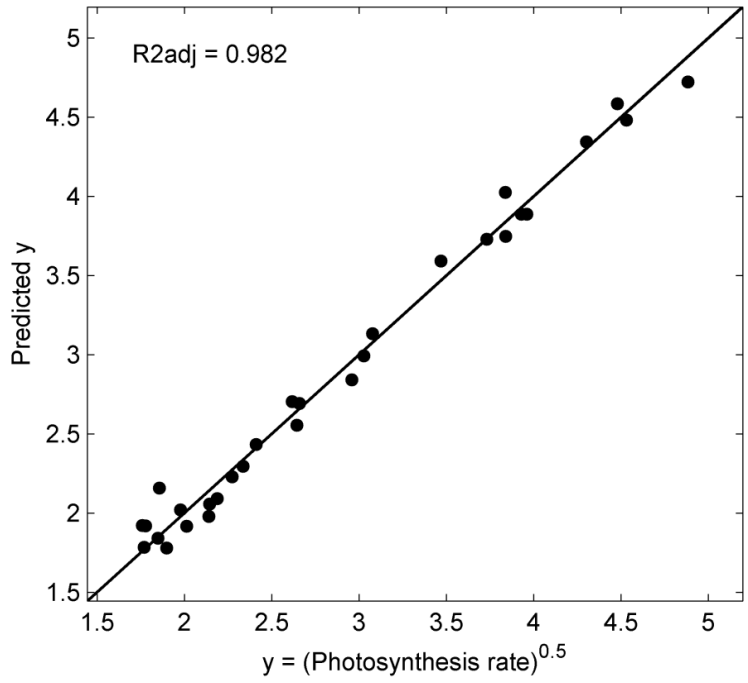


Figure iv. Linear model of photosynthesis for Roterno and Piccolo tomato cultivars.

Further analysis of data tentatively suggested that for certain months, and after compensating for variations in five continuous explanatory variables, that the rate of photosynthesis is higher in the morning compared with the afternoon. This can be seen where morning photosynthetic rate was in general less affected by a reduction in light levels compared with the afternoon, from 12:00 h (cf. **Figures 9, 13, 17 and 21**). This was particularly the case in the later months, and as the plants were "stopped" towards the season end, resulting in a shift in source sink allocation between leaf and fruit load (**Figure v**).

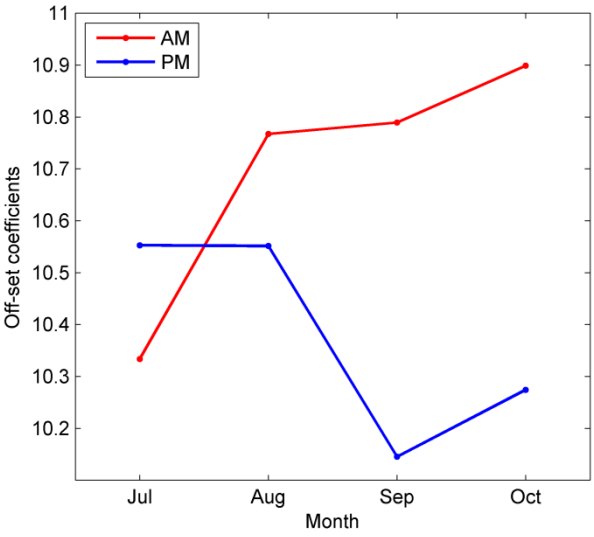


Figure v. Variation in the intercept coefficient with month and cultivar type derived from a model of photosynthesis.

When yield was plotted against accumulated radiation for eight weeks preceding pick, strong positive associations were observed for Roterno (r^2 = 0.72) and Dometica (r^2 = 0.84), but a much poorer association for Piccolo (r^2 = 0.52), particularly above an accumulated solar radiation value of 70000 J/cm^2. It also shows that, as expected, weekly yield for Piccolo are much smaller compared with the two other two cultivars (**Figure vi**).

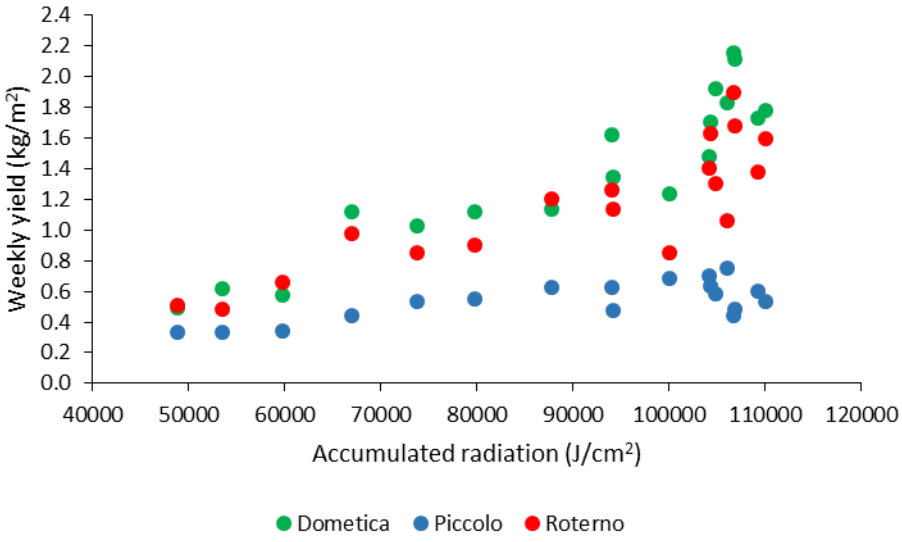


Figure vi. Weekly yields plotted against the accumulated solar radiation for 8 weeks prior to pick.

Financial Benefits

- The data suggest that there is scope to target CO_2 enrichment but also manipulate crop management to make maximum use of available resources (light and CO_2) to drive sustainable intensification of UK tomato production.

Action Points for growers

- Despite marked differences in light use, yield and assimilate partitioning between Roterno (large vine) and Piccolo (cocktail cherry), it is too early to provide new robust management guidelines to tomato growers for commercial speciality types.