

Understanding Functional Relationships Affecting Growth and Quality of Field Grown Leaf Lettuce in the Greenbelt of Buenos Aires, Argentina

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Abstract

Earlier studies in the horticultural production area around Buenos Aires (Argentina) indicated that field grown leaf lettuce fertilised with 150 kg N ha⁻¹ accumulated NO₃-N in the leaves up to concentrations well above the reference limits adopted by European countries. Previous studies also showed that the planning of sowing dates and a sound management may help overcome nutritional quality problems, reduce risks of environmental pollution and increase the efficiency of the system. As an aid to crop planning, a management decision-tool is being developed following a modelling approach to predict growth and quality (i.e. NO₃ content) of field-grown lettuce in the area. The model was conceptually based on that of Seginer et al. (1997) for greenhouse lettuce, in which a negative correlation between C assimilates and NO₃ concentrations in vacuole is used. The first step in the development of the model was to assess the simplest (and satisfactorily accurate) approach to model growth of a leaf lettuce crop under field conditions relying on few, easily available parameters, and then to identify source-limited conditions along the year. The model was calibrated with data from several experiments in the area. The model predicted crop (R² = 0.97) and plant (R² = 0.98) growth quite accurately when compared with independent data. A first analysis revealed that since leaf lettuce does not need to form a “head” to be commercially mature, growth can be fairly described by a simple exponential model. NO₃ contents varied widely (from 990 to 7590 ppm) under different growing conditions, suggesting that there is room to model the interaction of factors creating source-limited conditions that eventually lead to NO₃ accumulation in leaves.

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a major crop in the horticultural ‘belts’ round the main urban centres of Argentina. Due to a sustained demand for fresh food items and to relatively mild winter conditions, fast-growing, leaf lettuce cultivars are grown all-year-round under open field conditions. To achieve marketable plants in a short period (ca. 30 days in spring-summer), lettuce crops are initiated by transplanting, well irrigated and heavily fertilised with different N sources. The efficiency and the consequences of such a system have been strongly questioned, as concerns on food quality, environmental health and agricultural sustainability arose.

Earlier studies in the area indicated that winter-grown leaf lettuce (cv. *Grand Rapids*) fertilised with 150 kg N ha⁻¹ accumulated NO₃-N in the leaves up to concentrations well above the reference limits adopted by European countries (Chiesa, 2002). However, environmental and management conditions such as temperature, radiation and plant density affected the relationships between crop growth and NO₃-N concentration in leaves, when different levels of N fertilisation (from 0 to 150 kg ha⁻¹) were tested. Planning of sowing dates and sound adjustments of plant density and N

fertilisation may help overcome quality problems, reduce risks of environmental pollution and increase the efficiency of the system, aiming also at avoiding the frequent low prices due to intermittent oversupply of lettuce in the market.

A decision-tool is being developed following a modelling approach to predict growth and quality (i.e. NO₃ content) of field-grown lettuce in the area, as an aid for crop management planning. The model was conceptually based on that of Seginer et al. (1997) for greenhouse lettuce, in which a negative correlation between C assimilates and NO₃ concentrations in vacuole is used. Thus, NO₃ accumulation occurs under source-limited conditions (i.e. winter), when C demands for growth and maintenance are not covered by C assimilation. This article reports the first steps in the development of a simple model for leaf lettuce, for which functional relationships affecting growth rates and NO₃ concentration are studied, as affected by environmental and management factors.

MATERIALS AND METHODS

The greenbelt of Buenos Aires (GBA) is representative of other vegetable production areas surrounding densely populated urbanisations, with climatic conditions of temperate to subtropical environments (Fig. 1). Crop growth is likely limited by radiation rather than by temperature during the mild, rainy winters; during summer, temperatures are high, shortening the growing period and affecting lettuce quality. Dry weight and leaf area data from experiments in the region was used to calibrate a simple model to mathematically describe growth and predict growing periods up to harvest maturity. Experimental factors included: sowing date, plant density, shading and N fertilisation (Table 1). The model approaches the functional source-sink relationships at crop level, by first analysing growth regulation by environmental (E) and management (M) factors, and statistically relating that to measured NO₃ levels and to the N balance at crop level. A growth analysis (Hunt, 1982) was performed using the experimental data. Variables and parameters from a single experiment were subjected to analysis of variance, and regression and correlation analysis were performed with GenStat 6th.

Modelling Approach

Two approaches were followed to describe crop growth: (i) considering a variable growth rate (GR, in g m⁻² d⁻¹) that depends on incident radiation and the fraction of it absorbed by the crop, for which measurements of leaf area index (LAI) and extinction coefficient (K) are needed, using a maximum growth rate or a radiation use efficiency (RUE, in g MJ⁻¹) index; and (ii) assuming a constant relative growth rate (RGR, in d⁻¹) and describing growth exponentially as $TDW = TDW_{initial} * e^{RGR * Time}$, where TDW is the total dry weight of the aboveground biomass of the crop (in g m⁻²), which also implies that $GR = TDW * RGR$. By choosing for the second approach, crop growth can be predicted from a single parameter, RGR, and the effect of E and M factors on this may be easily studied to calibrate the model for a wider range of conditions.

RESULTS AND DISCUSSION

Plant growth could be well described by exponential models under widely different, contrasting growth conditions (Fig. 2). RGR (for individual plants) decreased with crop age, though the decrease was stronger in spring and RGR remained almost constant during winter (Table 2); the main factor affecting RGR was sowing date, followed by shading and N fertilisation. The relationship between TDW and LAI was approximately linear ($R^2 = 0.75$) for non-shaded plants, for which it holds that: $LAI = SLA * LWR * TDW$, where SLA is the specific leaf area (m² g⁻¹) and LWR is the leaf weight ratio. Both SLA and LWR decreased with the development stage (leaf thickening, stem growth) and were affected by the different E and M factors. Since RGR can also be expressed as the product: $RGR = RLER * SLA * LWR$, where RLER (d⁻¹) is the relative expansion rate of the leaf area, knowing the functional variation of these parameters when changing the growing conditions is of main importance to predict crop growth for on-farm situations.

Model Testing and Performance

The curve of the exponential model ($TDW = 1.0 * e^{0.1411*Time}$) parameterised for spring growth had a fair agreement with crop growth curves plotted from independent data (Fig. 3), with a R^2 value of 0.97 ($P < 0.05$). Fig. 3 also shows that crop biomass increased during spring as did the amount of incident radiation. RUE values for incident radiation were rather low, fluctuating around 0.1 g MJ^{-1} , and increased with crop biomass (soil cover) until harvest; consequently, RUE was larger for denser crops. Such dependence of RUE on canopy architecture makes it more difficult to count on a model of general applicability, as farmers in the region use different patterns for the spatial arrangement of their crops, based on their particular irrigation system, mechanisation and harvesting procedures, etc. Measuring RUE values for absorbed PAR would require extensive experimental work, not available at the moment for the local conditions.

For winter crops, the accuracy of the model to describe crop growth was less ($R^2 \sim 0.6$ to 0.8) when contrasted with independent data (not shown). However, the model simulated plant growth fairly accurately (Fig. 4) for winter crops conducted during three different years; these three crops received 80 kg N ha^{-1} and were used as control treatments in a parallel, independent experiment (Frezza et al., 2004). Among the model parameters for which the model was most sensitive, which can partly explain the lack of good accuracy for winter crops was the specific leaf area (SLA). This parameter tended to vary strongly with crop age, N fertilisation and with the level of radiation received by the crop (Fig. 5).

NO₃ Content

NO₃ contents in leaves increased with N fertilisation (Table 3), particularly in winter. However, non-shaded, non-fertilised plants grown at 33 pl m^{-2} in winter and in spring had comparable NO₃ levels in their leaves ($P < 0.05$), in spite of a presumably greater N availability in the soil via N mineralisation in spring. NO₃ content was weakly but significantly associated with larger plant fresh and dry weights ($R^2 \approx 0.6$) and to lower dry matter contents ($R^2 \approx 0.5$). This confirms the observations by Dapoigny et al. (2000), who reported a close association between NO₃ and water accumulation in lettuce leaves, from experiments on soilless media. NO₃ levels expressed as total amounts per ground area ($\text{mg m}^{-2}\text{soil}$) increased with N fertilisation in both seasons, and were larger in spring. NO₃ contents per leaf area ($\text{mg m}^{-2}\text{leaf}$) were the highest for plants fertilised with 75 kg N ha^{-1} , affecting crop N balance.

CONCLUSIONS

Leaf lettuce cultivars do not need to form a “head” to be commercially mature, and are harvested in a relatively juvenile development stage. Then, growth could be fairly described by a simple model, assuming that the crop remains in the exponential growth phase till harvest maturity. RGR was significantly affected by growing conditions when comparing autumn vs. late winter sowing dates (winter and spring crops), representing source-limited and sink-limited growth conditions, respectively. An approach to crop growth modelling by using a potential value of RUE for incident radiation (which can be derived from weather data) can be used to simulate source activity (C supply). This, coupled with simulation of sink activity (C demand), can be used to predict source-limited situations that lead to NO₃ accumulation in leaf tissues (as in the rainy winters of the GBA), and thus adjust management, aiming at keeping NO₃ levels below prudential limits. However, RUE values for incident radiation are highly dependent on the spatial arrangement of the crop canopy. Thus, an empirical approach to relate the fraction of radiation intercepted to plant population densities and crop spatial arrangements (to those normally used in the region) is firstly needed to improve our predictions under on-farm growing conditions.

NO₃ content in lettuce leaves varied strongly under different growing conditions, suggesting that there is room to model the interaction of factors at field level that create source-limited conditions that eventually lead to NO₃ accumulation in leaves. Basically,

the modelling approach proposed by Seginer et al. (1997) for greenhouse lettuce, combining mechanistic and descriptive models to predict nitrate concentration, can be potentially extended to lettuce crops growing under field conditions.

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Tables

Table 1. Experimental data used for model calibration.

Experimental factors	Measured variables	References
Radiation, N fertilisation	Leaf area, fresh and dry weights of leaves and stems, growth rates, marketable yield	De Grazia et al., 2000
Radiation, sowing date, N fertilization	Leaf area, fresh and dry weights of leaves and stems, growth rates, marketable yield	De Grazia et al., 2001a
Radiation, sowing date, plant density, N fertilization	Leaf biomass, nitrate content, marketable yield	De Grazia et al., 2001b
Plant density, N fertilization	Fresh and dry weights of leaves, nitrate content, growth rates, marketable yield	Tittonell et al., 2001
Radiation, sowing date, plant density, N fertilization	Leaf area, fresh and dry weights of leaves and stems, nitrate content, growth rates, marketable yield	Chiesa, 2002
Temperature, N fertilization	Leaf area, fresh and dry weights of shoots, leaf area, growth rates, yield	De Grazia et al., 2003
Plant density, N fertilisation	Leaf area, fresh and dry weights of leaves and stems, nitrate content, growth rates, marketable yield	Tittonell et al., 2003

Table 2. Linear models for the decrease in the values of RGR with crop age (days after transplanting).

Growing season	Model		R^2
	Intercept	Slope	
Spring crop ($n = 48$)	0.1963	-0.0029	0.36**
Winter crop ($n = 63$)	0.0712	-0.0005	0.22**

**Significant at $P < 0.01$

Table 3. Nitrate content ($\text{ppm } 10^{-2}$) in fresh leaves of lettuce under different N fertilization rates and as affected by different growing conditions.

Growing conditions	N fertilisation rate (kg ha^{-1})			SED_F	SED_{GC}	Interaction significance
	0	75	150			
Spring crop	28.2	49.8	63.4	16.7	20.0	0.650
Wintercrop	20.8	56.3	75.9			
No shading	9.9	49.8	56.6	11.6	11.6	0.833
35% shading	15.5	58.1	71.9			
65% shading	36.9	61.0	99.3			
33 plants m^{-2}	26.1	47.0	68.5	11.4	9.3	0.747
50 plants m^{-2}	30.4	52.6	58.2			

SED: Standard error of the differences (SED_F : for comparisons between fertilization rates; SED_{GC} : between growing conditions)

Figures

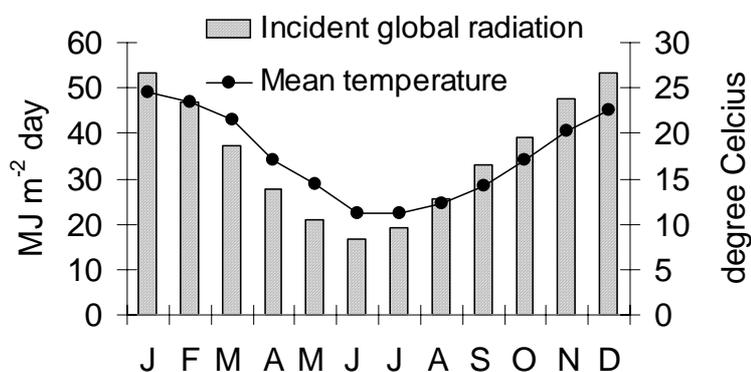


Fig. 1. Average incident global radiation and mean air temperature in the horticultural production area of Buenos Aires, Argentina. Lettuce is grown in two main seasons: winter (April – September) and spring (August – November).

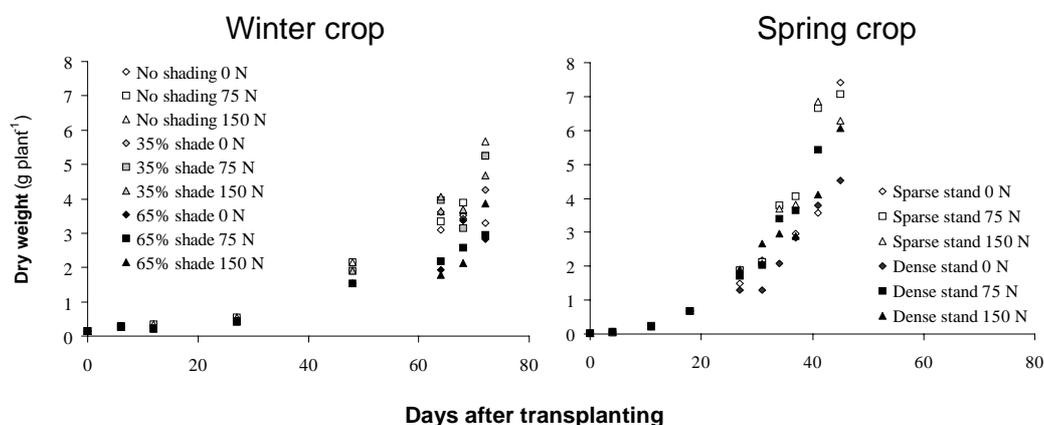


Fig. 2. Temporal evolution of plant biomass for a leafy lettuce cultivar grown in the field in GBA under different experimental conditions. Winter crop was planted on early May whereas the Spring crop was in mid September (cf. Fig. 1). Treatments included shading with 35 and 65% mesh, different plant densities (33 and 50 plants m⁻²) and N fertilisation rates (0, 75 and 150 kg N ha⁻¹).

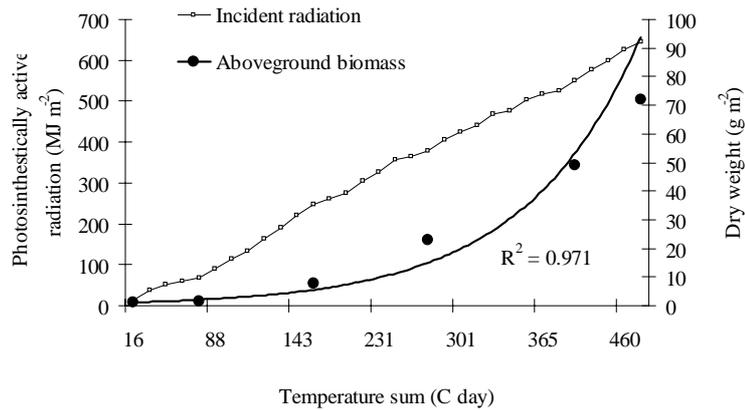


Fig. 3. Testing the exponential crop growth model for field grown leafy lettuce. Black dots indicate biomass measurements at different development stages; the continuous line represents the model simulation for those conditions (Spring crop); the upper curve indicates the evolution of the amount of incident PAR during crop growth.

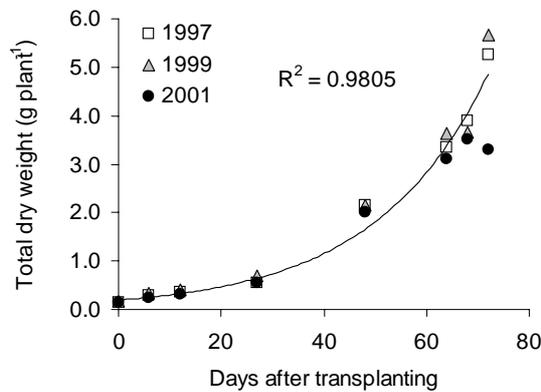


Fig. 4. Plant growth from transplanting to maturity for winter crops of leafy lettuce grown in the field during three different years (Frezza et al., 2004). The line represents the model simulation and the level of statistical agreement with the entire set of observation points.

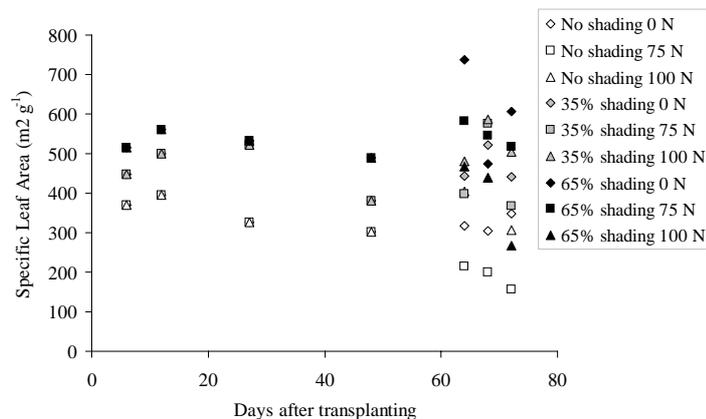


Fig. 5. Temporal evolution for the value of the specific leaf area during growth of a winter field crop of leafy lettuce subject to different shading treatments and N fertilisation rates.