

Canopy development of sweet corn in response to phosphorus

AL Fletcher¹, DJ Moot¹, and PJ Stone²

¹Field Service Centre, PO Box 84, Lincoln University, Canterbury

²Crop and Food Research, PO Box 85, Hastings

Abstract

There is a recognisable yield response of sweet corn (*Zea mays* L.) to fertiliser phosphorus (P), but little quantitative research describing the mechanisms responsible. This study investigated how radiation interception and associated processes (leaf appearance and individual leaf area) of sweet corn responded to five fertiliser P levels (0, 50, 100, 150, and 200 kg P/ha) when grown in a low P soil (Olsen P= 6 µg/ml) at Lincoln, Canterbury in 2001/02.

The time taken to reach maximum radiation interception or maximum canopy development was progressively reduced by each addition of fertiliser P from 840 °Cd in the control crops to 678 °Cd with the addition of 200 kg P/ha. This was explained by a decrease in the duration of the linear increase in radiation interception of low P crops caused by slower leaf appearance rates and smaller final areas of individual leaves.

Leaf tip appearance was linearly related to thermal time (Tt) (base temperature = 8°C), but the phyllochron was reduced from 31.3 to 25.8 °Cd as P increased from 0 to 200 kg P/ha. The relationship between Tt and fully expanded leaf appearance rate was exponential indicating later leaves expanded at a faster rate particularly with increased P levels. The final areas of individual leaves were related to position on the stem by a peaked function. The largest leaf was always leaf 11 or 12 but its area increased from 415 to 570 cm² as P increased from 0 to 200 kg P/ha. Given that leaf appearance rate and individual leaf area are important components in regulating canopy development, these variables must be considered when modelling canopy responses to P.

Additional Key Words: leaf appearance, leaf area, phyllochron, radiation interception, *Zea mays*

Introduction

Sweet corn (*Zea mays* L.) is a vegetable crop grown for both fresh and process markets, with New Zealand production expanding rapidly. From 1990 to 2000 the area in sweet corn increased from 2,898 to 6380 nationally (Anon, 2000). Although genetically related to maize (*Zea mays* L.) sweet corn accumulates less starch and is harvested at a physiologically immature stage compared with maize. Despite such differences, many of the current agronomic recommendations for sweet corn are based on maize research. In most cases these recommendations are appropriate. However, previous research has shown that sweet corn may be more responsive to phosphorus (P) than maize (Bole and Freyman, 1975). Recommended Olsen P soil levels for optimum yields are higher for sweet corn, 30-35 µg/ml (Clarke *et al.*, 1986), than for maize, 15 µg/ml (White *et al.*, 1999). Yield responses of sweet corn to applied fertiliser P have been reported (Sanchez *et al.*, 1989; Sanchez *et al.*, 1991), but there is limited quantitative research or understanding of the mechanisms responsible for this response.

In all crops dry matter yields are related to the interception of solar radiation by the canopy (Monteith, 1977; Gallagher and Biscoe, 1978), which then influences potential grain yield through partitioning of assimilate. These relationships form the basis of many crop models (e.g. Muchow *et al.*, 1990) for predicting growth and development of crops such as maize however few models include subroutines to predict the impact of P. P deficiency may reduce solar radiation interception in crops by influencing the development and maintenance of an efficient canopy. Simulation of the canopy or green area index (GAI) is therefore an important step in accurately simulating crop yield (Goudriaan and van Laar, 1994). A common model structure for this used in maize (Muchow *et al.*, 1990; Wilson *et al.*, 1995), involves the prediction of fully expanded leaf appearance and individual leaf area related to leaf position. This approach can also be used to analyse sweet corn (Rogers *et al.*, 1999). This model structure has been utilised for predicting nitrogen responses in maize (Sinclair and Muchow, 1995) and maybe appropriate for modelling P responses. Thus

the initial objective of this experiment was to determine the pattern of solar radiation interception that occurred in sweet corn crops grown in a low P soil in response to five rates of P fertiliser. The second objective was to relate any differences in these patterns to changes in canopy development as described by leaf appearance rates and individual leaf area.

Materials and Methods

Experimental design and management

An experimental site at Lincoln, Canterbury was selected on the basis of its low soil P level of 6 µg/ml (Olsen P). Levels of all other nutrients, except sulphur, were adequate for sweet corn growth (Table 1). Therefore, a basal application of 35 kg S/ha as Potassium sulphate (0, 0, 40, 7) was applied on 5 October and basal applications of 100 kg N/ha as Calcium ammonium nitrate (26,0,0,0) were also applied on 15 October and 20 December 2001, and 16 January 2002. The predominant soil type was a Templeton fine sandy loam, moderately deep phase with small areas of an Eyre shallow fine sandy loam. Both soil types are well drained, with the Templeton soil having 460-600 mm of fine sandy loam on sandy gravels compared with the Eyre soil having 250-460 mm of fine sandy loam over gravels (Cox, 1978). On

5th October 2001 a randomised complete block experiment with five fertiliser P treatments (0, 50, 100, 150, and 200 kg P/ha) and three replicates was established at the site. P treatments were broadcast in split applications on 5 and 14 October as triple super phosphate (0, 21, 0, 0) and incorporated to 0.15m using a roto-crumbler.

Each plot was 4.9m (7 rows 0.7m row spacing) wide and 10m long. Plots were hand sown using jab planters with 'Challenger' sweet corn on 25th October at a target population of 71,000 plants/ha or 0.2m between plants within rows. Two seeds were planted per hole and where both emerged, thinned to ensure crop uniformity. Pesticides and herbicides were applied as necessary to control, insects such as Greasy Cutworm (*Agrotis ypsilon*) and Argentine Stem Weevil (*Listronotus bonariensis*) prophylactically, and the main target weed of subterranean clover (*Trifolium subterraneum*) and a variety of other dicotyledonous weeds. Additional hand weeding was used for subsequent control of these species. Rainfall during the experimental period was markedly above the long term average, particularly during November and January, therefore the crops received a total of only 36mm of irrigation. (Table 2).

Table 1. Soil test results for field site at Lincoln, Canterbury, and recommended soil nutrient levels for sweet corn crops. Sample taken 14th May 2001.

Nutrient	pH	P	K	S (SO ₄)	Mg	Ca	Na
MAF QT Soil test value	5.7	6	12	2	14	4	5
PPM in soil	-	6.6	240	2	70	500	25
Recommended for Sweet corn (Clarke <i>et al.</i> , 1986)	5.3- 6.8	30- 35*	8#	-	-	-	-
Recommended for Maize (Cornforth and Sinclair, 1984)	-	-	-	5	5	-	-

Assuming *Low P retention site; #Loam soil

Table 2. Monthly total rainfall (mm) and mean temperature (oC) for the experimental period (October 2001 – March 2002), and long term mean (LTM), 1975-1991, monthly rainfall and temperature measured approximately 1 km south of the experimental site, at Lincoln, Canterbury.

Month	Actual Rainfall (mm)	LTM Rainfall (mm)	Actual Mean Temperature (°C)	LTM Mean Temperature (°C)
October	63.2	54	12.2	11.3
November	70.4	55	18.3	13.1
December	32.8	61	15.5	15.7
January	124.6	50	16	17
February	61.4	51	14.9	16.3
March	19.8	58	15	15

In general, rainfall during the experimental period exceeded long-term means (1975-1991, LTM), particularly in the month January (124.6 mm compared with 50 mm). However, rainfall in December and March was below average. Mean temperatures during the experimental period were greater than the LTM in October and November (18.3 °C compared with 13.1°C) and lower in January and February. Temperatures during December and March were similar to the LTM. (Table 2).

Measurements

Air temperature and rainfall data were recorded approximately 1km south of the experiment at the Broadfields meteorological station. All development measurements were related to cumulative thermal time (Tt) from emergence, using Equation 1.

$$Tt (^{\circ}Cd) = \Sigma (T_{mean} - T_b) \quad (\text{Equation 1})$$

Where T_{mean} = mean daily temperature, and T_b = base temperature (8°C).

Crop emergence was observed in the 0, 100, and 200 kg P/ha treatments. Two 1m lengths of row (20 seeds) were marked and daily counts of visible coleoptiles were made. Crop emergence was defined when 50 % of the final number of seedlings had emerged.

The proportion of solar radiation interception was measured using a 'Sunfleck ceptometer', Decagon devices Inc., set on sunfleck mode. Measurements were made on six occasions at 65-115 °Cd intervals, beginning approximately 250 °Cd after emergence. Counts of leaf tips and fully expanded leaves were made at 3-4 day intervals on five marked plants per plot until final leaf number had been reached on all plants in a plot. A leaf tip was considered to have appeared when it was visible in the whorl of the plant. A leaf was defined as fully expanded when it had reached its maximum area (when the ligule was visible above the laminae of the next emerging leaf).

Individual leaf area at full expansion was determined for leaves at each position on the main stem, on three occasions (7th December, 30th December, and 14th February). Sampling dates were chosen so that the fully expanded area of all leaves was determined on at least one occasion. To do this, individual leaves were removed from five contiguous plants and their area determined on a 'Li-cor 3100 area meter'. Leaf

1 was defined as the first leaf to emerge from the soil; leaves were then counted acropetally until the final flag leaf immediately below the tassel.

Statistical analyses

Functions were fitted to plot data and then analysed using one-way analysis of variance, with means separation based on Fischer's protected least significant difference (LSD) ($p < 0.05$).

Curves relating the proportion of incident radiation intercepted (RI) to Tt were fitted using a Gompertz curve (Equation 2). Curves were used to calculate the duration of the lag phase (5 % of maximum radiation interception, a), time to the end of the linear phase (95 % of maximum radiation interception, a), the duration of the linear phase, and the rate of increase in radiation interception during the linear phase. For one control plot (0kg P/ha) insufficient data points were available to adequately describe the upper asymptote of the curve. Therefore this plot was not included in subsequent analyses of radiation interception and missing plot analyses of variance were used. However, this plot was included in analyses of leaf appearance and individual leaf area data.

$$RI = a \exp(-b \exp(-c Tt)) \quad (\text{Equation 2})$$

Where a = maximum proportion of incident radiation intercepted (%); and b and c describe the shape of the function.

Leaf tip appearance was fitted to Tt data using a linear function forced through the origin. The phyllochron (Tt time between successive leaf tips) was calculated as the reciprocal of the slope of these functions. Fully expanded leaf appearance was quantified by fitting a two parameter exponential function (Equation 3) to Tt (Muchow *et al.*, 1990).

$$LN = d e^{(f Tt)} \quad (\text{Equation 3})$$

Where LN= fully expanded leaf number; d = y intercept; and f = the degree of curvature.

Individual leaf area data was related to position on the plant using a four parameter peaked function (Equation 4) as described for maize, by Dwyer and Stewart (1986).

$$LA = Y_0 \exp[-g (X - X_0)^2 + h (X - X_0)^3] \quad (\text{Equation 4})$$

Where LA = area of individual leaf (cm²); Y_0 = Area of largest leaf (cm²); X = Position of individual leaf being estimated; X_0 Position of largest leaf; and g and h are parameters describing the shape of the curve.

Table 3. Calculated variables describing the Gompertz curve (Equation 2) relating percentage of radiation intercepted to Tt after emergence for ‘Challenger’ sweet corn crops grown with 0, 50, 100, 150 and 200 kg applied P per ha at Lincoln, Canterbury in the 2001-2002 season. Values not followed by the same letter are significantly different ($\alpha < 0.05$).

P treatment (kg P/ha)	Time to end of linear phase ($^{\circ}\text{Cd}$)	Duration of linear phase ($^{\circ}\text{Cd}$)	Rate of increase during linear phase ($\% ^{\circ}\text{Cd}^{-1}$)	Duration of lag phase ($^{\circ}\text{Cd}$)
0	840 a	566 a	0.135 a	274 a
50	728 b	452 b	0.181 b	276 a
100	726 b	456 b	0.179 b	270 a
150	673 b	437 b	0.191 b	236 a
200	678 b	409 b	0.212 b	269 a
s.e.	25.7	28.1	0.0129	12.0

Results

Crops reached 50 % emergence 13 days (58°Cd) after sowing, with no differences between treatments. Therefore Tt calculations began at this point for all plots. A mean plant spacing of 22.7cm (CV of 27 %) was obtained. For clarity only data from three treatments (0, 100 and 200 kg P/ha) are shown in figures but values for all treatments are reported in tables.

Radiation interception

The Gompertz curve (Equation 2) described the time course of radiation interception in these crops very well ($R^2 > 0.97$) (Figure 1). There were no differences in any of the parameters of the equation (a, b or c) between treatments.

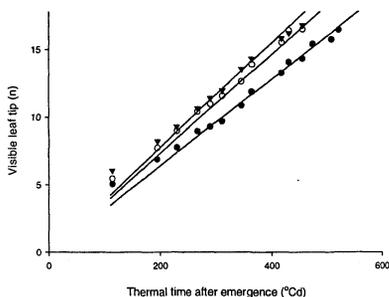


Figure 1. Solar radiation interception (%) against Tt ($T_b = 8^{\circ}\text{C}$) for ‘Challenger’ sweet corn crops grown with 0 (●), 100 (○) and 200 (▼) kg P/ha at Lincoln, Canterbury in 2001/02. Solid lines represent fitted functions up until the end of the linear phase; dotted lines represent functions beyond the linear phase.

The duration of the lag phase (Tt to 5 % of maximum radiation interception) was not influenced by P but the duration of the linear phase (Tt between 5 and 95 % of maximum radiation interception) decreased ($p < 0.05$) from 566°Cd to 409°Cd as P increased from 0 to 200 kg/ha (Table 3). The rate of increase during this linear phase was also affected by P with an increase from 0.135 to $0.212\% ^{\circ}\text{Cd}^{-1}$ as P increased from 0 to 200 kg/ha (Table 3). This led to a difference in the Tt from crop emergence to 95 % of the maximum radiation interception (the end of the linear phase) which was decreased ($p < 0.05$) from 840°Cd in the non fertilised to 678°Cd with the addition of 200 kg P/ha (Table 3; Figure 1).

Leaf tip appearance

A strong linear ($R^2 \geq 0.89$) function was fitted to the relationship between visible leaf tip appearance and Tt after emergence (Figure 2) for each P treatment. The phyllochron for the 0 kg P/ha control crops (31.3°Cd) was longer ($p < 0.05$) than those found in all other treatments (25.8 - 27.4°Cd) (Table 4).

Fully expanded leaf appearance

Fully expanded leaf appearance was exponentially related ($R^2 > 0.97$) to cumulative Tt after emergence (Figure 3). Increased rates of P fertiliser markedly increased the rate of appearance of fully expanded leaves, particularly as the crop matured and fully expanded leaves began to appear at a faster rate. For example when the 16th and final leaf appeared in the crop with 200 kg P/ha there were only 11.5 fully expanded leaves in control crops. There were no differences ($p > 0.369$) in the y intercept (d) of this relationship (Table 5), which gave a mean value of 2.16 leaves. However, the degree of curvature (f) increased with P (Table 3)

from 3.00×10^{-3} with no fertiliser P to about 3.50×10^{-3} when more than 100 kg P/ha was applied.

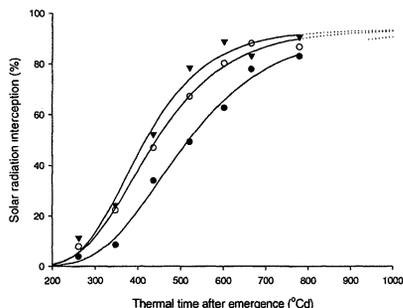


Figure 2. Visible leaf tip appearance of ‘Challenger’ sweet corn against Tt for crops grown with 0 (●), 100(○) and 200 (▼) kg P/ha at Lincoln, Canterbury in 2001/02.

Individual leaf area

The bell shaped function (Equation 4) gave a strong fit ($R^2 \geq 0.99$) between main stem leaf position and individual leaf area for all treatments (Figure 4). There were no differences in the coefficients that describe the shape (*g*, and *h*) of these curves nor in the position of the largest leaf (X_0), which was consistently between leaf 11 and 12 (Table 6). However, the area of the largest leaf (Y_0) increased ($p < 0.05$) with P treatment from 415 cm^2 in control crops to 570 cm^2 when 200 kg P/ha was applied.

Discussion

Canopy development

The interception of solar radiation was increased by the application of fertiliser P (Figure 1) for sweet corn crops grown on this low P fertility (Olsen P = $6 \mu\text{g/ml}$) site. Not surprisingly this result was consistent with those for maize that have shown yield responses to depend on initial soil P levels (Singh and Uriyo, 1980). Crops would not be expected to be sown commercially on such sites so smaller responses are likely. However, some insight into previously reported yield reductions in sweet corn under P deficiency (Sanchez *et al.*, 1989; Sanchez *et al.*, 1991; Bole and Freyman, 1975) can

be gained by examining the differences in canopy development.

The Gompertz function described ($R^2 > 0.97$) (Figure 1) solar radiation interception over Tt (Figure 1) and this equation has been used previously for maize leaf area (Baker *et al.*, 1975). Therefore, it is likely to be an appropriate function for investigating the pattern of solar radiation through Tt in sweet corn. Specifically, the results showed that canopy development rate was increased by P fertiliser. For example, The Tt taken to reach maximum radiation interception (95 % of maximum) decreased from 840 to 678 °Cd as applied fertiliser increased from 0 kg P/ha to 200 kg P/ha (Table 3, Figure 1). The primary cause of this acceleration was a decrease in the duration and an increase in the rate of canopy development, with the duration of the lag phase unaffected (Figure 1, Table 3).

The lack of effect on the lag phase indicates that until this point fertiliser P had no effect on growth or development. This is probably because, the plants were utilising seed reserves of P and the small amount available from the soil for much of this period. Maize plants have been reported to have a short “growth crisis” at about the four leaf stage, when resources for growth begin to be supplied by photosynthesis. Up until this time resources have been supplied by seed reserves (Tollenaar and Dwyer, 1999). Using the values of the phyllochron calculated in the current experiment (Table 4) this corresponds to between and 100-125 °Cd after emergence depending on P treatment. This makes up about half of the lag phase in this study (Table 3). Also, the overall demand for P was low during the lag phase with only 5-6 fully expanded but comparatively small leaves produced (Figure 4).

Table 4. Phyllochron (°Cd) for leaf tip appearance in ‘Challenger’ sweet corn crops grown with 0, 50, 100, 150 and 200 kg applied P per ha at Lincoln, Canterbury in the 2001-2002 season. Values not followed by the same letter are significantly different ($\alpha < 0.05$).

P treatment (kg P/ha)	Phyllochron (°Cd)
0	31.3 a
50	27.7 b
100	27.4 b
150	25.8 b
200	25.8 b
s.e.	0.86

Table 5. Y intercept and curvature parameters (Equation 3) for fully expanded leaf appearance in ‘Challenger’ sweet corn crops grown with 0, 50, 100, 150 and 200 kg applied P per ha at Lincoln, Canterbury in the 2001-2002 season. Values not followed by the same letter are significantly different ($\alpha < 0.05$).

P treatment (kg P/ha)	Y intercept (d)	Curvature ($f \times 10^{-3}$)
0	2.148 a	3.00 a
50	2.256 a	3.20 ab
100	2.078 a	3.47bc
150	2.137 a	3.57c
200	2.173 a	3.50bc
s.e.	0.0582	9.66×10^{-5}

Table 6. Parameters relating individual leaf area (cm^2) to leaf position on plant (Equation 4) for ‘Challenger’ sweet corn crops grown with 0, 50, 100, 150 and 200 kg applied P per ha at Lincoln, Canterbury in the 2001-2002 season. Values not followed by the same letter are significantly different ($\alpha < 0.05$).

P treatment (kg P/ha)	Area (cm^2) of largest leaf (Y_0)	Position of largest leaf (X_0)	Shape parameter ($g, \times 10^{-2}$)	Shape parameter (h)
0	415 a	11.147 a	6.25a	-3.00×10^{-4} a
50	475 a	11.729 a	5.4 a	1.03×10^{-3} a
100	487 ab	11.381 a	6.47 a	-1.43×10^{-3} a
150	566 b	11.447 a	5.45 a	9.30×10^{-4} a
200	570 b	11.608 a	5.84 a	-6.00×10^{-4} a
s.e.	27.4	0.1595	4.22×10^{-3}	9.02×10^{-4}

The change in the duration and slope of the linear phase indicated that as canopy development began to accelerate, the control crops were unable to maintain an adequate supply of P for growth and development compared to the fertilised crops. As crop development advanced the number of fully expanded leaves for the two extreme treatments began to diverge markedly (Figure 3). This led to accelerated canopy development in the crops receiving 200 kg P/ha. Also, the size of individual leaves as crop development advanced was greater in all treatments consequently the difference in canopy area between the control crops and fully fertilised crops was greatest when the fully fertilised crops had reached the end of the linear phase. This is consistent with previous research (Plenet *et al.*, 2000a) which showed that the major causes of reduced LAI in P stressed maize were a decrease in leaf appearance rate and individual leaf area, with changes in final leaf number and senescence only slightly modified. Therefore similar mechanisms for canopy development in response to P appear to operate in sweet corn and maize.

The delay in canopy development with P deficiency will have a major influence on cumulative

radiation interception, and hence crop yield (Monteith, 1977), if comparisons are made on a common date. However, if comparisons are made at a similar development stage then the differences may not be so large. P deficiency will have the effect of lengthening the vegetative stages of the crop (until silking) and thereby maximising radiation interception. However, in a sowing date experiment with maize, Sorenson *et al.*, (2000) showed that delays in the peak of LAI past the peak of maximum incident solar radiation (mid summer) led to systematic decreases in yield, due to a reduction in cumulative radiation interception. In Canterbury, where temperatures are cool (Table 2), and sweet corn crops are sown late, the peak of LAI is always delayed in comparison to the peak in incident solar radiation. Therefore any further delay in peak LAI due to P deficiency will further reduce yield.

To mechanistically describe yield in terms of cumulative solar radiation interception a measure of assimilate production is also required. In maize radiation use efficiency does not appear to change in response to P stress (Plenet *et al.*, 2000b). However, this is counter-intuitive to laboratory studies such as Usuda and Shimogawara (1991) that have indicated

a decrease in photosynthetic capacity of P deficient maize. Therefore further measurements of this growth factor are justified for both sweet corn and maize in response to P.

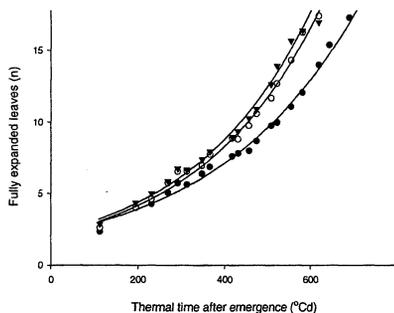


Figure 3. Fully expanded leaf appearance of 'Challenger' sweet corn against Tt for crops grown with 0 (●), 100(○) and 200 (▼) kg P/ha at Lincoln, Canterbury in 2001/02.

Leaf appearance

Leaf appearance is a development process; therefore under 'normal field' conditions the key driver is temperature (Hay and Walker, 1989), which can be quantified by Tt. This was true in the current experiment, when P was applied (50-200 kg P/ha), with the phyllochron (27.7-25.8 °Cd leaf⁻¹) unchanged between treatments. However, when no P was applied, and crops were no longer growing in 'normal field conditions', the phyllochron (31.3°Cd leaf⁻¹) increased markedly (Table 4). Clearly, there is a component of growth involved in leaf appearance, which must be considered when modelling responses to P in sweet corn.

In the current experiment, it remains to be seen whether the delay in leaf appearance (Figure 2, Figure 3) was caused by a delay: in leaf primordium initiation at the vegetative apex or the rate at which these primordia extended to become leaves. In an experiment with wheat Rodriguez *et al.*, (1998) found a decrease in leaf appearance rate under P deficient conditions. This was attributed to both an extended plastochron (decreased rate of leaf primordia initiation) and a reduced leaf elongation rate.

There is normally a consistent relationship between leaf primordia initiation and leaf tip appearance. Leaf primordia extend at consistent intervals to become visible leaf tips; therefore leaf numbers are an

acceptable approximation of apical development. Such a relationship has been demonstrated in wheat (Kirby, 1990) and oats (Sonogo *et al.*, 2000). In wheat the number of initiated primordia was found to be 1.7 times the number of visible leaves (Kirby, 1990). It remains to be seen whether this relationship holds and leaf development is able to approximate apical development under conditions of severe P deficiency. Ongoing field research with sweet corn aims to resolve these issues.

The delay in leaf appearance with P deficiency is not atypical and has been shown before in a variety of crops e.g. maize (Plenet *et al.*, 2000a), wheat (Rodriguez *et al.*, 1998) and soybean (*Glycine max* L.) (Chiera *et al.*, 2002). Therefore the effect of P availability on leaf appearance deserves additional attention in future studies of all crops.

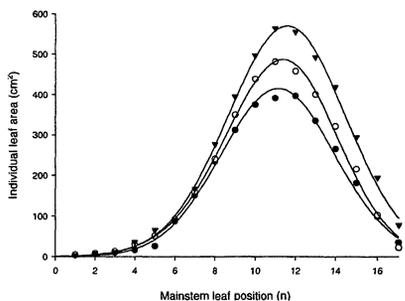


Figure 4. Individual leaf area for 'Challenger' sweet corn against main stem leaf position for crops grown with 0 (●), 100(○) and 200 (▼) kg P/ha at Lincoln, Canterbury in 2001/02.

Individual leaf area

The area of individual leaves was described by a bell shaped curve as found by Dwyer and Stewart (1986) for maize ($R^2 \geq 0.99$) (Figure 4). This is consistent with other experiments (Muchow and Carberry, 1989) that have shown a similarly good fit for this equation in maize. In the current experiment the largest leaf (X_0) was consistently between 11 and 11.7 for a 16 leaf hybrid. This is consistent with Birch *et al.*, (1998), who showed that X_0 was consistently two thirds of the way up the main stem.

Applying fertiliser P increased individual leaf area (Figure 4). However, the nature (shape and position) of the relationship between leaf position and area was unaffected (Figure 4). Therefore a single function could be fitted to the data, varying only the area of the largest leaf (Y_0). The response of

this parameter to plant or soil factors will need to be determined to allow mechanistic modelling of sweet corn canopies. In their study with maize, Dwyer and Stewart (1986) also showed that the shape of this function was unaffected by a range of soil types and years, with only the area of the largest leaf being altered. They plotted normalised data against leaf position and showed that a single curve fitted this well ($R^2=0.98$). A series of individual equations were then used to attempt to predict the area of the largest leaf. The implications of this finding were that the area of any leaf was strongly influenced by the area of preceding leaves and therefore the timing of stress was unimportant rather the extent of any stress during the early stages was more important. The data of the current experiment indicate a similar conclusion for sweet corn responses to P. This would mean that any stress during the early stages of crop growth would adversely affect leaf area and hence radiation interception for the duration of the crop.

With maize, Plenet *et al.*, (2000a) also found a consistent bell shaped relationship for the relationship between individual leaf area and main stem leaf position under varying P treatments. However, they did not fit a curve to this data. The magnitude of the responses was not as marked as in the current experiment with sweet corn. This may explain why sweet corn appears to be more exacting than maize in its soil P requirements. However, the soil test value in their experiment (Olsen P = 23 $\mu\text{g/ml}$) far exceeded that in the current experiment (Olsen P = 6 $\mu\text{g/ml}$).

It remains to be seen how sweet corn plants reduce individual leaf area in response to decreased P availability. It may be either leaf expansion rate or the duration of leaf expansion that accounts for this decrease in individual leaf area. It also remains to be seen if there is a minimum leaf P concentration per unit leaf area that sweet corn requires for efficient growth. Under P deficient conditions the plant may be acting to reduce individual leaf area to maintain this minimum concentration as has been observed for nitrogen (Grindlay, 1997).

Conclusion

Fertiliser P markedly accelerated canopy development and solar radiation interception in sweet corn crops. Mechanisms responsible for this included both increased leaf appearance rates (leaf tips and fully expanded leaves) and individual leaf areas. Future attempts to model sweet corn canopy

responses to P availability must include changes in both leaf appearance and individual leaf area.

Acknowledgements

FRST provided financial support for A.L. Fletcher's ongoing Ph.D research; NZIAS/ NZHS provided a travel award to present this paper at the New Zealand agronomy Conference, Massey University, Palmerston North 25-27 June 2002.

References

- Anonymous. 2000. Agricultural Production Survey – Horticultural Statistics. Statistics New Zealand.
- Baker, C.H., Horrocks, R.D. and Goering, C.E. 1975. Use of the Gompertz function for predicting corn leaf area. *Transactions of the American Society of Agricultural Engineers* 18: 323-330.
- Birch, C.J., Hammer, G.L. and Rickert, K.G. 1998. Improved methods of predicting individual leaf area and senescence in maize (*Zea mays*). *Australian Journal of Agricultural Research* 49: 249-262.
- Bole, J.B. and Freyman, S. 1975. Response of irrigated field and sweet corn to nitrogen and P fertilizers in southern Alberta. *Canadian Journal of Soil Science* 55: 137-143.
- Chiera, J., Thomas, J. and Ruffy, T. 2002. Leaf initiation and development in soybean under P stress. *Journal of Experimental Botany* 53: 473-481.
- Clarke, C.J., Smith, G.S., Prasad, M. and Cornforth, I.S. 1986. Fertiliser recommendations for horticultural crops. New Zealand Ministry of Agriculture and Fisheries.
- Cornforth, I.S. and Sinclair, A.G. 1984. Fertiliser recommendations for pastures and crops in New Zealand, 2nd Edition. New Zealand Ministry of Agriculture and Fisheries.
- Cox, J.E. 1978. Soils and agriculture of part Papanua county, Canterbury, New Zealand. New Zealand Soil Bureau Bulletin 34: 128pp.
- Dwyer, L.M. and Stewart, D.W. 1986. Leaf area development in field-grown maize. *Agronomy Journal* 78: 334-343.
- Gallagher, J.N. and Biscoe, P.V. 1978. Radiation absorption, growth and yield of cereals. *Journal of Agricultural Science, Cambridge* 91: 47-60.

- Goudriaan, J. and van Laar, H.H. 1994. Modelling potential crop growth processes. Kluwer Academic Publishers.
- Grindlay, D.J.C. 1997. Towards an explanation of crop nitrogen demand based on optimisation of leaf nitrogen per unit leaf area. *Journal of Agricultural Science*, Cambridge 128: 377-396.
- Hay, R.K.M. and Walker, A.J. 1989. An introduction to the physiology of crop yield. Longman Scientific and Technical.
- Kirby, E.J.M. 1990. Co-ordination of leaf emergence and leaf and spikelet primordium initiation in wheat. *Field Crops Research* 25: 253-264.
- Monteith, J.L. 1977. Climate and efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society of London B*. 281: 277-294.
- Muchow, R.C. and Carberry, P.S. 1989. Environmental control of phenology and leaf growth in a tropically adapted maize. *Field Crops Research* 20: 221-236.
- Muchow, R.C., Sinclair, T.R. and Bennett, J.M. 1990. Temperature and solar radiation effects on potential maize yield across locations. *Agronomy Journal* 82: 338-343.
- Plenet, D., Etchebest, S., Mollier, A. and Pellerin S. 2000a. Growth analysis of maize field crops under P deficiency. I. Leaf growth. *Plant and Soil* 223: 117-130.
- Plenet, D., Mollier, A. and Pellerin, S. 2000b. Growth analysis of maize field crops under P deficiency. II. Radiation use efficiency, biomass accumulation, and yield components. *Plant and Soil* 224: 259-272.
- Rodriguez D., Pomar, M.C. and Goudriaan, J. 1998. Leaf primordial initiation, leaf emergence, and tillering in wheat (*Triticum aestivum* L.) grown under low-P conditions. *Plant and Soil* 202: 149-157.
- Rogers, B., Sorenson, I. and Stone, P. 1999. Is sweet corn just another maize hybrid? *Proceedings Agronomy Society of New Zealand* 29: 87-90.
- Sanchez, C.A., Burdine, H.W. Martin, F.G. 1989. Yield and quality responses of three sweet corn hybrids as affected by fertilizer P. *Journal of Fertilizer Issues*. 6: 17-24.
- Sanchez, C.A., Porter, P.S. and Ulloa, M.F. 1991. Relative efficiency of broadcast and banded P for sweet corn produced on histosols. *Soil Science Society of America Journal* 55: 871-875.
- Sinclair, T.R. and Muchow, R.C. 1995. Effect of nitrogen supply on maize yield: I. Modeling physiological responses. *Agronomy Journal* 87: 632-641.
- Singh, B.R. and Uriyo, A.P. 1980. The relationship between response to N and P fertilizers and soil N and P. *Journal of Agricultural Science*, Cambridge 94: 247-249.
- Sonego, M., Moot, D.J., Jamieson, P.D., Martin, R.J. and Scott, W.R. 2000. Apical development in oats predicted by leaf stage. *Field Crops Research* 65: 79-86.
- Sorenson, I., Stone, P. and Rogers, B. 2000. Effect of sowing time on yield of a short and a long season maize hybrid. *Proceedings Agronomy Society of New Zealand* 30: 63-66.
- Tollenaar, M. and Dwyer, L.M. 1999. Physiology of maize. In *Crop yield physiology and processes* (eds., Smith, D.L. and Hamel, C.), pp 169-204. Springer-Verlag.
- Usuda, H. and Shimogawara, K. 1991. Phosphate deficiency in maize. I. Leaf phosphate status, growth, photosynthesis and carbon partitioning. *Plant and Cell Physiology* 32: 497-504.
- White, J.G.H., Millner, J. and Moot, D.J. 1999. Cereals. In *New Zealand pasture and crop science* (eds., White, J.G.H. and Hodgson, J.), pp 213-234. Oxford University press.
- Wilson, D.R., Muchow, R.C. and Murgatroyd, C.J. 1995. Model analysis of temperature and solar radiation limitations to maize potential productivity in a cool climate. *Field Crops Research* 43: 1-18.