Relationships between growth duration, leaf area and yield of maize hybrids

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Introduction

Given an appropriate sowing time, long season maize hybrids yield more than short season hybrids, and it seems likely that this is related to the amount of radiation intercepted by the crop canopy (Biscoe and Gallagher, 1977; Gallagher and Biscoe, 1978). Long season hybrids are likely to intercept more radiation for three main reasons: 1) their greater duration of crop growth increases the incident radiation available for absorption by the crop; 2) long season hybrids have more leaves so, even if their leaves were the same size as short season hybrids, they would intercept more radiation; and 3) longer season hybrids appear to have larger leaves (Birch *et al.*, 1998). Here we examine the relationship between the area of individual leaves and leaf number for maize hybrids of a wide range of maturation time (crop duration), and investigate the ability to predict their yield using systematic relationships between these factors.

Materials and methods

On 24 October, 1998, 30 maize hybrids, from the ortest to the longest season hybrids grown in New aland, were hand-planted at a population of ca. 90,000 ants/ha. The experiment was performed in a cool-mperate climate at Hastings, New Zealand (lat. 39.47 S, long. 176.64 °E) where temperature and radiation during the maize growing season average ca. 16 °C and 18 MJ/m^2/d. A site description is given in Stone *et al.* (1999). Plants were sown at 5 cm depth with an inter-row spacing of 70 cm and an intra-row spacing of 16 cm. Plots were 6 x 4.2 m. Fertiliser (250 kg N/ha as urea and 100 kg P/ha as double superphosphate) and irrigation (to maintain potential soil moisture deficit above a ritical level of 100 mm) were applied for maximum ield. Five tagged plants were observed weekly, and the nes of leaf tip appearance, full leaf expansion and complete leaf senescence were recorded for each plant. The leaf area profile was constructed for each hybrid by destructively measuring the individual leaf area of five plants per plot on three occasions. At maturity, crop biomass and yield were measured on 20 plants selected randomly from each plot. Results were analysed by simple regression of data pooled by leaf number. Regression analysis and standard deviations were calculated using 'Statview' (BrainPower Inc, Calabasas, CA, USA).

Results and Discussion

As outlined in the introduction, there appear to be three main reasons why long season hybrids have higher grain yields than short season hybrids. First, the duration of growth is greater in long season than short season hybrids. Whereas short season hybrids may reach physiological maturity by mid-February, long season hybrids frequently continued to grow into April. This can give long season hybrids an extra six weeks in which to absorb radiation and convert it to biomass and yield. Daily solar radiation during this period of 'extra' growth typically averages ca. 13 MJ/m^2. Consequently, the solar radiation available for absorption by long-season hybrids may total ca. 550 MJ/m^2 more than for short season hybrids. If all of this radiation was intercepted it would provide for an additional 7 t/ha of biomass or 3.5 t/ha of grain (for a typical crop with a radiation use efficiency of 1.3 g/MJ and a harvest index of 0.5 (Muchow *et al.*, 1990; Wilson *et al.*, 1995)). Of course, radiation interception by the crop is not complete, and during this period averages ca. 80%. As a result, a six-week extension in growth duration may, in the absence of other variables, increase yield by ca. 2.8 t/ha.

One of the important distinguishing variables between long and short hybrids is their leaf number. As the rate at which fully expanded leaves appeared was the same for all hybrids (data not shown), an increase in leaf number was associated with an increase in hybrid maturation time. Consequently, there was a two-fold effect of leaf number on the ability of a crop to intercept radiation. First, higher leaf number results in a greater capacity to intercept radiation because of an increase in crop growth duration, as outlined above. Second, even if the size of leaves of equivalent number was the same for short and long season hybrids the longer season hybrid would still intercept more radiation because the increase in leaf number would give an increase in leaf area. How great is this second effect?

Using the known relationship between leaf size and leaf number (Muchow *et al.*, 1990), it is clear that if leaf size stays constant (area of largest leaf = 750 cm^2) an increase in leaf number alone has only a minor effect on radiation interception (assuming a constant extinction coefficient). For a short season hybrid with 15 leaves the maximum total leaf area per plant (TLA) would be 6,357 cm^2, which at a standard population of 90,000 plants/ha gives a leaf area index (LAI) of 5.72. Assuming an extinction coefficient of 0.4 (Muchow *et al.*, 1990) the maximum fractional radiation interception (FRI) for this hybrid would be 0.90. By comparison, for a long season hybrid with 20 leaves, the TLA would be 6,976 cm^2, the LAI 6.28 and the FRI 0.92. It is clear that, if leaf size stays constant, the effect on FRI of the additional five leaves is negligible.

Does leaf size change with hybrid maturation time (e.g., leaf number)? These results show that the area of the largest leaf (A_{max}) on a maize plant increases linearly with leaf number, as demonstrated previously (Birch *et al.*, 1998). Whereas Birch *et al.* found that A_{max} increased by 38 cm^2 for each addition to total leaf number (r^2 = 0.82; n=18), we found an increase of 50 cm^2 (r^2 =0.92; n=30) across a range of 30 hybrids (data not shown). The effect of this on FRI can be demonstrated by recalculating the results from the simple example used for leaf number. For a short season hybrid with 15 leaves, A_{max} is 500 cm^2, which gives a TLA of 4239 cm^2, an LAI of 3.82 and an FRI of 0.78. For a long season hybrid with 20 leaves, A_{max} is 750 cm^2, TLA is 6976 cm^2, LAI is 6.28 and FRI is 0.92. Consequently, at the time of peak LAI, a long season (20 leaf) hybrid is able to intercept 14% more of the incident radiation than a short season (15 leaf) hybrid almost entirely because of the effect of the relationship between leaf number and leaf size. For a typical crop yielding 12 t/ha, this increased peak LAI would amount to an extra 0.84 t/ha of grain. Of course, it must be remembered that as peak LAI increases so does the FRI during the season. Consequently, the effect of A_{max} on grain yield is likely to be much greater than 0.84 t/ha.

The above analyses show that long season hybrids generally yield more than short season hybrids because: 1) greater crop duration increases the amount of incident radiation available for absorption by the crop; and 2) longer season hybrids have bigger leaves than short season hybrids, which increases their FRI (the proportion of available radiation that is used by the crop). The effect of leaf number, per se, on radiation interception and yield is minimal.

While we have attempted to separate the contributions to yield of each of the above factors, in reality they act jointly to influence yield. The relationships between leaf number, leaf size, crop duration, radiation interception and yield are shown in Figure 1. Basically, long season hybrids yield more than short season hybrids because: as

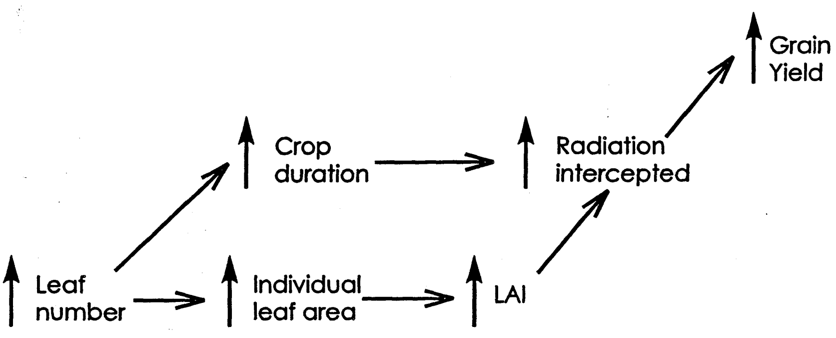

Figure 1. Proposed mechanism for relationship between leaf number and yield.

leaf number increases so does crop duration and leaf size (and, hence, leaf area index). Together, these increase the radiation intercepted by the crop canopy and, consequently, its biomass and yield.

In fact, these factors are inter-related to such an extent that one variable (A_{max}) can be used to integrate the overall effect of hybrid maturition time on grain yield. Because of the systematic effect of leaf number on A_{max}, and the simultaneous effect of leaf number on crop duration, A_{max} is significantly correlated with radiation intercepted and grain yield. In this experiment, grain yield of maize increased by 28 kg/ha for every 1 cm^2 increase in A_{max} (Fig. 2). This relationship may form the basis of a simple method for estimating grain yield differences between maize crops. However, when applying this method it is important to be aware of the fact that differences in A_{max} are correlated with, rather than the direct cause of, differences in grain yield. That is, A_{max} integrates the effect of leaf number on both crop duration and LAI and, of the two, crop duration has a much bigger direct influence on yield, as outlined in the discussion.

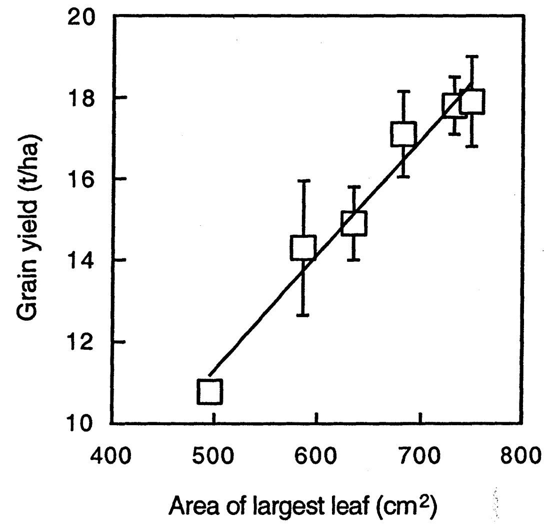

Figure 2. Relationship between A_{max} and grain yield for 30 hybrids of maize differing widely in leaf number. A_{max} data are averaged for each leaf number. Error bars indicate standard deviation of grain yield for hybrids of each leaf number.

Conclusions

Using the close and systematic relationships that exist between leaf number, leaf size, crop duration and yield it was possible to estimate the yield of maize using simple measures of the area of the largest leaf on a maize plant (A_{max}).

References

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