Studies on the Effect of Plant Density on Maize Growth using the Richards Function

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Abstract

In two-factorial split plot experiments, carried out at Martonv?s?r, Hungary in 1997-1999, the growth analysis method was used to examine the effect of six plant densities (20, 40, 60, 80, 100 and 120 thousand plants/ha) on the dynamics of growth and growth indices of three maize hybrids with different vegetation periods (FAO 290–FAO 530). The Richards function was used for the functional method of growth analysis. The plant density had a significant effect on the dry matter accumulation, the absolute growth rate (AGR) and the absolute acceleration rate (AAR) of the maize plant and grain yield. The multiple linear regression analysis showed that the asymptotic maximum of the maize plant and the AAR_{max} were the most important in determining grain yield.

Media summary

The Richards function for the analysis of maize growth was presented. The methodology described here should be applicable to any biological system or subsystem.

Key words

Richards function, absolute growth rate, absolute acceleration rate, maize, functional growth analysis

Introduction

Growth analysis is one approach to the analysis of yield-influencing factors and plant development. The pattern of maize growth over a generation is typically characterized by a growth function referred to as the sigmoid curve. The S-shaped curve results from differential rates of growth during the life cycle. The genetic improvement of maize hybrids has been associated with an increase in the plant density at which maximum grain yield is attained. In this study, the Richards function was used to precisely analyse plant growth as affected by plant density.

Methods

In two-factorial split plot experiments, carried out at Martonv?s?r, Hungary (N 47? 21’, E 18? 49’) in 1997-1999, the growth analysis method was used to examine the effect of six plant densities (20, 40, 60, 80, 100 and 120 thousand plants/ha) on the dynamics of growth and growth indices of three maize hybrids (*Mara SC, Mv 355 SC and Florencia SC*) with different relative maturity (FAO 290–FAO 530). Plant samples for the destructive growth analysis were taken 10 times at 14-day intervals from the 4-leaf stage to physiological maturity. Leaf area was measured with a leaf area meter (type Delta-T). The growth indices were calculated according to Causton and Venus (1981) and Hunt (1982). The Richards function was used for the functional method of growth analysis:

$$W = A(1 \pm e^{(b-kt)})^{-1/n}$$

where W is the size of a given growth attribute at time t, and A, b, k and n are constants. Parameter A gives the asymptotic maximum size of the maize plant or plant organ. Richards (1959) proposed three different combinations of parameters that have biological significance: weighted mean absolute growth rate ($\overline{AGR}$), weighted mean relative growth rate ($\overline{RGR}$) and the duration of growth (D). The computer program developed by Nath and Moore III (1992) was used in this study. This program demonstrates the use of the first, second and third derivatives of the Richards function in growth analysis. Recently Gregorczyk (1998) confirmed the usefulness of the Richards function.

Results

Statistical analysis shows that maize growth can be depicted with high approximation efficacy using the Richards function (R^2 >98%). Figure 1 shows the effect of plant density on the dynamics of dry matter accumulation (a, b), absolute growth rate (c, d) and absolute acceleration rate (e, f) for the whole plant and grain yield of maize hybrid Mv 355, determined by fitting the Richards function. During plant growth there are three characteristic critical moments that can be marked as P_1, P_i, P_2 on the graphs. Point P_1 represents the maximum acceleration of growth and the first inflection of the growth rate curve. At point P_i the growth rate attains its maximum value. Point P_2 indicates maximum deceleration, i.e. the maximum negative acceleration of growth, while at the same time there is a second inflection of the growth rate curve. Points P_1 and P_2 separate the entire growth period into three phases: the exponential phase, the linear phase (from P_1 to P_2) and the ageing phase.

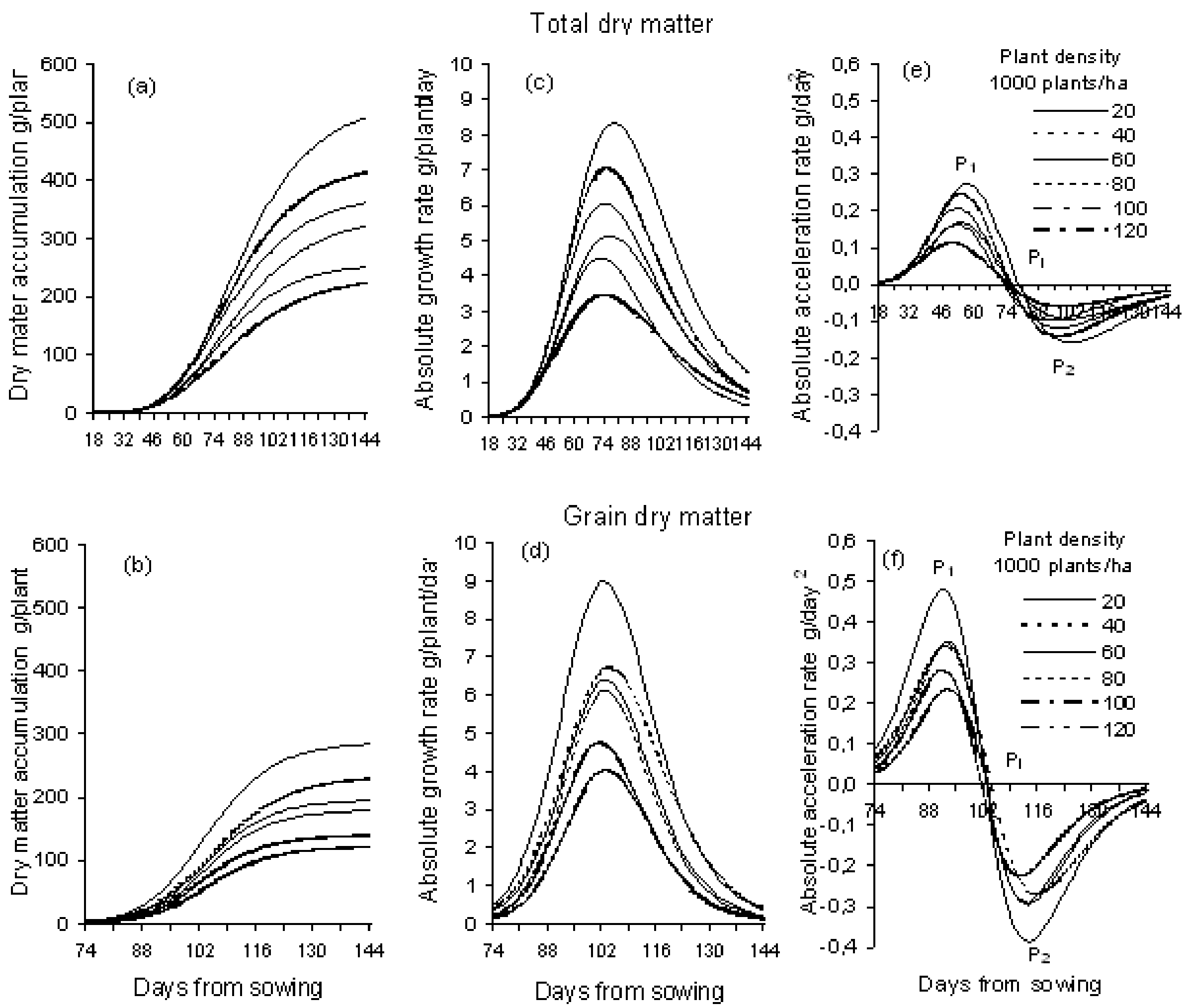

Figure 1. Dynamics of dry matter accumulation (a,b), absolute growth rate (c,d) and absolute acceleration rate (e,f) of the whole plant and grain of the maize hybrid Mv 355, as determined by fitting the Richards function.

Figure 1 illustrates the significant effect of plant density on the dry matter accumulation, the absolute growth rate (AGR) and the absolute acceleration rate (AAR) of the maize plant and grain yield. According to the analysis of multiple observation data, the analysis of variance showed that plant density had no significant effect on total dry matter accumulation at the 1st and 2nd sampling times (18 and 32 days from sowing). From the fourth sampling onwards there was a significant difference in dry matter production at all plant densities. In the case of grain yield, plant density had significant effect from the first sampling time. The dynamics of the absolute growth rate was characterised by a bell-shaped curve, the course and particularly the maximum value of which differed significantly at each plant density. The acceleration/retardation curves in Figure 1 (e, f) show just how dynamic the growth of maize plant and grain yield actually is. It can be seen from these graphs that AAR becomes negative, i.e., retardation begins, at the instant when AGR begins declining.

Table 1 demonstrates the dry matter accumulation at the critical times, the absolute growth rates and the absolute acceleration rates as affected by plant density. Plant density had a significant effect on the dry matter accumulation of the whole plant and the grain yield at the critical times (AAR_{max}, inflection point, AAR_{min}) and on the asymptotic maximum values as well. The asymptotic maximum value of grain yield was 280 g/plant at the lowest and 103.6 g/plant at the highest plant density. The asymptotic maximum for the whole plant was 544.2 g/plant at the lowest and 196.5 g/plant at the highest plant density. Plant density had no significant effect on the relative growth rate (RGR), but the absolute growth rate (AGR) and the absolute acceleration rate (AAR) decreased significantly as the plant density increased. The values of AGR and AAR were significantly higher for grain yield than for the whole plant.

Table 1. Effect of plant density on the dry matter (DM) accumulation, absolute growth rate (AGR) and absolute acceleration rate (AAR) of the whole maize plant and the grain yield, calculated by fitting the Richards function (average of 3 hybrids and 3 years)

Parameters	Plant density 10^3 plants/ha					
	20	40	60	80	100	120
DM at AAR_{max} (g/plant)						
Grain yield	53.0 a	44.3 ab	35.4 abc	26.6 bcd	20.0 cd	13.5 d
Maize plant	64.5 a	51.9 ab	39.5 bc	32.1 bc	25.9 c	22.4 c
DM at the inflection point (g/plant)						
Grain yield	133.6 a	106.0 b	85.6 bc	69.6 cd	53.8 de	46.2 e
Maize plant	225.4 a	176.0 b	140.4 c	118.9 cd	95.6 de	78.5 e
DM at AAR_{min} (g/plant)						
Grain yield	213.9 a	166.3 b	133.3 c	112.6 cd	88.3 de	73.4 e

Maize plant	389.7 a	309.1 b	246.2 c	208.7 c	169.5 d	139.9 d
Asymptotic maximum (A) (g/plant)						
Grain yield	280.0 a	215.3 b	169.4 c	147.8 c	116.7 d	103.6 d
Maize plant	544.2 a	431.0 b	345.0 c	295.2 d	23.4 e	196.5 f
AGR_{max} (g/day)						
Grain yield	11.69 a	9.32 ab	7.69 bc	5.98 cd	4.72 d	3.81 d
Maize plant	8.62 a	6.95 b	5.83 bc	4.58 cd	3.90 d	3.25 d
$\overline{AGR}$ (g/day)						
Grain yield	6.97 a	5.81 ab	4.85 bc	3.77 cd	3.05 de	1.88 e
Maize plant	5.77 a	4.66 b	3.83 bc	3.17 cd	2.61 d	2.17 d
$\overline{RGR}$ (mg/g/day)						
Grain yield	82.3 a	84.9 a	88.6 a	83.8 a	86.0 a	70.2 a
Maize plant	38.8 a	39.4 a	40.6 a	38.9 a	40.7 a	40.9 a
AAR_{max} (g/day^2)						
Grain yield	0.813 a	0.661 ab	0.563 abc	0.407 bcd	0.326 cd	0.273 d
Maize plant	0.272 a	0.223 b	0.189 bc	0.147 cd	0.132 d	0.110 d
AAR_{min} (g/day^2)						
Grain yield	-0.841 a	-0.743 ab	-0.593 ab	0.374 abc	0.296 bc	0.208 c
Maize plant	-0.194 a	-0.158 ab	-0.126 abc	-0.097 bc	0.085c	0.073 c

Within rows, means followed by the same letter are not significantly different according to LSD (α=0.05).

The mean values of $\overline{AGR}$ for the grain yield decreased from 6.97 g/plant/day to 1.88 g/plant/day as the result of increasing plant density. For the whole plant the $\overline{AGR}$ decreased from 5.77 g/plant/day to 2.17 g/plant/day as the plant density increased. Research showed that during the straight line phase of growth (between the times when d^2W/dt^2 is maximum and minimum) the value of AGR was very close to that of AGR_{max}, indicating that during this period the growth of the maize plant approaches the maximum value of the absolute growth rate. The absolute acceleration rate (AAR_{max}) was also a good indicator of the effect of plant density. Its value for grain yield was 0.813 g/day^2 at the lowest plant density, decreasing to 0.273 g/day^2 at the highest plant density. The same values for the whole plant were 0.272 and 0.110 g/day, respectively. The plant density had a significant effect on the occurrence of the critical times (AAR_{max}, inflection point, AAR_{min}) for the maize plant, but the density effect was not significant in the case of grain yield. AAR_{max} was recorded at 57.9 days (from sowing) at the lowest density, significantly decreasing with a rise in density to 49.9 days at the highest plant density. For grain yield the time of AAR_{max} varied from 95.7 to 93.2 days, but the density effect was not significant. The inflection point of the maize plant was observed at 80.3 days at the lowest plant density, decreasing to 70.8 days at the highest plant density. For the grain yield the inflection point was observed at almost the same time (between 102.3 and 103.8 days) for all plant densities. AAR_{min} was recorded significantly later, at 102.8 days, at 20,000 plants/ha than at 120,000 plants/ha (91.8 days) for the maize plant, while it was not significantly different for grain yield (ranging from 110.3 to 111.6 days). Neither the grand period of growth (D) nor the linear phase of growth was significantly affected by plant density.

In the next step multiple linear regression was used to analyse the effect of different growth parameters in determining the grain yield per plant. The independent or predictor variables were the dry matter accumulation of the maize plant at different critical times, the asymptotic maximum, the AGR and AAR values for the maize plant and the cumulative value of leaf area duration. The value of R^2 for the model was 0.969. The two predictor variables in the final model were the asymptotic maximum (β value: 0.800) and the AAR_{max} (β value: 0.219) for the total dry matter. Figure 2 illustrates the partial correlation between these two variables and the asymptotic maximum of grain yield. The results of regression analysis are in agreement with the results of Tollenaar (1991) and Otegui et al. (1995), who emphasized the importance of the total dry matter accumulation and plant growth rate from 10 d before to 20 d after silking in the determination of grain yield.

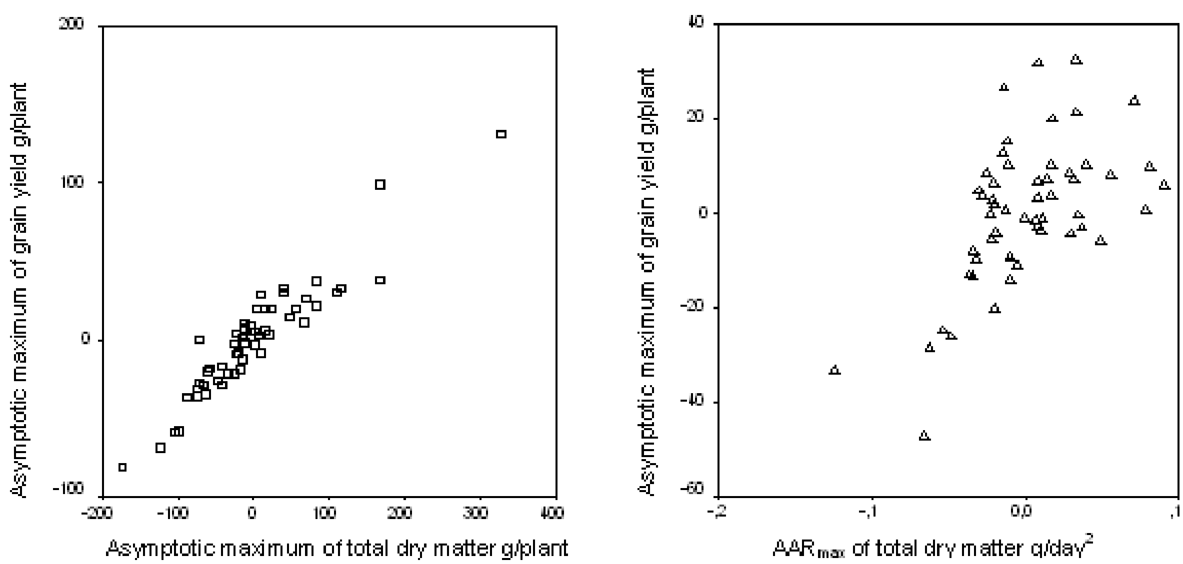

Figure 2. Partial residual plots for the two sets of residuals from the multiple regression analysis

Conclusions

Growth analysis provides an excellent opportunity to monitor the independent and interactive effects of various factors affecting maize yields, and opens the way to managing these factors in integrated systems. The diagnosis of growth-limiting factors and the forecasting of grain yield through growth analysis should significantly improve site-specific farming. The method provides us with information on features of growth at its critical times. Thus, agronomic, genetic and environmental effects on growth and development are better understood. Although the growth analysis parameters presented here refer to individual plants, they can easily be converted to plant stands, making the method suitable for the determination of optimum plant density and maximum yield.

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