

SZENT ISTVÁN UNIVERSITY

**ANALYSIS OF THE GROWTH DYNAMICS AND YIELD OF
MARTONVÁSÁR WHEAT GENOTYPES AT VARIOUS NITROGEN
FERTILISER LEVELS**

Main points of the PhD thesis

Eszter Sugár

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Details of the Doctoral School

Name: Doctoral School of Plant Sciences

Branch of Science: Crop Production and Horticultural Sciences

Head: **Prof. Lajos Helyes, DSc**
Head of the Institute of Horticultural Technology,
Faculty of Agricultural and Environmental Sciences,
Szent István University

Supervisors: **Zoltán Berzsenyi, DSc**, Professor Emeritus
Agricultural Institute, Centre for Agricultural Research,
Hungarian Academy of Sciences, Martonvásár

Márton Jolánkai, DSc, Professor Emeritus
Institute of Crop Production,
Faculty of Agricultural and Environmental Sciences,
Szent István University

Approved by

Dr Zoltán Berzsenyi

Supervisor

Dr Márton Jolánkai

Supervisor

Dr Lajos Helyes

Head of Doctoral School

1. BACKGROUND AND AIMS

The achievement of sustainable development in wheat production depends to a great extent on a satisfactory choice of cultivar and the optimisation of nutrient supplies, while yield reliability is constantly declining due to climate change. The cultivars chosen should have good adaptation to the given climatic conditions, satisfactory resistance to various pathogens, good weed suppression ability, good tolerance of water deficit and the ability to form a strong stand before the winter frosts, while flowering in time to avoid very hot days. Some cultivars can be grown with relatively high yield reliability even at lower N supplies. The nutrient quantities required for the growth of wheat are provided primarily in the form of mineral fertilisers. Among the macronutrients, a satisfactory quantity of N fertiliser, adjusted to the development of the crop, is of outstanding importance. Satisfactory N supplies are able to reduce the yield fluctuations caused by the year. Low N fertiliser doses mainly influence the yield quantity, while doses of over 100 kg N ha⁻¹ also have a positive effect on quality traits (Árendás et al., 2001). Excessive N fertilisation, on the other hand, is unfavourable for wheat.

Problems caused by the contamination of surface and subsurface waters due to the excessive use of N fertilisers are becoming increasingly serious in the member states of the European Union, so restrictions have been placed on the application of N fertiliser.

If more detailed knowledge is to be obtained on the nutrient responses of individual wheat genotypes in years with diverse weather conditions, it is necessary to monitor the effect of the year not only in the yield but throughout the course of phenological development. With the help of growth analysis, plant growth can be interpreted in terms of plant dry matter production, and answers can be obtained to how various agronomic and ecological factors influence the growth and growth dynamics of wheat (Berzsenyi, 2000b). Growth analysis makes it possible to compare the growth dynamics of different cultivars.

A vast amount of research is underway on climate change and its expected effects. Due to the uncertain weather conditions characteristic of Hungary, the year effect is of great significance for crop production.

In the three years examined, the development of three wheat cultivars with different maturity dates (the very early Mv Toborzó, the early Mv Palotás and the medium early Mv Verbunkos) was investigated throughout the growing season in treatments given N rates of 0, 80, 160 and 240 kg ha⁻¹, combined with 120 kg ha⁻¹ each of P and K. Growth analysis was performed at the plant organ, individual plant and plant stand levels. Various methods of growth analysis were applied to determine the effect of the experimental factors on the growth of wheat and on the dynamics of growth parameters.

Aims of the thesis in the Martonvásár long-term crop rotation experiment:

1. Comparison of the dynamics of dry matter production and leaf area in various winter wheat genotypes in diverse N treatments in three consecutive years.
2. Use of the classical and functional methods of growth analysis to analyse the effects of diverse N treatments on the dynamics of growth parameters and their mean and maximum values when the wheat cultivars were grown in different years.
3. Analysis of the effect of N fertilisation on the yield, yield components, area of the flag-leaf and quality parameters in different wheat cultivars.
4. Analysis of the correlation between the yield and the growth dynamics, growth parameters, yield components and quality parameters.
5. Selection of suitable genotypes for the expected weather conditions, and determination of the optimum N dose required to achieve more stable yields.
6. The use of growth dynamics and growth parameters to characterise the yield responses of the genotypes on the basis of the correlations detected.

2. MATERIALS AND METHODS

2.1. Description of the experiment

The effect of nitrogen treatments was examined in the years 2006/2007, 2007/2008 and 2008/2009 in winter wheat grown on chernozem soil with forest residues and a deep fertile layer in a long-term crop rotation experiment set up with a crop sequence of peas, winter wheat, maize and spring barley in the László-puszta nursery of the Agricultural Research Institute of the Hungarian Academy of Sciences (now MTA AKT).

The small-plot experiment was originally set up by Árpád Koltay and was started up again in 1980 in a modified form. Based on the original mineral fertiliser doses, modifications were made in both the N fertiliser treatments and the plants in the crop sequence.

The experiment involved two factors in a split-plot design with four replications, with the N dose in the main plot and the wheat cultivars in the sub-plots. The N fertiliser doses examined in the main plot were 0, 80, 160 and 240 kg ha⁻¹ (designated as N₀, N₈₀, N₁₆₀ and N₂₄₀) with identical supplies of P and K fertilisers (120 kg ha⁻¹ each). Three Martonvásár wheat genotypes with different maturity dates (Mv Toborzó: extra early, Mv Palotás: early and Mv Verbunkos: medium early) were sown in the sub-plots. The year effect was also examined in this work.

2.2. Description of the weather conditions in the three years

The quantity of precipitation during the vegetation period was only about a third as much in 2007 (200 mm) as in 2008 and 2009 (637.8 and 616.6 mm, respectively). This was less than half the 30-year mean (513 mm), and the rainfall distribution was also unfavourable for wheat. The years 2008 and 2009 could be described as favourable from the point of view of rainfall. The rainfall distribution was the most favourable in 2008.

2.3. Description of the research performed in the experiment

The destructive plant samples required for growth analysis were collected at random, starting during the winter when frosts were no longer recorded in the daytime and continuing at weekly intervals right up to harvesting, on a total of 24 occasions in 2007, 20 in 2008 and 17 in 2009. At each sampling date, 240 plant samples were processed.

Sample processing involved measuring the length of the whole plant and the spikes, and determining the number of tillers, nodes and spikes and the number of leaves on each tiller. The samples were then divided into leaf, stem and spike portions. The leaf area was recorded using an ADC AM300 leaf area meter for the whole plant and for the flag-leaf on the main tiller. The leaf, stem and spike samples were then dried to constant weight in a drying cabinet (MEMMERT ULE/800) at 65°C for 48 hours. The dry weight of the individual plant organs was then recorded using an analytical balance. At flowering the chlorophyll content of the flag-leaf was measured using a portable Minolta SPAD 502 chlorophyll meter. The number of grains per spike was determined at the last sampling date. Prior to harvesting the number of spikes per metre was counted by placing a 1-m ruler alongside the rows.

A laboratory mill (Perten 3100) was used to prepare groats from the grain samples. The protein and gluten contents of the grain yield were then determined using a Perten INFRAMATIC 8600 NIR instrument (Micskei, 2011).

2.4. Growth parameters and how they were calculated

The seasonal dynamics and the mean and maximum values of the growth parameters were determined using the classical and functional methods of growth analysis for individual plants and for the plant stand. Among the individual plant parameters, the absolute and relative growth rate (AGR, ALGR, RGR), the net assimilation rate (NAR), the leaf area ratio (LAR), the specific leaf area (SLA) and the leaf weight ratio (LWR) were calculated. The growth analysis of the plant stand

involved the following growth parameters: leaf area index (LAI), crop growth rate (CGR), leaf area duration (LAD), biomass duration (BMD) and harvest index (HI).

The values of the RGR, NAR, LAR, LWR and SLA growth parameters were calculated from the dry weight and leaf area data of the samples using the modern growth analysis program elaborated by Hunt et al. (2002). The mean values of the other parameters (AGR, ALGR, CGR, LAI, LAD, BMD, HI) were calculated using equations from the Microsoft® Windows Excel (2003) program. The basic data of dry weight and leaf area were evaluated using the functional approach in the Hunt–Parsons (1974) growth analysis program (HP model). First, second and third degree polynomial functions were fitted to the dry weight (Y) and leaf area (Z) data as a function of time (X) using the stepwise regression method in this program.

2.5. Biometrical evaluation of the experimental data

All the measured and calculated data were statistically evaluated with analysis of variance for a two-factor split-plot design using the MSTAT-C program package.

Correlations between the yield components, growth parameters and individual morphological parameters and the yield were detected using partial correlation analysis with the help of the GenStat 13.1 (2002) program package.

Two-factor linear regression analysis was performed to find correlations between the yield (dependent variable) and individual growth parameters (independent variable), while regression analysis for two independent variables was applied to reveal correlations between the yield and the yield components, and between the growth rates (RGR, CGR) and their components. The stepwise method of multiple regression analysis was used to identify the variables with the greatest influence on the dependent variable (the yield).

3. RESULTS

3.1. Effect of the year on the dry matter production, growth parameters and yield of winter wheat cultivars

The dynamics of dry matter accumulation per plant could be described using a sigmoid curve. The total dry plant yield was the highest in 2007 ($4.07 \text{ g plant}^{-1}$), with values of 3.84 and $3.68 \text{ g plant}^{-1}$ in 2008 and 2009, respectively. The leaf and stem weight per plant were higher in the dry year, and the spike weight in the favourable years.

The growth dynamics of the leaf area followed a bell-shaped curve. The maximum leaf area per plant was greatest in 2008 (158.4 cm^2), while the values were similar in 2007 and 2009 (141.7 and 144.8 cm^2 , respectively). The area of the flag-leaf was considerably larger in 2008 (28.6 cm^2) than in 2007 (16.4 cm^2) and 2009 (18.0 cm^2).

The mean and maximum values of the growth parameters gave a good description of the year effect. The absolute and relative growth rates of the dry matter (AGR_{mean} , AGR_{max} , RGR_{mean} , RGR_{max}), the components (NAR_{mean} , LAR_{mean}) of the relative growth rate of the dry matter (RGR_{mean}), the absolute growth rate of the leaf area ($\text{ALGR}_{\text{mean}}$, ALGR_{max}), the specific leaf area (SLA_{mean}) and the leaf area duration of the flag-leaf (LAD_{fl}) were the highest in 2008. The absolute growth rates (AGR_{mean} , $\text{ALGR}_{\text{mean}}$), the relative growth rate of the dry matter (RGR_{mean}), the net assimilation rate (NAR_{mean}), the leaf area ratio (LAR) and the harvest index (HI) all had higher values in the favourable years of 2008 and 2009.

The grain yields achieved in 2008 and 2009 (7.28 and 7.11 t ha^{-1} , respectively) were significantly higher than the yield in 2007 (6.11 t ha^{-1}). The number of spikes per square metre (spikes m^{-2}) was substantially higher in the dry year of 2007 (692.4) than in 2008 (596.1) or 2009 (560.5). The number of kernels per spike, however, was around three times as great in 2008 and 2009 (35.5 and 33.3 kernels spike $^{-1}$, respectively) than in 2007 (12.6 kernels spike $^{-1}$). The thousand-kernel

weight was higher in the dry year (47.7 g) than in 2008 and 2009 (44.01 and 44.68, respectively).

3.2. Effect of N fertilisation on the dry matter production, growth parameters and yield of winter wheat cultivars

The dynamics of dry matter accumulation gave a good reflection of the effect of the nitrogen treatments. The dry weight per plant was lowest (2.97 g plant⁻¹) in the N₀ treatment, while the maximum dry weight per plant was recorded in the N₁₆₀ and N₂₄₀ treatments (4.25 and 4.32 g plant⁻¹). The dry weight of the individual plant organs was also smallest in the N₀ treatment and increased up to the N₁₆₀ and N₂₄₀ rates.

Right from the earliest stages of development up to the withering of the foliage, N treatment had a significant effect on the size of the leaf area. The dynamics of the leaf area differed to the greatest extent between the N₀ and N₈₀ treatments. The maximum leaf area was recorded in the N₂₄₀ treatment (186 cm²). N fertilisation also had a significant effect on the size of the flag-leaf area for the wheat cultivars tested.

All the growth parameters had the lowest mean and maximum values in the N₀ treatment and the highest values in response to N fertilisation in the N₁₆₀ treatment.

Averaged over the cultivars, the grain yield was smallest in the N₀ treatment (5.45 t ha⁻¹), rising significantly in the N₈₀ treatment in 2007 and 2008 (6.45 and 7.99 t ha⁻¹), but not until the N₁₆₀ treatment in 2009 (7.44 t ha⁻¹). Higher N rates did not lead to a further significant increase in yield.

Nitrogen fertilisation had a substantial influence on the spike number per m², the number of kernels per spike and the thousand-kernel weight. Averaged over years and cultivars, the spike number per m² and the number of kernels per spike exhibited the highest values in the N₁₆₀ and N₂₄₀ treatments, respectively, while the thousand-kernel weight was greatest in the N₀ treatment. The SPAD value

indicative of the chlorophyll content of the flag-leaf increased in response to N fertilisation up to the N₈₀ dose in 2007 and up to the N₁₆₀ dose in 2008 and 2009.

3.3. Effect of genotype on the dry matter production, growth parameters and yield of winter wheat cultivars

The dynamics of dry matter production over time clearly reflected the differing maturity dates of the wheat cultivars. The maximum value of dry matter production, averaged over years and N treatments, was 3.98 g for Mv Verbunkos, 3.91 g for Mv Palotás and 3.71 g for Mv Toborzó.

The dry matter production of the plant organs differed for the three cultivars tested. Mv Palotás and Mv Verbunkos developed greater leaf mass (0.81 and 0.80 g, respectively) than Mv Toborzó (0.70 g), while the stem mass was similar for all three cultivars (1.92–2.01 g). The cultivar had a significant effect on the spike weight in 2007 and 2008, with the greatest value for Mv Palotás in 2007 (2.05 g) and for Mv Verbunkos in 2008 (2.15 g).

The seasonal dynamics of the leaf area also clearly depended on the maturity dates of the cultivars. The cultivar had a significant effect on the size of the leaf area from the initial stages of development right up to the withering of the foliage. In 2007 the maximum value was recorded for Mv Toborzó (206.11 cm²) and in 2008 and 2009 for Mv Verbunkos (211.75 and 184.50 cm², respectively). The area of the flag-leaf was greatest for Mv Verbunkos, averaged over the years and N treatments (21.7 cm²), followed by Mv Palotás (20.7 cm²) and Mv Toborzó (17.9 cm²).

There were differences between the cultivars in the mean and maximum values of most of the growth parameters. Mv Verbunkos exhibited the highest absolute and relative growth rates (AGR_{mean} , AGR_{max} , $ALGR_{\text{mean}}$, $ALGR_{\text{max}}$, RGR_{max}), mean net assimilation rate (NAR_{mean}), crop growth rate (CGR_{max}) and leaf area duration (LAD_{LAI}), and also had the highest value for the leaf area duration of the flag-leaf (LAD_{fl}).

In all three years the cultivar had a significant effect on the yield. In 2007 Mv Palotás and Mv Verbunkos had the highest yields (6.25 and 6.21 t ha⁻¹, respectively), while in 2008 and 2009 Mv Verbunkos was the best-yielding cultivar (7.63 and 7.51 t ha⁻¹, respectively).

There was also a significant cultivar effect for the number of spikes per m² in 2007 and 2008 and for the number of kernels per spike in all three years. The number of kernels per spike was the greatest for Mv Verbunkos (31.6), followed by Mv Palotás (28.2) and Mv Toborzó (21.7). The thousand-kernel weight was highest for Mv Toborzó (52.5 g).

The SPAD value expressing the chlorophyll content of the flag-leaf was highest for Mv Verbunkos, averaged over N treatments and years (52.8), while lower values were recorded for Mv Palotás (51.6) and Mv Toborzó (50.7).

3.4. Correlations between yield and growth parameters

Partial correlation analysis showed that among the yield components the kernel number per spike and the thousand-kernel weight were in close positive correlation at the P=0.1% level with the grain yield per plant, while there was a close negative correlation, also at the P=0.1% level, between the number of kernels per spike and the thousand-kernel weight. AGR_{mean} was in close positive correlation with BMD at the P=0.1% level, while RGR_{mean} exhibited a moderate positive correlation with its components, NAR_{mean} and LAR_{mean}.

Among the yield components of the plant stand, partial correlation analysis revealed a moderate positive correlation between the number of kernels per m² and the grain yield. Among the growth parameters, LAI_{max} exhibited a loose correlation and HI a moderate positive correlation with the yield (P=5%), and these parameters were also in positive correlation (at the P=5% level) with the number of spikes per m². The number of kernels per m² was in moderate positive correlation with the LAD of the flag-leaf at the P=0.1% level, while CGR_{mean} exhibited a moderate positive correlation with its components, NAR_{mean} (P=1%) and LAI_{max} (P=0.1%).

The plant dry weight was in close correlation with the dry weight of the spike ($P=0.1\%$), in moderately close correlation with the leaf dry weight ($P=1\%$) and in loose positive correlation with the stem dry weight ($P=5\%$).

3.5. Linear regression analysis between the yield (yield components) and the growth parameters

The mean value of CGR exhibited a significant correlation with the yield in 2007 and 2008 and for each cultivar. On the basis of R^2 , CGR_{mean} explained 45.6% of the yield variation in the dry year and 80.6% in the most favourable year. The correlation between the yield and LAD_{LAI} was significant in all the years. In the favourable years of 2008 and 2009, LAD_{LAI} explained 73.7 and 61.7% of the yield variance, while this figure was 52.9% in 2007. A significant correlation was found between the yield and the flag-leaf LAD value, which explained 62.0 and 74.6% of the yield variance in the favourable years and 41.6% in the dry year. The effect of BMD on the yield was significant in all the years, explaining 44.5 and 42.4% of the yield variance in 2007 and 2009, respectively, and 86.1% in 2008 on the basis of the R^2 values.

Using two-factor linear regression analysis a positive correlation was found between the integral growth parameters. Based on R^2 , LAD explained 78.4% of the variance in BMD. Based on the data of three years, there was a very close correlation between the absolute growth rate of the leaf area ($ALGR_{\text{max}}$) and the maximum value of the leaf area index (LAI_{max}). $ALGR_{\text{max}}$ explained 79.6% of the variance in LAI_{max} . A significant correlation was found each year between the absolute growth rate of the dry matter (AGR_{mean}) and the biomass duration (BMD). AGR_{mean} explained explained 86.9–96.9% of the variance in BMD.

With the help of regression analysis for two independent variables, the yield components number of kernels per m^2 and thousand-kernel weight were found to explain 54.9% of the yield variance in the N_{80} treatment, 88.6% in the N_{160} treatment and 76.9% in the N_{240} treatment on the basis of R^2 values. Of the two

yield components, the effect of the kernel number per m^2 was decisive. Regression analysis for two independent variables also revealed a significant correlation, averaged over the three years, between RGR_{mean} and its two components, NAR_{mean} and LAR_{mean} , and between CGR_{max} and its components, NAR_{mean} and LAI_{max} . NAR_{mean} and LAR_{mean} explained 83.6% of the RGR_{mean} variance, while NAR_{mean} and LAI_{max} explained 58.8% of the CGR_{max} variance.

3.6. Multiple regression analysis

On the basis of multiple regression analysis the single variable with the greatest influence on the yield per plant was the kernel number per spike. This was followed (in decreasing order of R^2 values) by RGR_{mean} , AGR_{mean} , LAD_{fl} , LAR_{mean} , the thousand-kernel weight and NAR_{mean} . The combination of two independent variables with the greatest effect on the yield was the kernel number per spike and the thousand-kernel weight, followed by the kernel number per spike and RGR_{mean} , the kernel number per spike and AGR_{mean} , and the kernel number per spike and HI. The combination of three independent variables with the greatest effect on the yield was the kernel number per spike, the thousand-kernel weight and RGR_{mean} , followed by the kernel number per spike, AGR_{mean} and HI. The combination of four independent variables with the greatest effect on the yield was the kernel number per spike, the thousand-kernel weight, NAR_{mean} and LAR_{mean} , followed by the kernel number per spike, the thousand-kernel weight, AGR_{mean} and BMD.

In the case of the yield of the plant stand, multiple regression analysis showed the most decisive single independent variable to be the number of kernels per m^2 . This was followed (in decreasing order of R^2 values) by LAD_{fl} , CGR_{mean} , LAI_{max} , HI, thousand-kernel weight and the number of spikes per m^2 . The combination of two independent variables with the greatest effect on the yield was the kernel number per m^2 and LAI_{max} , followed by the kernel number per m^2 and CGR_{mean} , and LAD_{fl} and HI. The combination of three independent variables with the greatest effect on the yield was the kernel number per m^2 , LAI_{max} and HI.

Regression analysis on the morphological parameters determining the yield per plant showed that the most decisive single variable was the number of kernels per spike, followed (in decreasing order of R^2 values) by the spike weight, leaf area, plant weight and thousand-kernel weight. The combination of two independent variables with the greatest effect on the yield was the kernel number per spike and the thousand-kernel weight, followed by the kernel number per spike and HI, the kernel number per spike and the leaf weight, and the spike weight and leaf weight. The combination of three independent variables with the greatest effect on the yield was the kernel number per spike, the leaf area and the leaf weight, followed by the kernel number per spike, the spike weight and the leaf weight.

3.7. New scientific results

1. A substantial year effect could be detected on the basis of rainfall quantity and distribution for the three years examined. Averaged over the N treatments and cultivars, the wheat yield was significantly higher in the two years with favourable weather conditions (2008: 7.28 t ha^{-1} , 2009: 7.11 t ha^{-1}) than in the unfavourable year of 2007 (6.11 t ha^{-1}). The year effect was clearly reflected by the mean and maximum values of the growth parameters.
2. N fertilisation had a significant effect on the seasonal dynamics of the dry matter accumulation of the whole plant and the individual plant organs (leaf, stem, spike) and of the leaf area per plant, and also on the size of the flag-leaf. Averaged over years and cultivars, the biomass, the leaf area and the mean and maximum values of the growth parameters were smallest in the N_0 treatment and significantly higher in the N_{80} treatment, while the increase recorded in the N_{160} and N_{240} treatments depended on the year and the cultivar.
3. N fertilisation had a significant effect on the yield and the yield components. The grain yield was lowest in the N_0 treatment (5.45 t ha^{-1} , averaged over years and cultivars), significantly rising in the N_{80} treatment (7.09 t ha^{-1}) or the N_{160}

treatment (7.28 t ha^{-1}), depending on the year. The number of spikes per m^2 and the number of kernels per spike were greatest in the N_{160} and N_{240} treatments.

4. The seasonal dynamics of the leaf area, the dry matter production and the growth parameters gave a clear reflection of the different maturity dates of the cultivars. Among the cultivars, Mv Verbunkos exhibited the greatest absolute and relative growth rates (AGR_{mean} , AGR_{max} , $ALGR_{\text{mean}}$, $ALGR_{\text{max}}$, RGR_{max}), mean net assimilation rate (NAR_{mean}), crop growth rate (CGR_{max}), leaf area duration (LAD_{LAI}) and leaf area duration of the flag-leaf (LAD_{fl}).
5. In all three years the cultivar had a significant effect on the yield, which was 7.12 t ha^{-1} for Mv Verbunkos, 6.81 t ha^{-1} for Mv Palotás and 6.58 t ha^{-1} for Mv Toborzó, averaged over the years and N treatments. Among the factors examined, the cultivar had the greatest effect on the thousand-kernel weight.
6. The Hunt-Parsons (HP) growth analysis program used second and third degree functions to describe the seasonal dynamics of dry matter accumulation and the leaf area in the various treatments and years. The HP model made it possible to describe the dynamics of winter wheat dry matter production and the increase in the leaf area throughout the growth period. The growth curves chosen using the stepwise method gave an exact reflection of the growth dynamics determined by the basic data.
7. The application of correlation analysis and various types of regression analysis made it possible to perform a thorough analysis of the correlations existing between the yield (yield components) and growth parameters. Among the yield components, partial correlation analysis and regression analysis revealed that the kernel number had the greatest effect on the yield at both the individual plant and plant stand levels.
8. Partial correlation analysis showed that the growth rate parameters (RGR , CGR) were positively correlated with their components (NAR and LAR , and NAR and LAI , respectively). According to regression analysis for two independent variables, 83.6% of the variance in RGR_{mean} was explained by NAR_{mean} and

LAR_{mean} , while 58.8% of the variance in CGR_{max} could be attributed to NAR_{mean} and LAI_{max} .

9. Two-factor regression analysis detected a significant correlation between the yield and the integral parameters (LAD, BMD). LAD and BMD were also positively correlated with each other. Significant correlations were found between the absolute growth rate of the leaf area ($ALGR_{max}$) and the leaf area index (LAI_{max}) and between the absolute growth rate of the dry matter (AGR_{mean}) and the biomass duration (BMD).
10. The 'stepwise and all subsets regression' method of multiple regression analysis showed that the three independent variables with the greatest influence on the yield were the kernel number per spike, the thousand-kernel weight and the RGR_{mean} parameter at the individual plant level, and the kernel number per m^2 , the harvest index (HI) and the LAI_{max} parameter at the plant stand level.

4. CONCLUSIONS AND RECOMMENDATIONS

The effect of N fertilisation on the growth dynamics of wheat cultivars and on the mean and maximum values of growth parameters in various years could be characterised well using the classical and functional methods of growth analysis. In terms of the dynamics of dry matter accumulation and leaf area the greatest differences were observed between the N_0 and N_{80} treatments. Knowledge of the growth dynamics and agronomic responses of individual wheat genotypes will help to avoid the excessive use of N fertilisers and make production more profitable.

The effect of the year could be detected not only in the yield, but also in the dynamics of leaf area and dry matter production, in the maximum and mean values of the growth parameters, and in the yield components. The results proved that higher rates of N fertiliser failed too increase yields in a dry year, while even in a very favourable year maximum yields could be obtained at relatively low N levels. In average or favourable years there may be justification for raising the N fertiliser

dose (up to 160 kg ha⁻¹ in the present experiments), but the application of 240 kg N ha⁻¹ did not lead to a further increase in yield in any of the years.

The diverse maturity dates of the cultivars were clearly reflected in the seasonal dynamics of leaf area and dry matter production and in the dynamics of the growth parameters. The effect of the genotype was also detected in the yield and the thousand-kernel weight.

The use of the Hunt-Parsons (HP) program made it possible to characterise the dynamics of dry matter production and the increase in the leaf area of winter wheat throughout the vegetation period. The growth curves chosen using the stepwise method gave a clear reflection of the growth dynamics determined by the basic data. However, despite the obvious advantages of the HP growth analysis program, it could be concluded from the present results that it is well worth combining the use of the classical and functional methods.

The application of correlation analysis and various types of regression analysis facilitated the detailed analysis of the correlations existing between the yield (yield components) and the growth parameters. In agreement with previously published data, both partial correlation analysis and regression analysis indicated that, among the yield components, the kernel number had the greatest influence on the yield, at both the individual plant and plant stand levels. Based on partial correlation analysis the growth rate parameters (RGR, CGR) were in positive correlation with their components (NAR and LAR, and NAR and LAI, respectively). Two-factor regression analysis demonstrated a significant correlation between the yield and the integral parameters (LAD, BMD), which were also in positive correlation with each other. Correlations were detected between the absolute growth rate of the leaf area (ALGR_{max}) and the leaf area index (LAI_{max}) and between the absolute growth rate of the dry matter (AGR_{mean}) and the biomass duration (BMD). These correlations could help to draw conclusions during the vegetation period on the expected final size of the dry matter and leaf area.

The 'stepwise and all subsets regression' method of multiple regression analysis showed that the yield was influenced to the greatest extent by the kernel number per spike, the thousand-kernel weight and the RGR_{mean} parameter at the individual plant level, and by the kernel number per m^2 , the harvest index (HI) and the LAI_{max} parameter at the plant stand level.

The increase in the world population will necessitate greater supplies of cereals, but climate change is making it increasingly difficult to produce a satisfactory quantity of good quality wheat. If the losses arising due to the uncertainty of the weather are to be reduced, it is extremely important to make a wise choice of cultivars with good adaptation and to optimise the nutrient supplies.

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Scientific papers

First author papers:

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