Netherlands Journal of Agricultural Science 41 (1993) 153-165

Growth, yield and composition of four winter cereals. I. Biomass, grain yield and yield formation

J. ELLEN

Department of Agronomy, Wageningen Agricultural University, Haarweg 333, NL-6709 RZ Wageningen, Netherlands

Received 14 August 1992; accepted 24 February 1993

Abstract

A field experiment with three cultivars of four winter cereals (wheat, rye, triticale and barley), sown at a seed rate for about 320 plants per m^2, was conducted on a fertile clay soil. The nitrogen (N) fertilizer was split-dressed: 120 kg/ha in total for wheat and triticale, and 60 kg/ha for rye and barley. The experiment had a split-plot design in six replications, with species as split factor.The fewest shoots/m^2 were found in triticale (828/m^2), and the most in barley (1477/m^2). The average decrease in number of shoots during shoot/ear development was 51% in wheat, 54% in rye, 49% in triticale and 67% in barley. The rate of crop development was largest in rye and barley; they flowered and matured earlier than wheat and triticale. Rye was the first to attain a closed canopy (leaf area index; LAI>3). This cereal had the least maximum LAI and shortest leaf area duration (LAD). Wheat and triticale stayed green longest. Average specific leaf weight (SLW) was 4.3 mg/cm^2 in wheat and triticale, and 3.7 mg/cm^2 in rye and barley. The growth rate of the grains at the linear stage was fastest in barley (1.89 mg/grain/day) and slowest in rye (0.89 mg/grain/day).

Total above-ground dry matter production was 18 790 kg/ha in wheat, 15 230 kg/ha in rye, 18 300 kg/ha in triticale and 12 460 kg/ha in barley. Grain yields (kg/ha) were 8740 (wheat), 6640 (rye), 8200 (triticale) and 6620 (barley). Cultivar differences in grain yield and in yield components were mostly smaller in wheat and rye than in triticale and barley. The harvest index was highest in barley (53.3%) and lowest in rye (43.7%); in some plant species there were marked differences between cultivars, but in others there were not.

Keywords: winter wheat, winter rye, winter triticale, winter barley, dry matter production, grain production, yield components, leaf area

Introduction

Winter cereals are the most important grain crops in Dutch arable farming. Currently their value lies mostly in their beneficial effect in the crop rotation for reasons of soil sanity and soil fertility. The falling cereal prices since 1983 have reduced their economic importance, so that to grow cereals at a reasonable revenue, the costs of variable production factors have to be limited. This may be achieved by reducing the costs of disease, pest and weed control and fertilization. Reducing nitrogen (N) application increases the use of soil N (Groot & Verberne, 1990; Widdowson et al., 1987) and reduces the risk of lodging, diseases, pests and weeds (Vereijken, 1992). A limited fertilizer application, however, is required to obtain a well-structured crop (Spiertz & De Vos, 1983).

Utilization for food or feed and differences in grain yield, price, and costs of production factors are currently important criteria in the selection of cereal species and cultivar. Soil type and quality also play a role, because the cereal species were distinctly adapted to different soil types.

For a well-founded choice insight is required in yield capacity and variability of the winter cereals, as governed by crop growth, yield formation and allocation of carbohydrates and nutrients in these crops. A field experiment with four winter cereals (wheat, rye, triticale and barley) was therefore conducted on a clay soil in 1985/1986. (The term 'winter' is ommitted in the cereal names in the rest of this article). This paper reports results on biomass, grain yield and yield formation, while a companion paper describes effects of nitrogen and carbohydrate economy (Ellen, 1993).

Methods

The experiment was laid out in a split-split-plot design in three replicates on a fertile clay soil in east Flevoland. The first and second split factors were fungicide and cereal type, respectively. As only limited amounts of fungicides appeared necessary and statistical analyses showed their effect on yield to be negligible, the experiment was treated as a split-plot experiment with cereal type as the only split factor in six replicates. For each cereal type three cultivars were grown (Table 1).

Within each species, yield potential of the cultivars was about similar, according to the Dutch variety list. For wheat, Obelisk (in 1985 a new variety and then not yet on the Dutch variety list), was known as having a moderate baking quality, whereas Arminda and Okapi are mostly used for animal feed. For rye, straw sturdiness was also used as a selection criterion. For triticale, Lasko and Salvo were the only ones on the Dutch variety list; Bolero was made available by the 'Semundo' nursery, Groningen. The selected four-row barley cultivars Hasso and Masto were in 1985 the most productive on the Dutch variety list; Marinka is a new two-row cultivar.

Meteorological conditions

Growing conditions were generally favourable in the 1986 growing season. The winter of 1985/1986 had periods of severe frost, especially in the second half of February. The temperature was below the long-term average until May 20, and subsequently remained above-average until mid-August. Rainy periods occurred from the beginning of March to the end of April and from May 20 until mid-June, but total amounts of rain were limited. June and July were dry. Radiation before May was below the long-term average, in May and later it was higher (Table 2).

Table 1. Crops and cultivars.

Crop	Cultivars
Wheat	Arminda, Obelisk, Okapi
Rye	Admiraal, Animo, Dominant
Triticale	Bolero, Lasko, Salvo
Barley	Hasso, Masto, Marinka

Table 2. Mean monthly diurnal temperature (°C), precipitation (mm) and radiation (MJ/m^2) for 30 years at De Bilt (= DB), in the centre of the Netherlands, and during the whole growing period of the crops in Flevoland (= F).

		Oct.	Nov.	Dec.	Jan.	Febr.	March	April	May	June	July	Aug.
Temperature												
1951-1980	DB	10.3	5.8	3.2	2.0	2.3	4.8	8.0	12.1	15.2	16.6	16.4
1985/1986	F	9.8	2.0	5.3	1.5	−4.5	3.4	5.8	12.9	15.4	16.0	15.0
Precipitation												
1951-1980	DB	67	78	78	67	50	52	52	57	68	81	89
1985/1986	F	25	60	56	71	1	11	52	40	38	30	91
Radiation												
1951-1980	DB	18.0	8.3	5.4	7.1	12.6	25.6	39.2	51.0	53.3	49.1	42.6
1985/1986	F	7.4	7.5	5.0	7.0	16.2	22.0	33.7	55.5	60.5	56.4	46.3

Crop management

The cereals were sown on 3 October 1985 following a potato crop. Distance between rows was 12.5 cm. Seed density differed for each cultivar per species, based on their 1000-grain weight, and was calculated for about 320 plants/m^2. Germination occurred on 18 October 1985. Plot size was 6 × 23 m, net plot size 3 × 20 m.

Superphosphate was applied at a rate of 325 kg per ha. N fertilizer rates (Table 3) were based on soil mineral N in early spring (60 kg/ha on 15 March; 0-100 cm depth). Rye and barley received less N because of a lower demand and their tendency to lodge. The basal N dressing could not be applied before April 17 because of conti-

Table 3. Timing and rate (kg/ha) of nitrogen application.

Date Growth stage (GS)*	17 April 25	28 May 34-40**	Total
Wheat	60	60	120
Rye	40	20	60
Triticale	60	60	120
Barley	40	20	60

* GS: growth stages according to Zadoks et al. (1974).

** GS: wheat = 34; rye = 40; triticale = 35; barley = 38.

nuous rainy weather.

Intermediate and final harvests

Plots (0.25 m^2 per plot) were periodically harvested on 29/4, 13/5, 3/6, 30/6, 29/7 (this was the last harvest for barley) and 12/8. In addition, ears were sampled on 17/6, 23/6 and 8/7. Barley was combine-harvested on 1/8, the other cereals on 14/8 (60 m^2 per plot).

Observations

Survival after winter was calculated from the number of plants counted along a marked line of 6 m on 9 November 1985 and 29 April 1986. At the periodic harvests the plants were cut at soil level. Roots of 10 plants per plot were sampled to a depth of ca. 30 cm. Total fresh weight was recorded and subsamples were taken to determine:

- stage of development
- number of shoots and ear-bearing shoots (culms)
- stem dry weight
- leaf area of green leaves and dry weight of both green and dead leaves
- number and dry weight of ears
- number and dry weight of grains.

Dry weights of the subsamples were determined after drying at 70 °C for 24 hours. Plant parts were pooled per treatment for analysis of N and water-soluble carbohydrates.

Results

Total dry weight and grain yield, harvest index (HI) and yield components

Clear differences among species were observed in total above ground yield, grain yield, harvest index and yield components (Table 4). Differences in N applications may have interfered in the crop and yield characteristics.

Within species, cultivar differences were mostly small. The interaction between species and cultivars was statistically significant. Total dry matter production differed among species and cultivars. Wheat and triticale produced about the same quantity, 18.8 and 18.3 t/ha, respectively, rye 15.2 and barley 12.5 t/ha. Grain yields were highest in wheat (8740 kg/ha) and triticale (8200 kg/ha) followed by rye and barley, 6640 and 6620 kg/ha, respectively. All four species showed inter-cultivar differences (mostly small) in dry matter and grain yield. In triticale the cultivar Bolero produced the lowest grain yield, in barley the cultivar Marinka.

Wheat and triticale hardly differed in harvest index (HI): 46.7 compared to 45.1, respectively, while that in rye (43.7) was significantly lower and in barley (53.4) significantly higher.

The low grain yield of rye was mainly associated with the lower 1000-grain weight, as the other yield components were comparable to those of wheat and triticale. The lower grain yield of barley was mainly associated with lower number of

Table 4. Total yield and grain yield (dm kg/ha), harvest index (g/g × 100) and yield components of three cultivars of four winter cereals (final harvest).

Crop	Cultivar	Total yield (kg/ha)	Grain yield (kg/ha)	Harvest index (×100)	Ear number (per $m^{2)}$	Grain number (per ear)	Grain number (per $m^{2)}$	1000-grain weight (g)
Wheat	Arminda	17940	8750	49.02	520	46.2	23950	36.52
	Obelisk	19050	8740	45.93	474	44.0	20840	41.96
	Okapi	19380	8730	45.05	452	42.0	18930	46.13
	average	18790	8740	46.67	482	44.1	21240	41.54
Rye	Admiraal	15270	6680	43.93	502	42.4	21250	31.43
	Animo	15070	6590	43.77	492	41.9	20530	32.11
	Dominant	15350	6660	43.43	480	42.0	20090	33.23
	average	15230	6640	43.71	491	42.1	20620	32.26
Triticale	Bolero	18480	7780	42.84	336	63.7	21050	36.96
	Lasko	18050	8380	46.43	460	49.5	22670	37.02
	Salvo	18380	8440	45.90	470	39.3	18400	45.87
	average	18300	8200	45.06	422	50.8	20710	39.95
Barley	Hasso	12150	6640	54.60	436	34.6	15040	44.12
	Masto	11770	6690	56.83	419	36.4	15010	44.57
	Marinka	13470	6540	48.61	622	20.6	12770	51.22
	average	12460	6620	53.35	492	30.5	14270	46.64
Significance:	Crop	****	****	****	****	****	****	****
	Cult.	*	**	***	****	****	****	****
	Cr × Cu	NS	****	****	****	****	****	****

(NS = not significant; *=P<0.1; **=P<0.05; ***=P<0.01; ****=P<0.001).

grains per ear and lower ear density. Together, this resulted in a lower number of grains per m^2, partly compensated by a high 1000-grain weight. The differences in yield components among cultivars of one cereal were rather small, the exceptions being Arminda (wheat), Bolero (triticale) and Marinka (barley). Table 4 shows that similar grain yields can be obtained in different ways.

Fig. 1 shows clear differences in canopy structure among the cereals. On 30/6 (Table 5) all species had the largest part of their total above ground biomass stored in the stems, rye highest and barley lowest; in leaves and chaff rye was lowest in both. Barley was most advanced in grain production.

Plant density and number of shoots and culms per m^2

On 9/11/85 plant density per square metre, averaged over the cultivars, was 338 in wheat, 332 in rye, 388 in triticale and 343 in barley. The severe winter of 1985/1986 resulted in losses of 61 (18%), 45 (14%), 150 (39%) and 43 (13%) plants/m^2, respectively. Within the species the losses were highest in Bolero (triticale; 52%), Okapi (wheat; 33%) and Hasso (barley; 20%). There was no difference in response among the rye cultivars.

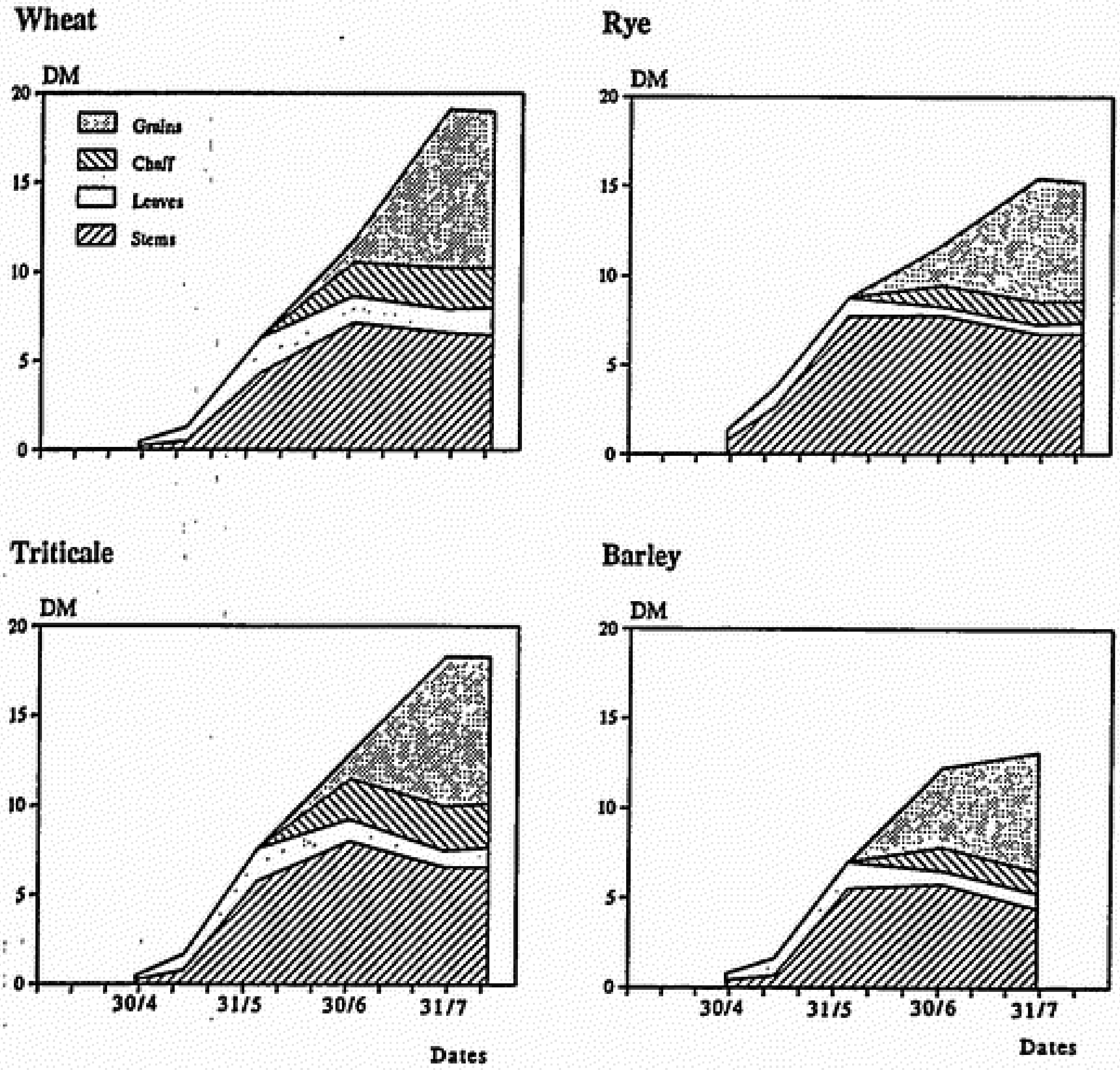

Fig. 1. Dry matter (DM) yield (kg/ha × 10^3) in different plant parts.

On 29/4/86 the number of shoots/m^2 was 981 in wheat, 1059 in rye, 828 in triticale and 1477 in barley. The highest number was observed in barley, cultivar Marinka (1856), the lowest number in triticale, cultivar Bolero (720). The number of ear-bearing shoots/m^2 (Table 4), averaged over the three cultivars, was 482 (49%) in wheat, 491 (46%) in rye, 422 (51%) in triticale and 492 (34%) in barley.

Development and growth of the crops

Growth stages (GS), cumulative temperature (base temperature 0 °C) and cumulative

Table 5. Distribution (percentage) of plant parts on 30 June.

	Stem	Leaf	Chaff	Grain
Wheat	61	13	16	10
Rye	66	5	10	19
Triticale	62	9	18	11
Barley	47	6	11	36

global radiation from sowing till the various sampling dates, and from sowing to final harvest are given in Table 6.

The average development rate (in terms of morphological stages) of the crops differed greatly as can be seen from the differences in growth stages. Rye was earliest in spring and maintained this lead until the end of flowering (GS 69) and it matured somewhat earlier than wheat and triticale. Barley developed fastest during May and June and matured first, followed by rye. Wheat and triticale differed little in maturity date, although from visual observation triticale somewhat later.

Average daily increase in dry matter (kg dm/ha) over the period 9/11/85 to 29/4/86, disregarding the exact dynamics, varied substantially among species with values of 2.6 in wheat, 7.7 in rye, 2.6 in triticale and 4.5 in barley; total above ground values on 29/4 were 444, 1310, 449 and 770 kg dm/ha, respectively.

Crop growth rate during linear growth

Crop growth rates during the linear growth phase per day-degree C, per MJ (total global radiation) and per kg N absorbed over this period, are given in Table 7. Number of days of linear growth were very different, i.e. 90 for rye and 48 for barley. Wheat and triticale did not differ in length and period of linear growth.

Growth rate per day-degree C was highest in wheat (15.7) and lowest in rye (10.8); per MJ wheat produced the highest amount of dry matter (120.3) and rye the lowest (82.8).

Table 6. Growth stage (GS), cumulative temperature (d °C, integrated over time) and cumulative radiation (MJ/m^2) at the various sampling dates.

Crop	Growth stage at sampling dates							
	29/4	13/5	3/6	17/6	25/6	30/6	28/7	14/8
Wheat	29	31	41	59	70	72	85	92
Rye	32	38	59	70	77	80	87	92
Triticale	30	32	47	62	72	73	85	92
Barley	30	32	57	70	78	81	92	–
Temperature sum	668	847	1113	1313	1440	1538	1981	2264
Radiation sum	95.5	118.7	157.8	184.4	201.5	214.8	266.5	294.5

Table 7. Crop growth rate during linear growth (kg/ha), per degree day (d °C), per mega Joule (MJ) and per kg N.

Crop	Period	Accumulated dry matter matter	Sum temp. (d °C)	Sum (MJ)	N yield (kg/ha)	Growth (d °C)	(MJ)	(kg N)
Wheat	13/5-28/7	17 800	1134	148	132	15.7	120.3	134.9
Rye	29/4-28/7	14 150	1313	171	85	10.8	82.8	166.5
Triticale	13/5-28/7	16 600	1134	148	98	14.6	112.2	169.4
Barley	13/5-30/6	10 660	691	96	39	15.4	111.0	273.3

The largest variation was observed in growth per unit of N taken up, with values for wheat and barley of 135 and 273, respectively.

Leaf area index (LAI), leaf area duration (LAD), culm length and length of flag leaf internode

Average leaf area indices (LAI, leaves only) per species are given in Fig. 2. On 29/4 and 13/5 LAI of rye was highest, followed by that for barley, triticale and wheat, which showed a linear increase until 3/6. Subsequently, LAI declined in all crops. This decline was sharpest in rye, followed by barley, triticale and wheat (from 29/7

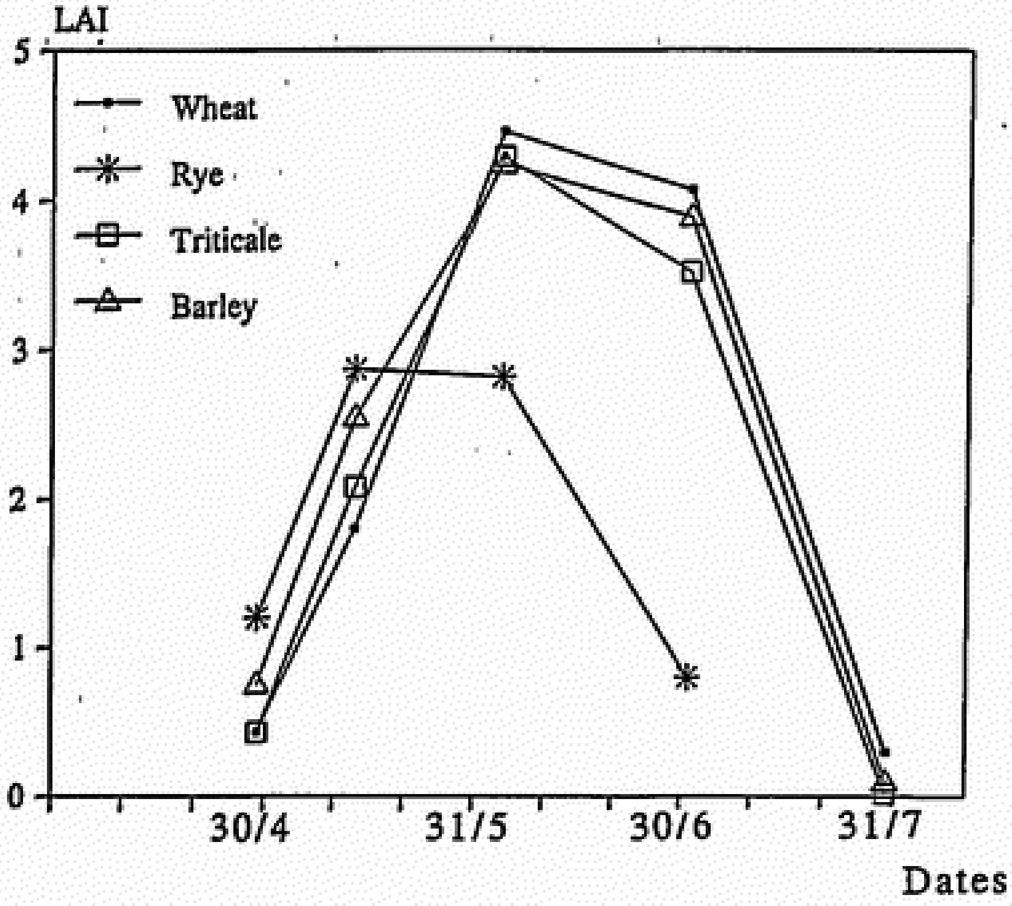

Fig. 2. Leaf area index (LAI) over time.

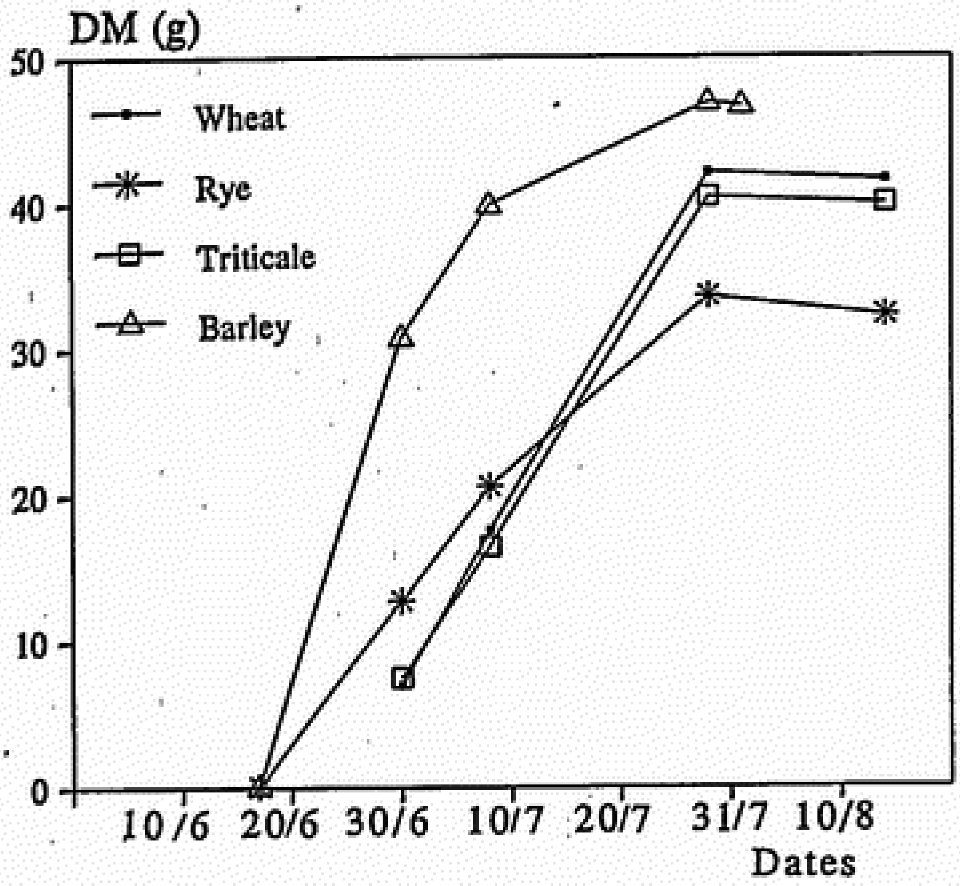

Fig. 3. Thousand grain weight (TGW); dm (g).

neither rye or barley had any green leaves).

Total LAD, expressed in m^2/m^2 weeks after 29/4, was lowest for rye (18.5) and was attained at the beginning of July; in barley (29.7) it was attained around mid-July and in wheat (31.5) and triticale (30.5) at the end of July. Average length of culms on 28/7, measured from soil level to the base of the ear, was 75 cm in wheat, 120 cm in rye, 95 cm in triticale and 80 cm in barley. The length of the flag leaf internode, leaf sheath included, was 30 cm in wheat, 45 cm in rye, 40 cm in triticale and 35 cm in barley.

Specific leaf weight (SLW)

Until July, SLW varied only among species ($P<0.01$); among cultivars no statistically significant differences were found. On 3/6 at average growth stage (GS) 41 in wheat, 59 in rye, 47 in triticale and 57 in barley, SLW was 4.4, 3.7, 4.3 and 3.6 mg/cm^2, respectively. From 30/6 onwards, SLW values were no longer comparable because of the leaf senescence in rye (Fig. 2).

Grain development and grain growth

Grain development was observed in rye and barley first on 17/6; in wheat and triticale on 24/6. The number of days from initiation until maximum grain dry weight was 45 in rye, 48 in barley and 35 in wheat and triticale. Fig. 3 shows cumulative grain dry weight. The linear growth rate was highest in barley: 1.89 mg dm/grain/d (period 17/6 to 8/7); it was 0.89 in rye (20/6 to 18/7; 18/7 as estimated date) and 1.21 and 1.14 in wheat and triticale, respectively (30/6 to 28/7).

Discussion

The results clearly show differences in total biomass and grain yield among the four cereals (Fig. 1). Different N application rates probably played an important role in the differences in production of biomass, grain yield and in yield characteristics. Averaged values sometimes masks the differences among varieties.

Grain yields of wheat were similar for all varieties, with differences in yield components. Arminda produced more ears per m^2 and more grains per ear than Obelisk and Okapi. The latter two compensated the lower grain density by higher grain weights. Harvest indices varied among cultivars, as earlier found by Ellen (1990) for Arminda and Okapi.

The low weight per grain in rye may be due to grain characteristic (Ford et al., 1984), the early senescence of leaves (Fig. 2), and the low LAD-value. The early senescence of leaves implies that only the stems contributed assimilates to grain filling. Harvest index was negatively correlated with plant height, as earlier found by Austin et al. (1980) in wheat, by Ford et al. (1984) in rye and by Riggs et al. (1981) in barley.

Among cultivars of triticale, grain yield of Bolero was lower than that of the other two cultivars Lasko and Salvo; mainly as a result of a lower ear density and lower grain weight, resulting in a lower harvest-index. The low number of ears per m^2 (28% less than Lasko and Salvo) was compensated by a substancially higher number of grains per ear, whereas Salvo compensated a low grain number per ear by a high grain weight.

Barley produced the lowest biomass; but through its higher harvest-index, it resulted in the same grain yield as rye. The number of ears produced, both for the two-row and the four-row barley crops was low (Riggs et al., 1980; Scot & Hines, 1991), probably due to late N application (Table 3), owing to unfavourable weather conditions. Nitrogen nutrition is probably more important to shoot survival in barley (barley with 24% more dying shoots) than in other species, which in turn gives more ears per m^2. Two-row cultivars should have more ears per m^2 (modern types about 800) than four- row ones (about 500), but their grain number per ear is much lower (Table 4). Compensation for grain yield in the two-row cultivar was found in a higher grain weight. Results from Riggs et al. (1981), showed not only differences among cultivars in 1000-grain weight, but also in number of ears per m^2.

On 29/4, rye was most advanced in development, but by June barley had caught up and both flowered at the same time. Earliness of the double ridge stage is clearly correlated with earliness of flowering. However, the rate of grain filling is independent of flowering date. Flowering in rye and barley was complete at a temperature sum of 1313 d °C, triticale at an estimated sum of 1380 (because triticale was somewhat more advanced in development on 25/6 than wheat), and wheat at 1440 (Table 6).

Growth rates were similar in wheat and triticale, contrary to the observation of

Ford et al. (1984), showing higher growth rates for triticale during winter and earlier flowering.

Ear differentiation in rye and barley is earlier than in wheat (Nicholls, 1974). Depending on sowing date, ear differentiation in rye may even occur before the onset of frost (Van Dobben, 1962). Scot & Hines (1991) observed that winter barley reached this stage one week before triticale, but spikelet differentiation started about one week later.

Grain filling first started in rye and barley, followed by wheat and triticale. Growth rate and duration of the period with linear growth varied markedly among species (Fig. 3). The duration of linear grain growth was shorter in barley (21 days) than in the other species (28 days), but its increase in grain weight per grain per day was much higher. In terms of grain production it was, on average, for wheat, rye, triticale and barley 317, 247, 297 and 272 kg/ha, respectively. Grain yield is related to grain density, but is also dependent on grain weight. This is clear within (wheat, triticale and barley) and among species (rye versus barley).

The effect of temperature, expressed in d °C, on growth rate during linear growth of the crops varied between species (Table 7). Optimum temperatures within species (and varieties) are not always similar, because cycle length differed. This implies that growth rate per d °C varies among species.

The response to radiation, leaf area was important as shown in rye versus wheat (Fig. 2; Table 7). However, differences in light intensity with a similar leaf area resulted in different crop production in spring barley (Ellen & Van Oene, 1989a). In connection with N, difference in SLW resulted not in obstruction for crop production during linear growth (wheat, triticale versus rye, barley (Table 7)).

N-use efficiency, expressed in dry matter production per unit N taken up during the relevant period, varied among species; it was lowest in wheat and highest in barley. In spring barley in a phytotron, Ellen & Van Oene (1989b) found a high N use efficiency at limited N application and, compared to natural conditions, low light intensity. In the current experiment light level was high (Table 2), and weather conditions optimal for crop growth. This resulted in a high N use efficiency for all crops, especially for barley. N use efficiency in rye, triticale and barley was respectively 23, 25 and 102 % higher than for wheat. For total crop growth uptake of N, especially before this periods, is important.

Leaf area index (LAI) and leaf area duration (LAD) of rye were much lower (60%) than those of the other species. This may be attributed to the faster development rate of rye. This crop was first to start tillering and to attain a closed canopy (LAI >3; Fig.2). After 3/6 LAI decreased and was already very low on 30/6 (LAI = 0.8; Fig. 2). Low N availability accelerated leaf senescence. The photosynthetic capacity of these leaves was lost early. Rawson & Bagga (1979) suggest that availability of carbohydrates influences initiation and development of plant organs. The period for leaf formation is short in rye and barley. Young ears are organs with a high metabolic rate and compete with leaves for carbohydrates (Ellen, 1990; Ellen & Van Oene 1989a). Carbohydrates are partitioned in proportion to the demand, and therefore rye, receiving only a limited carbohydrate supply, remain small. Highest demand as derived from grain density is about the same in rye and wheat (Table 4).

More leaf growth in rye and hence a longer leaf area duration would enhance grain filling in this crop. Genetically, shortening the stems could result in a harvest index, as found by Austin et al. (1980) in wheat. In wheat, for instance, introduction of this trait reduced lodging (Cox et al., 1988; Spiertz & De Vos, 1983) and as a consequence resulted in considerably higher grain yields. Results from Riggs et al. (1981) with spring barley, indicate that the number of grains per m^2 (on average) increased from 13 600 (period 1880-1965) to 16 400 per m^2 (1966-1980) (= 17 %), an increase in HI with 15 % and a decrease in straw length with 20 %. In addition to straw length, N application and crop protection are important causes.

Barley attained a similar LAI to wheat and triticale (Fig. 2), but lost its green leaf area rapidly after 30/6, as a consequence of the lower N dressing, leading to faster N depletion of the leaves and accelerated senescence. The estimated decrease in LAI was 0.096 $m^2/m^2/d$ (from 3/6 to 18/7) in barley, 0.061 (from 3/6 to 30/6) in rye and 0.078 (from 3/6 to 28/7) in wheat and triticale. In oats, Ellen (1991) found a decrease in LAI of 0.046 to 0.077 $m^2/m^2/d$, depending on N application.

Results reported by Asana & Mani (1955) show that the flag leaf internode can contribute considerably to photosynthesis, because it is exposed to light from all sides. The flag leaf internode in this experiment stayed green until about 10 days before harvest in all cereals, except triticale, where it lasted until 7 days before harvest. Rye had a longer flag leaf internode than the other cereals. Hence, its contribution to photosynthesis is more important than in the other cereals.

Specific leaf weight (SLW) was higher in wheat and triticale than in rye and barley. In an experiment with six winter wheat cultivars, Herzog (1980) measured similar SLW values to those for wheat and triticale in this experiment. Ellen & Van Oene (1989a) observed differences in SLW as a result of differences in light intensities in spring barley. Criswell & Shibles (1971) observed differences in SLW in oats between cultivars and also between years. They found positive correlations between SLW and photosynthesis, which were expressed in grain yields. Groot & Spiertz (1989) demonstrated the positive effects of N content on photosynthetic rate. In this experiment the correlation between SLW and N was not high, 0.40 for wheat and triticale and 0.42 for rye and barley ($n=16$; $P<0.05$ for both). These values correspond to values found for oats (Ellen, 1991).

The results of this experiment show that:

- with relative small N applications under favourable weather conditions for growth, high crop and grain yields can be achieved;
- similar grain yields within species can be obtained in different ways;
- growth stages and growth rates differ between species;
- green area of leaves (and stems) and duration are important for crop and grain growth.

Acknowledgments

The author wishes to thank Dr J.H.J. Spiertz and Professor P.C. Struik for their valuable comments on this manuscript, and Mr. H.J. van Hartingsveldt and Mr. C. van der Meer, who collected the data for their MSc theses.

References

Asana, R.D. & V.S. Mani, 1955. Studies in physiological analyses of yield. II. Further observations on varietal differences in photosynthesis in the leaf, stem and ear of wheat. *Physiologia Plantarum* 8: 7-19.

Austin, R.B., J. Bingham, R.D. Blackwell, L.T. Evans, M.A. Ford, C.L. Morgan & M. Taylor, 1980. Genitic improvements in winter wheat yields since 1900 and associated physiological changes. *Journal of Agricultural Science (Cambridge)* 94: 675-689.

Cox, T.S., J.P. Shroyer, Liu Ben-Hui, R.G. Sears & T.J. Martin, 1988. Genetic improvement in agronomic traits of hard red winter wheat cultivars from 1919 to 1987. *Crop Science* 28: 756-760.

Criswell, J.G. & R.M. Shibles, 1971. Physiological basis for genotypic variation in net photosynthesis of oat leaves. Crop Science 11: 550-553.

Ellen, J., 1993. Growth, yield and composition of four winter cereals. II. Nitrogen and carbohydrate economics. *Netherlands Journal of Agricultural Science* 41: in press.

Ellen, J., 1991. Effects of sowing rate and nitrogen fertilization on growth and yield of oats (*Avena sativa* L). Mededeling No. 101. Department of Field Crops and Grassland Science, Wageningen Agricultural University, Wageningen. (In Dutch, with English summary), p. 1-39.

Ellen, J., 1990. Effects of nitrogen and plant density on growth, yield and chemical composition of two winter wheat (*Triticum aestivum* L.) cultivars. *Journal of Agronomy and Crop Science* 164: 174-183.

Ellen, J. & H. van Oene, 1989a. Effects of light intensity on yield components, carbohydrate economy and cell-wall constituents in spring barley (*Hordeum distichum* L.). *Netherlands Journal of Agricultural Science* 37: 83-95.

Ellen, J. & H. van Oene, 1989b. Effects of light intensity on nitrogen economy of spring barley (*Hordeum distichum* L.). *Netherlands Journal of Agricultural Science* 37: 205-211.

Ford, M.A., R.B. Austin, R.S. Gregory & C.L. Morgan, 1984. A comparison of the grain and biomass of winter wheat, rye and triticale. *Journal of Agricultural Science (Cambridge)* 103: 395-403.

Groot, J.J.R. & J.H.J. Spiertz, 1989. Photosynthesis and nitrogen translocation in cereals during grain filling and implications for crop yield. Proceedings International Congress of Plant Physiology, New Delhi, p. 1027-1034.

Groot, J.J.R. & E.L.J. Verberne, 1990. Long-term effects of reduced nitrogen fertilization on soil fertility and crop yield. (In Dutch, with English summary). *Meststoffen* 1/2: 14-19.

Herzog, H., 1980. Source and sink relationship during grain filling in six winter wheat varieties. (In German). *Zeitschrift für Acker- und Pflanzenbau* 149: 472-487.

Nicholls, P.B., 1974. Inter-relationship between meristematic regions of inflorescences of four cereal species. *Annals of Botany* 38: 827-837.

Rawson, H.M. & A.K. Bagga, 1979. Influence of temperature between floral initiation and flag leaf emergence on grain number in wheat. *Australian Journal of Plant Physiology* 6: 391-400.

Riggs, T.J., P.R. Hanson, N.D. Start, D.M. Miles, C.L. Morgan & M.A. Ford, 1981. Comparison of spring barley varieties grown in England and Wales between 1880 and 1980. *Journal of Agricultural Science (Cambridge)* 97: 599-610.

Scott, W.R. & S.E. Hines, 1991. Effects of grazing on grain yield of winter barley and triticale: the position of the apical dome relative to the soil surface. *New Zealand Journal of Agricultural Research* 34: 177-184.

Spiertz, J.H.J. & N.M. de Vos, 1983. Agronomical and physiological aspects of the role of nitrogen in yield formation of cereals. *Plant and Soil* 75: 379-391.

Van Dobben, W.H., 1962. Ear differentiation, photoperiodical induction in winter rye and the direct influence of day-length on the shooting process. Jaarboek I.B.S. p. 69-76.

Vereijken, P., 1992. A methodic way to more sustainable farming systems. *Netherlands Journal of Agricultural Science* 40: 209-223.

Widdowson, F.V., A. Penny, R.J. Darby, E. Bird & M.V. Hewitt, 1987. Amounts of NO_3-N and NH_4-N in soil, from autumn to spring, under winter wheat and their relationship to soil type, sowing date, previous crop and N uptake at Rothamsted, Woburn and Saxmundham, 1979-85. *Journal of Agricultural Science (Cambridge)* 108: 73-95.

Zadoks, J.C., T.T. Chang & C.F. Konzak, 1974. A decimal code for growth stages of cereals. *Weed Research* 14: 415-421.