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The characteristics of spring cereals in changing weather in Estonia

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Abstract. The objective of this investigation was finding out the impact of weather on yield, length of growing period, plant height, lodging resistance and protein content of spring cereals over 19 years (1991–2009). Two varieties per each crop were selected for testing. Historical weather and crop yield data from the Jõgeva Plant Breeding Institute were analyzed by the linear correlation analysis. To estimate the variation of grain yield, the minimum and maximum values, averages and coefficients of variation were calculated.

It can be stated that the both stress conditions – drought and excess precipitation caused decrease of yield and quality of all the crops. The highest yields developed in 180–250 mm precipitation range from sowing to maturity. Oat requires more moisture than wheat and barley. Significant positive correlation between the amount of precipitation and oat yield was found when three years of severe lodging were eliminated. Positive correlation between yield and plant height was found. In the years of severe lodging there was remarkable yield decrease of oat. Yield of oat and barley had negative correlation with sunshine hours in June. The same correlation for wheat was not significant. Extra-low protein content for all the cereals, especially for wheat, formed in a cool year with the lowest sum of sunshine hours during the whole growing period (2009). For oat and barley positive correlation between sunshine hours in June and protein content was found. For formation of higher protein content, warm and dry weather conditions are required. Protein content was inversely associated with yield.

Key words: spring wheat, barley, oat, precipitation, temperature, yield, quality

INTRODUCTION

In fluctuating weather conditions variation of yield and other characteristics may increase. Heavy rains and drought periods influence yield, quality and the length of growing period. In selecting crops and varieties for a particular climatic environment a farmer or a breeder must make a choice between high yield potential or stability of yield. Under ideal growing conditions certain varieties produce high yields, but they may be sensitive to stress conditions. Since crops are grown under varying environmental conditions, the ability to adapt quickly to stress is important (Fox & Rosielle 1982; Gusta & Chen, 1987). The response of a plant to a stress depends on its genetic potential to adapt, the duration of exposure, and stage of growth (Gusta & Chen, 1987).

Water deficits affect every aspect of plant growth from germination to seed set and final yield. Water stress at certain stages of growth is more injurious than at other stages. In cereals, the critical period is usually just before reproductive organ formation and right after pollination (Kramer, 1980; Forsberg & Reeves, 1995; Araus, 2002; Kutchera et al., 2010).

Ensuring the stability of crop varieties across years is a critical breeding goal when dealing with the uncertainty of climate change. Many researchers believe that higher temperature, drought and rainfall excess caused by climate change will depress on crop yield in the nearest future (Márton, 2005; Watts, 2005; Márton et al., 2007; Tammets, 2007; Márton, 2008a; 2008b). There are several agricultural investigations focused on understanding the relation between mean climate change and crop production (Karing et al., 1999; Rosenzweig & Iglesias, 2003; Márton, 2005; Watts, 2005).

The extent and yield of agriculture in high latitude regions is largely determined by thermal parameters (Carter, 1996). Estonia belongs to the Atlantic continental region of the temperate zone. Summers are moderately warm. The climate is humid because precipitation exceeds evapotranspiration. Nevertheless, there are often droughts during the summer period. A drought is a complex phenomenon that is difficult to describe accurately. In this paper, we focus only on the agricultural drought. The uncertainty about weather conditions is one of the key risk factors associated with crop production. In the last years, extreme dry as well as extreme wet periods have occurred in Estonia (Tammets, 2007).

The objective of this investigation was finding out the impact of weather on yield, length of growing period, plant height, lodging resistance and protein content of spring cereals over 19 years.

MATERIALS AND METHODS

In this paper the effect of weather on yield and quality characteristics was evaluated from several experiments in Estonia during the years of 1991–2009. The field trials were conducted at the Jõgeva Plant Breeding Institute, on soddy-podzolic soil. Fertilizer level $N_{70}P_{16}K_{29}$ was used for oat and $N_{90}P_{20}K_{38}$ for barley and wheat. Chemical control of weeds was carried out every year and insects were controlled only in the years of severe attacks. Seeding rate of 500 (barley) and 600 (wheat, oat) germinating seeds per m² was used. The plot size was 10 m² in 3 replicates. The trials were organised by randomised complete block design. Three different cereal crops were included – spring wheat, barley and oats. Two varieties per each crop – the Estonian barley varieties Anni, Elo, the oat varieties Villu and Jaak and the foreign varieties Satu (Sweden) and Munk (Germany) were selected.

Data collected included: yield, plant height, the incidence of lodging (1–9 points scale where 1 – severe lodging, 9 – no lodging), protein content, the days from sowing to heading, from heading to maturity.

Weather data for this experiment – precipitation and sum of effective temperatures (over +5°C) for these growth phases, and the sum of sunshine hours by months from May to August were available from the meteorological station of the Jõgeva Plant Breeding Institute (Fig. 1, 2). The years with exceptionally low total rainfall were 1992, 1999, 2002 and 2006. In 2007 there was an early drought before heading when especially wheat and oat were sensitive. The exceptionally high rainfall was in 1998. The years of higher than average rainfall (>300 mm) were also in 1991, 2000, 2001, 2003, 2004 but its distribution during the vegetation period was different.

The experiment years were characterized by frequent extremes of weather. Six years had an over rainfall and four years had drought. Nine years had closer to average rainfall that was more evenly distribution during the growth. The unfavorable effects of weather anomalies (drought, over-abundance of water) on yield and quality were registered.

Historical weather and crop yield data from the Jõgeva Plant Breeding Institute were analyzed with linear correlation analysis. Data were analyzed by factorial analysis of variance using the Agrobase II statistics software. To estimate the variation of grain yield, the minimum and maximum values, averages (*avg*) and coefficients of variation (*CV*) were calculated.

RESULTS AND DISCUSSION

The actual final yield and quality of a crop is determined by many factors: weather, crop variety, fertiliser supply, soil conditions, occurrence of pests and diseases. When the crop is sufficiently supplied with nutrients, yield and quality variation depends mostly on weather conditions. In our investigation all the spring crops reacted somewhat differently to weather conditions.

The increase of the annual number of extreme wet and dry days together indicates to the rising trend of the extreme precipitation events in Estonia in 1957–2006 (Tammets, 2007). In July 2006, the precipitation was only about 22% of the average level, which caused big harm to crops; the heavy precipitation in summer 2004 caused flooding in the fields of many districts all over Estonia (Tammets, 2007). A recent wave of higher than average temperature was experienced throughout Central Europe during 2000, 2001 and 2003 (Trnka et al., 2007). In Estonia we experienced during 2000–2003 the highest sum of effective temperatures within the tested 19 years. It was found by Karing et al., (1999) that the degree-days above 0 and 5°C have had a noticeably positive trend (about 1 degree-day per year) for almost 2 centuries in Estonia, and from this follows an important conclusion that heat accumulation has increased in early spring in the Estonian area. During our trial period we have also noticed the shift to earlier sowing time. High values of precipitation in Estonia are mainly of two different kinds. Firstly, heavy rainfall lasting for a few hours and secondly, multi-day wet spells, which are connected with the cyclones bringing heavy precipitation (Scientific Handbook…, 1990).

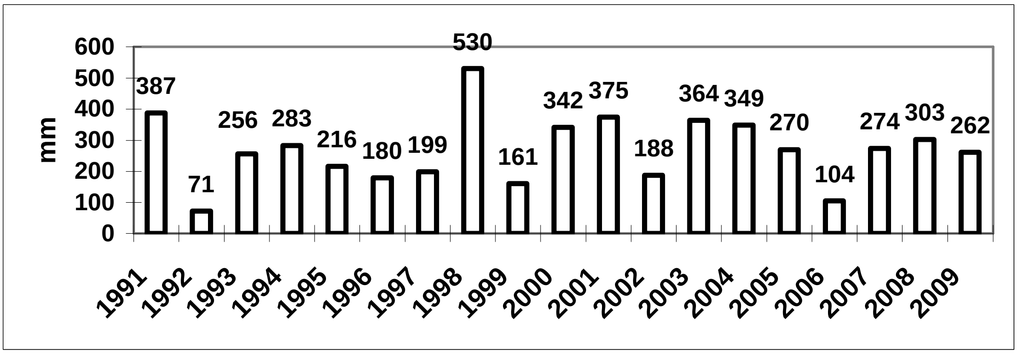

Figure 1. Precipitation of the growing period of spring cereals in 1991–2009.

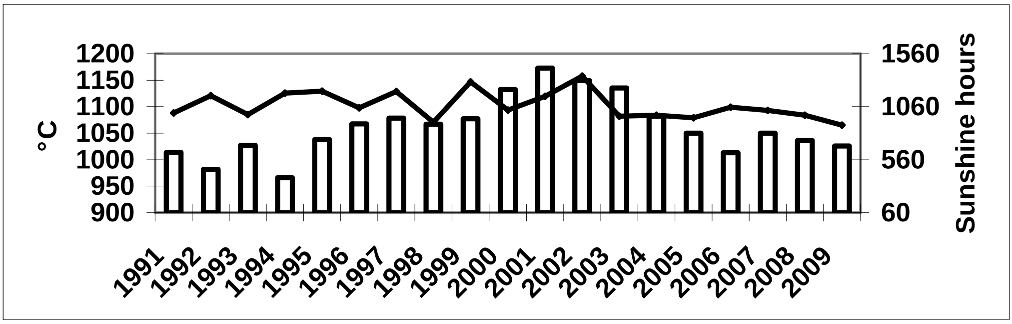

Figure 2. Sum of effective temperatures (> +5°C) and sunshine hours of growing period in 1991–2009.

Yield. The unfavorable effects of weather anomalies (drought, over-abundance of water) on the yield formation, quantity and quality depended on the time of vegetation when they were experienced and the period for which they lasted.

Variation in yield was high during the years (Fig. 3). Yield variation depended mostly on the year (52%) (Table 1) but crop x year interaction was also important (27%). Crop had minor influence to the yield variation (12%). The yields differed over three times for oat and barley and over two times for wheat (Table 2). The years of high yield capacity for all the spring cereals were 1993, 1995, 1996, 1997 and 2000. Higher yield was produced mostly in the years without extremely low or high amount of precipitation.

All the crops are sensitive to drought for any significant period especially at stem elongation, heading and flowering when the leaves are exposed to high temperatures, photosynthesis slows down and plant respiration increases (Forsberg & Reeves, 1995; Araus, 2002; Kutchera et al., 2010). The result is a loss of yield. The yields of all the crops in our trials were low in the years of drought (1992, 1999, 2006) and in early drought in June (2007). In Czech Republic only extremely dry seasons lead to a significant reduction of the spring barley yields. Forty years (1961–2000) data showed the tendency for more intensive droughts at the majority of the analyzed stations (Trnka, 2007).

The biggest yield loss for oat occurred when there was severe lodging or serious drought. Therefore the yield of oat was the most unstable (*CV* = 29%). The yields of barley and wheat varied less (*CV* = 22%). Oat was the most sensitive to the lack of water from sowing to heading. Oat requires more moisture to produce a given unit of dry matter than any other cereal except rice (Forsberg & Reeves, 1995). Significant positive correlation between the amount of precipitation and oat yield was found when the years of severe lodging (1998, 2001 and 2003) were eliminated: from sowing to heading (R = 0.73**), two weeks before heading (R = 0.52*) and the whole period from sowing to maturity (R = 0.55*). The same relationship between rainfall quantity during the vegetation period and yield was also found in Canada (Kutchera, 2010). Scientists from Czech Republic found that the seasonal water balance (April–June) significantly influences the spring barley production. Coefficients of correlation varied in individual districts from 0.19 to 0.70 (Trnka et al., 2007).

The yield of oat and barley had negative correlation with sunshine hours in June (oat R = –0.60**, barley R = –0.58*). The same correlation for wheat was not significant. Unsuitable for formation of high yield were also the years of excess precipitation (1998 especially for wheat and oat), 2003 and 2001 (oat and barley). All mentioned years moderate to severe lodging was estimated. Yield drop in Hungary (Márton, 2008b) in the very wet year was 43%, in our trial period 22% drop for oat and wheat was estimated in 1998.

High yield of all the crops formed in the years of moderate precipitation and temperature (1993, 1997). All the cereals reached the yield maximum in these years exceeding 7 t ha^{-1}. In the most unfavourable years the yields of oat and barley were close to 2,5 t ha^{-1} and wheat 3,3 t ha^{-1}.

Although the spring crops reacted somewhat differently still there were found significant positive correlations between the grain yields of the three crops over the years 0,65**–0,75** (Table 3).

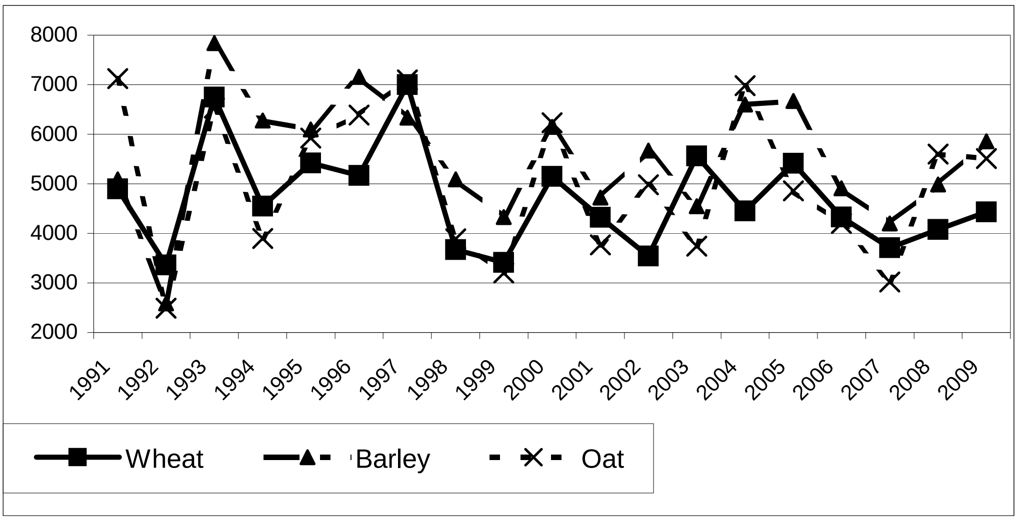

Figure 3. The average grain yield of spring cereals in 1991–2009.

Lodging. It has been estimated that lodging can reduce yields up to 40% depending on its severity and time of occurrence (Fischer & Quail, 1990). Weather conditions explained 38% of the variation of lodging and co-effect of year x crop was 37%. All the crops lodged in unfavourable years, mainly the years of excess precipitation or heavy thunderstorms. Negative correlation between lodging and the amount of precipitation from sowing to heading was found (R = –0.54* wheat, R = –0.53* oat, R = –0.51* barley). Moderate lodging (6–7 points) had no considerable effect to yield of all the crops. As average of the years oat lodged the most. In two years (1998, 2003) out of 19, oat had severe lodging (1.7 and 2.2 points respectively). No lodging of barley and wheat over 5 points occurred. Despite the considerable differences in the lodging of the crops during the years there were positive correlations between the lodging of all the cereals (R = 0.52*–0.60**).

Plant height. From environmental conditions plant height foremost is affected by nutrients, water, temperature and sunshine (Coffman & Frey, 1961). Drought conditions, especially early drought, decreased plant height. In our trials there was positive correlation between plant height and grain yield (R = 0.67** wheat, R = 0.62** oat, R = 0.43* barley). But when plant height increases the situation may change, as longer plants are more prone to lodging. Plant height was the most depending on the weather of the year (43%) and crop (38%). The oat plants had the highest straw length. The difference between maximum and minimum plant height for oat was 67 cm, barley 41 cm and wheat 35 cm. Plant height of oat varied the most (CV = 20%). There was similar reaction of plant height of all the cereals to weather conditions. Strong positive correlation between the crops was found (R = 0.83***–0.88***). Plants grew taller in the years of higher precipitation and less sunshine hours. Positive correlations between amounts of precipitation from sowing to heading were found (R = 0.48* wheat, R = 0.82*** barley, R = 0.66** oat).

Growing period from sowing to heading. There was similar length of the period from sowing to heading of all the cereals (59–60 days) (Table 4). In the drought years the period was 51–52 days and in cooler and more rainy years it extended up to 65–68 days. Strong positive correlation between the crops was found (R = 0.84***–0.93***). This period was mainly depending on the weather of the year (77%). Sunny weather in June decreased the period from sowing to heading. There was negative correlation between the length of this period and sunshine hours in June for all the cereals (R = –0.58* wheat, R = –0.60* oat, R = –0.73*** barley).

Growing period from heading to maturity. This period of wheat was longer than that of barley and oat (respectively 46, 36 and 39 days). It extended in cooler and rainier years. The longest period from heading to maturity of all the cereals was in 2008 (53–60 days) exceeding the crops average by 11–21 days. Difference in length of the period from heading to maturity in maximum was even more than 3–4 weeks. Compared to the period from sowing to heading, it varied more – CV = 13% for wheat, 17% for barley, and even 22% for oat. This period was depending not only on the weather of the year (51%) but also on the crop (25%).

Growing period from sowing to maturity. Spring wheat had the longest period from sowing to maturity in most of the years. The spring crops length of growing period differed in maximum of 28–40 days. Cool and wet weather increased the length of total growing period. There was positive correlation between the length of the whole growing period and the sum of precipitation from sowing to maturity (R = 0.49* wheat, *R* = 0.46* oat, *R* = 0.40* barley). The shortest growing period was in the years of drought. This period depended on the weather of the year (61%) but also from the crop (21%). The length of growing period varied similarly. The correlation coefficients of this trait between the crops were high (*R* = 0.76***–0.90***).

Protein content. The variation of protein content was depending from weather of the year (39%), crop (35%) and their co-effect (12%). The protein was higher in the dryer years when the yield was lower (1992, 1999, 2002, 2006 and 2007 – early drought). Protein content was inversely associated with yield (*R* = –0.45* wheat and oat, *R* = –0.46* barley). Positive correlation between sunshine hours in June and protein content (oat *R* = 0.54*, barley *R* = 0.59*) was found. Average protein content of wheat was over 2% higher than that of barley and oat. Variation coefficients of the crops were similar (10–12%). Exceptionally low protein content, especially for wheat, was measured in 2009. This was a cool year and the number of accumulated sunshine hours during the whole growing period was the lowest in the tested 19 years. The crops reacted to the weather conditions by rather similar pattern. There were positive correlations between the crops (*R* = 0.65*–0.67**).

Table 1. The share of factors in the total variation %.

				Growing time			
Source of the variation	Grain yield	Lodging resistance	Plant height	Sowing to heading	Heading to maturity	Sowing to maturity	Protein content
Year	52	38	43	77	51	61	39
Crop	12	5	38	1	25	21	35
Crop by year	27	37	11	15	11	15	12
Variety	1	1	2	3	ns	1	5
Total	93	80	84	96	87	98	91

Table 2. Variation of yield, lodging, plant height and protein content of spring cereals during 1991–2009.

	Grain yield kg ha^{-1}			Lodging resistance, 1–9 points			Plant height Cm			Protein content %		
	Wheat	Barley	Oat	Wheat	Barley	Oat	Wheat	Barley	Oat	Wheat	Barley	Oat
Avg	4,695	5,533	5,009	8.2	8.4	7.6	87	69	98	14.2	12.0	11.6
Min	3,360	2,590	2,490	5.8	5.8	1.7	64	44	60	10.6	9.5	9.3
Max	7,000	7,840	7,100	9.0	9.0	9.0	99	85	127	16.7	14.5	14.3
CV	22	22	29	11	12	31	13	17	20	11	10	12

Table 3. The correlation coefficients (*R*) between the characteristics of spring cereals during 1991–2009.

				Growing period			
	Grain yield	Lodging resistance	Plant height	Sowing to heading	Heading to Maturity	Sowing to maturity	Protein content
Wheat/barley	0.67**	0.54**	0.86***	0.84***	0.68**	0.76***	0.65**
Wheat/oat	0.65**	0.60**	0.88***	0.93***	0.89***	0.87***	0.67**
Barley/oat	0.75**	0.52*	0.83***	0.89***	0.74***	0.90***	0.65**

* significance at $p< 0.05$; ** significance at $p<0.01$; *** significance at $p<0.001$; ns – non-significant

Table 4. The variation of growing period of spring cereals during 1991–2009.

	Sowing to heading, days			Heading to maturity, days			Sowing to maturity, days		
	Wheat	Barley	Oat	Wheat	Barley	Oat	Wheat	Barley	Oat
Avg	60	59	60	46	35	39	106	94	99
Min	52	51	52	34	28	28	90	83	80
Max	66	68	65	57	53	60	118	113	120
CV	7	7	6	13	17	22	7	8	11

CONCLUSIONS

Long-term experiments are ideal for evaluating the complex influences of weather to yield and other characteristics. It can be stated that biological yield potential is important but in the analysed test period the weather in Estonia was quite fluctuating, influencing both – the yield and agronomic potential. The both stress conditions – drought and excess precipitation caused decrease of yield and quality of all the crops. The highest yields formed in 180–250 mm precipitation range from sowing to maturity. Above and below this range of rainfall yields mostly decreased. Yield of oat and barley had negative correlation with sunshine hours in June (oat R = –0.6**, barley R = –0.58*). The same correlation for wheat was not significant.

In the years, when weather conditions were not favorable for straw growth, yields tended to be lower. In our data series was found positive correlation between yield and plant height. But when plant height increases the situation may change, as longer plants are more prone to lodging. In the years of severe lodging there was remarkable yield decrease of oat.

The lowest protein content was formed in cool year with the lowest sum of sunshine hours during the whole growing period (2009). Therefore can be concluded that for formation of higher protein content warmer and dryer weather conditions are required. Protein content was inversely associated with yield (R = –0.45* wheat and oat, R = –0.46* barley). Positive correlation between sunshine hours in June and protein content (oat R = 0.54*, barley R = 0.59*) was found.

Summing up our findings can be concluded that the more the frequency of weather extremes increase, the more there appear variation in yield and other characteristics and the more adaptation ability in the current location is of major importance. One of the most important impacts of climate change in Estonia is the increase of extreme wet and extreme dry periods and challenge is the prolonging of the total growing season. As different spring crops reacted somewhat differently to weather conditions, cultivation of various crops can erase risks. Thus, farmers must take into consideration the changeability of climate to optimize their crop and variety selection and management in the nearest future.

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