JOURNAL OF AGRICULTURAL SCIENCE IN FINLAND
Maataloustieteellinen Aikakauskirja
Vol. 62: 227—236, 1990

The effect of climatic factors on production of spring wheat quantity to quality ratio in southern Finland

JARI PELTONEN*, TUOMO KARVONEN* and ERKKI KIVI**

* *University of Helsinki, Department of Crop Husbandry, Viikki, SF-00710 Helsinki, Finland*
** *Hankkija Plant Breeding Institute, SF-04300 Hyrylä, Finland*

Abstract. Interrelationships between climatic factors and spring wheat yield and quality were examined with 21 years field experiments. The formation of gluten was less at dry conditions (total precipitation under 50 mm) and total precipitation exceeded 130—140 mm. The optimum daily temperature for gluten production was some 15—17°C during grain filling. The gluten content decreased if daily minimum and maximum temperatures exceeded 11—12°C and 21—22°C, respectively. The effect of temperature and rainfall were not, however, significant in early maturing varieties. The climatic factors and grain yield did not correlate. Grain yield and protein yield had strong positive relationship, which was perhaps a consequence of supply and utilization of nitrogen. It is concluded that climatic factors affecting yield to quality ration in wheat may be excessive rains before heading and high temperature during grain filling. Interaction between weather and nitrogen are discussed to optimize correct timing of nitrogen fertilization for amount and quality of economic wheat yield.

Index words: Spring wheat, climatic factors, grain yield, protein content

Introduction

The wheat processing industry needs high quality wheat for milling. The flour mills in Finland have, however, limited access to imported high quality wheat to compensate crop of poor technological quality. There was little annual variation in protein content of wheat grain before 1974 (Suomela et al. 1977), however since 1974 there has been a decrease in the protein content. An explanation for this could be increased cultivation of late high-yielding wheat varieties. However, the effect of the choice of wheat variety on the decrease in protein content was only 0.5—0.6 % and does not alone explain the declining trend in protein amount (Juuti 1985).

Another factor causing the decrease in protein content may be weather conditions during the growing season. Excessive rains in June has been observed to decrease grain protein content (Rekunen and Juuti, unpublished data), however, according to KONTTURI (1979) sufficient rainfall and high radiation during early summer seemed to increase protein content. This may be attributed to better uptake of nitrogen by wheat (KAILA and ELONEN 1970). Rain during harvesting activates enzymes that split starch and proteins, but the protein quality only decreases when sprouting of the ear is advanced (LALLUKKA 1971).

The effect of climatic factors on the yield of wheat has been studied by many researchers in 1960—1970's (e.g. LIPSETT 1963, ASANA and WILLIAMS 1965, STOY 1966, CAMPBELL and READ 1968, LALLUKKA 1971, PETERS et al. 1971, BREMNER 1972, HORHIKAWA ref. EVANS et al. 1975, KONTTURI 1979), but the role of weather in the yield quantity quality ratio in spring wheat has not yet been carried out under northern growing conditions. The object of the present study was to evaluate the role of climatic factors in the relationship between wheat quantity and quality.

Material and methods

Test material

The study period covered the years from 1968 to 1988. The material was cultivated at Tammisto 1968—72 and Anttila 1973—88, at experimental farms of Hankkija Plant Breeding Institute. Both are located in Southern Finland, some 20 km apart, at latitudes 60° 16′ N, and 60° 25′ N, respectively. Test varieties used were; 'Ulla' and 'Heta' with growing time less than 100 days; and late cultivars 'Ruso', 'Kadett', 'Drabant', and 'Tähti' — which need over 100 days to ripe. 'Ulla' and 'Heta' are characterized as low yielding varieties with high protein content, while 'Drabant' and 'Kadett' are cultivars of high yield potential, but low protein content — lower than the average for wheat varieties of Finnish origin (MUSTONEN et al. 1987). Data of the spring wheat varieties in official trials are given in Table 1. The soil type was predominantly sandy clay. Fertilization was applied according to analysis of soil nutrient status: 50 kg N/ha in 1968, 60 kg N/ha in 1969, 90 kg N/ha in 1970, and during 1971—1988 the standard nitrogen application was 110 kg N per hectare. Plot-based observations were made for the days to heading, at growth stage (GS) 54 (ZADOKS et al. 1974) and days to yellow ripeness (GS 85). The plots were considered to be fully ripened (GS 91) 5—7 days after the yellow ripeness. This was dependent on daily temperature after yellow maturation. Grain yield and thousand grain weight were measured from harvested yield. The protein content was determined by using the common Kjeldahl procedure and multiplied by nitrogen conversion factor of 5.7. From 1983 Near Infrared Reflectance (NIR) analyser was used to measuring the protein content. Wet gluten content was used to estimate the quantity of storage protein. Measured grain yield and quality are given in Table 2.

Table 1. Data of spring wheat varieties in the results of official trials in Finland 1979—1986 (MUSTONEN et al. 1987).

	Variety					
	Ruso	Ulla	Heta	Tähti	Drabant	Kadett
Breeder	Hja	Hja	Hja	Jo	WW	WW
Year of release	1967	1975	1988	1972	1972	1981
Days to ripeness	102	98	99	109	108	106
Grain yield (kg/ha)	3768	3403	3693	3559	3931	4068
1000 grain weight (g)	37.2	35.2	34.0	34.3	35.2	36.6
Protein (%)	14.0	15.9	15.9	14.7	13.2	13.4

Hja = Hankkija Plant Breeding Institute, Finland
Jo = Plant Breeding Institute of the Agricultural Research Centre, Jokioinen, Finland
WW = Weibullsholm Plant Breeding Institute, Sweden

Table 2. Data of grain yield, protein content, and wet gluten amount in examined wheat varieties in study period 1968—88.

Year		Variety					
		Ruso	Tähti	Ulla	Drabant	Heta	Kadett
1968	a	5450	5360				
	b	15.8	17.8				
1969	a	4950	4670				
	b	13.8	14.6				
1970	a	2700	2250	2180			
	b	17.8	17.9	19.6			
1971	a	4350	4900	4300			
	b	14.1	16.2	16.0			
1972	a	5180	5010	4280			
	b	11.2	11.6	13.5			
1973	a	3520	3680	3340			
	b	15.3	16.4	18.2			
1974	a	5630	6250	4800	6760		
	b	17.5	17.4	18.3	15.2		
1975	a	3380	4380	3990	4890		
	b	13.8	15.9	16.3	14.4		
1976	a	5180	5260	6000	6620		
	b	*	*	*	*		
1977	a	2550	2910	3350	2510	3570	4630
	b	11.8	13.4	13.2	12.1	14.6	12.6
1978	a	4450	3960	4500	4910	4220	5610
	b	12.8	12.0	15.0	11.5	15.0	12.0
1979	a	2530	2450	3380	3070	3560	5000
	b	9.5	10.3	12.1	10.5	10.1	11.6
1980	a	4180	4450	4950	5330	4820	5170
	b	10.7	10.6	11.0	10.2	14.2	10.3
1981	a	2630	1910	2430	2230	2900	2770
	b	10.5	11.1	11.1	9.5	11.6	8.8
	c	19.0	22.5	23.2	19.8	27.8	17.9
1982	a	3570	4760	4420	5330	4250	4880
	b	14.3	15.3	15.4	13.2	14.8	13.3
	c	35.9	37.0	35.6	29.5	38.7	29.1
1983	a	4550	3660	4510	4640	4100	5550
	b	11.9	14.3	12.1	11.0	13.5	11.9
	c	25.3	34.4	25.3	22.8	34.3	26.2
1984	a	4460	3740	3920	4640	4070	4870
	b	11.3	12.7	12.7	10.0	12.1	10.6
	c	27.8	27.2	25.1	23.0	30.7	22.3
1985	a	3530	4110	3040	4340	3270	4060
	b	14.3	12.7	14.5	12.4	15.4	12.7
	c	34.4	31.8	34.7	30.0	44.3	39.8
1986	a	3520	3250	2800	3590	3460	3670
	b	10.8	11.2	13.5	11.0	11.9	10.2
	c	23.4	31.4	34.8	30.8	36.3	27.5
1987	a	3380	2460	3470	*	3690	3640
	b	11.0	10.7	11.8	*	11.2	9.0
	c	0.0	0.0	24.7	*	27.9	0.0
1988	a	2960	2910	2500	3380	2740	3420
	b	10.1	10.8	13.0	9.7	12.3	9.7
	c	19.7	22.4	28.7	21.2	27.5	20.3

a = grain yield (kg/ha), b = protein %, c = wet gluten %
* = result not determined

Table 3. The climatic data of air temperature, precipitation, global radiation, and the lenght of growing period in 1968—1988.

Year	Mean air temp. (°C)		Precipit. sum (mm)		Mean glob. rad. (MJ m^{-2})		Lenght of period (d)	
	SH	HR	SH	HR	SH	HR	SH	HR
1968	12.0	14.9	115	129	19.1	15.8	65	51
1969	12.7	16.3	93	37	20.7	21.8	60	45
1970	14.1	15.9	59	128	22.4	17.2	56	45
1971	13.2	17.2	39	45	21.1	20.1	56	45
1972	14.4	19.6	75	94	21.5	21.4	57	35
1973	15.5	19.4	62	47	22.9	20.7	53	34
1974	12.5	15.2	81	144	20.0	14.4	65	57
1975	13.5	18.3	54	27	21.5	20.6	59	40
1976	13.3	14.7	119	120	19.7	15.2	60	54
1977	12.8	14.5	152	101	17.3	14.0	76	43
1978	14.4	14.9	63	122	21.9	15.9	52	55
1979	15.8	15.8	123	105	22.4	15.5	57	46
1980	14.3	16.8	246	107	19.3	17.1	54	47
1981	14.8	15.3	151	172	19.3	12.4	57	48
1982	12.6	16.8	93	115	19.9	17.8	64	46
1983	13.6	18.4	110	39	18.8	21.2	60	41
1984	15.2	15.5	98	107	20.4	16.4	51	53
1985	14.1	16.2	81	153	19.0	13.9	53	52
1986	14.9	17.3	59	98	21.2	19.1	51	41
1987	13.5	11.5	149	215	19.1	10.8	58	70
1988	16.5	19.4	44	89	22.1	18.8	49	33

SH = period between sowing and heading
HR = period from heading to yellow ripening

Data of climatic factors

The basic daily climatic data for each year and locality was obtained from the Finnish Meteorological Institute. The following climatic factors were used; mean, maximum, and minimum daily air temperature (°C), precipitation (mm d^{-1}), and daily global radiation (MJ m^{-2}), measured at the Helsinki-Vantaa Airport, located between Tam.misto and Anttila experimental farms. Data given in table 3.

The statistical analysis was carried out using regression analysis in order to clarify significance of individual climatic factor on proportion of grain yield, grain size and protein properties.

Results and Discussion

Individual climatic factors explained poorly the variation in grain yield per hectare and grain weight. The coefficient of determinations (R^2) between climatic factors and both grain yield and grain weight ranged 0.01—0.25, and 0.02—0.27, respectively (Table 4). Grain yield is the end-result of interaction of climatic factors and several plant characteristics (Miedema 1984). Thus any individual factor does not necessarily explain such a complex system as yield.

The coefficient of determination (R^2) between protein yield per hectare and minimum air temperature after sowing was 0.53 for early maturing varieties, and 0.51 for late maturing varieties, respectively. The lower the minimum air temperature was, the higher was the protein yield per hectare (Fig. 1).

Nitrogen absorption from the soil depends on soil moisture content (e.g. Kaila and Elonen 1970, 1971, Elonen et al. 1975). According to figure 2a, it seemed that excessive rains before heading caused leaching of nitrogen which was followed the decrease in gluten con-

Table 4. Coefficient of determination (R^2) in climatic data versus grain yield, thousand grain weight, protein content, protein yield, and wet gluten content in study period 1968—88.

	Grain yield (kg/ha)	1000 grain weight (g)	Protein content (%)	Protein yield (kg/ha)	Wet gluten (%)
Average air temperature (°C)					
SH e	0.20	0.17	0.14	0.31	0.11
l	0.20	0.17	0.32	0.38	0.02
HR e	0.05	0.17	0.05	0.05	0.13
l	0.06	0.11	0.08	0.08	0.76
Average min. air temperature (°C)					
SH e	0.19	0.27	0.44	0.53	0.20
l	0.25	0.24	0.50	0.51	0.05
HR e	0.21	0.20	0.07	0.19	0.14
l	0.06	0.11	0.08	0.08	0.72
Average max. air temperature (°C)					
SH e	0.14	0.05	0.08	0.21	0.09
l	0.14	0.08	0.20	0.28	0.00
HR e	0.04	0.18	0.07	0.06	0.16
l	0.07	0.10	0.06	0.08	0.79
Precipitation sum (mm)					
SH e	0.10	0.05	0.28	0.04	0.42
l	0.01	0.17	0.12	0.07	0.54
HR e	0.08	0.03	0.05	0.12	0.13
l	0.06	0.04	0.06	0.04	0.55
Average global radiation (MJ m^{-2})					
SH e	0.10	0.02	0.04	0.07	0.02
l	0.13	0.10	0.02	0.10	0.02
HR e	0.03	0.08	0.09	0.10	0.13
l	0.09	0.10	0.06	0.05	0.54

SH = period between sowing and heading
HR = period from heading to yellow ripening
e = early maturing varieties, l = late maturing varieties

tent. When total precipitation exceeded 130—140 mm, the gluten content decreased to below 25 %, and thus below that regular from bread wheat quality (Salovaara 1983). The heavy rains during grain filling contributes the decrease in wet gluten amount, too (Fig. 2b). Rain fall under 50 mm before heading may cause the same type decrease in wet gluten content (Fig. 2a). The reason for this was perhaps that in dry soils the uptake of nitrogen was decreased (Kaila and Elonen 1971).

The mean daily temperature during grain filling was below 20°C for the whole study period (Table 3). The optimum daily mean temperature for gluten formation appeared to be some 15—17°C in all wheat varieties (Fig. 3). The wet gluten amount decreased if daily minimum and maximum temperatures exceeded 11—12°C and 21—22°C, respectively (data not shown). Temperatures exceeding 25—30°C have been found to cause decreases in grain yield and grain size (e.g. Asana and Williams 1965, Peters et al. 1971 and Hoshikawa ref. Evans et al. 1975). According to Lawlor et al. (1988), the high temperature decreases protein synthesis more

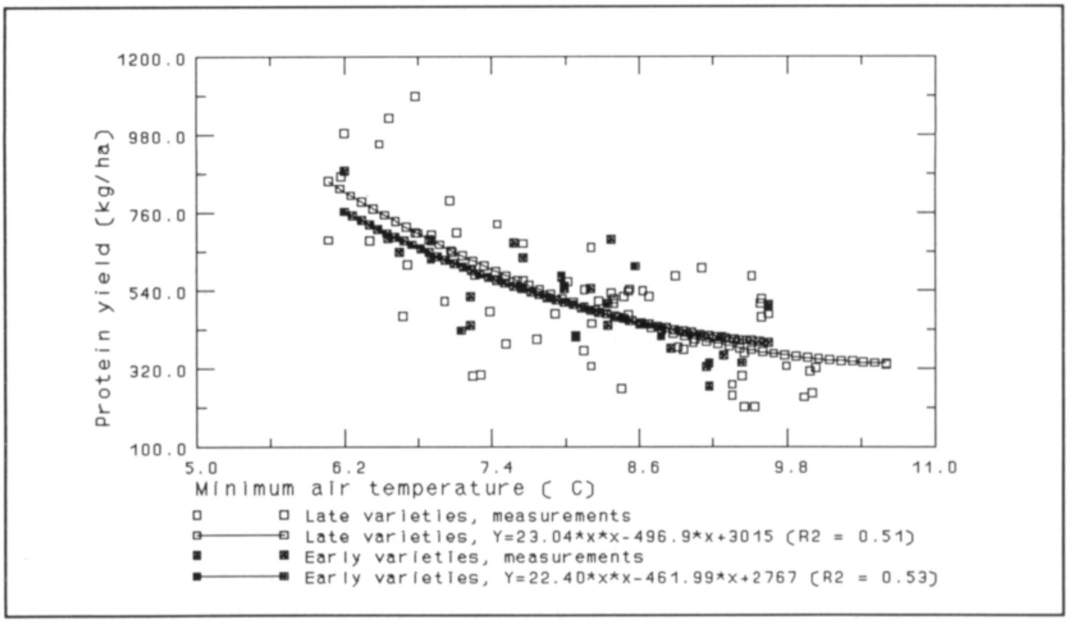

Fig. 1. The effect of minimum air temperature on protein yield from sowing to heading.

than it decreases carbon assimilation. It is concluded that high temperature during grain filling affects quantity to quality ratio in wheat.

The effect of temperature and precipitation on formation of wet gluten content was not significant in early maturing varieties 'Ulla' and 'Heta' (cf. Figs. 2 and 3), perhaps due to their better ability to utilize nitrogen effeciently and an advantageous weather during grain

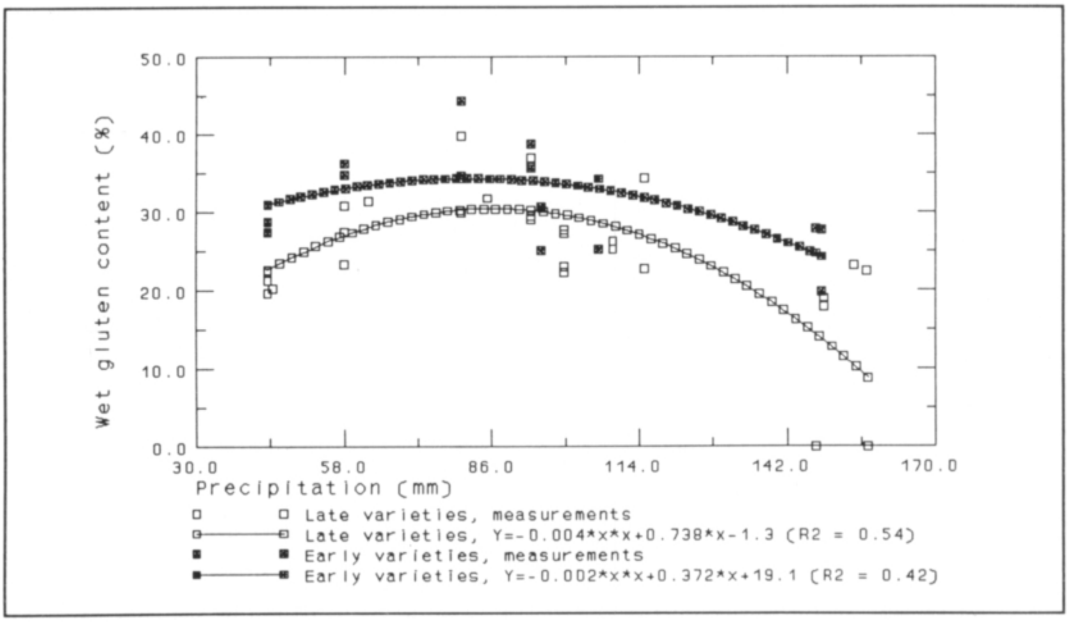

Fig. 2a. The effect of precipitation on wet gluten content from sowing to heading.

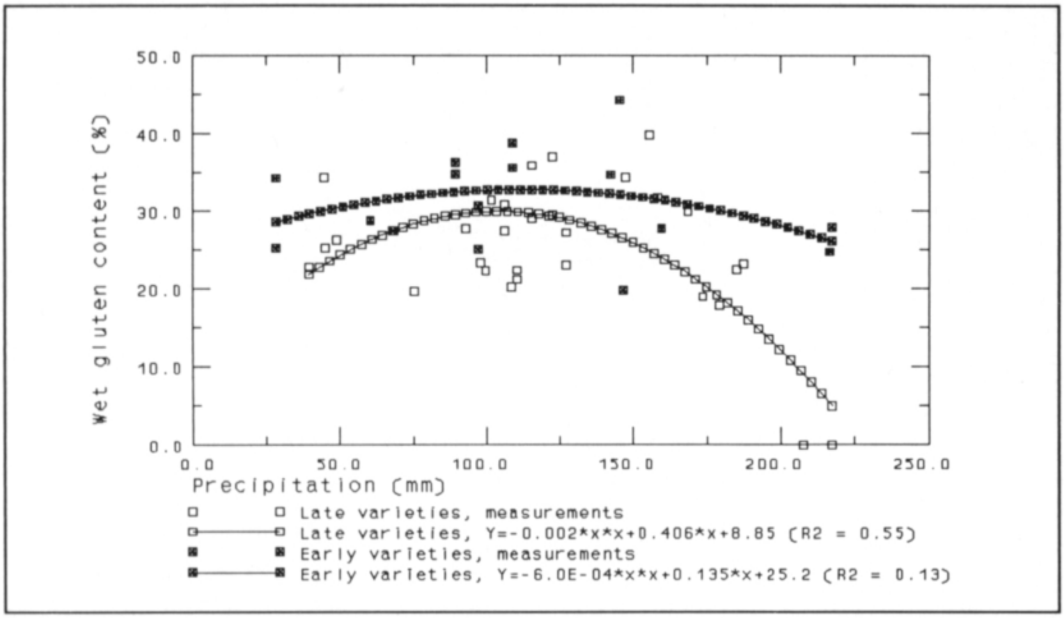

Fig. 2b. The effect of precipitation on wet gluten content from heading to ripening.

filling. Conversely, the late cultivars ('Ruso', 'Kadett', 'Drabant', 'Tähti') were more susceptible to lose their quality in unfavourable growing conditions (cf. data at Table 2, e.g. year 1987).

It has been suggested that grain yield and amount of protein in grain have a negative phenotypic relationship in Finnish cultivation conditions (e.g. KONTTURI 1979). This type of relationship was not, however, observed in

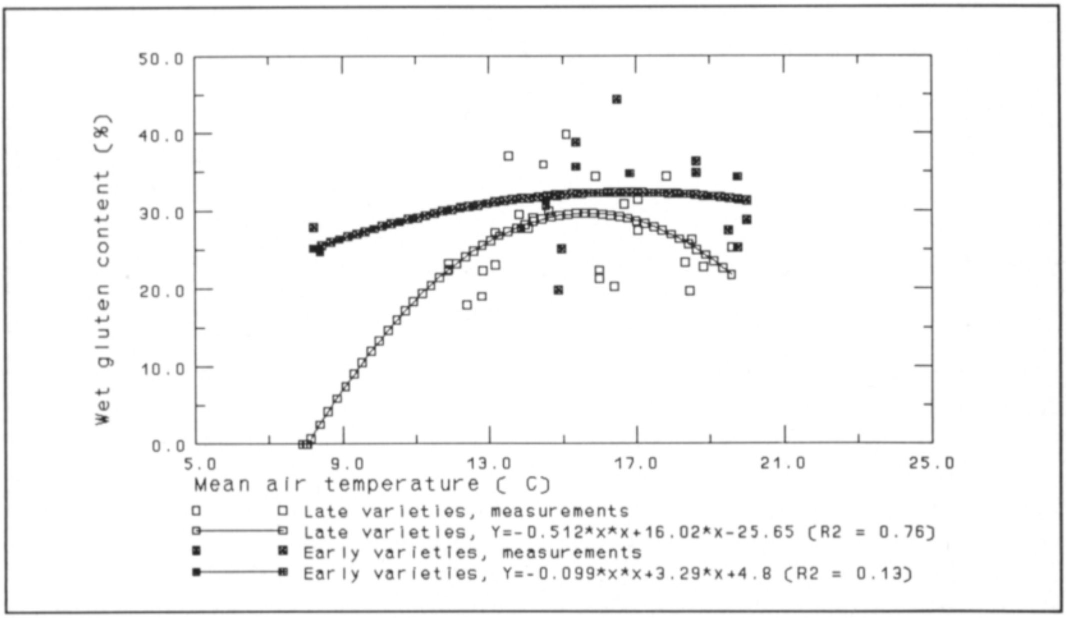

Fig. 3. The effect of mean air temperature on wet gluten content from heading to ripening.

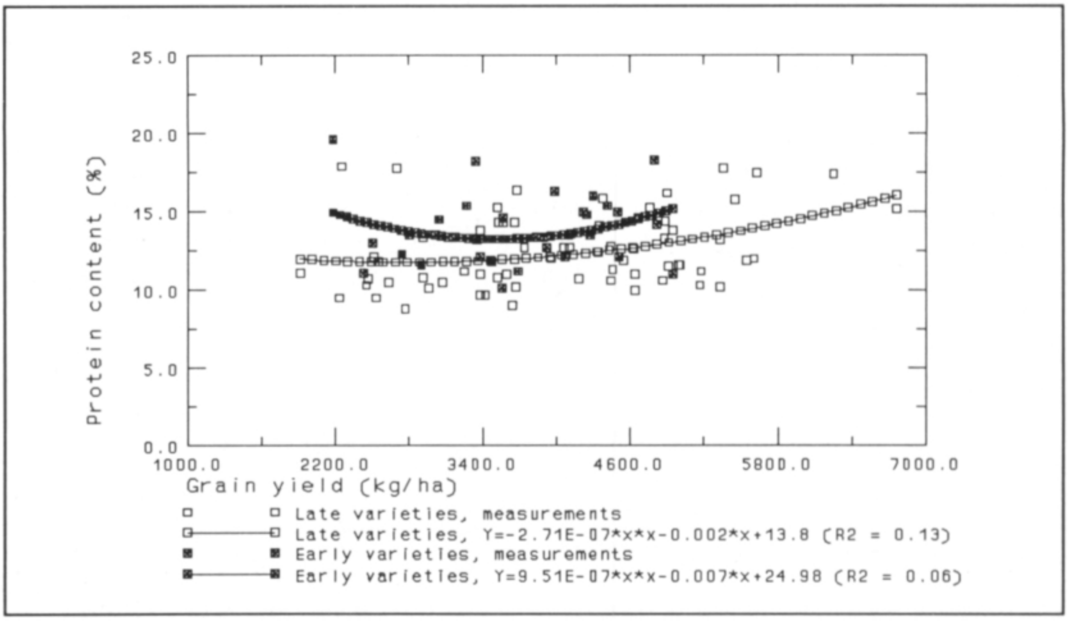

Fig. 4a. Relationship between grain yield and protein content of spring wheat.

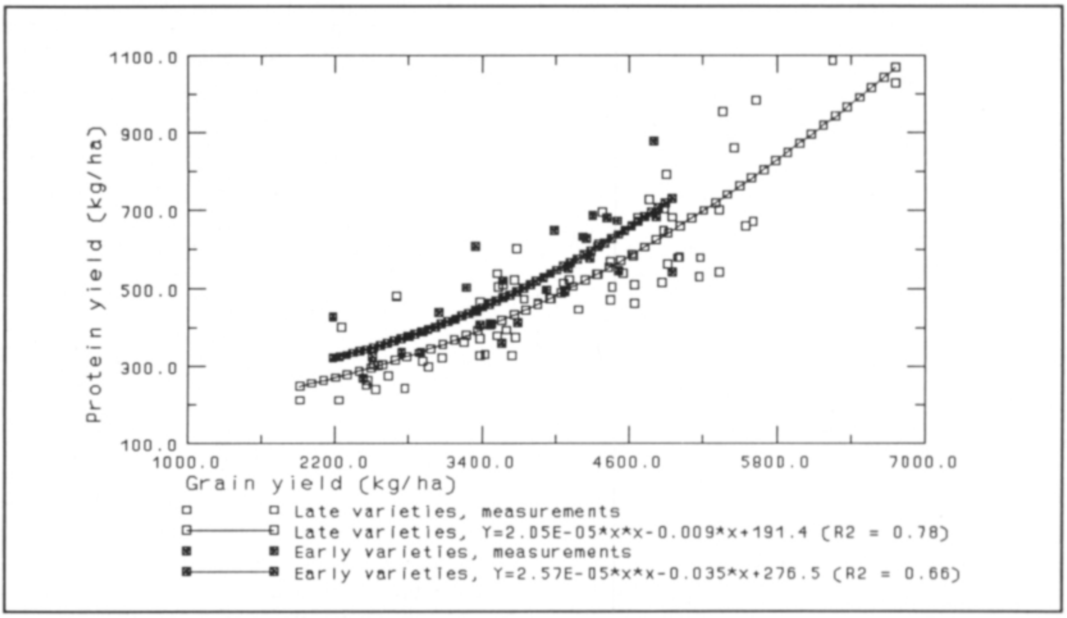

Fig. 4b. Relationship between grain yield and protein yield of spring wheat.

our examination (Fig. 4a). The present study showed that there was a strong positive correlation between grain yield and protein yield (Fig. 4b). According to KRAMER (1979), within a wheat genotype the correlation between grain yield and grain protein content can be either close to zero, positive, or negative, depending on the level of fertilization. But between genotypes the correlation is strongly negative. It has also been suggested that grain protein content can be used as an indicator to evaluate if nitrogen fertilization was sufficient (Goos et al. 1982 and Goos 1984). Perhaps, supply and utilization of nitrogen by wheat are the main factors changing quantity and quality proportion in wheat and the utilization of nitrogen is dependent of weather e.g. precipitation. However, more detailed experimental data is required to understand: the interaction between weather, nitrogen supply and quantity and quality of wheat yield. This would lead to a more efficient use of nitrogen in agricultural systems to optimize correct timing of nitrogen supply for amount and quality of economic wheat yield in Finland.

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Ms received March 26, 1990

SELOSTUS

Säätekijöiden vaikutus kevätvehnän jyväsadon ja valkuaisen muodostumiseen

Jari Peltonen,* Tuomo Karvonen* ja Erkki Kivi**

* *Helsingin yliopisto, Kasvinviljelytieteen laitos, Viikki, 00710 Helsinki*

** *Hankkijan kasvinjalostuslaitos, 04300 Hyrylä*

Tutkimuksessa tarkastellaan, 21 vuoden mittaisen jakson perusteella, säätekijöiden vaikutusta kevätvehnän jyväsadon ja valkuaisen määrän muodostumiseen. Tutkimusaineistona olivat kevätvehnät: Ulla, Heta, Ruso, Kadett, Drabant sekä Tähti peruslannoitetuissa kenttäkokeissa.

Yksittäiset säätekijät eivät selittäneet jyväsadon muodostusta. Kostean sitkon muodostusta kuitenkin rajoitti alkukesän kuivuus (sade alle 50 mm) tai liiallinen yli 130—140 mm sade, jonka seurauksena vehnän typenotto heikkeni. Yli 15—17°C keskilämpötila jyvän täyttymisjaksolla aiheutti vehnäsadon alhaisen sitkopitoisuuden. Säätekijät eivät kuitenkaan vaikuttaneet voimakkaasti aikaisin tuleentuviin lajikkeisiin. Kevätvehnän jyväsadon sekä valkuaissadon välillä oli voimakas positiivinen korrelaatio, mikä osoitti ilmeistä lisätyppilannoituksen tarvetta sellaisina kasvukausina, jolloin säätekijät vaikeuttavat peruslannoituksen hyväksikäyttöä.