Principal morphological and agronomic characteristics of some durum wheat varieties in central Italy influenced by meteorological anomalies

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Abstract: *In a climatic change scenario, plant phenological adaptation, and the variability of reproductive structure development during anthesis, represents a primary trait for surviving to particular growing conditions reducing the negative effects of anomalous environmental conditions. The objective of this study was to determine the effect of the principal climatic variables on winter durum wheat phenology and to assess the constraints associated with these environmental factors on annual yield in an area characterized by flooding problems. Moreover, the investigation provided useful information about the phenological adaptation, morphological and productive characteristics of durum wheat cultivars testing at the same time their suitability to specific agroclimatic conditions in a central Italy area (Rieti plain), where several durum wheat cultivars were evaluated during 11 years of investigations from 2006 to 2016.The correlation and regression analyses evidenced as some biological parameters related to durum wheat vegetative and reproductive developments were in accordance with particular climatic phenomena confirming as the developmental phases length optimization may favour the wheat adaptation to climatic anomalies. Really, both the plant height and above all the number of spikes/m² resulted highly related with the phenological phases length considering their link with the same plant morphology. Moreover, yield appeared greatly related with the number of spikes/m² and so with the plant tillering rate while the exclusion of flooding years in the Rieti plain showed the kernel weight as the variable more important to determine the final yield not considering in this database the plant tillering problem.*
Keywords: *Climate, durum wheat varieties, morphology, phenology, yield.*

Riassunto: *L'adattamento fenologico delle piante e soprattutto la variabilità dello sviluppo della struttura riproduttiva all'antesi rappresenta un tratto primario per sopravvivere a particolari condizioni di crescita riducendo gli effetti negativi di condizioni ambientali anomale, in uno scenario di cambiamento climatico.Obiettivo della ricerca è quello di determinare l'effetto delle principali variabili climatiche sulla fenologia del grano duro in primavera e di valutare i vincoli associati a questi fattori ambientali sulla resa annuale in un'area caratterizzata da problemi di allagamento. Inoltre, l'indagine ha fornito informazioni utili su adattamento fenologico, caratteristiche morfologiche e produttive delle cultivar di grano duro testando contemporaneamente la loro idoneità a specifiche condizioni agroclimatiche in una zona dell'Italia centrale (piana di Rieti), dove sono state valutate diverse cultivar di grano durante 11 anni di indagini dal 2006 al 2016.Le analisi di correlazione e regressione hanno evidenziato la sensitività di alcuni parametri biologici come il tasso di sviluppo vegetativo e riproduttivo in relazione a particolari fenomeni ambientali. Ciò conferma che l'ottimizzazione della lunghezza delle fasi di sviluppo può favorire l'adattamento del frumento alle anomalie climatiche. In realtà, sia l'altezza della pianta che, soprattutto, il numero di spighe/m² risultavano fortemente correlati con la lunghezza delle fasi fenologiche considerando il loro legame con la stessa morfologia vegetale. Inoltre, la resa è risultata molto correlata al numero di spighe/m² e quindi al tasso di accrescimento delle piante. L'esclusione dall'analisi degli anni caratterizzati da elevate intensità di pioggia che hanno determinato l'allagamento della piana Reatina, ha mostrato come il peso delle cariossidi sia la variabile più importante per determinare la resa finale, in assenza di tali eventi estremi.*
Parole chiave: *Clima, varietà di frumento duro, morfologia, fenologia, resa.*

1. INTRODUCTION

Grain yield in wheat is determined mainly by environmental factors, particularly under Mediterranean conditions. A study that tested 191 durum wheat accessions in nine Mediterranean environments reported that the percentage of yield variability explained by the environment was 98 %, with mean daily maximum temperature from emergence to heading accounting for 59 % of yield variations (Royo *et al.*, 2010).

The uncertainty associated with weather patterns is one of the greatest contributors to the gap present between potential and actual yield (Zhang *et al.*, 2013) – estimated at 20 % by Lobell *et al.*, (2009). Luo *et al.*, (2005) reported that, by 2080, climate change is likely to cause a reduction between 13.5 % and 32 % in wheat yield in Mediterranean-type environments, mostly because of changes in rainfall and temperature.

Environmental limiting factors differ from site

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to site (Erekul and Köhn 2006). Phenological adjustment through the variation and modulation of the duration of the different developmental phases, has been one of the most useful strategies available to adapt wheat to highly erratic environmental conditions (Gouache *et al.*, 2012). Time to anthesis is considered a primary trait determining wheat adaptation to a particular set of growing conditions (Worland *et al.*, 1998; Snape *et al.*, 2001). Variability in time to anthesis can be used to fine-tune growth and development patterns to the most prevailing environmental conditions in any particular environment (Blum 2011).
The objective of this study was to ascertain the effect of the principal climatic variables on winter durum wheat phenology and to assess the constraints associated with these environmental factors on annual yield in a central Italy area. Moreover, the investigation wants to provide useful information about the phenological adaptation, morphological and productive characteristics of durum wheat cultivars (with different lengths of growing season) testing at the same time their suitability to specific agroclimatic conditions in an agricultural experimental farm of the University of Perugia located in Rieti (Lazio Region) a central area of Italy, where several wheat cultivars, representing a considerable amount of the durum wheat commercialized seed in Italy, were evaluated during 11 years of investigations from 2006 to 2016.

2. MATERIALS AND METHODS

Study area

Field experiments were conducted in Rieti plain inside the "Centro appenninico del Terminillo-CAT" a research-service structure of the University of Perugia in the foothills of the same Terminillo Mountain. Here several plots were planted with cereals varieties such as wheat, barley and grain sorghum to record their performances for genetic selection studies.
In particular the CAT centre has 11 hectares of experimental fields, a heated greenhouse for the production/multiplication of plant species and 2 automatic weather stations, carrying out tests, included in the National evaluation network, on the benchmarking of grain sorghum, wheat, durum wheat and oats. Meteorological influences on pheno-morpho-yield data of grain sorghum varieties in central Italy, (2017), Orlandi F., Bonofiglio T., Ruga L., Fornaciari M., Agronomy Journal 109(5), 2182-89.

Durum wheat varieties

From the large database of durum wheat (*Triticum durum* Desf.) cultivars, planted in the CAT centre plots, only some cultivars were always present for a uninterrupted series of years, so only few cultivars were selected considering their regular presence during the longest period possible. We considered eight cultivars for length of growing cycle, from the earliest (Anco Marzio, Duilio, Saragolla) to the latest (Achille, Claudio and Dylan) (Tab. 1).

Cultivar	Length of growing cycle	DH (days)	PH (cm)	SM2	GM (%)	TKW (gr)	Yield (t/ha)	Test weight (kg/hl)
Achille	M	139	81	344	9,48	43,36	5,24	81,65
Anco Marzio	E	133	80	382	9,27	49,15	6,17	82,72
Claudio	M	135	84	380	9,65	48,96	6,14	83,91
Duilio	E	131	75	361	10,10	52,05	5,00	80,23
Dylan	ML	134	77	357	9,52	49,73	5,62	81,87
Iride	ME	132	73	357	9,77	46,29	6,00	81,28
Saragolla	E	132	72	370	10,22	45,89	5,24	79,40
Simeto	ME	132	72	347	9,84	56,63	4,65	78,68

DH, days from emergence to heading; PH, plant height; SM^2, number of spikes per m^2;
GM, grain moisture at harvest; TKW, 1000 kernel weight

Tab. 1 - Phenological, morphological and productive variables of eight Italian durum wheat cultivars tested during a eleven-year period (2006-2016) in central Italy (length of growing cycle, E = early, ME = medium early, M = medium and ML = medium late).
Tab. 1 - Variabili fenologiche, morfologiche e produttive di otto cultivar italiane di grano duro testate durante un periodo di undici anni (2006-2016) nell'Italia centrale (lunghezza del ciclo di crescita, E = precoce, ME = semi precoce, M = media e ML = semi tardiva).

Meteorological data

The meteorological data during the 11-year considered period (2006-2016) for the Rieti area were available directly from the meteorological stations located nearby the same wheat field and managed by the CAT centre (http://www.cat.unipg.it). The variables considered were: Temperature °C (Maximum and minimum), Precipitation (mm), Relative Humidity (%), Solar Radiation (KJ/m^2). Moreover, the daily temperature data were elaborated to obtain Growing Degree Days (GDD) amounts calculated to full heading phase and grain yield harvest phase. The GDD were calculated using the method proposed by Arnold (1960), which is based on the maximum and minimum temperatures.

Phenological and agronomical data

In the CAT centre several investigations were realized to observe and record the main phenological, morphological, agronomic, productive characteristics of the wheat tested cultivars.

At the first, by an agronomic point of view the sowing of the Durum wheat plots was realized averagely from the second half of November to the first half December, the emergence dates were recorded 1 month after sowing. The Fertilization of the plots were realized in the pre-sowing stage with 100 kg/Ha P2O5 and as cover fertilization in 3 stages (3-leaves unfolded, tillering and stem elongation). In the 3 cited stages a total of 150 kg/Ha of Urea were distributed respectively at 25% of the total during the first stage, 35% during the second and 45% during the third.

No chemical weed control were realized in winter wheat during sowing, while averagely during April (cover weeding) a treatment included mesosulfuron-methyl plus iodosulfuron-methyl-sodium plus mefenpyr-diethyl (0.3 kg/Ha) and an adjuvant to increase the leaves uptake (1 l/Ha), was realized.

Moreover, the harvesting period of the wheat plots was ranged between the second half of July and the first half of August and it was realized through a compact plot combine harvester.

By a phenological point of view, the days from emergence to heading (DH) were determined for the different wheat cultivars, through periodic (twice a week) observations, when approximately half of the spikes in the plot had already extruded (BBCH 09, Emergence: coleoptile penetrates soil surface; BBCH 55, Middle of heading: half of inflorescence emerged). At maturity and for each plot the plant height (PH) of the different trials, up to the extreme of the spike, was measured, the number of spikes per square metre (SM2) were determined for a 1 m length of an inside row, the test weight and 1000 kernel weight (TKW) were determined in 25 spikes taken at random. Grain yield was assessed by harvesting the whole plot.

RESULTS

In Fig. 1, a climate chart was realized with the mean values (2006-2016) of the monthly mean temperatures and rain amounts from January to August during the principal Wheat vegetative and reproductive cycles of development. The figure permits to evidence as commonly the wheat cultivars emergence phase (from final part of

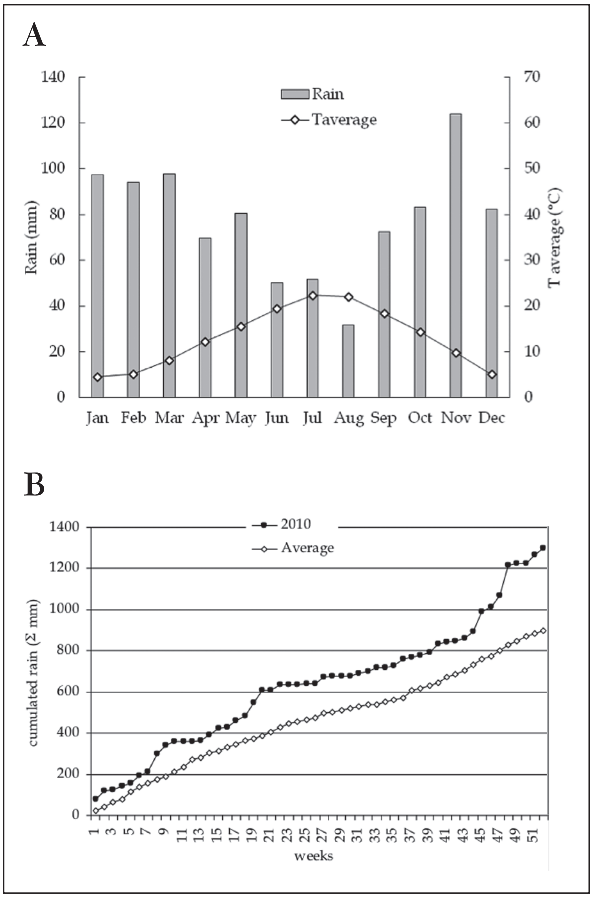

Fig. 1 - A) Climate chart with the mean monthly values (calculated during 2006-2016 period) of the average temperatures and precipitation amounts from January to August (Wheat vegetative-reproductive cycle). B) Mean weekly rain summation, from January to December, during the entire study period and in 2010 during flooding phenomenon recorded in the Rieti plain area.

Fig. 1 - A) Grafico con i valori medi (nel periodo 2006-2016) delle temperature medie e delle precipitazioni da gennaio ad agosto (ciclo vegetativo-riproduttivo del frumento). B) Sommatoria settimanale media della pioggia, da gennaio a dicembre, durante l'intero periodo di studio (2006-2016) e nel 2010 con il fenomeno di alluvione registrato nella piana Reatina.

December to January) was favoured in presence of sufficient rainfall (around 100 mm/month) and average temperature lowest than 5°C. Moreover, heading was generally recorded during the warmest and wet spring period (half May), suggesting above all the great importance of the water deficit during this plant stage, while the harvest, at the end of August, generally was realized during the highest temperature values and the lowest rain volumes period.

In the second part of the same Figure (B) the cumulative monthly rain, during the whole study period and those recorded in 2010, when a flooding of the region occurred, have been reported to evidence the anomaly of the last five weeks of the 2010 explaining the seeding delay of 2011.

The Fig. 2 shows the phenological data concerning the days from emergence to heading with the exclusion of 2011 when the very high seeding delay due to the precedent winter flooding determined a phase length lower by 50% than the average (68 days respect the 133 as mean). The figure permits to evidence the low phenological variability of the different cultivars during the years with only the first year (2006) that show the highest standard deviation (St. Dev.) due to the particular behaviour of Achille cultivar.

In Fig. 3, some production evidences are reported considering the yearly yields, the number of spikes per square metre and the thousand kernel weight. All the three respective charts in Figure show the average values and St. Dev. considering all the wheat cultivars during the study period.

The mean yield series evidenced a quite constant trend (y = -0.08x + 6.01; $p<0.05$) during the 11-

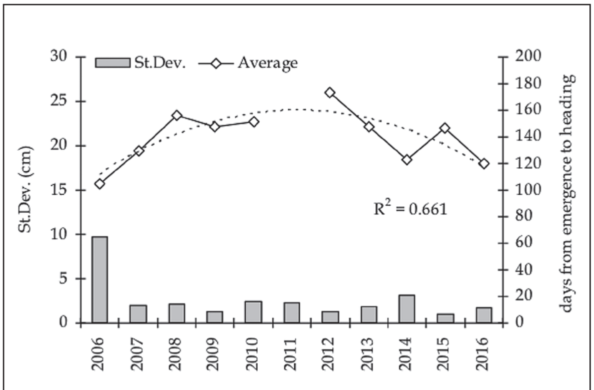

Fig. 2 - Mean values and standard deviations of the phenological data (emergence-heading period) considering all the Wheat cultivars.
Fig. 2 - Valori medi e deviazione standard dei dati fenologici (periodo emergenza-levata) considerando tutte le varietà di frumento duro.

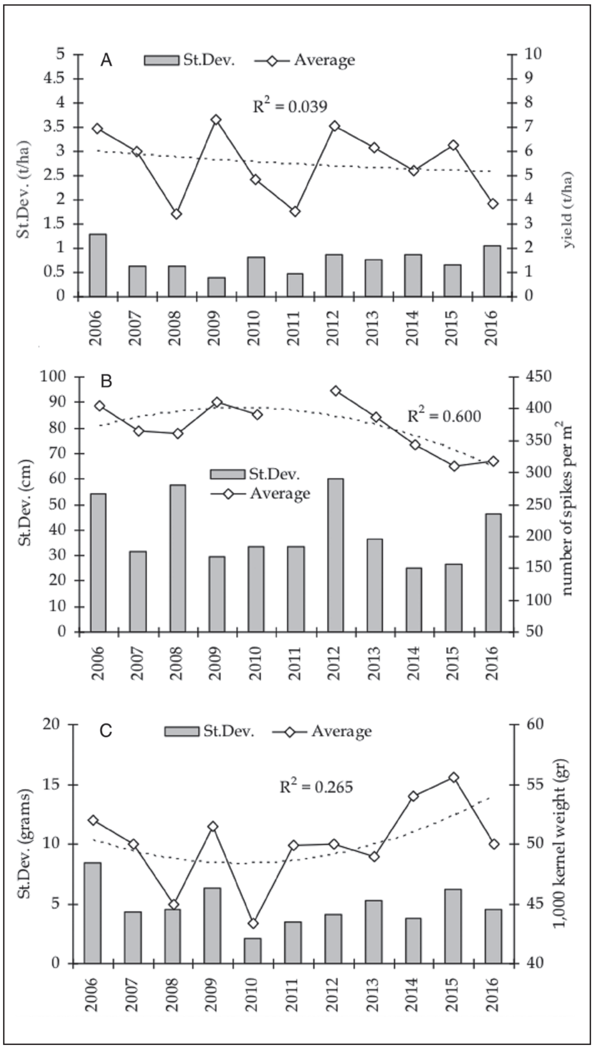

Fig. 3 - Production evidences of all the wheat cultivars. Mean crop yields (A); mean number of spikes/m^2 (B); mean 1.000 kernel weight (grams) (C). R^2 significance (p is less than .05).
Fig. 3 - Rese produttive di tutte le varietà di Frumento duro. (A) Resa media (ton/Ha); (B) numero medio di spighe/m^2; peso medio (grammi) di 1,000 cariossidi (C). Significatività R^2 ($p<0.05$).

year period (chart A) and the related second degree polynomial trend lines calculated in relation to the mean annual values not showed particular tendencies.

On the other hand in chart B the mean number of spikes per square metre showed a certain decrease in the final part of the series (2013-2016) determining a good interpretative level (y = $-2.25x^2 + 20.57x + 354.02$; $p<0.05$; R^2=0.60) of the second degree polynomial trend line (also in this chart the 2011 value was excluded considering it as an outlier). In Fig. 3 C the 1.000 kernel weight (grams) were reported, the interpretation of the data by a trend line showed low interpretative level ($y = 0.14x^2 - 1.33x + 51.48$; $p<0.05$; $R^2=0.26$) with minimum values during the central years of the considered period.

In Tab. 1, the mean values of different phenological, morphological and productive variables are shown for the eight Wheat cultivars. The days from emergence to heading (DH) ranged in an interval from 131 (Duilio "early" cultivar) to 139 (Achille "medium" cultivar). The number of spikes/m^2 was from 344 to 382, while the yield for the study period were ranged between 4.65 t/ha (Simeto cultivar) and 6.17 t/ha (Anco Marzio cultivar).

Test weight and thousand kernel weight were not so variables and no great differences were detected between the cultivars with the unique exception of Simeto cultivar for which an high kernel weight was recorded respect a low value of test weight.

Tab. 2 shows the correlation coefficients (r) between the phenological and productive values with the meteorological variables for all the considered Wheat varieties both during the complete study period that excluding the "anomalous" 2011. The r values summarize the principal relationships showing as the emergence-heading phase (DH) not resulted particularly influenced by forcing temperature, rainfall, solar radiation and humidity, considering all data. On the other hand, the exclusion of 2011 showed a more conventional situation in which all the precedent meteorological variables manifested their influence in relation to the phenological development.

	Entire period		2011 excluded	
	Yield	*DH*	*Yield*	*DH*
Yield				
DH	0,32		-0,02	
GDD H	-0,03	-0,12	-0,23	-0,57
GDD Har	0,66*		0,54	
RAIN H	-0,30	0,37	-0,54	0,21
RAIN Har	-0,37		-0,59	
RAD H	0,01	-0,01	0,27	0,51
RAD Har	0,49		0,46	
HR H	-0,47	0,32	-0,50	0,55
HR Har	0,04		-0,66*	
PH	0,39	0,42	0,06	-0,31
SM2	0,68*	0,61*	0,56	0,23
TKW	0,71**	-0,20	0,87**	-0,17
TW	0,73**	0,04	0,78**	-0,05

DH, days from emergence to heading; PH, plant height; SM2 number of spikes per m^2; TKW, 1000 kernel weight; TW, Test weight (kg/hl)

Tab. 2 - Correlation coefficients (r) between phenological and productive parameters with the meteorological variables (GDD, Rain, Solar radiation, HR) calculated at Heading (H) and Harvest (Har) for all the considered Wheat varieties during the entire study period (2006-2016) and excluding 2011. Correlation coefficient significance, .< 0.05, *< 0.01, **< 0.005, ***< 0.001.

*Tab. 2 - Analisi di correlazione tra parametri fenologici-produttivi e variabili meteorologiche (GDD, Pioggia, Radiazione solare, HR) calcolate alla levata (H) e alla raccolta (Har) per tutte le varietà di Grano duro considerate durante l'intero periodo di studio (2006-2016) ed escludendo il 2011. Significatività dei coefficient di correlazione, .< 0.05, *< 0.01, **< 0.005, ***< 0.001.*

In both the series yield evidenced significant correlations with GDD, rainfall and solar radiation (HR showed high correlation only excluding 2011). The number of spikes/m^2 and kernel weight showed similar high correlations with yield considering the entire series of years while excluding 2011 the kernel weight was significantly more correlated in comparison to the number of spikes/m^2.

Finally the same spikes/m^2 and plant height were correlated with the phenological phase DH considering also 2011 while its exclusion limited highly these relationships.

The regression analysis between DH and meteorological data for all wheat cultivars during the two year series confirmed the anomalous cause-effect relationships realized during the same 2011 (Tab. 3). Only the exclusion of this year permitted to estimate a linear model with a discrete amount of explained variability (R^2 about 0.71) by utilizing GDD and HR sums to heading.

Moreover, the regression analysis between the number of spikes per square metre (SM2) and DH (Tab. 4) during the entire study period (2006-2016) and excluding 2011 confirmed that during this year one of the more important variable (SM2) for determining the annual yield (besides the kernel weight) was highly influenced by the "anomalous" phenological phase development (very short period). Only considering the entire year series the DH variable "explained" more than 50% of the morphological variation (SM2, P=0.0071).

DISCUSSION AND CONCLUSION

The correlation and regression analyses evidenced how some biological behaviours of winter durum wheat, as the vegetative and reproductive phases are in relation to particular meteorological parameters confirming as the developmental phases length optimization permits wheat adaptation also to climatic anomalies (Gouache *et al.*, 2012; Snape *et al.*, 2001; Worland *et al.*, 1998).

The low correlation coefficients between the number

Parameter	Value	Independent Variable	Slope Coefficient	Standard Error	T-Value to test	Prob Level
		entire study period (2006-2016)				
Dependent Variable	DH	Intercept	15,827.1759	23,113.9682	0.6850	0.5239
Number Ind. Variables	4	GDD H	-0.2740	0.4399	-0.6230	0.5607
R^2	0.2147	RAIN H	0.0768	0.1568	0.4900	0.6449
Adj R^2	0.0000	RAD H	-0.0014	0.0039	-0.3460	0.7431
Coefficient of Variation	0.2799	HR H	0.0088	0.0229	0.3830	0.7176
Mean Square Error	1.35E+13					
Square Root of MSE	3,668.4680			Ave Abs Pct Error 16,417		
		study period (2006-2016) excluding 2011				
Dependent Variable	DH	Intercept	12,985.2051	6,846.6227	1.9970	0.0967
Number Ind. Variables	2	GDD H	-0.4324	0.1493	-2.8970	0.0275
R^2	0.7076	HR H	0.0165	0.0059	2.8060	0.0309
Adj R^2	0.6101					
Coefficient of Variation	0.1020			Square Root of MSE 1,408,883		
Mean Square Error	1,984,950			Ave Abs Pct Error 6.5720		

Tab. 3 - Regression analysis between the period from emergence to heading (DH) as dependent variable and meteorological data as independent variables for all the Wheat varieties during the entire study period (2006-2016) and excluding 2011.
Tab. 3 - Analisi di regressione tra la durata dei periodi "emergenza-levata" (DH) come variabile dipendente e alcuni parametri meteorologici come variabili indipendenti per tutte le varietà di grano duro durante l'intero periodo di studio (2006-2016) ed escludendo il 2011.

of days emergence-heading and temperature summations (GDD) considering the entire study series (2006-2016) was caused above all by the "anomalous" values during 2011 when temperature summations (S GDD) similar to those recorded in the other years were recorded in about half the time. In this sense, during 2011 the GDD amounts required by the reproductive cycle to heading have been satisfied also with a very delayed seeding (because of flooding) showing as a great part of post emergence period is not necessary for the GDD amount but probably is essential to obtain regular wheat tillering phenomena.

The very low temperature effect recorded during winter (December-January in the study area) was evidenced also by other studies in climatic change adaptation. Really, the advance of wheat sowing dates, modifying the crop cycle, does not appear

Parameter	Value	Independent Variable	Regression Coefficient	Standard Error	T-Value to test	Prob Level
		entire study period (2006-2016)				
Dependent Variable	SM2	Intercept	19,724.1611	5,500.3623	3.5860	0.0071
Number Ind. Variables	1	DH	1.2683	0.4122	3.0770	0.0152
R^2	0.5420					
Adj R^2	0.4848					
Coefficient of Variation	0.1000	Square Root of MSE		3,627.5170		
Mean Square Error	1.32E+07	Ave Abs Pct Error		6.4360		
		study period (2006-2016) excluding 2011				
Dependent Variable	SM2	Intercept	24,459.4260	9,048.5583	2.7030	0.0305
Number Ind. Variables	1	DH	0.9367	0.6517	1.4370	0.1938
R^2	0.2279					
Adj R^2	0.1176					
Coefficient of Variation	0.1006	Square Root of MSE		3,758.0640		
Mean Square Error	1.41E+07	Ave Abs Pct Error		7.0070		

Tab. 4 - Regression analysis between the number of spikes per square metre (SM2) as dependent variable and DH as independent variables during the entire study period (2006-2016) and excluding 2011.
Tab. 4 - Analisi di regressione tra il numero di spighe/m² (SM2) come variabile dipendente e la durata dei periodi "emergenza-levata" (DH) come indipendente per l'intero periodo di studio (2006-2016) ed escludendo il 2011.

to be an efficient solution to advance heading dates as an adaptation strategy toward increasing heat stress during late spring. Although early sowings allow an important gain in available thermal time, this gain occurs in a period during which vernalization and photoperiod responses greatly limit this effect (Distelfeld *et al.*, 2009; Trevaskis, 2010).

Really, both the plant height and above all the number of spikes/m^2 resulted highly related with the phenological phases length considering their link with the same plant morphology. Moreover, considering the entire year series, yield appeared greatly related with the number of spikes/m^2 and so with the plant tillering rate while the exclusion of 2011 showed the kernel weight as the variable more important to determine the final yield not considering present in this database the plant tillering problem.

Statistical analysis evidenced that if 2011 is considered as an outlier and its data are not evaluated, regression results show the reproductive phenological phase influenced by GDD and HR amounts at heading in line with conventional results reported in literature according to which for example the number of days from sowing to anthesis is strongly and negatively related to the temperature during the same period, particularly the mean daily minimum temperature (Villegas *et al.*, 2016). Other investigations showed that the longer duration of spike growth allowed more assimilates to be available to the spike, determining more fertile florets per spikelet at anthesis (Gonzalez *et al.*, 2005; Alvaro *et al.*, 2008).

Much of the grain yield of wheat occurs on tillers that develop from buds in the axils of lower leaves and under normal conditions, as much as 70% of the grain yield comes from the tillers (Thiry *et al.*, 2002). Date of seeding greatly affects development of tillers in winter wheat. Late seeding gives plants a short time to develop tillers, resulting in inadequate numbers of spikes (heads) for high yields the following spring. The warmer environment during late winter and spring accelerates vegetative development (Mitchell *et al.*, 2012) so plants derived by late seeding tillered inadequately during spring and had too sparse of a stand to produce a high yield of grain.

Sowing date greatly affects yield of wheat, and particularly through the development, survival, and harvest index of tillers, in this sense planting during the optimum period encourages tillering during fall and spring, reducing competition among the same tillers, and promoting a high harvest index (Thiry *et al.*, 2002).

During the "anomalous" year of the series, the plant morphological development and in particular the number of spikes/m^2 was deeply influenced by the late seeding due to the heavy precipitation volumes recorded during the last weeks of 2010. In this case the water table level of the study area, relatively near to the surface, can provoke easily flooding phenomena, Rieti plain is inserted in the hydrographic basin of the Velino river characterized by the presence of a ground water at the depth of 1.5-2.0 m for most of the growing season. But the climate change phenomena and the highest frequency of extreme events (cloud burst) in large cultivation areas could induce necessarily the displacement of agronomic techniques such as the field operations, the same seeding. In this sense the experimented low number of tillers as consequence of a flooding demonstrated the need of genotypic adaptation through the seeding of modified crop phenology wheat cultivars (earlier crop phenology or rapid tillering cultivars) increasing also the seeding rate when wheat is planted late.

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