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Professional paper

YIELD, GROWING DEGREE DAYS, PHENOTHERMAL INDEX, AND HEAT USE EFFICIENCY OF WHEAT (*TRITICUM AESTIVUM)* AS INFLUENCED BY SOWING DATES

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ABSTRACT

The study aimed to predict: 1. the different stages of wheat development, depending on planting time and the GDD accumulated. 2. To calculate the phenothermal index (PTI) for different stages of development 3. To calculate the heat use efficiency (HUE) for grain yield. A trial was set up using a randomized complete block with three replications in the Botanical Garden of the Agricultural University of Tirana. Three sowing dates (Nov.11, Nov. 26, and Dec 11) and one wheat cultivar (Dajti), were tested. The results showed the plant cycle and GDD required from planting to ripening is reduced in late sowing dates.
The values of PTI in the early stages of development, from germination till tillering, decreased, while from the tillering till flowering, these values increased for all three planting dates. The highest heat use efficiency for grain yield (2.82 kg/ha/0C day) was recorded under normal sowing i.e. 11th November sown crop. Subsequent delay in sowing resulted in a decrease in HUE. November 26 and December 11 sowing time, had values of 2.49 and 1.89 kg/ha/0C day, respectively. The yield was significantly affected by planting dates. The maximum grain yield (6430 kg/ ha) was recorded when planting was done on November 11th, which decreased gradually and significantly to 4130 kg/ ha when planting was done on Dec.11. The yield attributes studied in this experiment showed a smaller decrease i.e. 22.4 % in grains/spike and 8.0% in 1000-grain weight as compared with the 35.8% decrease in the grain yield when sowing was delayed till Dec.11th as compared with Nov.11th.

Key words: Growth degree day, Heat use efficiency, Phenothermal index, Sowing date, Yield.

INTRODUCTION

For many years, researchers have tried to find effective ways to predict how different organisms grow and develop in different environments. Although genetic factors play an important role in the speed of development and reproduction of an organism, of interest has been the question, of how environmental conditions affect its growth and development. The physiological process of plants depends on integrated atmospheric parameters (Ko et al., 2010), in which temperature is an important weather parameter that affects plant growth, development, and yield.
It is especially important to be able to model and predict how plants and other organisms are impacted by changing environmental conditions. This has become particularly relevant in recent years as scientists are trying to predict the potential impact of climate change and climate variability on the development and adaptability of different organisms.
Therefore, a crop variety grown in a cool environment would normally take longer to develop and reach maturity compared to growing the same crop variety in a warmer environment. Calendar time is not a very reliable indicator when trying to compare when a crop would mature or reach a certain stage of development in different growing environments. Because ambient temperatures can vary greatly with locations, growing seasons, time of day, and time of year, it is difficult to

predict crop growth based on calendar time. Therefore, researchers have tried and developed other ways of expressing some measure of "time" to characterize growth.

Wheat productivity is highly variable and is mainly affected by rainfall, temperature, and solar radiation. Each plant is exposed to different of weather conditions during different growth and development stages, resulting in large variations in growth rate and yield. For the quantification of thermal connectivity of winter crops (wheat, barley, rye), and other crops, thermal units have been widely used (Ramteke et al., 1996) and have been modified to include, in addition to GDD, photo-thermal units and helio-thermal units (Rao et al., 1999). Temperature controls the rate of development of many organisms. Plants require a certain amount of heat to develop from one point in their life cycle to another. This amount of accumulated heat is known as physiological time. Theoretically, physiological time provides a common reference for the development of organisms. The amount of heat required to complete the development of a given organism does not change; the combination of temperature (between thresholds) and time will always be the same. Physiological time is often expressed and approximated using degree-hour (°hr) or degree-day (°D) units. Plant development is largely influenced by temperature and accumulated heat. GDD is a measure of accumulated heat and can be well correlated with plant development. The amount of active temperatures accumulated by the plant is a better measure to predict the development of the plant than the calendar date, because the heat required by the plant to reach a certain stage of development is constant, while the calendar date is not constant. It is difficult to predict plant growth based on calendar dates because temperatures can vary greatly from year to year. Instead, growth and development predictions, based on current temperatures, are a simple and accurate way to predict when a particular plant stage will occur.

MATERIALS AND METHODS

The aim of the study was: 1. to predict the different stages of wheat development, depending on planting time and the GDD accumulated by the plant. 2. To calculate the phenothermal index (PTI) for different stages of development 3. To calculate the heat use efficiency (HUE) in wheat for grain yield.

The experiment was set up in the Botanical Garden of the Agricultural University of Tirana. To achieve the objectives, Dajti (a soft wheat cultivar) was planted in three different periods (November 11, November 26, and December 11).

The experimental design was a randomized complete block design with three replications. The phenological observations were carried out every 10 - 15 days for all the planting periods, using descriptions for the main phases of wheat development according to the Feekes scale. Each stage was recorded when 50% of the plants had reached the stage. For example, the tillering phase is marked when 50% of the plants have formed a new tiller. The number of plants after full germination and the number of spikes after heading will also be done. For each planting period, 10 spikes will be taken randomly, which will be analyzed for the number of grains in the spike, the weight of the grains in the spike, and the weight of 1000 grains. This will serve to calculate the yield kg/ha.

Measured parameters

Agrometeorological indicators: maximum, minimum and average daily temperatures during the plant cycle and calculation of growing degree days (GDD), phenothermal index (PTI), and heat use efficiency (HUE) which were calculated based on the following formulas:

Calculation of GDD

Wheat growing degree days (GDD) are calculated by subtracting the plant's lower base or threshold temperature of 5 °C from the average daily air temperature. Average daily air temperature is calculated by averaging the daily maximum and minimum air temperatures measured in any 24 hours.

$$\mathbf{GDD\ (^oC) = ((Temp_{max} + Temp_{min})/2) - T_b}$$

Phenothermal index (PTI)

The temperature units accumulated for the days between the two phenological phases were used to calculate the phenothermal index (PTI) and it is expressed in active temperatures per day (degree-days) per growth day: Its calculation was based on formulas proposed by Nuttonson (1948), Chakravarty and Sastry (1983).

$$PTI = \frac{\text{GDD between two phenological stages}}{\text{No of days taken between two phenophases}}$$

Heat use efficiency (HUE)

It was used to compare the relative performance of the cultivar in different planting periods, in relation to the utilization of heat in terms of GDD during the period of the wheat plant cycle. HUE was calculated based on the formula proposed by Sastry et al. (1985).

$$HUE = \frac{\textit{Grain Yield (kg ha}^{-1})}{\textit{Accumulated heat units C day}}$$

RESULTS AND DISCUSSION

Effect of sowing time on phenology

The data of Tables No. 1 and No. 2 show that the planting time has a significant impact on the progress of the phenological phases and their duration. The first phase (planting - germination) lasted 14 days in the first planting time, 22 days in the second, and 36 days in the third. This is because in the first period (November 11) the air and ground temperatures were higher than in the other two periods. Such a trend continues until the appearance of the second and third leaf, and later, starting from tillering until full ripening, a significant shortening of the development stages is observed in the late planting times, compared to the first, which has also affected the length of the plant cycle of the same cultivar. Thus, the length of the plant cycle in the first term of planting was 193 days, in the second 175, and the third 149 days. The calculations show that for every day of delay in planting wheat, its plant cycle is shortened by on average of 1.4 days.

Tab.1 Effect of planting date on phenological stages of wheat

Nr	**Phenologycal stages**	Description of the stages	Scales		Date of development stage
			Feekes	Zadoks	

					Sowing I	Sowing II	Sowing III
	Sowing				11.11	26.11	11.12
1	Emergence	1 leaf unfolded	1.0	10	25.11	18.12	16.01
2	2 leaves	2 leaves unfolded	-	12.2	5.12	1.01	1.02
3	Tillering	Main shoot and one tiller	2.0	21	5.01	3.02	20.02
4	Joint	First node visibile	4.0	31	12.03	24.03	3.04
5	Heading	Emergence of head comleted	10.1	59	5.04	12.04	19.04
6	Flowering	Bigining of pollination	10.5	61	10.04	20.04	26.04
7	Grain filling	Ripening begins (water ripening)	10.5.4	71	17.04	24.04	29.04
8	Grain dough stage	Kernel will have a doughy consistence	11.2	87	28.05	05.06	10.06
9	Ripening stage	Kernel hard, harvest ready	11.4	93	5.06	11.06	14.06

Tab.2 Duration of growth stages in relation of planting date

Nr	**Growth stages**	**Duration of growth stages**		
		First sowing time	**Second sowing time**	**Third sowing time**
1	Sowing – emergence	14	22	36
2	Emergence – 2 leaves	11	14	16
3	2 leaves – tillering	31	33	19
4	Tillering – joint	66	49	42
5	Joint – heading	24	19	16
6	Heading – flowering	5	8	7
7	Flowering – begin of grain filling	7	4	3
8	beginning of grain filling - ripening	49	48	46
9	Emergence - ripening	**193**	**175**	**149**

Effect of GDD on the progress of development stages

Plant development is driven by heat accumulation. GDD is an indicator of the accumulation of temperatures, which is strongly correlated with plant growth and development. The early sown crop required more thermal time in comparison with the crop sown on later dates and it might be due
to an increase in mean temperature which shortened the later stages of the wheat crop. The GDD values or heat accumulated for attaining maturity were 2282.9, 2240.3, and 2184.5 respectively, in three different times of planting (Table 3). The requirement of a heat unit was higher for a timely plant crop than a late sown crop due to the longer period for all the phenological stages in the timely sown crop. The data in Table 3 showed that the GDD requirement to attain the different phonological stages (from emergence to tillering) are almost the same for all three planting times, whereas after the tillering the requirements significantly decreased, especially starting from the

joint stage to full ripening, i.e. there was a reduction in GDD from the November 11 to December 11 for these stages. This phenomenon is explained by the fact that in late sowing, the plant is placed in specific conditions, related not only to higher temperatures but also to the photoperiod (day length). These results are in harmony with those obtained by other authors such as Khichar and Niwas, who studied the effect of two sowing dates (November 20 and December 20) on GDD and found that wheat plants sowing early (November 20) needed more GDD than those planted late (December 20).

Tab. 3 Requirements of GDD for different growth stages of wheat

Nr	Growth stages	Sowing time		
		11.11.2018	26.11.2018	11.12.2018
1	Emergence	172.8	176.9	170.8
2	2 leaves	272.4	277.0	299.6
3	Tillering	479.4	457.2	476.9
4	Joint	989.1	941.6	943.1
5	Heading	1291.4	1204.2	1173.9
6	Flowering	1364.8	1321.5	1288.5
7	Grain filling	1465.8	1386.0	1338.2
9	Ripening	2282.9	2240.3	2184.5

Phyllochron (0C d) (The phyllochron concept, which is defined as the time interval between the appearances of successive leaf tips (Klepper *et al*., 1982), is used to predict the appearance of individual leaves, expressed in thermal time, with units of degree days.
Our data showed that the amount of GDD necessary for the emergence of a new leaf is influenced by the time of planting. Thus, in the first planting time (November 11), the GDD for the unfolding of the new leaf was 86 0C, in the second (November 26), 91.6 0C, and in the third (December 11) 116.8 0C, with a average of 98.1 0C. In late plantings, a higher amount of active temperatures is needed than in early or normal plantings. This means that, in general, wheat planted later forms a smaller number of leaves in their stem than those planted in the optimal period. In this regard, many data indicate different values of the sum of the active temperatures necessary for the appearance of the leaf (Phyllochron) in wheat. According to (Frank and Bauer, 1995) it takes 77 0C, (Bauer et al., 1984) 80 0C (Kirby, 1988), 101 0C (Biscoe and Willington, 1985) 105 0C, and (Baker et al., 1986) 124 0C d. The changes in values reported by different authors, the result of different temperatures in different stages of development, and the different reactions of the plant to these temperatures.

Number of grains/spike

Differences in GDD between different planting dates have influenced the main components that determine wheat production Results in Table 4 indicated that sowing dates had a significant effect on the number of grains/spike. Sowing wheat on 11th November attained the highest number of grains /spike (40.2), compared with those obtained when wheat was sown on 25th November, and 11th December which produced 37.4 and 31.2, respectively. The increase in this trait with sowing wheat on November 11th may be due to the available weather conditions during plant life that helped rapid growth and formation of good canopy able to make good photosynthesis. These results are in line with those obtained by Rakesh Kumar Sharma [19] and Nohe et al. [21]. They found that sowing dates significantly affected the number of grains/spike which increased when wheat was sown on optimum date compared with late sowing dates.

Tab. 4 Yield and its attributes

Nr	Planting date	Nr plants/m^2	Nr spikes/m^2	Average No of grain/spike	1000 grain weight g	Yield kg/ha
1	Nov.11	362	442	40.2	41.7	6430
2	Nov.26	357	428	37.4	40.3	5870
3	Dec.11	344	385	31.2	38.4	4130

1000 grain weight

Delayed sowing shortens the duration of each development stage, which ultimately reduces the grain-filling period and lowers the grain weight (Spink et al., 2000). A subsequent decrease in 1000-grain weight in wheat with delayed sowing was reported by Joarder et al. (1981).

In our present study (Table 4), it was noticed that November 11 produced a higher 1000-grain weight (41.7g) and December 11 produced the lowest 1000-grain weight (38.4 g). It might be due to favorable temperature at the growth stage of the crop, especially the grain-filling stage of the November 11 sown. On the other hand, in later sowing (December 11), the temperature was higher at the grain filling stage, which ultimately reduced the grain yield of the wheat due to the shortening of the grain filling stage. The early sowing resulted in better development of the grains due to longer growing periods. Similar results were also found by Sofied et al. (1977), who reported that higher grain weight was observed due to favorable temperature associated with a longer grain filling period.

Grain yield (Kg/ha)

Grain yield is an important trait in assessing the adaptability of a crop to environmental variations. The data in Table 4 showed that wheat yield was significantly affected by planting dates. The maximum grain yield (6430 kg/ ha) was recorded when planting was done on November 11th, which decreased gradually and significantly to 4130 kg/ ha when planting was done on Dec.11. The value of the wheat yield planted on November 26, was 5870 kg/ha. Thus, we can conclude that the most suitable time for wheat planting for the warm area of our country is considered the second decade of November. Delaying planting until December 11 reduced wheat yield by about 38% compared to November 11 and 30% compared to November 26. Decrease in the yield attributes i.e. grains/spike and 1000-grain weight due to delay in sowing date contributed to the decrease in the grain yield for which the main reasons are the decrease in growing degree days (Sandhu et al. 1999), longer photoperiod and higher temperature during the reproductive stage (Slafer and Whitechurch, 2001).

The yield attributes studied in this experiment showed a smaller decrease i.e. 22.4 % in grains/spike and 8.0% in 1000-grain weight as compared with the 35.8% decrease in the grain yield when sowing was delayed till Dec.11th as compared with Nov.11th. It shows that the rest of the decrease in grain yield might be due to a decrease in the number of productive tillers per unit area. Decreased wheat yield under thermal stress of the filling stage (in late plantings), also can be caused by accelerated senescence, increased respiration, reduced photosynthesis, and accelerated phase development. Based on the results obtained, the delay in planting from November 11 to December 11 caused a decrease in wheat yield by 66 kg every day.

Heat use efficiency

Heat use efficiency was influenced due to different weather conditions. The timely sown crop used heat more efficiently than the late sown crop. According to (Pal and Murty, 2010) genotypes with a low value of PTI and a high value of HUE showed more important yield. In our study, the highest heat use efficiency for grain yield (2.82 kg/ha/0C day) was recorded under normal sowing i.e. 11th November sown crop. Subsequent delay in sowing resulted in a decreased in heat use efficiency (Table 5). In the plantings of November 26 and December 11, the HUE values were 2.49 and 1.89 kg/ha/0C day. respectively This is because, in late plantings, plants suffer different stresses such as higher temperatures, lack of moisture, etc., which accelerate the stages of development and shorten the plant cycle. As a result, the plants sowing in the optimal conditions have given a higher yield, since they have efficiently used the accumulated heat units. Since the temperature was favorable during normal growing conditions, it accumulated heat more efficiently and increased the physiological activities that confirmed the higher grain yield. The same results are reported by many other authors, who emphasize the reduction of HUE when planting deviates from the optimal time.

Tab. 5 Heat use efficiency (HUE) of wheat for grain yield

Nr	Sowing time	Total GDD	Yield kg/ha	HUE values (kg.ha^{-1} / ^{0}C
1	11 November	2282.9	6430	2.82
2	26 November	2240.3	5570	2.49
3	11 December	2184.5	4130	1.89

Phenothermal Index (PTI)

The phenothermal index (PTI) is the plant's ability to use heat for its development. In this way, this index is related to the temperature required by the plant to pass from one stage of development to another and changes in different seasons of the year. In general, its values are higher during the summer period. The phenolthermal index from emergence till tillering, from tillering till stem elongation, from stem elongation till heading, and from heading till flowering for all three sowing dates, show significant changes. The values of this indicator (Table 6), in the early stages of development, from germination till tillering, decrease, while from the tillering development stage till flowering, these values increase for all three planting dates. The greatest values are observed for plantings carried out in late periods. This is explained by the fact that the stages of plant development in the late planting period are shortened due to the displacement in time that corresponds to high temperatures.

Table 6: Phenothermal index (PTI) of wheat as influenced by three sowing days at different periods.

Growth stages	Planting date Nov. 11			Nov. 26			Dec. 11		
	Duration Days	GDD ^{0}C	**PTI (GDD/ growth days)**	Duration Days	GDD ^{0}C	**PTI (GDD/ growth days)**	Duration Days	GDD ^{0}C	**PTI (GDD/ growth days**

Sowing - emergence	14	172.8	**12.3**	22	176.9	**8.0**	36	170.8	**4.7**
Emergence – 2 leaves	11	99.6	**9.1**	14	100.1	**7.2**	16	128.8	**8.1**
2 leaves - tillering	31	207.0	**6.7**	33	180.2	**5.5**	19	187.3	**9.9**
Tillering - joint	66	509.7	**7.7**	49	484.4	**9.9**	42	466.2	**11.1**
Joint - heading	24	302.3	**13.1**	19	262.6	**13.8**	16	230.8	**14.4**
Heading - flowering	5	73.4	**14.9**	8	117.3	**14.6**	7	114.6	**16.4**
Flowering – begin of grain filling	7	101.0	**14.4**	4	64.5	**16.1**	3	49.7	**16.3**

REFERENCES

[1]. Baker JT, Printer PJ, Reginato RJ, Kanemasu ET .1986. Effects of temperature on leaf appearance in spring and winter wheat cultivars. Agron. J. 78: 605-613.

[2]. Bauer, A., C. Fanning, J.W. Enz, and C.V. Eberlein. 1984. Use of growing-degree days to determine spring wheat growth stages. North Dakota Coop. Ext. Ser. EB-37. Fargo, ND.

[3]. Biscoe PV, Willington VBA .1985. Crop physiological studies in relation to mathematical models. In: Day, W., Atkin, R.K. (Eds.), Wheat Growth and Modeling. Plenum Press, New York, pp. 257-269.

[4]. Chakravarty, N. V. K and Sastry, P. S. N. 1984. Phenology and accumulated heat unit relationships in wheat under different planting dates in the Delhi regions. *Agric. Sci. Prog*.**1,** 32-42.

[5]. Frank AB, Bauer A .1995. Phyllochron differences in wheat, barley and forage grasses. Crop Sci., 35:19-23. 6. G. A.

[6]. Slafer and E. M. Whitewchurch, "Manipulating wheat development to improve adaptation," in *Application of Physiology in Wheat Breeding*, M. P. Reynolds, J. I. Ortiz-Monasterio, and A. M. C. Nab, Eds., pp. 160–170, CIMMYT, Texcoco, Mexico, 2001.

[7]. J H Spink, T Semere, D L Sparkes, J M Whaley, M J Foulkes, R W Clare, R K Scott **Effect of sowing date on the optimum plant density of winter wheat**

[8]. Khiehar, M.L. and L. Ram Niwas, 2006. Microclimatic profiles under different sowing environments in wheat. Journal of Agrometeorology, 8(2): 201-209.

[9]. Kirby EJM .1988. Analysis of leaf, stem and ear growth in wheat from terminal spikelet stage to anthesis. Field Crop. Res., 18:127-140.

[10]. Ko, J., L. Ahuja, B. Kimball, S. Anapalli, L. Ma, T.R. Green, A.C. Ruane, G.W. Wall, P. Pinter, and D.A. Bader, 2010: Simulation of free air CO_2 enriched wheat growth and interactions with water, nitrogen, and temperature. *Agric. Forest Meteorol.*, **150**, 1331-1346, doi:10.1016/j.agrformet.2010.06.004.

[11]. Nohe, T.A., M.M. Abd-Alla and T.F. Hussein, 2009. Effect of sowing dates and seeding rates on yield, yield components and quality of durum wheat (*Triticum durum* L.) under AL-Gabal AL-Akdar conditions, Libya J. Agric. Res. Kafer EL-Shekh Univ., Egypt, 35(3): 841-857

[12]. Nuttonson MY (1955). Wheat climate relationship and the use of phenology in ascerting the thermal and photo thermal requirement of wheat. American Institute of crop ecology.Washington DC, USA. P. 388.

[13]. Pal RK, Murty NS. Thermal requirements of wheat under different growing environments of Tarai region (Uttarkhand) Workshop Proceedings: Impact of Climate Change on Agriculture, 2010, 78-79.

[14]. RakeshKumar Sharma, S.N., 2003. Effect of nitrogen on wheat as influenced by dates of sowing. Annals of Agricultural Research, 24(4): 104-110.

[15]. Ramteke, S.D, M.B. Chetti and P.M. Salimath. Heat unit requirement of chickpea genotypes for various phenological stages during kharif and rabi seasons. Annals of Plant Physiology. 10 (2), 1996, 176-181.

[16]. Rao, V.U.M., Singh, D. and Singh, R. (1999). Heat use efficiency of winter crops in Haryana. *J. Agrometeorol.*, 1(2): 143-148.

[17]. Sandhu IS, Sharma AR, Sur HS. Yield performance and heat unit requirement of wheat (*Triticum aestivum* L.) varieties as affected by sowing dates under rainfed conditions. Indian Journal of Agricultural Science. 1999; 69:175-179.

[18]. Sastry, P.S.N., Chakravarty, N.V.K. (1982). Energy summation indices for wheat crop in India. *Agric. Meteorol.*, 27: 45-48.

[19]. Sofield, L, Evans, L. T., Cook, M. G. and Wardlaw, l. F. 1977. Factors influencing the rate and duration of grain hlling in wheat. Aust. J. Plant Physiol. 4z 785-797.