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RELATIONSHIP BETWEEN CROP DEVELOPMENTAL PHASES AND AIR TEMPERATURE AND ITS EFFECT ON YIELD OF THE WHEAT CROP *(Triticum aestivum* L.*)* GROWN IN JAVA ISLAND, INDONESIA

I. HANDOKO[1,2]

[1]*SEAMEO BIOTROP, Jalan Raya Tajur Km 6, Bogor, Indonesia*
[2]*Department of Geophysics and Meteorology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Kampus IPB Darmaga, Bogor, Indonesia*

ABSTRACT

About four million tonnes of wheat has been imported annually, because hardly no wheat crop is cultivated in Indonesia. High temperature is probably the major limiting factor for cultivating the crop in a large scale. This research aims to find out the relationship between temperature and wheat (DWR162 cultivar) crop development to derive its developmental parameters (base temperature and thermal unit) and to further study its effects on grain yield. Experiment was conducted at five locations in Java Island with distinct altitudes range from 28 to 1,650 m to represent a wide range of averaged air temperature (27.5 to 16.5 °C). The base temperatures derived from this experiment were 8.3, 3.8 and 15.1 °C while the parameters of thermal unit were 189, 1053 and 290 d. °C, respectively for the phases of sowing-emergence, emergence-anthesis, and anthesis-physiological maturity. Grain yield of the wheat crop decreased with increasing temperature of about 10 % per 1 °C increase above averaged temperature of 16.5 °C. Increasing temperature caused shorter duration during vegetative growth (emergence-anthesis) and grain filling period (anthesis-maturity) which resulted in smaller biomass and the grain yield.

Key words : wheat, temperature, development, growth, yield, Indonesia.

INTRODUCTION

Indonesia, with its population of more than 220 million, imports wheat about four million tonnes a year and there is almost no wheat cultivation in the country. There is very limited information on whether wheat could be economically cultivated in Indonesia on a large scale. We consider that the major limiting factor is high temperature as shown by other workers (Tashiro & Wardlaw 1990; García del Moral *et al.* 2003; McMaster *et al.* 2003) for which this research aims to find out the relationship between temperature and crop developmental phases of the wheat crop grown in various locations in Java Island. Parameters of crop development were also developed based on the thermal-unit concept. This will be employed to further explore the response of grain yield to temperature.

Corresponding author: handoko@biotrop.org

Air temperature rather than soil temperature was used to derive the parameters of crop development. Previous studies (McMaster & Wilhelm 1998, 2003; McMaster *et al.* 2003) have shown that the use of soil temperature did not significantly improve prediction of crop phenology as compared with air temperature.

MATERIALS AND METHODS

Wheat crop originated from India (cultivar of DWR 162) was grown in five locations in Java Island, Indonesia, to represent various environments. The crop was assumed unimportantly influenced by photoperiod considering the small variation in daylength in Java Island which is located near equator. This assumption is required to employ thermal-unit concept which could only be applied to neutral plant (*i.e.* photoperiod insensitive). Thermal unit concept only considers that period of crop developmental phases is only determined by temperature while other environmental factors are assumed to be unimportant. To verify this assumption, we introduced treatments of three levels of nitrogen fertilizers and four different sowing dates at each experimental site.

Sites

The five locations were selected for altitudes from 28 to 1,650 m to represent a wide range of temperature differences. There were one site in West Java (Bogor) characterized by wet climate, and four sites in East Java with drier climates, namely Mojosari, Malang, Nongkojajar and Cangar. Table 1 presents the distribution of locations relative to altitudes, and air temperatures at the experimental plots. The experiments commenced on May until November 2000 while the preparation had been conducted since October 1999. Because of the very low soil pH (pH$\leq$ 3.0) at the site in Bogor, some analyses excluded the data of Bogor.

Table 1. Location, altitudes and temperature of various experimental sites.

No	Location	Altitude (m)	T_{min} (°C)	T_{max} (°C)	T_{mean} (°C)
1	Mojosari	28	22.2	32.7	27.5
2	Bogor	300	21.7	31.0	26.4
3	Malang	450	20.4	28.9	24.7
4	Nongkojajar	900	16.1	27.8	22.0
5	Cangar	1650	13.2	19.7	16.5

Note:
T_{min}, T_{max} and T_{mean} are respectively minimum, maximum and averaged air temperatures

Materials

Wheat seeds of DWR162 cultivar were obtained from Wheat Research Institute, New Delhi, India. After the seeds were screened and approved by Quarantine Institute of Indonesia, the seeds were distributed to the five experimental fields for planting.

Experimental Design

The hypotheses of this experiment were :

(1) The durations of developmental phases were longer under lower temperatures.

(2) Yield of the wheat crop increased with altitudes having lower temperatures due to the longer crop life cycle.

At each location, the experiment employed split-plot design with treatments of sowing time (W) as the main plot and nitrogen fertilizer (N) as the subplot. There were four sowing times (W_1, W_2, W_3 and W_4) and three levels of nitrogen fertilizer (0, 50 and 100 kgN/ha) using urea.

The crop was firstly sown at all experimental sites on the 1st May 2000 (W_1) at 50 kg seeds/ha followed by weekly intervals (W_2, W_3 and W_4). Fertilizers (P and K), irrigation water and control of pests and diseases were applied as necessary to maintain the crop growth.

Measurements

Measurements consisted of tiller number, crop biomass, grain number and yield; time length between crop developmental stages {sowing time (S), seed emergence (E), anthesis (A) and maturity (M)}, and weather variables particularly air temperature for deriving parameters of crop development based on the concept of thermal-unit (*i.e.* base temperature and thermal unit). Crop developmental stages, tiller number and air temperature were observed on a daily basis. Total biomass was measured at anthesis, while grain number and yield were measured at harvest.

Deriving Parameters for Crop Development

Thermal-unit concept considers that crop developmental rate is determined by temperature only and no photoperiodism response of the crop involved. Wheat crop which is classified as a long-day plant is responsive to daylength when it is grown in temperate climate. By assuming that variation of daylength in Java Island is unimportant, parameters of crop development that determine the duration of developmental phases can be derived using the thermal unit concept as follows:

$$TU = \sum_{i=1}^{n} (T_i - T_b) \qquad (1)$$

TU : thermal unit (d. °C)

T_b : base temperature (°C)

T_i : daily averaged temperature at day i

n : period of the developmental phase under consideration (days), for this research includes S-E, E-A and A-M

Rewriting Equation 1,

$$TU = \sum_{i=1}^{n} T_i - n\,T_b$$

$$= n\,T_{mean} - n\,T_b \qquad (2)$$

where T_{mean} is averaged temperature during the developmental phase under consideration (°C) that can be calculated as,

$$T_{mean} = \sum_{i=1}^{n} T_i / n \qquad (3)$$

Equation 2 can be alternatively written as :

$$T_{mean} = TU\,(1/n) + T_b \qquad (4)$$

By employing regression analysis of T_{mean} against 1/n as dependent and independent variables respectively, we can derive the parameters TU and T_b.

RESULTS AND DISCUSSION

Varying Temperature and Crop Developmental Phases

Variation of Air Temperature among Experimental Sites

Temperature is a major factor determining crop development and hence growth of the crop. The range of averaged temperature of the experimental sites was from 16.5 °C at the highest altitude (1,650 m) to 27.5 °C at the lowest altitude (28 m). Likewise, the ranges of minimum and maximum temperatures were 13.2 – 22.2 °C and 19.7-32.7 °C, respectively, corresponding to their altitudes (Table 1). The relationships between altitude against minimum, averaged and maximum temperatures are presented in Figure 1. This Figure shows that the rates of decreasing temperature with increasing altitude are different among minimum, averaged and maximum temperatures; *i.e.* 6.0, 6.9 and 7.8 °C per 1 km altitude, respectively.

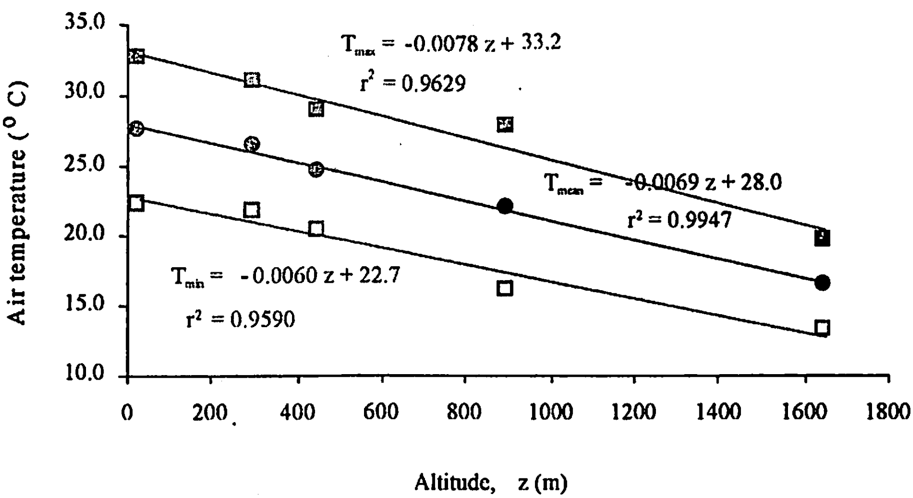

Figure 1. Relationships between altitude and minimum (T_{min}), averaged (T_{mean}) and maximum (T_{max}) air temperatures.

Response of Crop Developmental Phases to Temperature

Other than temperature, the experimental treatments (W and N) at all sites did not affect the duration of developmental phases. Decreasing air temperature with altitude has caused longer growing period of the wheat crop { between sowing (S) and harvest at maturity (M) } among the experimental sites significantly. Cangar (1.650 m) with averaged temperature of 16.5 °C had (144.0 $\pm$ 0.0) days of growing period as compared with (75.9 $\pm$ 2.1) days at Mojosari (28 m) with averaged temperature of 27.5 °C. The growing periods for the other locations were (103.0 $\pm$ 1.4), (100.9 $\pm$ 0.7) and (113.8 $\pm$ 0.9) days at Nongkojajar (22.0 °C), Malang (24.7 °C) and Bogor (26.4 °C), respectively. The correlations between duration of each developmental phase over all the respective treatments (N and W) against the associated averaged air temperature are presented in Figure 2. The small standard deviations at each location (Figure 2) suggest that the developmental phases are more responsive to temperature differences than both treatments of nitrogen supply from fertilizer and different sowing times.

The period of sowing to seed emergence (S-E) slightly increased with lower temperature from 4 to 8 days. Lower temperature significantly increased the periods from emergence to anthesis (E-A), and during grain filling period from anthesis to maturity (A-M). These findings approve the first hypothesis and explain that the longer crop-growing season with altitude caused by lower temperature as shown in Figure 2.

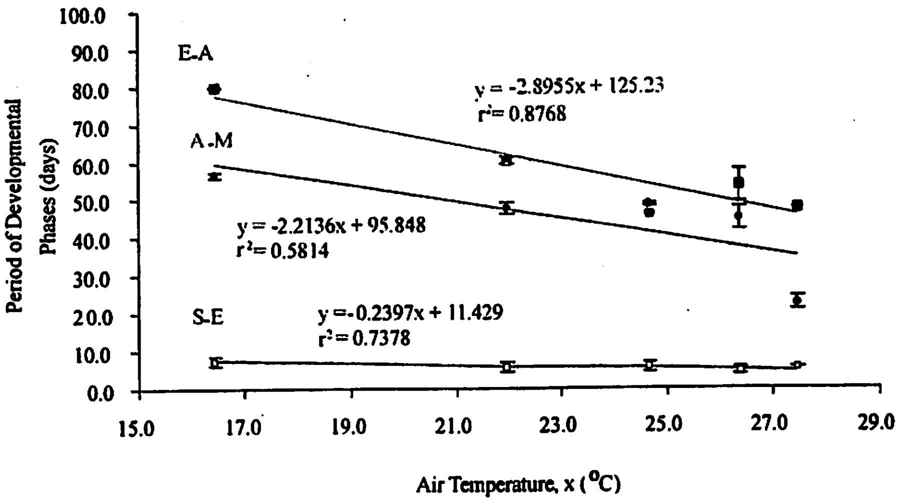

Figure 2. Relationships between averaged air temperature and duration of various developmental phases (S-E, E-A and A-M).

Number of Tillers and Grain Yield

The development of tillers represented by tiller number was highly determined by air temperature as in the case of crop developmental phases. Figure 3 presents the progression of tiller number over time after planting under various nitrogen treatments (N). While nitrogen treatment does not indicate significant effect, it clearly shows that tiller number was higher while its occurrence was slower under lower temperature. This slower rate of occurrence indicates slower developmental rate, as both are caused by the lower temperature, resulting in longer duration of developmental phases (Figure 2). This provides longer time for the crop to accumulate more biomass. Having higher biomass production, greater number of tillers will provide more sink (*i.e.* spikes) to produce higher grain yield. This is relevant with the one shown in Figure 4 that grain yield increases with higher altitudes associated with lower temperatures which agrees with the second hypothesis. In other words, grain yield decreases with increasing temperature and the decrease was about 10 % per 1 °C increase above averaged temperature of 16.5 °C at Cangar (1650 m). In comparison, Gibson & Paulsen (1999) found that high temperature is a major determinant of wheat (*Triticum aestivum* L.) growth and development, decreasing yields by 3 to 5% per 1 °C increase above 15°C in plants under controlled conditions.

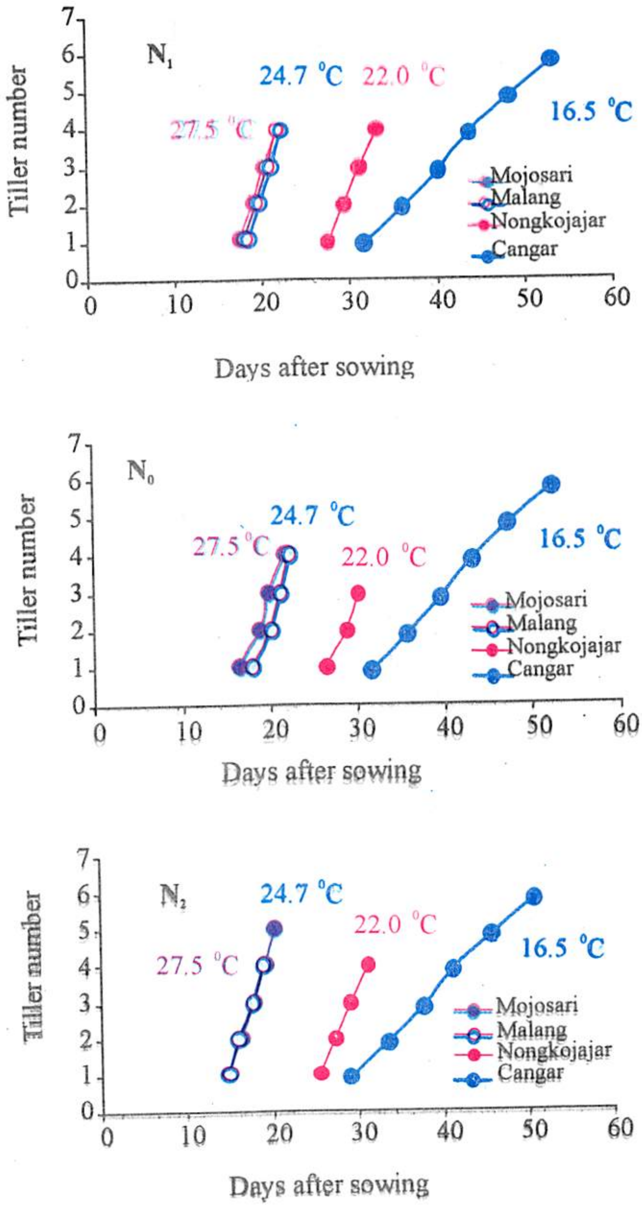

Figure 3. Relationships between tiller number and days after sowing for the three levels of nitrogen treatment (N_0, N_1 and N_2) at four experimental sites [numbers indicate averaged air temperatures at the respective experimental sites].

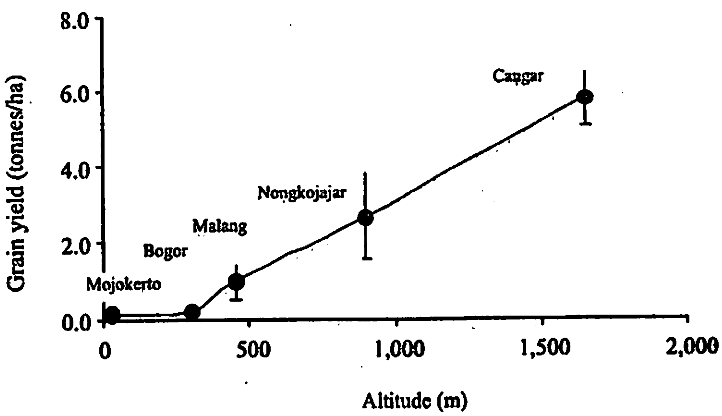

Figure 4. Relationship between altitude and grain yield.
[vertical bars are 2 x standard deviations]

Parameters of Wheat Crop Development

Relationships between averaged air temperature (T_{mean}) and inversed duration (1/n) of each developmental phase (*i.e.* S-E, E-A and A-M) are presented in Figure 5. From the Figure, the parameters of T_b and TU for each developmental phase are summarized and presented in Table 2.

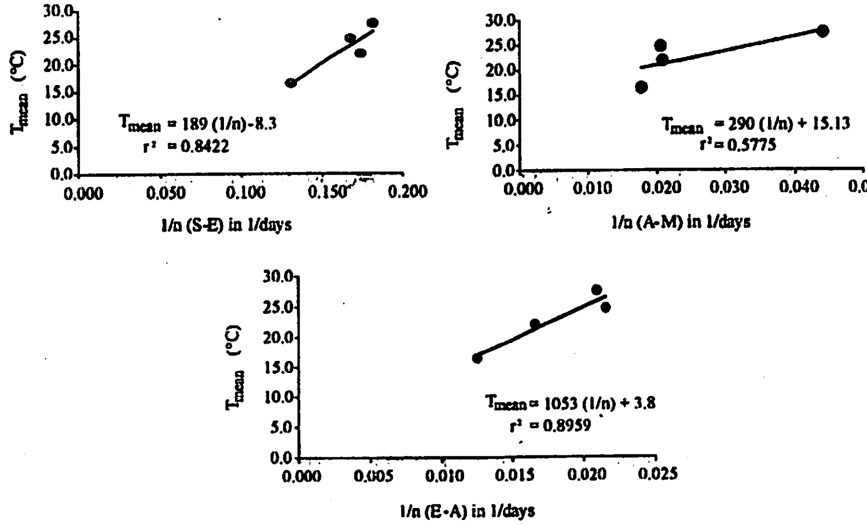

Figure 5. Relationships between (1/n) and averaged temperature of three developmental phases (S-E, E-A and A-M)

Table 2. Derived developmental parameters of the wheat crop.

No	Developmental Phases	Parameters	
		T_b (°C)	TU (d. °C)
1	Sowing-Emergence [S-E]	8.3	189
2	Emergence-Anthesis [E-A]	3.8	1053
3	Anthesis-Physiological Maturity [A-M]	15.1	290

Table 2 shows that both parameters T_b and TU differ between developmental phases. The grain filling period (A-M) has the highest T_b of 15.1 °C, while the lowest is 3.8 °C during vegetative growth prior to anthesis (E-A). This information on T_b indicates that the wheat crop can be grown in mostly any altitude in Java Island provided the averaged temperature is higher than T_b = 15.1 °C. On the other hand, the low T_b of 3.8 °C will cause fast crop developmental rate causing the crop reaches anthesis very quickly leaving very small biomass at anthesis when it is grown at low altitudes with high temperatures, due to large difference between air temperature and T_b (Equation 1). There is correlation between total biomass at anthesis and grain number (O'Leary *et al.* 1985a,b; Handoko 1992) at harvest. The grain number will then determine grain yield at harvest for it acts as the sink for the assimilate during grain filling period (A-M). Figure 6 presents the relationship between total biomass at anthesis and grain number at harvest derived from this experiment.

The importance of biomass at anthesis also correspond to the highest TU (1,053 d.°C) which indicates that during the crop's life cycle, the longer growing period is required to produce vegetative organs (root, leaf and stem) prior to grain filling period. Grain will not be produced if total biomass at anthesis is less than a certain critical amount. This may be the reason that a longer duration of grain filling period does not necessarily improve grain yield (Talbert *et al.* 2001). Using equation in Figure 6, the critical amount of biomass at anthesis derived from this experiment is 125 g/m^{-2} which equals to 1.25 tonnes/ha. Total biomass at anthesis for the site at Mojosari (28 m) which has the highest temperature (T_{max} = 32.7 °C) was less than 1.50 tonnes/ha; and the grain yield from various treatments was so small ranging from 0.11 to 0.23 tonnes/ha.

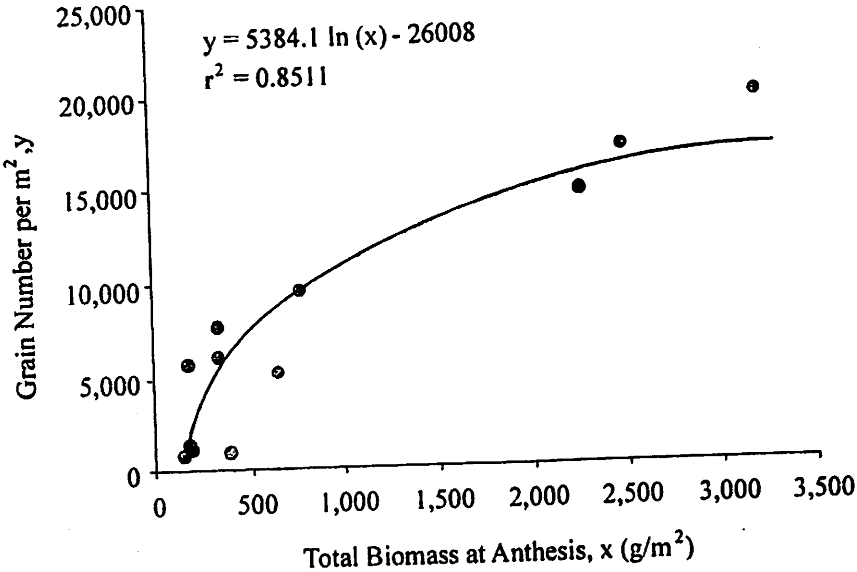

Figure 6. Relationship between total biomass at anthesis and grain number at harvest.

CONCLUSION

Lower temperature reduced the developmental rate of the wheat crop causing longer periods of the developmental phases. In general, the periods from sowing to emergence (S-E), emergence to anthesis (E-A), and during grain filling period from anthesis to maturity (A-M) increased with lower temperature associated with higher altitude. The growing seasons (S-M) of the crop at varying temperatures were (75.9 ± 2.1), (103.0 ±1.4), (100.9 ± 0.7), (113.8 ± 0.9) and (144.0 ± 0.0) days, respectively at temperatures of 27.5, 26.4, 24.7, 22.0 and 16.5 °C.

Parameters of base temperature (T_b) and thermal unit (TU) vary between developmental phases. The magnitudes of T_bs are 8.3, 3.8 and15.1°C while TUs are 189, 1053 and 290 d.°C, respectively for S-E, E-A and A-M. These two parameters indicate that the wheat crop can be grown in most areas of Java Island having averaged air temperature of higher than 15.1°C. On the other hand, the low T_b of 3.8°C (E-A) will result in shorter duration of vegetative growth particularly when the crop is grown at low altitudes with high temperatures.

Yield of the wheat crop increased with higher altitudes associated with a longer crop life cycle which results in more dry matter accumulation. Higher yield corresponded to bigger vegetative organs at anthesis which determined grain number at harvest.

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