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Simulation study of past survival trends in over-wintering of wheat in Iran

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Abstract

The snow-cover on soil, the factor that protects wheat from the biting cold, has generally declined; on the other hand, the surface air temperature has warmed. It is not clear whether these changes decrease winter-killing of wheat or favor it in Iran. Therefore, this study was mainly aimed to determine the past trend in frequency of winter-kill events (Y) for wheat with -4 ^{o}C frost tolerance, using the framework of acclimation/de-acclimation of wheat to temperature. The rate of change in Y was estimated over phases I (frost tolerance increases with decreasing temperature; hardening), II (it shows plateau state for a period with coldest temperature), and III (it decreases with warming; de-hardening) of wheat response to temperature. The input data for model was 39 to 44 years daily weather data for five locations as representative of major agricultural zones in Iran. The results indicated that the surface air temperature has warmed; consequently, the value of snow-falling has been decreasing and changes in acclimation/de-acclimation of wheat over the phases found to be happened in slowed manner. Over phase I, the frequency of winter-killing has remained constant just for Shiraz; for other four locations, the value of frequency has decreased (0.9 to 3.8 times decade^{-1}). Over phase II, the decline varied between 0.8 to 4.7 times decade^{-1} across all five locations. Over other phase, the frequency has shown downwardly trend (1.3 to 3.7 times decade^{-1}) just for three locations. Generally, it can be said that the over-wintering survival has been improving during past decades.

Keywords: Winter wheat; Climate change; Frost; Acclimation; Snow.

Introduction

Generally, in the last century, the global temperature has increased by 0.7 $^{\circ}$C (Rosenzweig et al., 2000). In Beiging, China, was shown that the linear rate of increase in T_{min} is 4.08 $^{\circ}$C/100 year (Karl et al., 1993; Xie and Cao, 1996). Other reports for China indicating that in north regions, increasing trend of temperature has been significant, especially for minimum temperature (Tao et al., 2003). Analyzing daily and monthly maximum and minimum (T_{min}) surface air temperatures at 66 weather stations over the eastern and central Tibetan Plateau for temporal trends also confirmed the warming (Liu et al., 2006). In Iran, results regarding Kermanshah showed that except for January, February and March, the increase in T_{min} is considerable for all other months, especially June (Gholipoor et al., 2006). In other regions, like Gorgan, T_{min} appears to be changed only in May; on the other hand, T_{max} shows no statistically change in all months (Ghorbani and Soltani, 2002). In Tabriz, the averaged mean temperature over growing season of five crops, and over six months of the year has had upwardly trend during past decades (Gholipoor, 2008a).

Because of warming, the portion of precipitation as snow has been diminishing. Satellite records indicate that the Northern Hemisphere annual snow-cover extent (SCE) has decreased by 10% since 1966 largely due to decrease in spring and summer since the mid-1980s over both the Eurasian and American continents (Robinson, 1997; Dore, 2005; Brown and Braaten, 1998). It was found no published report regarding the change in snow falling an SCE for Iran; but because of the rises in air temperature (Gholipoor et al., 2006; Ghorbani and Soltani, 2002; Gholipoor, 2008a; Gholipoor and Shahsavani, 2008), the SCE has probably been decreasing. In contrary with all these reports, some reports, like Leathers and Ellis (1996) and Folland et al. (2001) show upwardly change of snow-falling.

Generally, the snow coverage on the soil has the insulating effect and tends to minimize the risk of winter-kill events by decreasing the fluctuation of crown temperature (Ritchie, 1991). Based on this fact, and on mentioned reports regarding decrease in snow-falling, it may be hypothesized that the successfulness of over-wintering has been decreasing for winter wheat; on the other hand, climate-change-resulted warming tends to enfeeble this hypothesis. Therefore, this simulation study was aimed to determine the past trend in frequency of winter-kill events for wheat. The framework of acclimation/de-acclimation of wheat to temperature was used as Fowler et al. (1999). The result of this evaluation can be used in breeding programs that aimed at the releasing of new cultivar (s) with enough frost tolerance.

Materials and Methods

Calculation procedure for the frost tolerance

In this study, like previous one (Gholipoor, 2008b), the approach of Fowler et al. (1999) was recoded in Qbasic programming language to estimate the daily value of frost tolerance in winter wheat during the autumn-winter. Briefly, in this approach, the LT50 (temperature at which 50% of the population is killed in a controlled freeze test) is used as an index for level of cold hardiness. The daily change in cultivar LT50 (RATEH) in the model is calculated as:

$$RATEH = 0.012\ (10.0-TC)\ (LT50-LT50C) \tag{1}$$

Where TC is daily mean crown temperature for temperatures below 10 °C, LT50 is the crown LT50 for the previous day, and LT50C is the cultivar LT genetic coefficient.

The threshold temperature (average daily crown temperature) for the initiation of cold acclimation is equal to 10 °C; daily rate of hardening is estimated using the assumption that acclimation rates at non-lethal below freezing temperatures are similar to those at 0 °C. Daily calculation of de-hardening (RATED) is as:

$$RATED = 0.000017\ (LT50i - LT50)\ (TC+4)^3 \tag{2}$$

Where TC is the mean daily crown temperature for temperatures above 8 °C and LT50 is the crown LT50 for the previous day. LT50i is the LT50 of an unacclimated crown as:

$$LT50i = -0.6 + 1.42\ LT50C \tag{3}$$

It is assumed that temperatures above 10 °C result in loss of cold hardiness at all stages of acclimation, while partially acclimated plants de-acclimate at temperatures above 8 °C. It is considered that the de-acclimation rates at temperatures above 18 °C are similar to those at 18 °C. In the model, the expected LT50 for different exposure times to constant temperature is calculated using the following equation:

$$LT50_{(T)} = LT50_{(0)} + 5.72 + 1.53\ \ln(T) \tag{4}$$

Where T is the number of days that plants are exposed to a constant LT stress. $LT50_{(0)}$ is the value that has been determined by Fowler and Carles

(1979). When the daily mean crown temperature (TC) is colder than -3 °C and the difference between the minimum LT50 (LT50M) attained during LT acclimation and the crown temperature (TC) is greater than -12 °C, the daily change in LT tolerance is calculated as:

$$LT50n = LT50-(LT50M-TC) / \exp[-0.654 (LT50M-TC)-3.47] \quad (5)$$

Where LT50 is the crown LT50 for the previous day and LT50n is the crown LT50 of the current day. At temperatures warmer than 3.5 °C, LT50M is equal to the daily adjusted LT50. LT50M is equal to the cultivar LT tolerance genetic coefficient (LT50C) when full acclimation is achieved. Death of the plant (winter-killing) is assumed to occur if the average daily soil temperature at crown depth falls below the daily adjusted LT50. In this approach, LT50 estimates are updated daily, thereby providing a current record of the plant’s ability to tolerate the low temperatures.

As mentioned, instead of air temperature, the mean daily crown temperature is used for calculating the rate of acclimation/de-acclimation to temperature. When mean air temperatures are less than 0 °C for long period, i.e. frozen soils, the plant crown temperature is higher than the air temperature due to heat retained in the soil. The insulating effect of snow at air temperatures less than 0 °C raises the temperature of the plant crown higher than the air temperature, and magnitude depends on snow depth (Ritchie, 1991). A sub-model was made using QBASIC programming to calculate the snow-cover and snow melting as report of Ritchie (1991). This procedure has been used by many researchers including Soltani et al. (2006) and Gholipoor (2009). In this sub-model the value of snow is calculated based on maximum temperature. This temperature is also used for daily calculating the amount of snow melting. The crown mean temperature was calculated for either snow-covered or no-covered frozen soil, as it has been implemented in CERES-Wheat model (Ritchie, 1991).

Locations, calculated attributes and estimation of trends

Five locations with long-term and reliable daily weather data were selected for the study to represent a large geographical area and several climatic zones in Iran. The selected locations included Isfahan (32.67 °N, 51.87 °E and 1600 m asl), Shiraz (29.55 °N, 52.60 °E and 1488 m asl), Kermanshah (34.32 °N, 47.12 °E and 1322 m asl), Tabriz (38.13 °N, 46.28 °E and 1364 m asl), and Mashhad (36.27 °N, 59.63 °E and 990 m asl).

The calculated attributes were mean temperature, rainfall, snow-falling, snow/rain ratio, and frequency of winter-kill events (decreasing the crown temperature below the level of adjusted frost tolerance) for winter wheat with -4 °C frost tolerance. The value of these attributes was calculated over three distinguished acclimation/de-acclimation phases, separately. The distinguishing and determining the length of each phase have been done using non-linear functions in previous study (Gholipoor, 2008b). In general point of view, the phase I, say acclimation, is characterized by increase in frost tolerance (hardening) of wheat with decreasing the temperature in late autumn and/or early winter; then shows plateau state for a period with the coldest temperature (II); finally appears to decrease with warming the temperature (III; de-acclimation). In particular point of view, across each phase, the plant experiences both acclimation and de-acclimation, due to temperature fluctuation; accordingly, both averaged daily increase in absolute value of LT50 (hardening; say acclimation), and averaged daily decrease in it (de-hardening; say de-acclimation) were also calculated over each phase, separately.

As other studies (Gholipoor, 2008a; Gholipoor, 2008b; Gholipoor, 2009; Gholipoor and Shahsavani, 2008), it was only used the simple linear regression model Y=a+bX to determine the rate of increase/decrease (b) in attributes; where Y, X, a, b are dependent variable (attributes), year, intercept and the slope of regression line, respectively; the values of parameters (a and b) was calculated, using the REG procedure in SAS (SAS, Institute, 1989). Like many researchers, including Soltani and Gholipoor (2006), the rates with probability level equal to and/or lower than 0.1 were considered as significant.

Results and Discussions

The rate of change (value of "b" in equation Y=a+bX) and its probability level for averaged temperature over each of three phases of acclimation-deacclimation have shown in Table 1. Over phase I, the past changes in value of temperature have been upwardly for all locations; among locations, Mashhad appeared to have the highest rate of warming (0.77 °C per decade); while the lowest rate was found for Isfahan (0.33 °C per decade); it ranged from 0.54 to 0.73 °C per decade for other three locations. Over phase II, the decrease in temperature tended to be statistically negligible for Isfahan; the probability level for increase in surface air temperature found to be higher than 0.1 for Kermanshah and Shiraz; therefore the changes in temperature have also been statistically negligible for these two locations; on the other hand, the rest two locations have experienced the inclining trend in temperature, especially for phase II. Over phase III, the value of temperature has been statistically the same across years 1961 to 2004 for Isfahan; while, it found to be increasing for the rest four locations; averaged over Kermanshah, Mashhad, Shiraz and Tabriz, the increasing rate in temperature was about 0.39 °C per decade for phase III, which appears to be lower than that (0.65 °C per decade) for phase I. The inclining trend in temperature is in agreement with many reports, including Linkosalo et al. (2009) and Hegerl et al. (2004).

The rate of change in amount of snow and rain has been presented in Table 1 and 2, respectively. Over phase I, the snow-falling has been diminishing by 0.04 mm decade^{-1} for Isfahan; it seems that the warming has only been responsible for this decline; because the value of rainfall has remained constant across the years 1961 to 2004; this is also confirmed by considerable decrease in ratio of snow to rain (Table 2). Compared to Isfahan, the declining trend in snow-falling appeared to be about twice in Kermanshah; expectedly, the rate of warming (sole cause of diminishing snow in this place) tended to be about two times higher in Kermanshah than in Isfahan. Mashhad was characterized by the highest reduction in snow-falling (about 0.2 mm per decade); no change in rainfall implies that the inclining trend of temperature has been the sole cause of such changes in snow. In some other countries, the warming of surface air temperature has also been the major cause of decline in snow-falling (Dore, 2005). In Tabriz, although the upwardly trend of surface air temperature, and downwardly trend of value of rainfall were statistically considerable, the diminishing trend of snow-falling tended to be negligible.

Shiraz never experiences snow-falling during the phase II; the value of rainfall has been the same across the tested years for this phase. No changes were found for rainfall and snow-falling in Isfahan and Mashhad. In Kermanshah, the probability level was 0.22 and 0.08 for the rate of snow-falling and rainfall, respectively; therefore, the lessening trend has statistically been negligible for snow-falling, but considerable for rainfall (0.6 mm decade^{-1}). The increase in temperature, and decrease in rainfall have synergistically caused that the diminution in snow-falling amounts to 2.7 mm per decade for Tabriz.

Table 1. The rate of change (value of b in equation Y=a+bX) and its probability level (P) for value of temperature (Temp; °C $year^{-1}$) and of snow (mm $year^{-1}$) over phases (I, II and III) of acclimation and de-acclimation of winter wheat to cold during past decades.

Location	Temp-I		Temp-II		Temp-III		Snow-I		Snow-II		Snow-III	
	b	P	b	P	b	P	b	P	b	P	b	P
Isfahan	0.033	0.00	-0.011	0.76	0.006	0.57	-0.004	0.06	-0.019	0.31	0.000	0.97
# Kerma	0.054	0.00	0.043	0.27	0.030	0.01	-0.009	0.09	-0.084	0.22	-0.001	0.69
Mashhad	0.077	0.00	0.110	0.08	0.039	0.02	-0.019	0.06	-0.006	0.86	-0.003	0.72
Shiraz	0.073	0.00	0.018	0.53	0.048	0.00	-0.003	0.07	-----	-----	-----	-----
Tabriz	0.055	0.00	0.122	0.01	0.038	0.01	-0.017	0.12	-0.270	0.01	-0.005	0.60

Kermanshah.

Table 2. The rate of change (value of b in equation Y=a+bX) and its probability level (P) for value of rain and of ratio of snow to rain (S/R) over phases (I, II and III) of acclimation and de-acclimation of winter wheat to cold during past decades.

Location	Rain-I		Rain-II		Rain-III		SI / RI		SII / RII		SIII / RIII	
	b	P	b	P	b	P	b	P	b	P	b	P
Isfahan	0.002	0.19	0.007	0.29	0.005	0.15	-0.017	0.03	-0.002	0.82	0.000	0.92
#Kerma	0.000	0.94	-0.062	0.08	-0.018	0.07	-0.008	0.07	-0.011	0.31	0.000	0.90
Mashhad	0.001	0.61	0.000	0.97	0.002	0.72	-0.029	0.01	-0.010	0.46	-0.002	0.71
Shiraz	0.010	0.12	-0.029	0.50	0.005	0.43	-0.003	0.08	-----	-----	-----	-----
Tabriz	-0.007	0.04	-0.012	0.03	-0.009	0.17	-0.021	0.12	-0.049	0.01	-0.003	0.71

Kermanshah.

The 3rd phase is characterized by alleviation of the biting cold. Similar to the phase II, this phase never faces with snow-falling in Shiraz; on the other hand, in the rest locations, snow-falling also tends to happen over this phase. Over phase III, the snow-falling has remained constant for Isfahan; the increase in rainfall was also found to be statistically negligible for this location; therefore, the ratio of snow to rain has showed plateau state over the tested years. Nearly similar situation was obtained for the other locations. The monthly- and/or yearly-decrease in snow-falling have been reported by many researchers, including Aizen et al. (1997) and Brown (2000) for other countries.

During the phase I, wheat acclimates (increase in absolute value of LT50) to the frost with decreasing temperature and photoperiod in fall/early winter; however, some de-acclimation is also happened due to fluctuation of the temperature; therefore, the value of increase in absolute value of LT50 is generally higher than that of decrease in it (Gholipoor, 2008b). Across the phase III (mid/late winter), the value of de-acclimation is expectedly more considerable than that of acclimation. Considering the happening of both decrease and increase in absolute value of LT50 across each phase, the past trend in both averaged value of hardening and de-hardening over each phase was estimated (Table 3). In wheat with high potential frost tolerance, there is direct relation between the value of acclimation-resulted hardness to the frost, and that of coldness of the fall/winter; in another words, the grown wheat in too cold weather tends to have higher acclimation-resulted frost tolerance than that in less cold weather. Based on this issue, and on above mentioned results regarding the warming, it is expected that the value of hardening to be decreasing over phase I for all locations; while as it can be seen in Table 3, the downwardly trend of hardening was not significant for Isfahan. In Kermanshah, the averaged value of hardening over the named phase has been declined by 0.95 $^{\circ}$C decade^{-1}; in another words, the hardening has tended to show slowed-happening trend with incrementing the year; this downwardly trend was 0.72, 0.97 and 0.87 $^{\circ}$C decade^{-1}, for Mashhad, Shiraz and Tabriz, respectively. During the phase II, despite of the negligible increase in temperature, it found the considerable decrease in value of hardening for Kermanshah; in Mashhad and Tabriz, the declining trend in hardening has been consistent with warming trend of surface air temperature; in the rest locations, that of hardening has showed the steady state, associated with no change in temperature. Over phase III, the downwardly trend for hardening was significant just for Kermanshah (0.34 $^{\circ}$C decade^{-1}) and Mashhad (0.46 $^{\circ}$C decade^{-1}).

Table 3. The rate of change (value of b in equation Y=a+bX) and its probability level (P) for value of hardening (Hard; $^{\circ}$C year^{-1}) and of de-hardening (Dhard; $^{\circ}$C year^{-1}) over phases (I, II and III) of acclimation and de-acclimation of winter wheat to cold during past decades.

Location	Hard-I		Hard-II		Hard-III		Dhard-I		Dhard-II		Dhard-III	
	b	P	b	P	b	P	b	P	b	P	b	P
Isfahan	-0.014	0.35	-0.021	0.18	-0.008	0.64	-0.039	0.00	-0.020	0.06	-0.018	0.29
#Kerma	-0.095	0.05	-0.044	0.04	-0.034	0.10	-0.057	0.00	-0.005	0.12	-0.027	0.00
Mashhad	-0.072	0.09	-0.037	0.07	-0.046	0.06	-0.089	0.00	-0.004	0.47	-0.037	0.00
Shiraz	-0.097	0.07	0.001	0.71	-0.016	0.51	-0.101	0.00	-0.001	0.79	-0.059	0.00
Tabriz	-0.087	0.08	-0.039	0.08	-0.009	0.72	-0.053	0.00	-0.010	0.38	-0.027	0.00

Kermanshah.

The rates of change in averaged value of de-hardening over each phase were shown in Table 3. Over phase I, the trend of de-hardening has been declining for all tested locations; in another words, the value of temperature-fluctuation related decrease in frost tolerance has been slowing down over the tested years; this deceleration appeared to be more considerable for Shiraz; while it found to be relatively little for Isfahan; for other locations, it ranged form 0.53 to 0.89 $^{\circ}$C decade^{-1}. Over phase II, the diminishing trend was just significant for Isfahan. Over phase III, the rate of change in de-hardening tended to be statistically negligible for Isfahan, but considerable for the rest locations; similar to phase I, the deceleration found to be the highest for Shiraz; the 2nd highest declining trend has been happened for Mashhad; Tabriz and Kermanshah have had the same rate of decrease in de-hardening (0.27 $^{\circ}$C decade^{-1}). Averaged over Kermanshah, Mashhad, Shiraz and Tabriz, the rate of slowing down in value of de-hardening was lower for phase III, as compared to phase I.

Figure 1 shows the trend of frequency of winter-kill happening for a winter wheat with frost tolerance up to -4 $^{\circ}$C. The results regarding phase I indicated that the probability level for changes in frequency of winter-killing was 0.35 for Shiraz, but lower than 0.05 for the other locations; therefore the named frequency has statistically remained constant across the tested years just for Shiraz; averaged over the tested years, frequency tended to be lower in Isfahan and Shiraz, when compared with other three locations; in Isfahan, the frequency has been diminished from 6.7 times year^{-1} in 1961 to 2.8 times year^{-1} in 2004; the rate of decrease in frequency was found to be about 2.6 and 3.8 times decade^{-1} for Kermanshah and Tabriz, respectively; in Mashhad, the frequency has been equal to 5.3 in 2004, which is lower than that in 1961 (18.9). Over phase II, it was found the inversed change in frequency with incrementing the year for all locations; the highest and 2nd highest rate of decline has happened in Tabriz and Mashhad, respectively; the frequency has been down warded by 2.5 and 0.86 times decade^{-1} for Kermanshah and Shiraz, respectively; the rate of decrease has been equal to 0.89 for Isfahan. Over phase III, Shiraz and Tabriz have never experienced any change in frequency across the tested years; in Isfahan, the frequency has been equal to 10 for 1961, which is considerably higher than that for 2004 (4.3); the value of slope of equation tended to be -0.29 and -0.37 times year^{-1} for Kermanshah and Mashhad, respectively. Averaged over locations, the rate of decrease appeared to be higher for phase II (3.8 times decade^{-1}), as compared to other two phases.

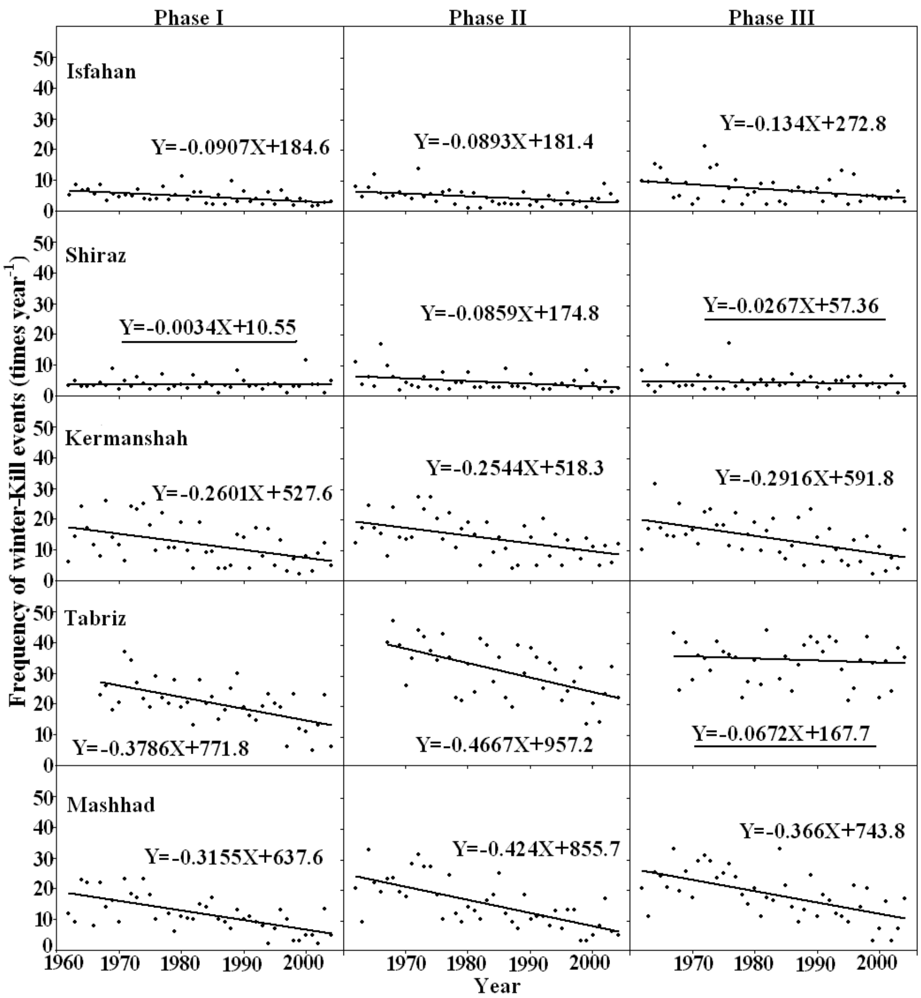

Figure 1. The past changes in frequency of winter-kill events (decreasing the crown temperature below the level of frost tolerance) over three phases of the acclimation / de-acclimation for a winter wheat with -4 °C frost tolerance. The decrease is statistically negligible for the figures that have under-lined equation.

Conclusion

The results indicated that the surface air temperature has shown the increasing trend with incrementing years from 1961 (1966) to 2004, especially during phase I. This change gave rise to (1) the value of snow-falling to be decreasing, and (2) change in frost tolerance of wheat during acclimation/de-acclimation period to be happened in slowed manner. Over phase I, the frequency of winter-killing has remained constant just for Shiraz; for other four locations, the value of frequency has decreased (0.9 to 3.8 times decade^{-1}). Over phase II, the decline varied between 0.8 to 4.7 times decade^{-1} across all five locations. Over other phase, the frequency has shown downwardly trend (1.3 to 3.7 times decade^{-1}) just for three locations. Generally, it can be said that the over-wintering survival has been improving during past decades; therefore, it will be needed to cultivars with lower frost tolerance in future, if this detrimental trend of climate change continues.

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