Indian J. Hort. 67(4), December 2010: 567-573

Short communication

Forecasting different phenological phases of apple using artificial neural network

Yazdan Panah Hojat* and Ohadi Delnaz**
Geography Department, Faculty of Humanities and Literature, University of Isfahan, Isfahan, Iran

ABSTRACT

Apple is one of the oldest trees in the world, which is widely cultivated because of its high compatibility with different climatic conditions. In this study, we applied phenological statistics of agricultural meteorology data of Golmakan to anticipate different phenologic phases in apple using Intelligent Neural Network. At first, the matrix of input data which is consisting of climatic parameters such as minimum temperature, maximum temperature, the mean of daily temperature, absolute minimum temperature, and absolute maximum temperature were established. The range of temperature changes, growing degree days and chill unit (in silver tip phase) had been prepared for different phenological stages during 1999-2005. The matrix of collected data was worked out which, in fact, were the occurrence dates of different phenological stages was prepared and the modeling of different phenological stages in apple by using neural network. The accuracy of model was examined by using RMSE index and by contrasting real and anticipation dates during two years. For this purpose observed climatic and phenological data was also used in similar figure at investigating zone. The phenological stages of apple could be anticipated with acceptable accuracy using climatic parameters.

Key words: Apple, phenology, climate, neural network.

Phenologic studies on various phenological stages of growth and biological cycles such as bud break, flowering and fruiting as a result of climatic factors and environmental condition plants have revealed obvious morphologic changes, in growth processes these morphologic changes are called phenological stages and the related observations are also called phenological observations. As a biological reaction against the temperature, apple tree passes through different phenological phases during annual growth cycle in which transfer speed from one stage to the other stages specified by climate factors, specially temperature; so, having heat units and weather forecast could help us in anticipating the beginning and the termination of each stage from budding to leaf fall. The anticipation of different phenological stages of plants has an important role on agricultural planning and management. So that it not only is exercising management in order to, increase production and decrease damages of all kind of stresses, pests and diseases, but also have to know the crucial role on issuing agricultural meteorology warnings and altering farmers against injurious atmospheric vagaries.

In general, phenology can be considered as one possible approach to observe the effects of climatic change (Roberto, 9). Several approaches have been proposed in phenological modelling. Empirical models that link phenophases to the time spent above a certain temperature have been proposed (Roberto, 9). Following the early development of phenological models, based mostly on daily data, and the increase in high time-resolution meteorological recording, phenologists have progressively focussed on hourly algorithms. Both chill unit and growing degree days (or growing degree hours) are cumulative, taking into account a threshold value below which no temperature contribution is effective. For fruit trees, the base values for growing degree hours or growing degree days thermal sums usually range between 0°C and 9°C (Cesaraccio *et al.*, 4). Chill unit are cumulative when the temperature range is between -2°C and 13°C. Nonetheless, a sound model calibration needs to take into account several thresholds for growing degree days and chill unit in order to choose the best-performing values against experimental outcomes (Ashraf, 2). Anderson (1) used triangular, rectangular or sine-wave models for estimation of growing degree days. Acceptable results have been obtained for fruit trees by models that use both maximum and minimum daily temperatures, by implicitly considering the dynamics of daily cycles of temperature (Cesaraccio *et al.*, 4). In this study, using intelligent neural network technique and climate data and phenological data of Golmakan area was used for modeling of anticipation of different phenological stages in apple.

*Corresponding author's E-mail: H.yazdan@geog.ui.ac.ir
**Department of Agricultural Meteorology, Meteorological Administration of Isfahan Province, Isfahan, Iran

Agricultural meteorology station of Golmakan, the site of study, is located at the west of Mashhad, Khorasan Province with a longitude of 59°, 17' a latitude of 36°, 29' and an altitude of 1,176 m above mean sea level. The mean temperatures of the locality during winter, spring, summer and autumn were 3.5, 18.1, 22.2 and 8.5°C, respectively.

Apple trees in this region show two distinct growth stages during its annual life cycle; *i.e.* rest period and active growth period. These two periods, involve several phenological stages, which have appeared following each other (Quanta, 10). Rest period, the period begins with fall of the leaf in autumn and continues till silver tip stage, and Active growth period, the period begins with silver tip in spring and terminates with fall of the leaf fall in autumn. During this period, phenological phases of apple will be complete from budding to leaf fall. According to this arrangement Silver tip, Green tip, Pink bud, Full bloom, Fruit set, Fruit development, Side bloom and finally Petal fall are phenological stages of apple tree.

Sufficient chilling during winter is necessary to break rest period of apple tree, so that insufficient chilling could be a limiting factor for majority of apple cultivars. This amount varies between 800 to 2000 h, but the average is 1600 h (hours below 7°C) (Milcous, 8). Data in Table 1 shows different phenological stages of apple at study site and the average of statistics related to the duration of each phenological stage. Phenological observations consisted only recording of the date on which a certain phenophase occurred; during a series of seven years long (1999-2005). All phenological data was obtained from Golmakan Agrometeorological Research Station Bulletin. Phenol-phases for any bud were recorded once or twice a week over the period 1999-2005. Before and after this period, the dates of initial, full and end flowering were also recorded.

To change the format of the data from date to numeric data, we transformed all data to Julian date. To do this the first of the January was chosen as a base (starting point) and all the dates were transformed to Julian data. In this section, timed chilling unit during day and night was calculated based on Utah method (Beers, 3) by using minimum temperature, maximum temperature and changed it to timed form. In this method, a unit of chilling unit was equal to an hour in which the plant put at 6.1°C, so that the temperature affect deduced in lower and / or higher temperatures. According to Utah method, in estimating chill unit, the rates of temperature are as: After calculating chill unit (CU) for each hour during night and day, accumulated chill unit get to its minimum limit. This time is a basis for calculating chilling unit which is calculated from the next day of this date to the blooming (Zinoni, 15).

The meteorological database stems from the agro-meteorological observational station of Golmakan during 1999-2005. Temperature data were taken from the station closest to each phenological observation point. In most cases, phenological and meteorological observation sites coincided and so no adjustment was needed for meteorological data. Both phenological and meteorological databases were checked to detect errors, and data were subjected to validation processes based on comparisons with nearby stations. In some cases, the series presented gaps or irregularities for two main reasons: (1) station malfunctioning, or (2) over certain periods, absence of a match between phenological observation site and location of the meteorological station, due to missing meteorological data.

Significant gaps in the meteorological dataset (full days) and missing periods were reconstructed by geostatistical methods on the basis of other stations in the network (Cesaraccio, 4). "Kriging with drift" has proved to be a precise interpolation method for temperatures in our area, according to (Roberto, 11), who tested several techniques for spatial interpolation; this method was applied to fill daily data gaps. Minor hourly gaps were filled by linear interpolation between existing records. The Utah Model was applied to

Table 1. Different phenological stages of apple at the study site.

Degree day	Stage duration (day)	End of stage	Beginning of stage	Phenological stage
22	7	14 March	8 March	Silver tip
91	15	3 April	19 March	Green tip
99	11	10 April	30 March	Pink bud
151	13	22 April	11 April	Side bloom
108	12	19 April	8 April	Full bloom
161	15	8 May	24 April	Fruit set
226	17	26 May	11 May	Fruit development
87	6	1 June	26 May	Petal fall

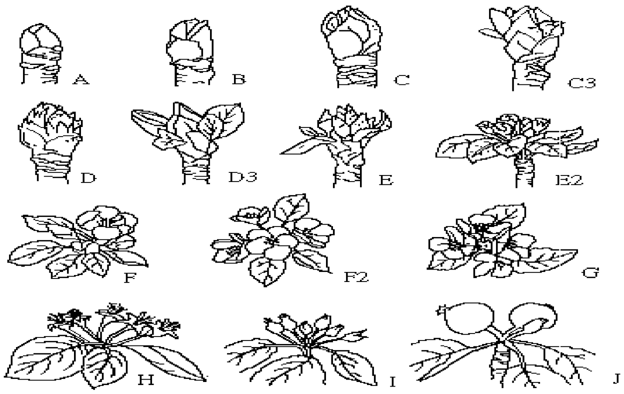

Fig. 1. Phenological stages for apple, A Dormant bud to J Fruit formation; Data day counting (day- counting of data).

approximated GDH and CU, and to the respective measured quantities, in periods with available hourly data. Phenological models, such as Utah Model, use of "chilling and forcing" algorithms with different parameterizations of the CU and GDH summation.

Richardson *et al.* (12), proposed an accumulation of CU based on a table (Table 3, Fig. 4) that sets the efficiency of CU according to a temperature-dependent broken line. At the end of summer, CU accumulation is negative, owing to the prevailing action of high temperatures. The start date of CU accumulation is fixed as the day in autumn when the largest negative value of CU is attained. After the chilling phase, this is required to release dormancy. Asharaf *et al.* (1997), proposed the application of an hourly, linear forcing model, expressing heat accumulation as GDH. The forcing stage is based on a fixed threshold and its equation is:

$$GDH(k)=\sum_{i=r}^{k}\sum_{h=1}^{24}\max[0,T_h(i)-T_b]$$

where k is a generic day (k≥r), r is the day of rest completion (fulfillment of chilling requirement), T_h (i) is the hourly mean temperature at hour h and day i, and T_b is the threshold (or base) temperature. The "Utah" approach used a value of 4.4°C for Tb. An equivalent daily model has been tested, which cumulates daily temperatures above the same 4.4°C threshold:

$$\mathrm{GDD(k)}=\sum_{\mathrm{i=r}}^{\mathrm{k}}\max\left[0,\overline{\mathrm{T}}_{\mathrm{i}}-\mathrm{T_b}\right]$$

Where; t = is the average temperature of day i.

For all phenological stages, it's necessary to calculate the rate of heat units distinctly during statistical period because the rate of heat units is one of the basic specifying parameters for passing period duration from one to the other phenological stage. The rate of heat unit for each stage was calculated by using this equation:

$$\mathrm{Hu}=\sum_{\mathbf{i=1}}^{\mathrm{N}}\left[\frac{\mathrm{TM}_{\mathbf{i}}+\mathrm{Tm}_{\mathbf{i}}}{\text{۲}}-\mathrm{Tt}\right]$$

In this formula:

H : The effective accumulated temperature in degrees during a phenological stage.

TMi : maximum daily temperature in day "i"

Tmi : minimum daily temperature in day "i"

N : phenological stage duration

and T_t is vital temperature threshold (basic temperature or vital zero point) which equals to 5°C in apple crop.

In this study, the modeling and the forecasting of different phenological stages of apple was performed by neural network. At first, maximum mean, minimum mean, mean temperature, absolute maximum, absolute minimum, temperature range, growing degree days in different phenological stages and chilling unit hours in Silver tip (according to daily statistics of station) were taken for each year. All of these climatic factors had been organized input vector to network and outcoming

Temperature (°C)	CU
T<1.4	0
1.5<*T*<2.4	0.5
2.5<*T*<9.1	1
9.2<*T*<12.4	0.5
12.5<*T*<15.9	0
16<*T*<18	-0.5
T<18	-1

vector of model was the various occurrence dates of different phenological stages of apple.

Phenological statistics of apple was prepared during six years (1999-2004) to set data matrix. Also meteorological data of the Golmakan Agro-meteorological Station was prepared from the Data bank of Meteorology Administration for the same period. Then the following meteorology factors were selected for each stage in every year and input data matrix was constructed (Table 2).

$C\mu$: chill unit hours; $t\max$: average of maximum temperature in each stage and each year (°C), $t\min$: average of minimum temperature in each stage and each year (°C), t : mean of daily temperature in each stage and each year (°C); $T\max$: absolute maximum of daily temperature in each stage and each year (°C), $T\min$: absolute minimum of daily temperature in each stage and each year (°C), and R : range of temperature changes

After preparing data matrix, four years of existing statistics (input and outcoming data) in each stage were allotted to network training. The other two years of statistics were applied for constructing the test file. One of the most important anticipation stages with the models of neural network was the determination of parameters of model including the number of input and outcoming layers and the amounts of neurons of model too (Safa, 13).

The neural network was constructed with six nodes in the hidden layer. Initially all input values were included. Neural networks were trained using input matrix data. Following training, the network was validated using the remaining data set. In transferring data to neural network, the initial figures were often abstention and the rate of training was determined in test and error form, so that the outcoming of model had the minimum error rate. In this study, the mathematic function of model was non-linear function and the middle layers of model were three layers. Some errors have been observed in transferring of existing data to different models. It seems that the reason of the existence of model error was the effect of the other environmental factors on natural function.

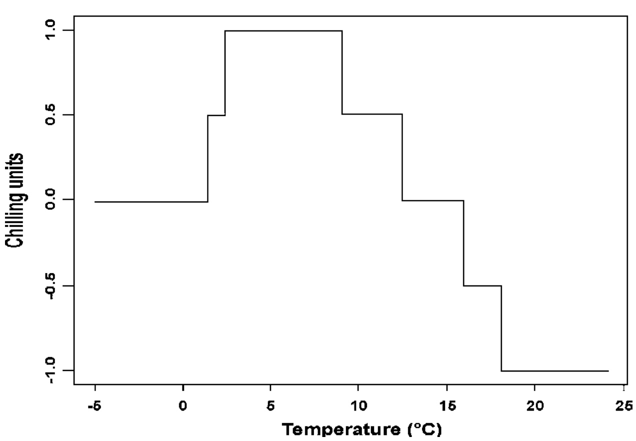

Fig. 2. Utah Model: chilling units (CU) as a function of temperature.

In order to examine the accuracy of model, the real statistics was used (Two years test) and contrasted them with the statistics of estimated function by model. A suitable quantitative index applied to determine the accuracy of model was 'd' index which was assessing the accuracy of model according to observed and estimated figures. The'd' index was calculated by the following equation (Yazdanpanah, 14).

$$d = 1 - \frac{\sum_{i=1}^{n} (\rho i - o i)2}{\sum_{i=1}^{n} (|\rho i| + |o i|)2} \quad 0<d<1$$

Where:

$$\rho i = P_i - O$$

$$o i = O_i - O$$

Where, O is the mean of real data and Pi & Oi respectively were estimated figures and real figures in each year. Whatever the 'd' index is close to '1' the accuracy of model is higher and whatever it is closer to '0' the accuracy of model is lower. In this study, the 'd' index was equal to 77%, which showed that the anticipation model of occurrence dates of different phenological stages of apple according to climatic data had sufficient accuracy in Golmakan area.

The study of data transferring to neural network model showed that most of the error was related to the anticipation of fruit development stage. So that this model by using parameters such as maximum mean, minimum mean, temperature mean, absolute maximum, absolute minimum, temperature range, growing degree day in different phenological stages and chilling unit hours in Silver tip stage. Anticipated the estimated rate of stage duration lower than what we considered (nearly three days) and the least error rate related to the anticipation of Side bloom stage. It was observed that the error rate of model was acceptable and the accuracy of model didn't have meaningful deduction. It is necessary to note the type of study apples similar at both of the areas. The other considerable case is the importance effect of climate and atmospheric parameters in determining the dates of different phenological stages.

Table 3. Input matrix of data in different phenological stages of apple.

CU	Temperature range	Absolute min.	Absolute max.	Mean temp.	Min. mean	Max. mean	GDD	Stage duration	Occurance date	Year	Stage
108	21.6	-3.6	18	5.6	2	9.24	21	10	3.13-3.22	1999	Silver tip
75.5	25.3	-6.8	18.5	5.7	-1.13	12.5	24	9	3.9-3.17	2000	
48	25.2	-3.8	21.4	9.1	2.48	15.68	25	5	3.6-3.10	2001	
45	28.2	-8.6	19.6	5.7	-2.48	13.88	19	7	3.4-3.10	2002	
79	19.6	-1	18.6	7.6	1	13.8	23	7	3.7-3.13	2003	
71	20.8	-1	19.8	7.7	2.1	13.3	20	6	3.9-3.14	2004	
	16.8	0.2	17	8.62	1.6	15.64	20	5	3.15-3.19	2005	
108	22.4	0.8	23.3	10.8	5.81	15.97	92	15	3.28-4.11	1999	Green tip
75.5	30.7	0.5	31.2	11.9	4.5	19.34	95	14	3.27-4.9	2000	
48	27.8	-5.4	22.4	9.3	1.96	16.65	87	16	3.7-3.22	2001	
45	34	-8.6	25.4	11.4	3.63	19.33	88	12	3.9-3.20	2002	
79	24	-0.6	23.4	9.7	4.2	15.1	86	17	3.19-4.4	2003	
71	25.2	0.2	25.4	10.5	3.8	17.1	98	17	3.26-4.11	2004	
	27.5	-5	22.5	8.43	0.33	16.53	56	12	3.17-3.28.	2005	
108	24.2	0.6	24.8	11.3	5.87	16.8	90	14	4.6-4.19	1999	Pink
75.5	24.2	0.6	24.8	18.4	9.55	27.17	107	8	4.8-4.15	2000	
48	25	-1.6	23.4	11.8	4.66	18.93	91	13	3.18-3.30	2001	
45	27.2	0.4	27.6	13.2	5.81	20.75	108	13	3.14-3.26	2002	
79	21.4	9.8	1.2	20.2	13	27.3	106	7	4.6-4.12	2003	
71	24.4	0.2	24.6	10.4	3.7	17.1	91	16	4.6-4.21	2004	
	27.6	-1.6	26	11.37	2.9	19.85	108	16	4.1-4.16	2005	
108	28	-3.2	24.8	11.9	5.3	18.69	94	13	4.14-4.26	1999	Side Bloom
75.5	20.8	8.4	29.2	18.2	10.44	25.86	11	10	4.20-4.29	2000	
48	26.2	2.4	28.6	14.2	7.06	21.35	120	12	3.26-4.7	2001	
45	24.2	3.4	27.6	12.8	7.01	18.73	95	12	3.25-4.5	2002	
79	31.2	-1.6	29.6	11.7	7.5	15.8	106	15	4.10-4.24	2003	
71	26	2.2	28.2	14.3	7.1	21.4	102	11	4.15-4.25	2004	
	30.3	1.7	32	15.84	7.71	23.96	150.5	15	4.9-4.23	2005	
108	23.3	7.2	30.4	16.7	10.1	23	152	13	5.4-5.16	1999	Full bloom
75.5	27	7.2	34.2	20	12.12	27.94	165	11	5.2-5.12	2000	
48	24.4	5.2	29.6	15.8	8.02	23.64	162	15	4.11-4.25	2001	
45	27.6	3.2	30.8	13.6	8.38	18.98	165	19	4.9-4.27	2002	
79	19.6	9.4	29	18.1	11.9	24.2	169	13	5.16-5.2	2003	
71	27.8	2.2	30	16.1	8.9	23.3	156	17	4.25-5.11	2004	
	19.4	12.6	32	14.8	5.92	23.68	178	18	4.10-4.23	2005	
108	29.4	3	32.4	18.2	9.94	26.5	209	19	5.13-5.31	1999	Fruit set
75.5	26	8.4	34.4	20.3	11.67	28.88	214	14	5.16-5.29	2000	
48	23.6	9	32.6	20.6	12.47	28.66	249	16	4.27-5.12	2001	
45	20.4	6	26.4	13.2	6.84	19.73	221	19	5.13-5.21	2002	
79	19.6	9.4	29	18.2	11.8	24.5	210	16	5.16-5.31	2003	
71	22.2	9.4	31.6	19.8	12.7	26.9	251	17	5.13-5.29	2004	
	22	8.2	30.2	19.1	12.1	25.2	250	17	5.3-5.25	2005	

Contd...

Contd...

CU	Temperature range	Absolute min.	Absolute max.	Mean temp.	Min. mean	Max. mean	GDD	Stage duration	Occurance date	Year	Stage
108	30	5.4	35.4	22	12.92	31.2	41	23	8.21-9.12	1999	Fruit development
75.5	26.2	9.2	35.4	22.5	13.2	31.77	454	25	8.20-9.13	2000	
48	35.2	1	36.2	19.3	10.53	28.07	401	28	8.20-9.24	2001	
45	30	6.2	36.2	20.9	11.77	30.19	416	27	8.23-9.18	2002	
79	22	11	33	22.4	14.3	30.5	435	25	8.21-9.14	2003	
71	27.2	8	35.2	22.2	13.2	31.2	430	25	8.21-9.14	2004	
	26	8.2	34.2	21.1	12.2	30	420	24	8.11-9.4	2005	

Table 4. Model predicted and real date comparison in different phenological stages with their RMSE index.

Phenological stage	Real	Model predicted	RMSE
Silver tip	6	5.3	0.42918
	5	5.0	
Green tip	17	14.2	7.75689
	12	12.4	
Pink Bud	16	13.6	12.278
	16	13.4	
Side bloom	25	24.8	0.03959
	25	25	
Full bloom	11	14.2	10.8711
	15	15.5	
Fruit set	17	17.2	3.55447
	17	18.8	
Fruit development	16	13.9	13.4938
	17	13.9	
	25	25.0	

REFERENCES

1. Anderson, J. and Richardson, M. 1982.Utilizing meteorological data for modeling crop and weed growth, biometeorology in integrated pest management, New York, pp. 449-61.
2. Ashraf, M., Loftiss, J.C. and Hubbard, K.G. 1997. Application of geostatistics to evaluate partial weather station networks. *Agric. Forest. Meteorol.* **84**: 225-71.
3. Beers, Elizabeth, 1993. Degree Day Models **In**: *Orchard Pest Management*, Good Fruit Grower. pp. 45-48.
4. Cesaraccio, C., Spano, D., Duce, P. and Snyder, R.L. 2001. An improved model for determining degree-day values from daily temperature data. *Int. J. Biometeorol.* **45**: 161-69.
5. Curt, H. 2001. Artificial Neural Network-Based Method of Screening Heart Murmurs in Children. *J. Circulation*, **103**: 2711-21.
6. Floyd, R.B. and Braddock, R.D. 1984. A simple method for fitting average diurnal temperature curves. *Agric. Forest Meteorol.* **32**: 107-19.
7. Jame, Y.W., Cutforth, H.W. and Ritchie, J.T. 1998. Interaction of temperature and day length on leaf appearance rate in wheat and barley. *Agric. For. Meteorol.* **92**: 241-49.
8. Milcous, Faust, Talaei, and Alireza. 1998. *The Physiology of Fruit Trees in Temperate Zones*, Tehran University Publications.

9. Ohadi, Delnaz. 2005. The qualitative study of chilling danger in different phenological stages on gardening crops (Case study of apple in Golmakan, Semirom and Karaj). Master Degree thesis, Agriculture College, Tehran University, Tehran.

10. Quanta, Consult Engineering, 1976. Meteorology and climatic factors and their effects on agricultural production. Meteorology Administration, Iran.

11. Roberto, Rea 2006. Phenological models for blooming of apple in a mountainous region. *Int. J. Biometeorol*. **51**: 1-16.

12. Richardson, E. 1974. A model for estimating completion of rest for peach trees. *HortSci*. **9**: 331-37.

13. Safa, Babak, 2005. The anticipation of different phenological stages of wheat. Master thesis, Agriculture College, Tehran University.

14. Yazdanpanah, Hojat-Allah. 2006. Modelling and finding climatic potential for cultivating common crops of East Azarbaijan Province, Ph.D. thesis, Tarbiat Moallem University, Iran.

15. Zinoni, 2002. Phenological stages of pome fruit forecasting. *J. Applied Sci*. 124-35.

Received: June, 2010; Revised: October, 2010; Accepted : November, 2010