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Forecasting Different Phenological Phases of Apple Using Artificial Neural Network

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ABSTRACT
Apple is one of the oldest trees in the world which is widely cultivated because of it's highly compatibility with various climatic conditions. In this study, we applied phenological statistics of agricultural meteorology of Golmakan to anticipate different phonologic phases of 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 has been established. The range of temperature changes, growing days and timed chilling unit (in silver tip phase) had been prepared for different phenological stages during 1999-2005; then the matrix of out coming data which, in fact, were the occurrence dates of different phenological stages of apple was prepared and the modeling of different phenological stages was performed by using neural network. In this study the accuracy of model was examined by using RMSE index and by contrasting real and anticipation dates during 2 years. For this purpose observed climatic and phenological data was also used in similar Figure at out of investigating zone. It's also specified we could anticipate phenological stages of apple with acceptable accuracy using climatic parameters.

Keywords: Phenology, Apple, Climate, Neural network

INTRODUCTION

Phenology studies various stages of growth and biological cycles such as sprouting, flowering, fruiting, as a result of climatic factors and environmental condition plants have revealed obvious outer changes, in growth processes these outer changes are called phenological stage or and the related observations are also called phenological observations. As a biological reaction against the temperature, apple tree passes different phenological phases during its annual life cycle in which transfer speed from stages 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 planting to cropping. 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 tensions, pests and diseases, but also have an crucial role on issuing agricultural meteorology warnings and for warnings in order to makes aware farmers against injurious atmospheric misfortunes.

In general, phenology can be considered as one possible approach with which to observe the effects of climatic change (Roberto, 2006). 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, 2006). 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 CU and GDD (or GDH) are cumulative, taking into account a threshold value below which no temperature contribution is effective. For fruit trees, the base values for GDH or GDD thermal sums usually range between 0°C and 9°C (Cesaraccio *et al.*, 2001). CU 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 GDD and CU in order to choose the best-performing values against experimental outcomes (Ashraf, 1999).

Anderson *et al.* (1986) used triangular, rectangular or sine-wave models for estimation of GDD. Good 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.*, 2004).

In this study, using intelligent neural network technique and climate and phenological data of Golmakan area help us in perform modeling of anticipation of different phenological stages of apple.

MATERIALS AND METHODS

Phenological data and survey sites

Agricultural meteorology station of Golmakan is located at the west of Mashhad, Khorasan province with a longitude of 59,17' and a latitude of 36,29' and an altitude of 1176 meter.

The means of temperatures are respectively in winter, spring, summer and autumn: 3.5, 18.1, 22.2 and 8.5 ºC.

The climate is particularly favorable for apple growing in this region.

Basic phenological stages of apple

Apple tree shows 2 distinct growth stages during its annual life cycle: sleep period and active germination period. These 2 periods, involve several phenological stages, which have appeared following each other (Quanta, 1976) .

Sleep period: this period begins with fall of the leaf in autumn and is continuing as long as we can see the martial signs of active germination (Silver tip).

Active germination period: this period begins with silver tip in spring and terminates with fall of the leaf in autumn. In this period, phenological stages will be occurred.

According to this arrangement Silver tip, Green tip, Pink, full bloom, fruit set, fruit development, Side bloom and finally Petal fall are phenological stages o apple tree.

Sufficient chilling during winter is necessary to break sleep period of apple tree, so that insufficient chilling could be a limiting factor for majority of apple Figureures. This amount changes between 800 hours to 2000 h, but the average is 1600h. (Hours below 7 ^{0}C) (Milcous, 1999).

Table 1 shows different phenological stages of apple in study site and the average of statistics related to the duration of each phenological stage.

Phenological observations consisted only of the recording of the date on which a certain phenophase occurred; these series are 7 years long (1999–2005). All phonological data was obtained from Golmakan agrometeorrological research station bulletins, phenophases 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 at this site.

Table 1. Different phenological stages of apple in study site

Phenological stage	Beginning of stage	End of stage	Stage duration(day)	Degree day
Silver tip	8 March	14 March	7	22
Green tip	19 March	3 April	15	91
Pink	30 March	10 April	11	99
Full bloom	8 April	19 April	12	108
Fruit set	24 April	8 May	15	161
Fruit development	11 May	26 May	17	226
Side bloom	22 August	16 September	25	428
Petal fall	27 October	9 November	14	79

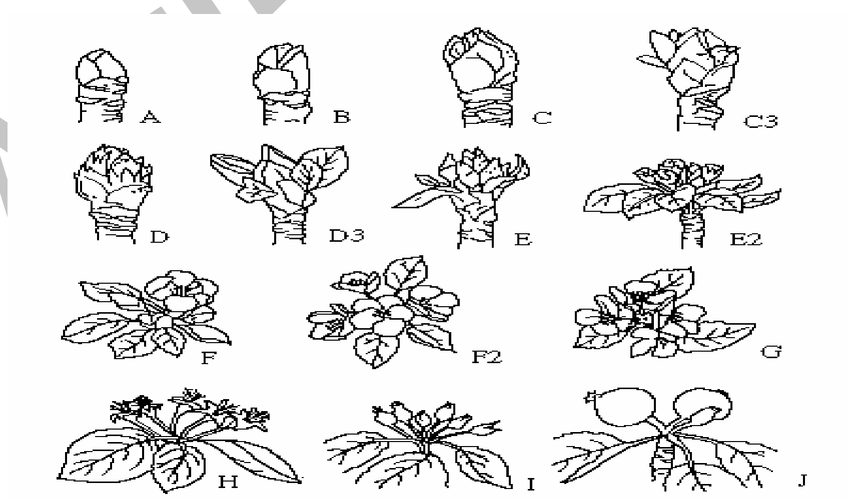

Figure 2. Phonological stages for apple, A budding to j fruit formation

Data day counting (day- counting of data)

At first regarding usual method to contrast among occurrence dates of different phenological stages of apple, occurrence dates of different stages become changed into day counting form.

We chose the 1st day of January as the basis (starting point) of counting of the day and then next day, were counted according to it.

Calculating timed chilling unit at Golmakan

In this section, timed chilling unit during day and night is calculated based on Utah method (Ref?) 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 ºC, so that the temperature affect deduced in lower and / or higher temperatures. According to Utah method, in estimating chilling unit, the rates of temperature are as follow:

After calculating chilling unit (cu) for each hour during night and day, accumulated cu gets 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, 2002).

Meteorological data

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 1993). “Kriging with drift” has proved to be a precise interpolation method for temperatures in our area, according to Roberto Rea (2004), 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 approximated GDH and CU, and to the respective measured quantities, in periods with available hourly data.

Choice of Utah phenological model

Phenological models, such as Utah model, use of “chilling and forcing” algorithms with different parameterisations of the CU and GDH summation. We used Utah model, proposed in 1977, (Richardson *et al.,* 1974) proposed an accumulation of CU based on a table (Table 3, Figure. 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, which is required to release dormancy, Ashcroft *et al.* (1977) 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 (fulfilment of chilling requirement), Th(i) is the hourly mean temperature at hour h and day i, and Tb is the threshold (or base) temperature. The “Utah” approach used a value of 4.4°C for Tb. An equivalent daily model (Eq. 5) has been tested, which cumulates daily temperatures above the same 4.4°C threshold:

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

where is the average temperature of day i.

Table 3.Value of CU as a function of hourly temperature(from Richardson *et al*.1974)

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

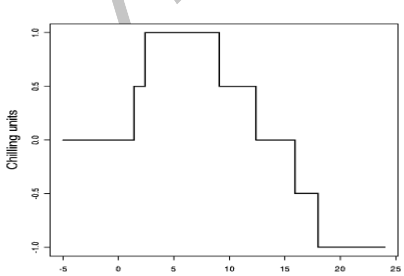

Figure 4. Utah model: chilling units (CU) as a function of temperature

Calculating heat units

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:

$$Hu = \sum_{i=1}^{N}\left[\frac{TM_i + Tm_i}{2} - Tt\right]$$

In this formula:

HU : the effective accumulated temperature degree during phenological stage

TMi : maximum daily temperature in day “i”

Tmi : minimum daily temperature in day “i”

N : phenological stage duration

And

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

Transfering data to neural network

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 day 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 organaized input vector to network and outcoming vector of model was the various occurrance dates of different phenological stages of apple.

The structure of date matrix

We prepared phenological statistics of apple during 6 years (1999-2004) to set data matrix. We also got meteorology statistics from meteorology stations of data bank of meteorology administration for the noted period. Then the following noted meteorology factors was selected for each stage in each year and input data matrix was constructed (Table 2).

Cu : chilling 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
$T\max$: 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)
R : range of temperature changes

After preparing data matrix, 4 years of existing statistics (input and outcoming data) in each stage were allotted to network training. The other 2 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, 2001).

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 datas. Following training, the network was validated using the remaining data set.

In transferring data to neural network, the initial Figure 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 3 layers.

Examining the accuracy of model

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.

In order to examine the accuracy of model, we used the real statistics (2 years test) and contrasted them with the statistics of estimated function by model.

A suitable quantitative index which you could apply to determine the accuracy of model was 'd' index which was assessing the accuracy of model according to observed and estimated Figure. The 'd' index was calculated by the following equation (Yazdanpanah, 2006).

$$d = 1 - \frac{\sum_{i=1}^{n} (\rho i - \alpha i)2}{\sum_{i=1}^{n} (|\rho i| + |\alpha i|)2}$$

0<d<1

where: $\rho i = Pi - O$

O is the mean of real data and Pi and Oi respectively were estimated Figure and real Figure 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 occurrance dates of different phenological stages of apple according to climatic data had sufficient accuracy in Golmakan area.

Table 2. Input matrix of data in different phenological stages of apple

CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	
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	12.25-12.29	2005	
CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	
	22.4	0.8	23.3	10.8	5.81	15.97	92	15	3.28-4.11	1999	Green tip
	30.7	0.5	31.2	11.9	4.5	19.34	95	14	3.27-4.9	2000	
		-5.4	22.4	9.3	1.96	16.65	87	16	3.7-3.22	2001	
		-8.6	25.4	11.4	3.63	19.33	88	12	3.9-3.20	2002	
	24	-0.6	23.4	9.7	4.2	15.1	86	17	3.19-4.4	2003	
	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	12.27-1.9	2005	
CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	
	24.2	0.6	24.8	11.3	5.87	16.8	90	14	4.6-4.19	1999	Pink
	24.2	0.6	24.8	18.4	9.55	27.17	107	8	4.8-4.15	2000	
	25	-1.6	23.4	11.8	4.66	18.93	91	13	3.18-3.30	2001	
	27.2	0.4	27.6	13.2	5.81	20.75	108	13	3.14-3.26	2002	
	21.4	9.8	1.2	20.2	13	27.3	106	7	4.6-4.12	2003	
	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	1.13-1.28	2005	
CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	
	28	-3.2	24.8	11.9	5.3	18.69	94	13	4.14-4.26	1999	Full bloom
	20.8	8.4	29.2	18.2	10.44	25.86	11	10	4.20-4.29	2000	
	26.2	2.4	28.6	14.2	7.06	21.35	120	12	3.26-4.7	2001	
	24.2	3.4	27.6	12.8	7.01	18.73	95	12	3.25-4.5	2002	

Table 2 . Continue

	31.2	-1.6	29.6	11.7	7.5	15.8	106	15	4.10-4.24	2003	
	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	1.21-2.4	2005	
CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	Fruit set
	23.3	7.2	30.4	16.7	10.1	23	152	13	5.4-5.16	1999	
	27	7.2	34.2	20	12.12	27.94	165	11	5.2-5.12	2000	
	24.4	5.2	29.6	15.8	8.02	23.64	162	15	4.11-4.25	2001	
	27.6	3.2	30.8	13.6	8.38	18.98	165	19	4.9-4.27	2002	
	19.6	9.4	29	18.1	11.9	24.2	169	13	5.16-5.2	2003	
	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	1.22-2.4	2005	
CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	**Fruit development**
	29.4	3	32.4	18.2	9.94	26.5	209	19	5.13-5.31	1999	
	26	8.4	34.4	20.3	11.67	28.88	214	14	5.16-5.29	2000	
	23.6	9	32.6	20.6	12.47	28.66	249	16	4.27-5.12	2001	
	20.4	6	26.4	13.2	6.84	19.73	221	19	5.13-5.21	2002	
	19.6	9.4	29	18.2	11.8	24.5	210	16	5.16-5.31	2003	
	22.2	9.4	31.6	19.8	12.7	26.9	251	17	5.13-5.29	2004	
CU	Temperature range	Absolute min	Absolute max	Mean temperature	Min mean	Max mean	GDD	Stage duration	Occurance date	year	**Side Bloom**
	30	5.4	35.4	22	12.92	31.2	41	23	8.21-9.12	1999	
	26.2	9.2	35.4	22.5	13.2	31.77	454	25	8.20-9.13	2000	
	35.2	1	36.2	19.3	10.53	28.07	401	28	8.20-9.24	2001	
	30	6.2	36.2	20.9	11.77	30.19	416	27	8.23-9.18	2002	
	22	11	33	22.4	14.3	30.5	435	25	8.21-9.14	2003	
	27.2	8	35.2	22.2	13.2	31.2	430	25	8.21-9.14	2004	

CONCLUSIONS

1. 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 3 days) and the least error rate related to the anticipation of Side Bloom stage.

2. It was observed that the error rate of model was acceptable and the accuracy of model hadn't meaningful deduction. It is necessary to note the type of study apples similar at both of the areas.

3. The other considerable case is the importance effect of climate and atmospheric parameters in determining the dates of different phenological stages.

Table 3. Estimated and real date comparison in different phenological stages with their RMSE index

Phenological stages	Real	Estimated	RMSE
Silver tip	6	5.3	0.42918
	5	5.0	
Green tip	17	14.2	7.75689
	12	12.4	
Pink	16	13.6	12.278
	16	13.4	
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	
Side bloom	25	24.8	0.03959
	25	25.0	

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