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Apple Tree Phenology in Relation to Temperature in Sauherad (Norway)

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Abstract: Plant's phenological development depends on multiple environmental factors and among these, temperature plays a key role during the early phenological development of plants. Temperature becomes even more significant in influencing phenological development in the areas that are covered with snow for a certain period a year. However, a rapid change in global temperature can be noticed in the scenario of climate change (CC). This study investigates the relationship between early phenological development of three apple cultivars i.e., Red Aroma, Summerred and Discovery with cumulative growing degree days (CGDDs) in the southern part of Norway and finds a strong positive correlation between them while moving from the green top stage to the fruit diameter (10mm) stage in the year 2016. In the similar way, study finds phenological development in two consecutive years i.e., 2015 and 2016 alike in a holistic approach. However, in the individual case of Discovery, phenological development of the year 2015 varies from 2016. In addition to that, CGGDs from first six months of two successive years seems to be similar. To gain all these results, this study made the use of multiple statistical tests. Study argues that; it is not always true that phenological development and CGDDs of one year vary from the next. Nevertheless, this study recommends for some long-term studies in the region that can generate concrete idea about phenology considering multiple environmental variables.

Keywords: Apple, Phenology, Temperature, Cumulative Growing Degree Days (CGDDs)

1. Introduction

Environment comprises multiple environmental factors and among these, temperature plays a vital role for the growth of plants [1, 27, 50, 62, 64]. This can be seen in apple trees too. Moreover, plant shows response to climate change (CC) in different forms, for example; shift in ecological range [5, 31, 35, 43] or change in phenological development [8, 13, 60, 61].

1.1. CC and Phenology

CC is being prominent in the recent decades with the increase in temperature and the global temperature is expected to rise by 1 to 4°C in this 21st Century [22]. In the similar way, natural variability and regional fluctuations along with global warming play a key role to determine climatic condition in the Northern Europe [12]. However, CC in Norway due to global warming can cause; an increase in temperature, precipitation and growing season length [15, 59]. Temperature in Norway has increased by ca. 1°C in the 20th Century and it is expected to rise by ca. 4.5°C by the end of 21st Century [18]. Although, temperature rise is observed throughout the year in Norway, the rise in temperature is more pronounced during summer and autumn than in winter [18]. In addition to this, Norway has a probability in the future to have short winters with mild temperatures [12, 15]. Among the many municipalities in Norway, Sauherad municipality, situated in the southern part of country is facing with the consequences of CC. Some of the expected changes in Sauherad municipality by the end of 21st Century due to CC are: a rise in annual precipitation and temperature by ca. 15% and ca. 4°C respectively, in a combination with a reduced time of snow coverage [26].

Phenology is the study of life cycle events related to seasonal timing [45]. The life cycle events like development of flowers and onset of leaves in plants are induced by different environmental factors such as temperature rise, increased rainfall, elevated CO_2 and nitrogen deposition [7, 56]. Among these environmental factors, temperature plays dual role in fruit tree phenology, such as, low temperature is required to break bud endodormancy and relatively high temperature is essential for flowering [6]. However, CC causes variation in phenological development [8] and phenological development is shifting earlier in many parts of the world. Earlier shift of phenological development can be seen in Europe too [10, 17].

1.2. Apple Cultivation in Norway

Apple tree mainly grows in the temperate regions of the world with some extension in tropical regions and has the highest economic value among fruits [23]. Apple production is facing problems due to CC in the entire world. For instance, due to increase in temperature and decrease in winter rainfall, the apple production in northern India has decreased by 0.4 tons/hectare in the period of 1985-2009 [51]. In a similar way, certain areas of Japan will be unable to grow apples with the increase in temperature in near future i.e., apple trees will shift their geographical range of growth [34]. It's not all about the quantity of apple production, quality of apple is also being diminished due to rise in temperature. The concentration of malic acid, which makes apple tasty, is slowly being diminished in some apple cultivars in response to an increase in temperature [55].

In Norway, the apple production has significant economic value [57] and apple is commercially cultivated in the southern part of country [52]. However, apples are cultivated in the other parts of country too that has mean temperature of 12.5 – 14°C in the period of May to September [47]. The annual increase in the land for apple cultivation in Norway shows the relevancy of apple production in Norway. Land for apple cultivation in Norway increased from 1,351 hectares to 1,429 hectares during the period of 2010 to 2016 [54]. Although, area for apple cultivation has increased, apples are responding to the change in temperature in Norway too. For example; a temporal advancement in the flowering of apple trees can be seen in southern Norway in response to an increase in temperature [58].

1.3. Rationality of the Study

The entire globe is struggling with the impacts of CC and some of the impacts like the rise in annual temperature and precipitation can be seen in the southern Norway (Sauherad Municipality) [26]. In the same way, phenological development of apple trees in the southern Norway has started to respond CC [46]. This situation makes phenological development in response to CC, an interesting subject to investigate. Moreover, further study of phenological development is essential [24], as it provides relevant information about the existing ecological system and evolution pattern [13]. Likewise, phenological studies contribute to build up knowledge in the field of biodiversity, agriculture, forestry and human health [48]. So, Sauherad municipality was selected for the study of phenological development in apple trees.

2. Methodology

2.1. Study Area and Apple Cultivars

The study was conducted in the farms located at Liagrend, Nyhus and Årnes, that lie within Sauherad municipality of Norway. Geologically, these farms have same bedrock called Charnockite [36] covered by a layer of Holocene marine sediments [37]. Sauherad municipality, situated in the southern part of Norway, has relatively warm summers and cold winters with snowfall. This study includes three apple cultivars i.e. Red Aroma, Summerred and Discovery. Red Aroma is the result of cross between Ingrid Marie and Filippa varieties [42] and originates from Sweden [44]. Whereas, Summerred originated from Canada in 1964 and the cultivar has medium sized fruits with sweet flavor [40]. The next cultivar; Discovery is a cross of Worcester Pearmain and Beauty of Bath varieties that were raised in England during 1949 [41].

From each farm 27 apple cultivars were observed, that includes nine trees of each type i.e., Red Aroma, Summerred and Discovery. In the similar way, one-third of the sample trees were provided with a specific tag number (one, two and three) in the field, which allows an easy identification of sample trees in the field.

*Total number of samples (apple trees) studied from three farms = (Number of the farms) * (Number of apple cultivars) * (Number of trees representing each type of apple cultivars in one farm) = (Three) (Three) (Nine) = 81 apple trees.*

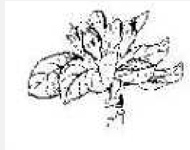
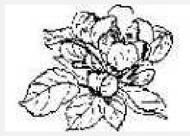
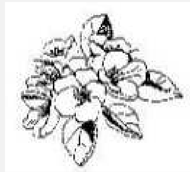
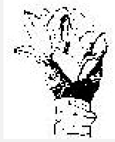
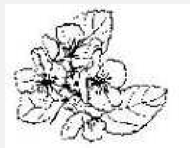
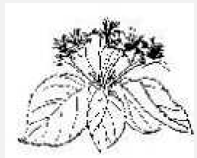
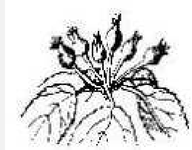
2.2. Data Collection and Statistical Analysis

This study includes phenological data and weather data. To collect the phenological data a standard diagram sheet i.e., Kernobst-Phenology developed by Agroscope ACW [20] (Table 1) was used. Standard diagram sheet consists of phenological stage from winter bud to fruit diameter (10 mm). However, this study includes phenological stages such as; green top (3), mouse ear (4), balloon stage (7), central bloom open (8), full bloom (9), pollination (10), fading (11) and fruit diameter (10 mm) (12). Numerical numbers were assigned to phenological stages to make data collection and analysis precise. To collect phenological data, field observation was carried out three times in a week, from mid-April to mid-June. Weather data was retrieved from the station, GVARV-NES (station number: 32060) that lies at an altitude of 93 masl and is the nearest station to all three farms [38]. This weather data was used to calculate maximum and minimum temperature of a day at all three respective farms using a lapse rate of 100 m rise in altitude causes a fall in temperature by 0.65°C [2, 16, 52]. From the maximum and minimum temperature, growing degree days (GDDs) were computed using a threshold temperature of 5°C. Various studies in Norway as well as Norwegian meteorological institute uses 5°C as threshold temperature to calculate growing degree days (GDDs) [11]. GDDs were calculated in the following way;

$$GDDs = (Maximum\ temperature\ (TAX) + Minimum\ temperature\ (TAN))/2 - Threshold\ temperature\ (5\ ^\circ C)$$

From GDDs, cumulative growing degree days (CGDDs) were calculated and calculation of CGDDs started from first of January. During the calculation of CGDDs, only positive values of GDDs were added from the successive Julian days, while the negative values of GDDs were replaced by zero. The method deployed to calculate GDDs for this study is termed as the average method [19]. After getting all the required data, Ms. Excel, SPSS and R were the tools used for the statistical tests. For all the statistical tests, a confidence interval of 95% was considered.

Table 1. *Different stage of flower.*

Code	Phenological Stage	Description		Code	Phenological Stage	Description	
A/1	Winter bud	Bud is in rest and it is closed.		E2/7	Balloon stage	Majority of the flowers look like balloon as bud gets swollen and is not covered.	
B/2	Bud swelling	Bud starts to get swelling and bud scales get longer.		F/8	Central bloom open	Flowering starts: about 10% of the flowers are open.	
C/3	Green top	Bud starts to break-up and have some green leaves.		F2/9	Full bloom	At least 50% of the flowers are open and petals fall off start.	
C3/4	Mouse ear	Green leaf tips move upward from bud shells by 10 mm and first leaflets spread.		G/10	Pollination		
D/5	Green bud	Bud is still closed, and single flowers start from each other to solve.		H/11	Fading	At least 80% of the petals have fallen off.	
E/6	Red bud	Petals start to stretch and become visible. The sepals are also slightly open.		I/12	Fruit diameter (10 mm)	Fruits develop to 10 mm diameter.	

After this stage, fruit matter starts to grow in diameter (>10 mm).

3. Results

3.1. Relationship Between Phenological Development and CGDDs in 2016

Phenological development of apple cultivars in 2016 shows; different temperature is required by cultivars to gain various phenological stages (Figure 1). Moreover, to know the relationship between phenological development and CGDDs, Spearman's rank correlation test was conducted, and the test gave a p-value of less than 0.05 in each individual case (Table 2). This indicates CGDDs played an important role for the phenological development of apple cultivars. Likewise, the Spearman's rank correlation coefficient of positive one in each individual case provides basis to say certain degree rise in CGDDs has an equivalent proportion of impact in phenological development too.

Table 2. *Spearman's rank correlation coefficient and p-value for the relationship between phenological development and CGDDs in 2016.*

Farm	Apple cultivar	Spearman's rank correlation coefficient	P-value
Liagrend	Red Aroma	1	0.003
	Summerred	1	0.017
	Discovery	1	0.017
Nyhus	Red Aroma	1	0.017
	Summerred	1	0.017
	Discovery	1	0.003
Årnes	Red Aroma	1	0.003
	Summerred	1	0.017
	Discovery	1	0.003

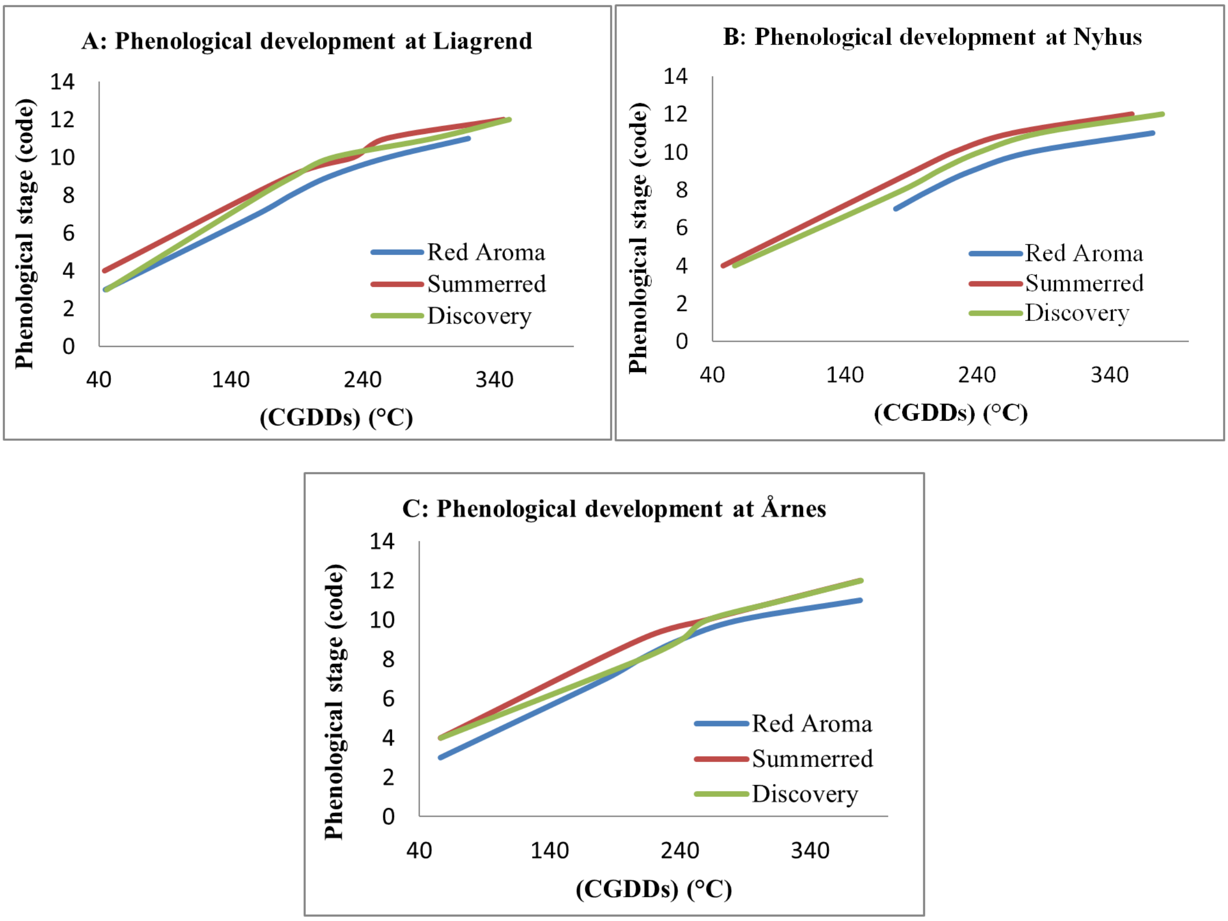


Figure 1. *Phenological development of apple cultivars at different three farms.*

Furthermore, to know the variation of phenological development within apple cultivars, Wilcoxon signed rank test was carried out. The test gave the p-value of more than 0.05 in the case of relationship between Summerred and Discovery (Table 3).

Table 3. *P-value from Wilcoxon signed rank test to know the relationship between the phenological development of three apple cultivars in 2016.*

Apple cultivar	P-value
Red Aroma-Summerred	0.007
Summerred-Discovery	0.285
Discovery-Red Aroma	0.010

However, p-value was less than 0.05 in the case of Red Aroma-Summerred and Red Aroma-Discovery. This indicates the phenological development of Red Aroma was different than the phenological development of Summerred and Discovery.

3.2. Phenological Development in 2015 Compared to 2016

To compare the phenological development of 2015 with 2016, Wilcoxon signed rank test was used. The statistical test gave a p-value of less than 0.05 in the case of Discovery but the p-values for other two apple cultivars were greater than 0.05 (Table 4). In this situation, it can be said that phenological development of Discovery in 2015 varies from the phenological development of Discovery in 2016. However, in a holistic approach, phenological development in 2015 does not differ from the phenological development in 2016 as the p-value is greater than 0.05 while considering phenological development of all three cultivars together (Table 4).

Table 4. *P-value to know variation of phenological development in the year 2015 with respect to 2016.*

Apple cultivar	P-value	Mean Julian day for phenological development in the year (using phenological stage from full bloom to fading)	
		2015	2016
Red Aroma	0.339	149.000	146.830
Summerred	0.796	145.570	144.710
Discovery	0.020	148.560	145.330
Considering all cultivars together	0.385	147.71	145.623

3.3. CGDDs in the Year 2015 and 2016

To study CGDDs of two consecutive years the temperature from January to June was used and a paired sample t-test was carried out. This test gave a p-value of greater than 0.05 (Table 5). It helps to conclude that, CGDDs of 2015 was not statistically different from CGDDs of 2016 in the first six months of the year.

Table 5. P-value to know about the variation of CGDDs in the year 2015 with respect to 2016 (from January to June).

Month	CGDDs		P-value
	2015	2016	
January	0	0.75	0.259
February	1.9	0.75	
March	20	22.9	
April	101.4	75.75	
May	234.15	319.4	
June	499.95	664.05	

4. Discussion

4.1. Phenological Development and Variation in CGDDs

Temperature controls the growth of plant and plays an important role for their phenological development [30, 49]. However, CGDDs was used as the temperature in this study. CGDDs or heat sum is the sum of an average daily temperature above a certain threshold temperature [14, 21]. Nordli et al. [39] mentions that particularly the early phenological development in plant is strongly correlated with temperature. The dependency of early phenological development on temperature can be seen in this study too i.e., CGDDs had a strong correlation with phenological development. Moreover, this study shows plants need a specific CGGDs to reach specific phenological stage. In a similar way, Miller et al. [32] also mentions that plant requires a certain temperature to move from one phenological stage to the next. However, all the apple cultivars do not have same trend of phenological development. Red Aroma was comparatively late in phenological development with respect to Summerred and Discovery at all three farms in 2016. According to this study, phenological development of Red Aroma was statistically late by ca. 4 days from the Summerred and ca. 3.5 days from the Discovery. Along with this, a study by Casique [3] at Ås in Norway, classified Red Aroma, Discovery and Summerred as late flowering, mid-season flowering and early flowering respectively.

Though, Wolfe et al. [63] claims that phenological development has been shifting in the recent time period. This study shows that phenological development in 2015 does not differ statistically from the phenological development in 2016 when the phenological development of all three apple cultivars is taken collectively. However, in the individual case, phenological development of Discovery in 2015 was late by ca. 3.23 days compared to the year 2016, while remaining the same in Red Aroma and Summerred. This study has phenological data from only two years, and it is difficult to analyze precisely the variation in phenological development using data from very short period of time. So, the study is unable to build concrete idea about variation in phenological development. Along with this, Nordli et al. [39] says, “it is easy to observe variations of phenological development in long time series data.”

While looking at the CGDDs from January to June from both the year, we do not see variability in it. In the same way Karmeshu [25] in USA also shows that the temperature of one year may not significantly differ from another year due to internal variability in the climate system. So, it is not always obvious that temperature in one year varies from the next year.

Although, this study shows similar monthly mean temperatures in two consecutive years, a decadal change in temperature can be seen throughout the planet. The IPCC [22] shows that global temperature has been rising in the recent decades and the temperature has increased by 0.55°C after 1970. In the similar way, increasing trend of temperature can be seen in whole Europe during the late 20th and early 21st century compared to the temperature of past 1500 years of time [28]. Based on the global future projections for the increase in temperature made by the IPCC, Hanssen-Bauer et al. [18] also made a projection for temperature rise in Norway and different counties within Norway. It makes clear that temperature will rise substantially in Norway too.

4.2. CGDDs and Apple Phenology in Sauherad

Both the CGDDs and phenological development from the year 2015 do not vary statistically from 2016. This indicates that, consecutive years can have similar rise in CGDDs and simultaneously rise in phenological development. However, the combined effort of various environmental factors such as; soil type, precipitation and altitude along with the temperature can play a crucial role to alter phenological development. Cole and Sheldon [9] also mention that different environmental factors like soil type and altitude play an important role to determine phenological development of trees. According to the study, earlier shift of phenological development in the year 2016 compared to 2015 can be seen in the case of Discovery. This may be possible, when Discovery responds to environmental components in a different way than Red Aroma and Summerred. A study by Massonnet et al. [29] shows that apple cultivars can respond to a particular environmental component in diverse way and their research finds two different apple cultivars using water in different quantity due to difference in stomatal structure. So, it can be said that Discovery may have responded to environmental factors in a different way than other two cultivars at Sauherad.

At Sauherad municipality (Telemark County) several environmental factors are being changed. According to Klimaservicesenter [26], by the end of 21st century Telemark County will have several changes such as; rise in annual temperature by ca. 4°C, increase in growing season length by

1-3 months, along with the rise in precipitation by ca. 15 % and change in the duration of snow cover. As the annual temperature is going to rise in Sauherad area, it can have negative consequences for apple cultivars that are growing well at the present environmental condition. So, apple cultivars growing well at present may not be useful after few decades. Moreover, a study by Rivero et al. [46] shows that apple phenology has already shifted earlier in Southern Norway in response to temperature. So, it is essential to find an apple cultivar that will grow well in the changed climatic condition.

5. Conclusion

This study finds phenological development and CGDDs from two consecutive years similar and advocates that, it is not always obvious to have shift in phenological development. However, upcoming studies should focus on apple production and phenology together. So, the farmers in the coming days can choose an appropriate apple cultivar and farming pattern to get maximum production. In a similar way, Chapman et al. [4], Moola and Mallik [33] and Ruml and Vulić [48] have advised to have more phenological studies to have exact idea about optimal time for plantation and organized farming system. This will help us to get desired production. Along with this, to draw conclusions about temperature change, we should try our best to use temperature data from as many years (≥30 years) as IPCC recommends. Therefore, a long-term monitoring of apple tree phenological development and CGDDs in Sauherad is recommended.

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