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Agrometeorological-Heat and Energy use of Kinnow Mandarin (*Citrus nobilis* Lour * *Citrus deliciosa* Tenore)

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ABSTRACT

Field experiment was conducted from 2011 to 2014 at Experimental Orchard, Department of Horticulture, CCS HAU, Hisar. Present study was carried out to determine the different agrometeorological indices, thermo-heat, hydro and energy utilization for the completion of different phenophases from flower bud initiation to physiological fruit maturity in kinnow mandarin in the semi arid region where annual rainfall is 450 mm and maximum temperature goes up to >46°C, number of heat wave as horizontal advection (summer) and minimum temperature <1.0°C (in winter) or grass minimum temperature ranged -0.3 to -9.3 °C (winter month of Dec. to Feb.) specially during the fruit harvesting to first flower initiation period. The average values for four consecutive year data revealed the utilization of thermal, heat, energy and photosynthetic active radiation under field condition. First flower bud initiation varies 21st February to 5th March in respective year, number of day taken from the fruit harvesting to next first flower bud initiation ranged 52 to 64 days, FFBI to DFF ranged 15 to 18 days, DFF to TF ranged 11 to 16 days, TF to DF 12 to 16 days and IFFS to FH 213 to 216 days. Radiation use efficiency was highest 20.46 kg ha^{-1} MJ^{-1} and lowest 15.84 kg ha^{-1} MJ^{-1}, the highest HYTU was at DF to IFFS phenophase, PTI varies 68.9 to 74 ^{0}C, Heat use efficiency (6.62 kg ha^{-1}°C day) was highest in the year 2013, required the lower amount of degree days units for the production of higher fruit yield and lowest HUE (4.77 kg ha^{-1}°C day) in 2012 to produce lower fruit yield. The highest hydrothermal unit was observed in the year 2011; maximum HYTU 318902 °C day % in FH to IFFS as compared to other year and phenophases and efficient optimum utilization of heat unit in 2013 and similar trend were observed with the other efficiency in consecutive years.

Key words: *Kinnow, Degree day, thermal indices, efficiencies, radiation, hydrothermal unit*

INTRODUCTION

Weather is a major variable affecting the production of the horticultural crop. Present study was aimed to determine the different agrometeorological indices for the completion of different phases from flower bud initiation to physiological maturity in the semi arid region of Haryana. The annual rainfall of the region is 450 mm and temperature goes to >46°C (summer) and minimum temperature <1.0°C (in winter) or grass minimum temperature up to -9.3 °C with 20 to 25 dense or thick foggy days.

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The knowledge of the prevailing weather conditions over a period of time at a particular site is important to raise the crops and this crop is successfully grown where temperature varies from too high in summer and low in winter months. The number of heat wave or horizontal advection condition was received specially during the summer season (May to June). An adverse weather condition during the different phenophases like flowering, fruiting and yield per tree throws the economy of the grower/farmers. It's successfully cultivated in arid or semi arid region of Haryana. The prevailing weather conditions on plants have been directly affecting the phenological stages of the kinnow. The duration of each physiological growth phase is directly results of crop responses to the meteorological factors or abiotic. The air temperature is one of the important weather parameters which is responsible to potential productivity, fruit quality and yield. Weather cannot be controlled like other inputs in agriculture, but one can manage to overcome the adverse effects of the weather to a certain extent by adopting the precautionary measures. Temperature is one of the main factors determining the duration of the growing period of the different phenophases[1,2,3] of soybean under the varying environment and different radiation used efficiency. Solar radiation is an important input for photosynthesis and evapotranspiration. These two phenomena are dependent not only on the intensity of radiation but also on the distribution of intercepted radiation within the canopy[4]. Heat use efficiency in terms of dry matter accumulation, depends on crop type, genetic factors and sowing environment and has great practical application[5]. The thermal indices are significant variable among the different variety of plum and also in term of plant growth, plant girth, annual extension, fruit set and other physical parameters[7].

MATERIAL AND METHODS

Field experiment was conducted from 2011 to 2014 at experimental orchard Department of Horticulture, CCS HAU, Hisar. Kinnow orchard research farm is 0.5 km away from the agrometeorological observatory situated at 29^0 10' N Latitude, 75^0 46' E Longitude and Altitude 215.2 meters. The study of agrometeorological indices (Growing degree day (GDD), Heliothermal unit (HTU), Photothermal unit (PTU), Hydrothermal unit (HYTU), photosynthetic active radiation (MJ/m^2), heat-energy use (Radiation use efficiency (RUE), Heat use efficiency (HUE), Hydrothermal use efficiency (HYTUE) used in the different stages (I, II, & III) or phenophases of 16 year old kinnow plants. Computation used the observatory data 2011 to 2014 as parameters like maximum temperature (T_{max}), Minimum temperature (T_{min}), mean temperature (T_{mean}) relative humidity (RH) and base temperature (T_b) as 10°C, it's finalized after taken the mean of three month from January to March month, date of fruit harvesting to next flowering. Kinnow plants planted with standard recommended spacing (6×6 meter) with total number of 275 plants per hectare were used. Five plants were selected at random and four shoots tagged in each plant in all the direction (north-south and east west) for further observation as per the objective. The different observational growth stages are divided as stage-1(April.-May): cell division stage; Stage-II (June –September): cell enlargement stage and stage-III (Oct.-December): maturity and ripening period (Table1). The agrometeorological indices, evapotranspiration, thermal time were computed on daily basis and accumulated from first to third stages.

Growing degree days (GDD)

Cumulative growing degree days were determined by summing the daily mean temperature above base temperature, expressed in °C day.

$$GDD = \frac{(\mathrm{Tmax} + \mathrm{Tmin})}{2} - \mathrm{Tbase} \quad \text{..... (i)}$$

Where, T_{max} = Daily maximum temperature (°C), T_{min}= Daily minimum temperature (°C) & T_{base}=Minimum threshold/base temperature (°C)

Photo thermal unit (PTU)

Cumulative photo thermal unit were determined by multiplying the GDD to the possible sunshine hours, expressed in °C day hours.

PTU (°C day) = GDD x Possible sunshine hours (N) at Hisar…….(ii)

Helio thermal unit (HTU)

Cumulative helio thermal unit were determined by multiplying the GDD to the actual bright sunshine hours, expressed in °C day hours.

HTU (°C day) = GDD x actual bright sunshine hours (n)…(iii)

Hydrothermal unit (HYTU)

HYT-unit was determined by multiplying the GDD to the average relative humidity, expressed in °C day percent.

HYTU (kg ha^{-1}°C day)=GDD x Average relative humidity (RH_a),

The computation of the hydrothermal unit used the growing degree days and average relative humidity during the different phenophases from FFBI to fruit harvesting.

Heat use efficiency (HUE)

HUE (kg ha^{-1}°$C^{-1}day^{-1}$)= Kinnow fruit yield (kg/ha.)/Accumulated GDD

Photothermal index (PTI)

For each phenophase, computed with using following formula[6,7].

PTI (°C)=GDD/Number of days taken between two phenophases

Radiation use efficiency (RUE)

Radiation use efficiency (Kg ha^{-1} MJ^{-1}) is defined as the amount of dry matter produced for the unit intercepted photosynthetically active radiation (PAR). RUE of kinnow at 15 days interval was computed by expression given below.

$$RUE = \frac{Yield\ of\ kinnow\ fruit\ (\frac{kg}{ha})}{Accumulated\ IPAR\ (MJ/m2)} \quad \ldots\ldots\ (iv)$$

Daily solar radiation data PAR data collected from department of Agricultural Meteorology, COA, CCS HAU, Hisar and computed the radiation use efficiency.

Thermal use efficiency (TUE)

The thermal use efficiency was computed to compare the relative performance of different year production efficiency with respect to utilization of heat, using following formula:

$$TUE\ \left(\frac{g}{m2}°C\ day\right) = \frac{\text{Yield of kinnue fruits } (^{kg}/_{ha})}{\text{Accumulated GGD from FLowering to fruit maturity}}$$

Hydrothermal use efficiency (HYTUE)

HYTUE=Kinnow fruit yield (kgha^{-1})/Accumulated HYTU

RESULTS AND DISCUSSION

During the period (winter season reference month December to February) of fruit harvesting to FFBI kinnow plants faced four or five days of frosting when minimum temperature varies with the range -0.2 to -1.5 °C in year 2011 and 2013, and grass minimum temperature ranged -1.3 to -5.7°C (2014), -1.3 to -6.8°C (2013), -0.3 to -8.8°C (2012) and -0.3 to -9.3°C (2011). The numbers of days taken for different phenophases from the first flower bud initiation to fruit harvesting are shown in the Table 1. The First flower bud initiation (FFBI) starting from 21st February to 5th March in different years of study and days taken from the fruit harvesting to next FFBI range from 52 to 64 days, from FFBI to DFF ranged from 15 to 18 days, DFF to TF ranged from 11 to 16 days, TF to DF ranged from 12 to 16 days and IFFS to FH ranged from 213 to 216 days (Table 1). Temperature is one of the main factors determining the duration of the growing period of the different phenophases[1,2,3] of soybean under the varying environment and different radiation used efficiency.

Agrometeorological indices

The different agrometeorological indices along with average values like growing degree days, Heliothermal unit, photothermal unit, evapotranspiration (Et) and absorbed photosynthetic active radiation (APAR), required for completion of various phenophases in the Kinnow mandarin plant from fruit harvested to next fruit physiological

maturity are presented in Table 2. Phenophases wise individual year and accumulated agrometeorological indices as GDD ranged 4988 to 5093 °C day from FFBI to FH and highest in the range (3386 to 3489 °C day) in IFFS to FH phenophases in respective year, accumulated PTU with range 62256.4 to 63567.9 °C day hour and highest PTU ranged between (42192.6 to 43633.7 °C day hour) was utilized at IFFS to FH phenophases and similar trend in HTU was observed in the respective year (Table 2). Accumulated growing degree days indices ranged between 4981 to 5093.1 °C days from FFBI to FH in different study period. Maximum GDD (5093.1 °C day) were consumed in the year 2013 in which maximum kinnow yield (33693 kg/ha) was produced. Highest GDD 3489.7 °C days are used between the phenophase IFFS to FH in the year 2014.

Hydrothermal and Phenothermal unit

The accumulated hydrothermal unit with phenophases wise varied from 299490.5 to 318902.0 ^{0}C day percent and the highest HYTU was in the 2011 and lowest in 2012 in the completion of different phenophases from FH to IFFS (Table 2). IFFS to FH phenophase was highest 235642.1 ^{0}C day percent in year 2013 and similar trend in rest of the year. Accumulated PTI value varies with different phenophase and varied from 68.9 to 74 ^{0}C, for completion of different phenophases (Table 2). The highest PTI (20.4) was observed between the phenophase DF to IFFS in the year 2013 and lowest (2.6) between the phenophase FH to FFBI in the year 2011 and 2012.

Thermal and energy use efficiency

The efficiency of heat, thermal and energy as, heat use, heliothermal, photothermal, hydrothermal and radiation are utilized for the conversion of the biological and economical yield depends upon the genetic characteristic of the kinnow and time of first flower bud initiation and other phenophases completion. Heat use efficiency (6.62 and 6.32 kg ha^{-1}°C day) was highest in the year 2013 and 2011 respectively, producing higher fruit yield and lower amount of degree days units for the production of higher fruit yield and lowest HUE (4.77 kg ha^{-1}°C day) in 2012 producing lower fruit yield. RUE is the efficiency of absorbed radiation to produce the above ground biomass production and fruit yield (Table 3) in the different phenophases and stages. RUE was highest 21.31 kg ha^{-1} MJ^{-1}in the year 2013 followed by 2011 (20.46 kg ha^{-1} MJ^{-1}). These years produced the higher fruit yield as more radiation was utilized for the conversion of biological and economical yield. Utilization of HTUE, PTUE and HYTUE showed similar trend in year 2011, 2013 and 2012, 2014. Radiation use efficiency was highest in 20.46 kg ha^{-1} MJ^{-1} in 2011 and lowest 17.13 kg ha^{-1} MJ^{-1} in 2014 (Table 3).

Stage wise thermal units and energy

The highest thermal unit was utilized in the maturity and ripening period (III stage) and lowest in cell division stage (I stage). Stage-1(April.-May): cell division stage utilized highest GDD 2554.8 °C day in year 2013 followed by 2011, HTU 19144 °C day, PTU 12277.5 °C day and 226.8 MJ/m^2; Stage-II (June –September): cell enlargement stage utilized highest GDD 2554.8 °C day in year 2013 followed by 2011, HTU 19144 °C day, PTU 32965.2 °C day and 477.1 MJ/m^2 and stage-III (Oct.- December): maturity and ripening period utilized GDD 898.5 °C day, HTU 6484.6 °C day, PTU 10049.8 °C day and 410.5 MJ/m^2 (Table 4). The higher kinnow fruit yield produced with the efficient higher heat unit in the year 2013 and 2011 due to quite 2.13 °C higher temperature during DF to IFFS phenophase.

Table 1: Number of days taken in the different phenophase in respective year

Phenophases	2011	2012	2013	2014
FH to FFBI	52 days (21/2//11)	64 days (3/3/12)	55 (24/2/13)	64 (5/3/14)
FFBI to DFF	18 days (9/3/11)	15 days (18/3/12)	18 (14/3/13)	15 (21/3/14)
DFF to TF	16 days (10/3 to 26/3)	13 days (1/4/12)	14 (29/3/13)	11 (1/4/14)
TF to DF	16 (12/4/11)	12 (13/4/12)	14 (13/4/13)	15 (16/4/14)
DF to IFFS	49 (30/5/11)	46 (28/5/12)	48 (31/5/13)	46 (31/5/14)
IFFS to FH	214 (31/12/11)	217 (31/12/12)	216 (31/12/13)	213 (31/12/14)
Fruit yield (kg/ha)	31523.25	23793	33695.75	27115

Note: FH: Fruit harvesting, FFBI: First flower bud initiation, DFF: Day of first flower, TF: Time of flowering, DF: Day of first fruit, IFFS: Initial fruit set was more than 54%.

Table 2: Phenophases wise individual year and accumulated agrometeorological indices, and PTI (2011-14)

Year	Phenophases codes	**GDD (°C day)**	**HTU (°C day hour)**	**PTU (°C day hour)**	**HYTU (°C day %)**	**PTI (°C)**
2014	FH to FFBI	201.7	1163.2	2261.3	16941.9	3.2
	FFBI to DFF	140.7	1139.9	1665.4	10111.9	9.4
	DFF to TF	128.4	886.7	1555.5	8558.3	11.7
	TF to DF	217.7	2047.0	2702.1	12436.1	14.5
	DF to IFFS	867.7	8226.3	11271.8	41002.6	18.9
	IFFS to FH	3489.7	27125.8	43613.7	210439.8	16.4
Accumulated		**5045.8**	**40588.8**	**63069.7**	**299490.5**	**74.0**
2013	FH to FFBI	149.0	870.2	1666.1	11457.8	2.7
	FFBI to DFF	155.4	1354.0	1814.7	10759.0	8.6
	DFF to TF	164.6	1312.1	1977.5	11432.5	11.8
	TF to DF	205.5	1822.6	2538.7	11300.2	13.7
	DF to IFFS	981.2	9200.4	12733.0	34696.5	20.4
	IFFS to FH	3437.5	25135.6	42837.9	235642.1	15.9
Accumulated		**5093.1**	**39694.9**	**63567.9**	**315288.1**	**73.2**
2012	FH to FFBI	165.7	995.2	1853.0	11222.9	2.6
	FFBI to DFF	125.5	1044.6	1479.1	7539.7	8.4
	DFF to TF	170.1	1342.5	2061.2	9226.3	10.6
	TF to DF	204.6	1848.7	2536.1	10858.6	12.8
	DF to IFFS	842.4	6995.8	10929.3	37577.7	18.3
	IFFS to FH	3481.7	24083.4	43633.7	214467.5	16.3
Accumulated		**4990.0**	**36310.3**	**62492.4**	**290892.7**	**69.0**
2011	FH to FFBI	132.7	971.6	1483.0	9097.0	2.6
	FFBI to DFF	89.4	566.8	1034.1	6875.5	5.0
	DFF to TF	181.6	1590.8	2167.5	11402.5	11.3
	TF to DF	232.3	1971.3	2856.1	14545.9	14.5
	DF to IFFS	966.6	8789.0	12522.6	47298.1	19.7
	IFFS to FH	3386.0	23376.3	42192.6	229683.1	15.8
Accumulated		**4988.4**	**37265.8**	**62256.0**	**318902.0**	**68.9**

Table 3: Thermal use efficiency, hydrothermal and radiation use efficiency (RUE) of Kinnow

Year	HUE (kg ha^{-1}°C day)	HTUE(kg ha^{-1}°C day)	PTUE (kg ha^{-1}°C day)	HYTUE (kg ha^{-1}°C day%)	RUE (kg ha^{-1} MJ^{-1})
2011	6.32	0.85	0.51	0.10	20.46
2012	4.77	0.66	0.38	0.08	15.84
2013	6.62	0.85	0.53	0.11	21.31
2014	5.37	0.67	0.43	0.09	17.13

Table 4: Accumulated stage wise agrometeorological indices and PAR of Kinnow

Stage (ST)	Year	GDD (°C day)	HTU (°C day hour)	PTU (°C day hour)	PAR (MJ/m^2)
ST-1	2011	938.3	8636.2	12184.4	221.1
	2012	875.5	7401.4	11378.2	202.6
	2013	944.8	8827.4	12277.5	226.1
	2014	877.2	8371.4	11387.8	230.4
ST-2	2011	2496.2	16372.2	32218.4	424.2
	2012	2637.7	17565.6	34094.8	419.6
	2013	2554.8	19144.0	32965.2	477.1
	2014	2649.6	20427.4	34193.9	489.5
ST-3	2011	888.3	6998.4	9914.3	422.0
	2012	800.9	6027.7	8959.0	400.5
	2013	898.5	6484.6	10049.8	410.5
	2014	876.7	6906.8	9826.8	389.2

CONCLUSION

The application of agrometeorological, hydrothermal, energy indices provides the scientific basis for determining the effect of temperature, radiation, relative humidity or photoperiod (bright sunshine hours) on different phenophases event of kinnow plants from days of first flower bud initiation to fruit physiological maturity. These results provided very clear stage wise or phenophases wise relations of weather parameters in term of amount, pattern and efficiency of heat energy consumption at different phenological events or stages. During the winter season (December to February) completion of period from fruit maturity to first flower bud initiation required less accumulated growing degree day, heliothermal and photothermal unit and needed more GDD, PTU, HTU during the days of first fruit to IFFS initiation more than 50%. These results can be used very effectively for forecasting the occurrence of different phenophases from day of FFBI to fruit harvesting and yield of the kinnow under the semi arid region of Hisar, Haryana.

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