AGRO- METEOROLOGICAL INDICES IN RELATION TO PHENOLOGY AND YIELDS OF PROMISING WHEAT CULTIVARS IN CHITWAN, NEPAL

Lal P. Amgain[1]

ABSTRACT

Agro-meteorological indices are the major yield governing factors especially under rainfed ecosystem. The major agro-meteorological indices (phenology, and heat and radiation use efficiencies) of four wheat cultivars were evaluated from the rainfed field experiment (2008-09). The experiment was conducted in RCBD with three replications. The total rainfall received during the winter season (1994-95 to 2008-09) showed satisfactory winter rainfall during wheat growing season except year 2008-09. The agro-meteorological results indicated that the number of days required to attain different phenological stages were comparatively longer in early sowing than the late sown wheat. None of the wheat cultivars could show stable yield in late planting conditions suggesting early planting for higher yield. Early sowing wheat achived the higher and stable heat, radiation and helio-thermal indices thus resulting into higher grain yield. The agro-meteorological indices could therefore be helpful in predicting the phenolgoy, growth and yields of wheat. However, more research is needed in other agro-ecological areas to validate the output further.

Key words: Agro-meteorological indices, growing degree days, heat use efficiency, helio-thermal unit, phenology, wheat

INTRODUCION

Weather variability is considered one of the major factors of inter-annual variation of crop growth and yield in all environments and it is more important in rainfed situation. The adverse agro-meteorological events like extreme hot and cold temperatures, the lesser brighter sunny days and irregular and unequal distributions of rains are the major factors for the decreasing growth and yields of any field crops especiallyunder rainfed environment. Rainfalls being vital, the growth phases of any variety of crops are determined basically with growing season in which the atmospheric ambient temperature and solar radiation are considered the major governing factors (Sastry et al., 2000). The planting of most of the crops in Nepal is rainfall dependent and the shift in sowing dates hence directly influences both the thermo and photoperiod. This in consequence has a great bearing on the phasic development and partitioning of the dry matter. Quantification of these effects may help in determining the sowing time and match the phenology of crop in specific environment to achieve higher heat and radiation use efficiencies.

Temperature based agro-meteorological indices such as growing degree days (GDD) and helio-thermal units (HTU) have been reported quite useful in predicting

[1] Assistant Prof . of Agronomy, IAAS Rampur, Chitwan email-amgain@gmail.com

the growth and yield of crops (Dooraiswamy and Thompsosn 1982, Jones et al. 2003). Other researchers also found the influence of temperature on phenology and yield of crops and expressed through accumulated heat unit system (Sikdar, 2009; Rao et al., 1999; Rao and Singh, 2007). Heat and radiation use efficiencies in terms of dry matter or yields are important aspects which have great practical applications. The total heat and radiant energy available to any crop is never completely converted to dry matter under even at the most favorable agro-climatic conditions. Moreover, the efficiency of conversion of heat and radiant energy into the dry matter depends upon the genetic factors, sowing time and crop type (Rao et al., 1999). Hence, the knowledge on the calculation of the growing degree days and their further mathematical derivations like helio-thermal unit (HTU), and heat and radiation use efficiencies (HUE and RUE) is the basic principle to understand the phenology and the proper planting times could be for different crop varieties over the spatial and temporal variations (Sreenivas et al., 2010).

Wheat is the third most important staple cropmainly grown in rice-wheat sequence in central Terai of Nepal. Being the dominance of rainfed agriculture system, Nepalese farmers rarely grow wheat on time by which there is marked reduction in yield (NWRP, 2010). The delayed planting of long duration photo-insensitive rice cultivars due to late onset of monsoon resulting late rice harvesting is causing delay in wheat sowing under rice-wheat system. The late planted wheat thus appeared to be affected by poor germination and post anthesis heat stress which reduces yield dramatically (Giri, 1998). November 15 is reported to be the optimum date of sowing wheat in Terai regions of Nepal and deviation from this date results nearly 30-50 kg/day/hectare reduction in yield depending upon climatic conditions (NWRP, 2010). It is also reported that about 30% of wheat area is under late planting in Nepal (Hobbs, 2000). It has also been reported that the average productivity and profitability of the rice-wheat system is quite low than its potential and the sustainability is at risk. The shorter growing duration, between sowing to harvesting of wheat was resulting for lesser growing degree days and unstable and low heat and radiant use efficiencies (Sreenivas et al., 2010, Reddy et al., 2004). There are several reports on sowing time and crop yield on rice and wheat (Giri, 1998) and winter maize (Amgain, 2011) but very few has analyzed the specific reasons of lower yield under late planting conditions in Nepal based on an agro-meteorology and physiological factors. Therefore, an attempt has been made to study the phenological behavior, and heat and radiation use efficiencies in prominent wheat cultivars for obtaining higher, stable and sustained grain yield.

MATERIALS AND METHODS

The major agro-meteorological indices (phenology, and heat and radiation use efficiencies) of wheat were evaluated from the rainfed field experiment (2008-09) done at Agronomy Farm of Institute of Agriculture and Animal Sciences Rampur Campus Rampur, Chitwan ($27^0 37'$N, $84^0 25'$E and 256 masl.). Four diverse wheat cultivars (RR-21, NL-297, BL-1473 and BL-1022) with early, mid and late maturity days were sown at three different dates (Nov 15, Dec 1 and Dec 15). The experiment was conducted in RCBD with three replications having slightly acidic (pH 6.5) sandy loam soil with27.33% soil moisture at field capacity, low organic carbon (0.45%) and total soil N (0.20% N), and medium phosphorus (23.2 kg/ha) and potassium (157.5 kg/ha). The records on the major phenological stages (emergence, crown root initiation (CRI), flowering, grain filling and physiological maturity) and yield and dry matter has been taken as standard international protocol given for wheat by CIMMYT, Mexico. Ten fixed plants in each plot were randomly selected from emergence and fixed up to the physiological maturity stages to visualize their different pheno-phases and 75% developmental stages have been marked. The standard package of practices was followed to grow wheat (Reddy, 2005). The daily weather data were collected from the Meteorological Observatory of National Maize Research Program, Rampur, Chitwan and the rainfall data of the last 15 years (1994-95 to 2008-09) has been compared to fix the normal sowing of wheat (Table 1). The average mean temperature and total sunshine hours attained by the various wheat cultivars from sowing to physiological maturity have been depicted in Figure 1 and 2, respectively. Similarly, the average temperature and mean sunshine hours from one developmental stage to the other stage for a particular planting date and cultivar was also taken for the further mathematical expressions (Rao et al.,2000; Singh et al., 1998; Ritchie and Nesmik, 1991).

1. Growing degree days (GDD) = {(T max + T min)÷2}-Tb
   (Tb= Base temperature =10 ^{0}C)
2. Helio-thermal unit (HTU)= GDD x Duration of sunshine hours
3. Heat use efficiency (HUI) = Biomass yield (kg/ha) ÷ GDD
4. Helio-thermal unit use efficiency (HTUE) = Biomass yield (kg/ha) ÷ HTU
5. Radiation use efficiency (RUE) = Biomass yield (kg/ha) ÷ Radiation hours

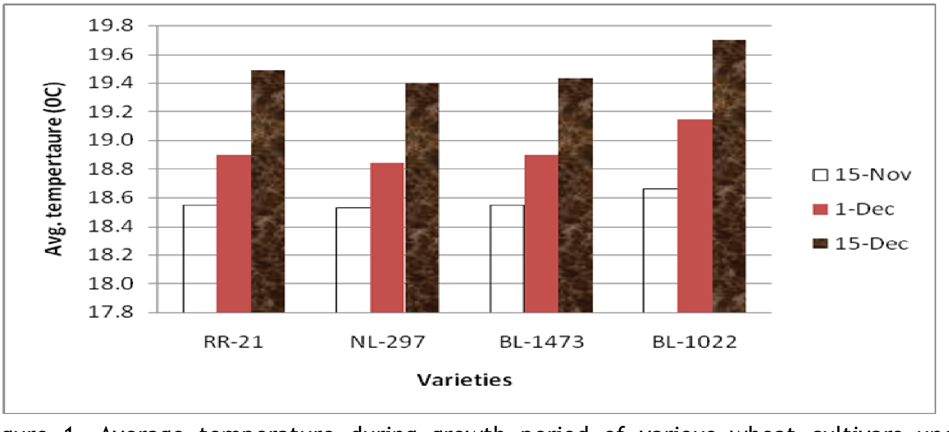

Figure 1. Average temperature during growth period of various wheat cultivars under different sowing dates

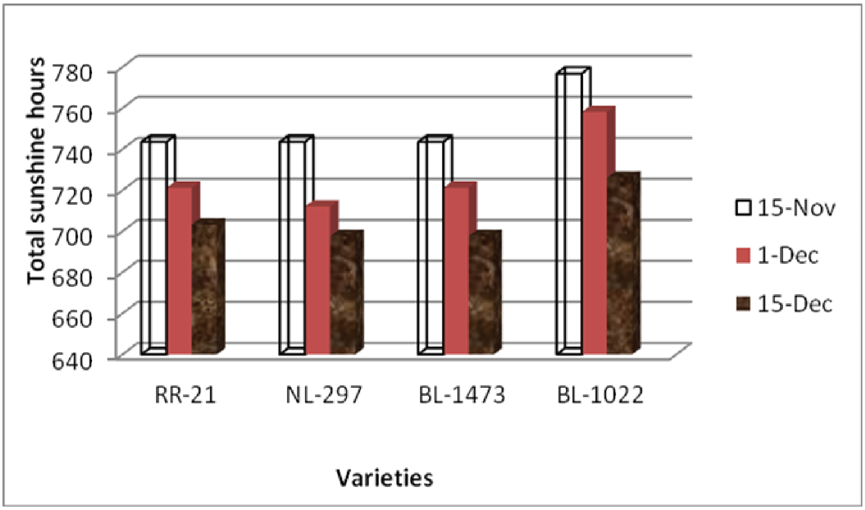

Figure 2. Total sunshine hours received by various wheat cultivars under different sowing dates

RESULTS AND DISCUSSIONS

RAINFALL PATTERN

The total monthly rainfall pattern of Chitwan over the last 15 years (Table 1) revealed that rainfed wheat could be a successful package to the farmers of central–terai region of Nepal providing life saving irrigation at critical growth stages. Except 2008-2009, the total amount of rainfall received during the wheat growing period was average of 140.8 mm and considered effective for growing wheat successfully. Though, wheat requires about 400-500 mm of water for its successful growth and development, the interval of rainfall and crop growth stages are more critical (Reddy, 2005). The crops planting on all dates did not receive any effective rainfall in 2008-09, however, the growth was optimum upto the harvest stage of crop due to the higher moisture holding capacity of the soil (27.33% soil moisture at field capacity) and some significant amounts of dew occurred at night during the crop growing season. Sharma et al. (1984) has also mentioned the successful growth of rainfed wheat under inner-terai region of central Nepal.

Phenology, growing degree days and helio-thermal units

The phenology, growing degree days, and helio-thermal unit results revealed that different phenological stages differed significantly from cultivar to cultivar and planting dates (Table 2). The stable temperature and sunshine hours from early vegetative phases to physiological maturity of all cultivars resulted in increased number of days for attaining different phenological stages under normal planting (Figure 1 and 2).

Table 1. Decadal history of monthly total rainfall pattern during winter in Chitwan

Year/ month	Nov	Dec	Jan	Feb	Mar	Apr	Total
1994-95	0.0	0.0	1.5	22.9	5.9	36.0	66.3
1995-96	1.7	3.5	55.7	40.4	0.0	6.0	107.3
1996-97	0.0	0.0	13.4	1.5	2.9	144.6	162.4
1997-98	7.6	146.0	4.4	13.2	87.2	88.3	346.7
1998-99	8.2	1.0	0.4	0.0	0.0	10.1	19.7
1999-00	0.2	0.0	0.8	9.8	24.9	7.6	43.3
2000-01	6.4	0.0	1.6	18.6	0.8	67.4	94.8
2001-02	20.4	0.0	31.9	28.3	45.6	57.7	183.9
2002-03	44.6	0.0	35.1	59.4	62.0	58.7	259.8
2003-04	79.8	10.7	62.7	0.0	0.0	180.2	333.4
2004-05	0.0	0.0	38.1	6.4	38.9	28.8	112.2
2005-06	2.1	19.0	0.0	0.0	3.0	125.9	150.0
2006-07	4.6	0.0	0.0	80.3	47.6	100.9	233.4
2007-08	0.0	0.0	17.1	1.7	33.8	40.4	93.0
Mean	11.0	11.3	16.7	17.7	22.0	62.1	140.8
2008-09	0.0	0.0	0.0	0.1	0.0	0.0	0.1

Source: National Meteorological Observatory of Rampur, National Maize Research Program, Chitwan

The similar results were found in maize (Amgain, 2011) and wheat (Ghosh et al., 2000; Paul and Sarker 2000; Sandhu et al., 1999). Late planting decreased the duration of all phenological stages compared to normal planting associated with less average temperature, more foggy days with less bright sunshine hours especially upto flowering stages of wheat. Sandhu et al. (1999) and Paul and Sarker (2000) also reported that requirement of heat units decreased for different phenological stages with delay in sowing of wheat. However, the late planted wheat abruptly come to flowering and maturity with in short time period due to high temperature after January months and the accumulative GDD records were also comparatively higher due to higher temperatures. The requirements of HTU for normal planting conditions were significantly higher than the late planting conditions with few exceptions with some cultivars and planting dates (Table 2). The variation in sunshine hours at different developmental stages of wheat has affected the magnitudes of the HTU though there was higher GDD at advanced growth stages. The random trend of HTU for different phenological stages was also found to be for late sown wheat (Rajput et al., 1987; Paul and Sarker, 2000; Hauqe et al., 2000).

Heat and radiation use efficiencies and grain yields

It was observed that all wheat cultivars were more efficient to show more heat and radiation use efficiencies at normal growing condition than the late growing conditions (Table 3). The date of planting is major governing factors in crop production and considered as low-cost high monetary returned technology under best management conditions. The wheat varieties planted on November 15 produced higher yield than subsequent late plantings. The results are in accordance to Amgain (2011) in maize, Paul and Sarker (2000) in wheat, Rao et al.(2000) in cluster bean and Singh *et al.* (1998) in pearlmillet.

The percentage reduction in yield was more for November 15 vs December 1 sowing than the December 1 vs December 15 planting for short duration NL-297 variety but the vice-versa with mid andlate maturing varieties RR-21, BL-1473 and BL-1022 (Table 4) suggesting that early planting is must for long duration varieties. This might be due to the late planting of wheat resulted less dry matter and metabolized less photosynthate as the result of less growing degree days and helio-thermal units. Rao and Singh (2007) have also found the lesser yield of pearl-millet when planted delayed in Rajsthan, India.

Table 2. Calendar days, accumulated growing degreedays (GDD), and helio-thermal units (HTU) during different pheno-phases of wheat in Chitwan.

Treatment	Emergence to crown root initiation			Crown root initiation to flowering			Flowering to physiological maturity			Emergence to physiological maturity		
	Cal days	GDD	HTU	Cal days	GDD	HTU	Cal days	GDD	HTU	Cal days	GDD	HTU
RR-21												
Nov 15	21	215	1549	70	519	4868	30	322	2816	121	1056	9263
Dec 1	25	218	1277	63	480	4121	28	343	3229	116	1041	8627
Dec 15	26	176	944	59	494	4106	27	402	3827	112	1115	8877
NL-297												
Nov 15	22	225	1406	68	500	4482	30	318	3026	120	1043	8914
Dec 1	26	225	1078	60	401	3917	29	349	2381	115	1025	7879
Dec 15	27	182	1199	57	502	4416	27	372	3220	111	1368	8836
BL-1473												
Nov 15	23	235	1754	64	463	3917	34	358	3692	121	1056	9366
Dec 1	27	232	1522	58	434	3722	31	348	3356	116	1014	8599
Dec 15	26	188	1298	57	507	3519	28	361	4019	111	1466	8836
BL-1022												
Nov 15	27	269	1390	73	553	5932	33	403	3492	133	1225	10814
Dec 1	30	250	1388	66	530	5084	31	434	3212	127	1214	9683
Dec 15	31	209	1162	56	510	4472	28	406	1935	115	1333	7570
LSD	3	77	213	6	109	524	2	125	689	4	287	829
CV%	5	6	8	4	8	10	5	6	11	8	10	12

Table 3. Radiation, dry matter, heat and radiation use efficiency of wheat cultivars in Chitwan.

Treatment	Radiation $MJ/m^2/day$	Dry matter Kg/ha	HUE Kg/ ^0C day	HTUE Kg ^0C hour	RUE Kg/MJ
RR-21					
Nov 15	2350	5735	5.43	0.62	2.44
Dec 1	2279	5526	5.31	0.64	2.42
Dec 15	2222	4972	4.43	0.56	2.24
NL-297					
Nov 15	2350	4851	4.65	0.54	2.06
Dec 1	2250	4474	4.36	0.57	1.99
Dec 15	2204	4166	3.05	0.47	1.89
BL-1473					
Nov 15	2350	6838	6.48	0.73	2.91
Dec 1	2280	6185	6.10	0.72	2.71
Dec 15	2204	5588	3.81	0.63	2.53
BL-1022					
Nov 15	2405	7722	6.30	0.71	3.15
Dec 1	2396	7350	6.05	0.76	3.07
Dec 15	2294	6652	4.99	0.88	2.90

Table 4. Grain yield (kg/ha) and yield reduction (%) due to delayed planting in different wheat cultivars

Wheat cultivars	Grain yield (kg/ha)			Yield reduction (%) due to late sowing		
	Nov 15	Dec 1	Dec 15	Nov 15 vs Dec 1	Dec 15 vs Dec 15	Nov 15 vs Dec 15
RR-21	2179	1934	1625	11.25	15.99	25.44
NL-297	1815	1520	1356	16.27	10.79	25.31
BL-1473	2872	2289	1896	20.31	17.15	33.98
BL-1022	3089	2646	2145	14.34	18.93	30.56

Correlation and regression

Correlation between the calendar days and AGDD and HTU indicated significant relationship between calendar days and AGDD and HTU during emergence to physiological maturity stage of all promising wheat cultivars while negatively correlated and non-significant during emergence to crown root initiation stages for all wheat cultivars (Table 5).

Table 5. Correlation coefficients between calendar days and AGDD and HTU during different pheno-phases of wheat under different planting dates

Phenophases	RR-21		NL-297		BL-1473		BL-1022	
	AGDD	HTU	AGDD	HTU	AGDD	HTU	AGDD	HTU
Emergence to crown root initiation	-0.614	-0.924	-0.654	-0.843	-0.331	-0.732	-0.886	-0.701
Crown root initiation to flowering	0.751	0.939	-0.227	-0.980	-0.248	0.920	0.991	0.981
Flowering to physiological maturity	-0.897	-0.951	-0.961	-0.401	-0.204	-0.493	0.033	0.972
Emergence to physiological maturity	0.993	0.652	0.698	0.132	1.0	0.675	0.913	0.993

RR-21 and BL-1022 being quite longer in duration than NL-297the flowering to physiological maturity stages was found to be significantly correlated. The correlation was found variable and inconsistent on NL-297 and Bl-1473 especially during crown root initiation to flowering and this might be due to the shorter phase of these cultivars due to lesser accumulated temperature and sunshine hours.

Following regression equations were established to predict the phenology of wheat using AGDD and HTU in all wheat cultivars.

RR-21: Y= 79.74 + 0.0132 AGDD + 0.001978 HTU R^2= 0.98

NL-297: Y= 134.84 + 0.0430 AGDD -0.094 HTU R^2= 0.49

BL-1473: Y= 82.92 + 0.0214 AGDD -0.0004 HTU R^2= 0.99

BL-1022: Y= 100.86 - 0.016 AGDD + 0.0046 HTU R^2= 0.83

Physiological maturity can be predicted using AGDD and HTU which accounted for 99, 99, and 83 percent, for RR-21, BL-1473 and BL-1022, respectively.

CONCLUSIONS

Wheat cultivars BL-1473, BL-1022 and RR-21 were better to show greater stability to solar energy, accumulated growing degree days (AGDD) and heat use efficiency than the NL-297 cultivar. NL-297 is suggested for late sowing and the less reduction in yield between Dec 1 and Dec 15 plantings. By sowing the wheat on 15 November, the higher and stable heat, radiation and helio-thermal indices were achieved and thus the higher grain yield. The agro-meteorological indices could therefore be helpful in predicting the phenolgoy, growth and yields of wheat in Chitwan. However, more research is needed in other agro-ecological areas to validate the output further.

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