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Research Article

Effect of Soil Temperature on Biophysical Parameters of Wheat Crop under Different Weather Conditions in Semi Arid Region

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ABSTRACT

Soil temperature is one of potential parameters that determine the crop growth and productivity. In arid and semi-arid zones, soil moisture retention and soil thermal regulation is an important aspect of crop establishment as high soil heat stress may damage seedling emergence and root growth and hence crop growth and yield. Keeping these in mind, field experiments was conducted to measure soil temperature at different depth and its effect on biophysical parameters of wheat crop under variable weather conditions at research farm of IARI, New Delhi during *Rabi* 2012-13 and *Rabi* 2013-14.Two varieties of wheat were sown on three different dates for creating different weather condition at different phenological stages of the crop. The crops were raised following the standard recommended agronomic practices with three replications in a randomized block design. Biomass, LAI and soil temperature was measured at weakly interval. Soil temperature was measured at different depth 0-5 cm, 5-10 cm and 10-15cm. Results showed that air temperature had statistically positive and strong relationship with the soil temperature both at morning (R^2 =0.76 to 0.89) measured at 7.21 AM and afternoon (R^2 =0.72 to 0.82) measured at 2.21 PM under different weather conditions. There was positive correlation between biophysical variables and cumulative surface soil temperature. Linear regression analysis showed that in biomass 87 to 95% variation in production and for leaf area index 79 to 96% variation in production in wheat crop under different weather conditions could be explained through the soil temperature.

Key words: Soil temperature, wheat crop, biophysical parameters

Introduction

Soil temperature is an important parameter for plant growth. Variation in soil temperature is much more pronounced because of varying characteristics and composition of soil. Soil temperature extremes influence the germination of seeds, functional activity of root system. Excessive high temperature is harmful to roots and also causes lesions of stem. Extreme low temperature impedes intake of nutrients. Soil moisture intake by the plants stops when the soil temperature is at a temperature of below 1°C. Day time soil temperature is more important because it is necessary to maintain favourable internal crop water status in the light of the high evaporation rate. Extreme low and high temperature influences the soil microbial population and rate of organic matter decomposition. Rate of decomposition is high under high soil temperatures. Soil temperature controls the nutrient availability (e.g., Nutrient release and N fixation). Soil temperature is one of potential parameters that determine the crop growth and productivity. In arid and semi-arid zones, soil moisture retention and soil thermal

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regulation is an important aspect of crop establishment as high soil heat stress may damage seedling emergence and root growth and hence crop growth and yield. Soil is a natural resource and soil temperature play important role in determining crop productivity and sustainability (Gliñskiand Walczak, 1998). Biological and biochemical processes in the soil is controls by the soil temperature which affect seed germination, plant development, soil organic matter, fertilizer efficiency, nutrient uptake and decomposition, and disease and insect occurrence (Jacobs *et al*., 2007; Karhu *et al*., 2010; Leifeld and Fuhrer, 2005; Vanhala *et al*., 2007; Verma *et al.*, 2011). In arid and semi-arid zones, soil moisture retention and soil thermal regulation is an important aspect of crop establishment as high soil heat stress may damage seedling emergence and root growth and hence crop growth and yield. The day today variation in the soil temperature depends upon the incoming solar radiation on the earth surface (Azadegan, 2011).

There is a spatiotemporal change in the soil temperature during crop growing period and is the function of the management system (Oliveira *et al*., 2001). The quantification of those changes is necessary to avoid any adverse effect of soil temperature and crop growth development.

Farmers try to alter the soil heat balance by drainage, mulching and adding organic fertilizers for preventing reflection of heat, to preserve heat within the soil and to provide appropriate soil temperature for obtaining the optimum temperature for seed germination. Inadequate soil temperature causes poor germination, retarded maturity and reduction in the quality and quantity of the product. The number of days required for the seed germination is depends upon the soil temperature and plant types (Kaspar and Bland, 1992).The aim of the present studies is to determine the spatiotemporal changes during growing season of wheat crop under different weather conditions in the semi arid region.

Materials and Methods

Field experiments were conducted during *Rabi* 2012-13 and *Rabi* 2013-14 at research farm of IARI, New Delhi (28º35′N, 7712′E) under variable weather conditions. Two varieties of wheat (HD-2851 and PBW-502) were sown on three different dates for creating different weather condition at different phenological stages of the crop. The crops were raised following the standard recommended agronomic practices with three replications in a randomized block design. The seed rate was 100 kg ha^{-1}, sowing depth was 4 cm, row to row distance was 22.5cm.

Soil temperature was measured at different depth 5 cm, 10 cm and 15cm in different varities using soil thermometers under different weather conditions. Weekly soil temperature was measured at 7:21 AM and 2:21 PM. This weekly soil temperature was then accumulated over weeks to determine soil heat accumulation. These soil temperatures were correlated with the biophysical parameters (LAI, dry biomass production) accumulated upto peak values to establish the relationship with soil temperature. Three randomly selected plant samples (above-ground) were taken and the leaf area was measured using leaf area meter (model LICOR-3100, Lincoln, NE,USA). The LAI was calculated using the formula: LAI=measured leaf area per plant (cm^2)/ground area covered by the plant (cm^2).The samples collected for estimating leaf area index were utilized for assessing the biomass production. The average seed yield was calculated. Statistical analysis viz., computations of correlation coefficients, linear and non-linear regression analysis, ANOVA, multiple correlation coefficients were carried out using Excel and SPSS packages (Version10.0). Regression equations were fitted through the origin. This procedure gives the best estimates of the average biophysical parameters over the treatments. The required graphs were drawn using MS Excel software packages.

Results and Discussion

The weather analysis during crop growing season showed that monthly mean temperature varied from 11.5 to 27.7ºC and mean relative humidity was varied from 47 to 82%, Total rainfall received was more in first season. During

2012-13 total rainfall was 223.8mm while during 2013-14 it was 148.8 mm. Pan evaporation was ranged between 2.1 to 7.2mm and bright sunshine hours was ranged between 2.4 to 8.5h (Table 1).

The total growing period during 2013-14 crop season was 131, 124 and 114 days in first, second and third sown crop and during 2012-13crop season it was 120, 118, 113 days in first, second and third sown crop. During 2012-13 crop season the total growing period is less as compared to 2013-14. During 2013-14 the growing degree days had higher value during vegetative stages and less value during pod formation and maturity stage as compared to the crop grown during 2012-13. This causes more yields during 2013-14 as compared to yield during 2012-13 (Table 2).

Temporal variations in soil and air temperatures are shown in the table 3. Mean minimum and maximum soil temperatures along with their statistical analysis are presented in Table 1. The soil temperature dynamics within the cultivars and sowing dates in two seasons indicated that there were indeed variations in minimum as well as maximum soil temperatures. The soil temperature measured at 2.21PM (evening) had 0-9ºC less temperature at 0-5cm depth, 1-10ºC at 5-10 cm depth and 2-11ºC at 10-15 cm depth as compared to air temperature under

Table 1. Weather parameters during Rabi 2012-13 and 2013-14

Months	Max. temp (°C)	Min. temp. (°C)	Mean temper-ature	Rainfall (mm)	Wind speed (kmph)	RH-I (%)	RH-II (%)	Mean RH (%)	BSS (hrs)	Evapo-ration (mm/ day)
Nov, 2012	27.3	9.9	18.6	0.0	2.1	89.0	35.0	62.0	3.4	2.4
Nov, 2013	26.9	9.9	18.4	0.4	3.4	90.9	48.2	69.6	4.9	3.1
Dec, 2012	21.7	7.5	14.6	8.6	4.7	84.2	49.8	67.0	4.1	2.6
Dec, 2013	22.2	7.1	14.7	6.8	3.5	93.8	56.4	75.1	4.0	2.1
Jan, 2013	18.2	4.8	11.5	40.8	4.5	92.1	65.2	78.6	3.8	2.9
Jan, 2014	18.7	6.8	12.7	18.6	3.9	96.7	66.5	81.6	2.4	1.9
Feb., 2013	22.0	9.3	15.6	150.2	4.4	91.8	55.6	73.7	5.1	2.7
Feb., 2014	21.3	7.5	14.4	82.1	4.1	96.0	63.8	79.9	4.2	2.5
March, 2013	30.0	13.7	21.9	12.6	5.6	87.3	35.1	61.2	8.0	4.7
March, 2014	27.4	12.8	20.1	24.5	5.0	89.8	46.9	68.3	6.5	3.8
April, 2013	36.1	19.4	27.7	11.6	6.0	67.2	27.5	47.4	8.4	7.2
April, 2014	34.8	17.9	26.3	16.4	6.0	73.4	40.1	56.8	8.5	6.8

Table 2. No of days and thermal time required for different phenological stages of wheat crop sown under different weather conditions in both the season during Rabi 2013-14 and 2012-13

Phenological stage→	First sowing		Second sowing		Third sowing	
Variety↓	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13
Number of days						
Emergence	8	6	9	6	14	10
50% Flowering	85	97	87	90	84	85
Maturity	131	120	124	118	114	113
Growing degree days (°C)						
Emergence	117.2	70	130.7	67	193.1	71
50% Flowering	701.95	700	707.4	760	633.84	681
Maturity	450	473	430.15	500	293.85	665
Average yield (kg ha^{-1})±SE	4493±42.03	3939±45.59	4311±62.33	3738±36.12	3795±48.12	3130±21.01

Table 3. Temporal variations in soil and air temperature measured at 2.21PM (evening) and at 7.21 AM (Morning) in wheat sown at different dates of sowing

Days after sowing	Air tempe-rature	Mean soil temperature	Standard deviation	Variance	CV %	Mean soil temperature	Standard deviation	Variance	CV %	Mean soil temperature	Standard deviation	Variance	CV %
		Soil temperature at 0-5cm depth				Soil temperature at 5-10cm depth				Soil temperature at 10-15 cm depth			
Soil temperature measured at 2.21 PM (Evening) in First sowing													
59	21.8	19.1	1.19	1.40	0.06	18.2	0.98	0.95	0.05	17.3	0.66	0.43	0.04
66	22.1	18.0	1.22	1.50	0.07	17.3	1.28	1.65	0.07	16.5	0.67	0.44	0.04
73	24.3	18.1	1.73	3.02	0.10	16.8	1.20	1.44	0.07	16.1	0.76	0.59	0.05
86	23.4	17.0	1.34	1.82	0.08	15.2	1.29	1.68	0.08	14.6	0.72	0.51	0.05
94	25.4	19.8	1.65	2.74	0.08	18.1	1.29	1.66	0.07	17.1	1.02	1.04	0.06
101	30.4	21.8	2.02	4.10	0.09	20.4	2.00	4.00	0.10	19.3	1.69	2.87	0.09
108	27.8	24.8	2.38	5.67	0.10	22.5	2.31	5.36	0.10	20.6	2.02	4.1	0.10
116	34.8	28.2	2.99	8.90	0.11	26.3	3.10	9.66	0.12	25.1	3.47	12.05	0.14
122	30.2	30.4	0.40	0.16	0.01	29.0	1.21	1.47	0.04	28.0	1.49	2.23	0.05
Soil temperature measured at 2.21 PM (Evening)in Second sowing													
44	21.8	21.3	1.02	1.05	0.05	20.1	0.67	0.46	0.03	18.7	0.49	0.24	0.03
51	22.1	18.8	0.34	0.12	0.02	17.5	0.16	0.02	0.01	16.8	0.05	0.01	0.00
58	24.3	18.5	0.80	0.65	0.04	17.2	0.68	0.47	0.04	16.7	0.45	0.21	0.03
71	23.4	17.2	1.21	1.48	0.07	15.9	0.81	0.67	0.05	15.2	0.52	0.27	0.03
79	25.4	19.5	0.60	0.36	0.03	18.4	0.74	0.56	0.04	17.5	0.8	0.65	0.05
86	30.4	22.0	2.54	6.47	0.12	20.8	2.58	6.67	0.12	19.7	2.07	4.29	0.11
93	27.8	25.7	2.89	8.40	0.11	23.7	2.61	6.85	0.11	22.1	2.27	5.17	0.10
101	34.8	29.7	1.38	1.90	0.05	27.0	2.39	5.75	0.09	25.2	2.22	4.95	0.09
107	30.2	30.1	0.45	0.20	0.01	29.3	0.53	0.28	0.02	27.8	0.6	0.36	0.02
Soil temperature measured at 2.21 PM (Evening)in Third sowing													
30	21.8	20.5	0.50	0.25	0.02	19.1	0.47	0.22	0.02	18.0	0.41	0.17	0.02
37	22.1	20.9	0.75	0.57	0.04	19.1	0.45	0.20	0.02	17.6	0.22	0.05	0.01
44	24.3	20.5	0.66	0.43	0.03	18.8	0.33	0.11	0.02	17.5	0.21	0.04	0.01
57	23.4	17.8	0.90	0.83	0.05	16.0	0.52	0.27	0.03	14.9	0.19	0.03	0.01
65	25.4	21.8	1.49	2.23	0.07	20.3	1.41	1.99	0.07	19.4	1.28	1.66	0.07
72	30.4	21.5	1.77	3.15	0.08	20.6	1.83	3.37	0.09	19.6	1.61	2.59	0.08
79	27.8	23.7	2.23	5.01	0.09	22.5	1.97	3.88	0.09	21.3	2.08	4.35	0.10
87	34.8	32.0	1.04	1.08	0.03	31.1	0.91	0.83	0.03	30.1	1.09	1.18	0.04
93	30.2	29.4	0.40	0.16	0.01	28.4	0.74	0.56	0.03	27.8	1.19	1.43	0.04

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Soil temperature measured at 7.21 AM (Morning) in First sowing													
60	11.5	14.1	0.35	0.12	0.02	14.6	0.25	0.06	0.02	15.1	0.14	0.02	0.01
67	12	14.1	0.45	0.20	0.03	14.7	0.38	0.14	0.03	15.2	0.35	0.12	0.02
74	15.6	15.7	0.16	0.02	0.01	16.3	0.17	0.02	0.01	16.7	0.22	0.05	0.01
87	6.2	11.2	0.75	0.57	0.07	12.7	0.66	0.44	0.05	13.8	0.43	0.18	0.03
95	13.5	15.1	0.71	0.51	0.05	16.4	0.59	0.35	0.04	17.1	0.56	0.31	0.03
102	10.5	12.8	0.87	0.76	0.07	13.9	0.95	0.92	0.07	15.0	0.9	0.81	0.06
109	10.5	14.2	0.84	0.71	0.06	15.6	0.93	0.87	0.06	17.0	0.91	0.84	0.05
117	18.1	18.9	0.40	0.16	0.02	19.7	0.45	0.20	0.02	21.0	0.58	0.33	0.03
123	20.9	19.9	0.57	0.32	0.03	20.7	0.75	0.57	0.04	21.7	0.61	0.38	0.03
Soil temperature measured at 7.21 AM (Morning) in Second sowing													
45	11.5	13.7	0.16	0.02	0.01	14.4	0.16	0.03	0.01	14.9	0.15	0.02	0.01
52	12	14.1	0.23	0.05	0.02	14.7	0.16	0.03	0.01	15.2	0.11	0.01	0.01
59	15.6	15.8	0.30	0.09	0.02	16.6	0.25	0.06	0.02	16.9	0.34	0.11	0.02
72	6.2	11.7	0.59	0.35	0.05	13.1	0.30	0.09	0.02	14.1	0.2	0.04	0.01
80	13.5	15.2	0.57	0.33	0.04	16.2	0.70	0.50	0.04	16.9	0.71	0.5	0.04
87	10.5	13.0	0.68	0.46	0.05	13.7	0.76	0.58	0.06	14.8	0.73	0.53	0.05
94	10.5	14.9	0.81	0.65	0.05	15.8	0.67	0.45	0.04	17.0	0.77	0.6	0.05
102	18.1	19.9	0.45	0.21	0.02	20.5	0.46	0.21	0.02	21.5	0.25	0.06	0.01
108	20.9	20.4	0.43	0.18	0.02	21.0	0.60	0.36	0.03	21.7	0.18	0.03	0.01
Soil temperature measured at 7.21 AM (Morning) in Third sowing													
31	11.5	13.6	0.10	0.01	0.01	14.3	0.09	0.01	0.01	14.9	0.18	0.03	0.01
38	12	14.2	0.19	0.30	0.01	14.8	0.10	0.01	0.01	15.4	0.11	0.13	0.01
45	15.6	15.1	0.23	0.05	0.02	16.0	0.15	0.23	0.01	16.5	0.14	0.02	0.01
58	6.2	10.5	0.43	0.19	0.04	12.1	0.45	0.20	0.04	13.2	0.36	0.13	0.03
66	13.5	15.5	0.25	0.06	0.02	16.5	0.41	0.17	0.02	17.3	0.35	0.12	0.02
73	10.5	13.8	0.64	0.41	0.05	14.6	0.68	0.45	0.05	15.5	0.54	0.29	0.03
80	10.5	14.7	0.97	0.95	0.07	15.6	0.87	0.76	0.06	16.7	0.82	0.67	0.05
88	18.1	19.9	0.29	0.08	0.01	20.5	0.25	0.06	0.01	21.5	0.2	0.04	0.01
94	20.9	20.0	0.40	0.16	0.02	20.8	0.26	0.07	0.01	21.8	0.14	0.02	0.01

different weather conditions. However, soil temperature measured at 7.21 AM (morning) had 0-6ºC more temperature at 0-5cm depth, 0-7ºC at 5-10 cm depth and 1-8ºC at 10-15 cm depth as compared to air temperature under different weather conditions. Results showed that soil temperature measured at 7.21 AM at different depth was found to be more in the soil as compared to air and with increase in depth the soil temperature increases. Soil temperature measured at 2.21 PM was found to be lower value in soil as compared to the air and with increase in the depth the soil temperature decreased in both the years. It is known that the soil temperature is normally affected by the surface characteristics, turbulent and radiative energy balance, incoming solar radiation, temperature and wind speed. Therefore, it is important to correlate the soil temperature with the ambient temperature. The soil temperature was correlated with the air temperature is shown in Fig.1. It was observed that there was indeed a positive and significant correlation between these two parameters. The linear trend in soil temperature measured at depth 0-5cm during morning 7.21 AM under different weather conditions observed that coefficient of determination R^2 was ranged 0.83 to 0.89 and each unit increase in ambient temperature would lead to increase in minimum soil temperature by 0.73 to 0.77 units while soil temperature measured during afternoon 2.21PM had coefficient of determination R^2 ranged 0.72 to 0.76 and each

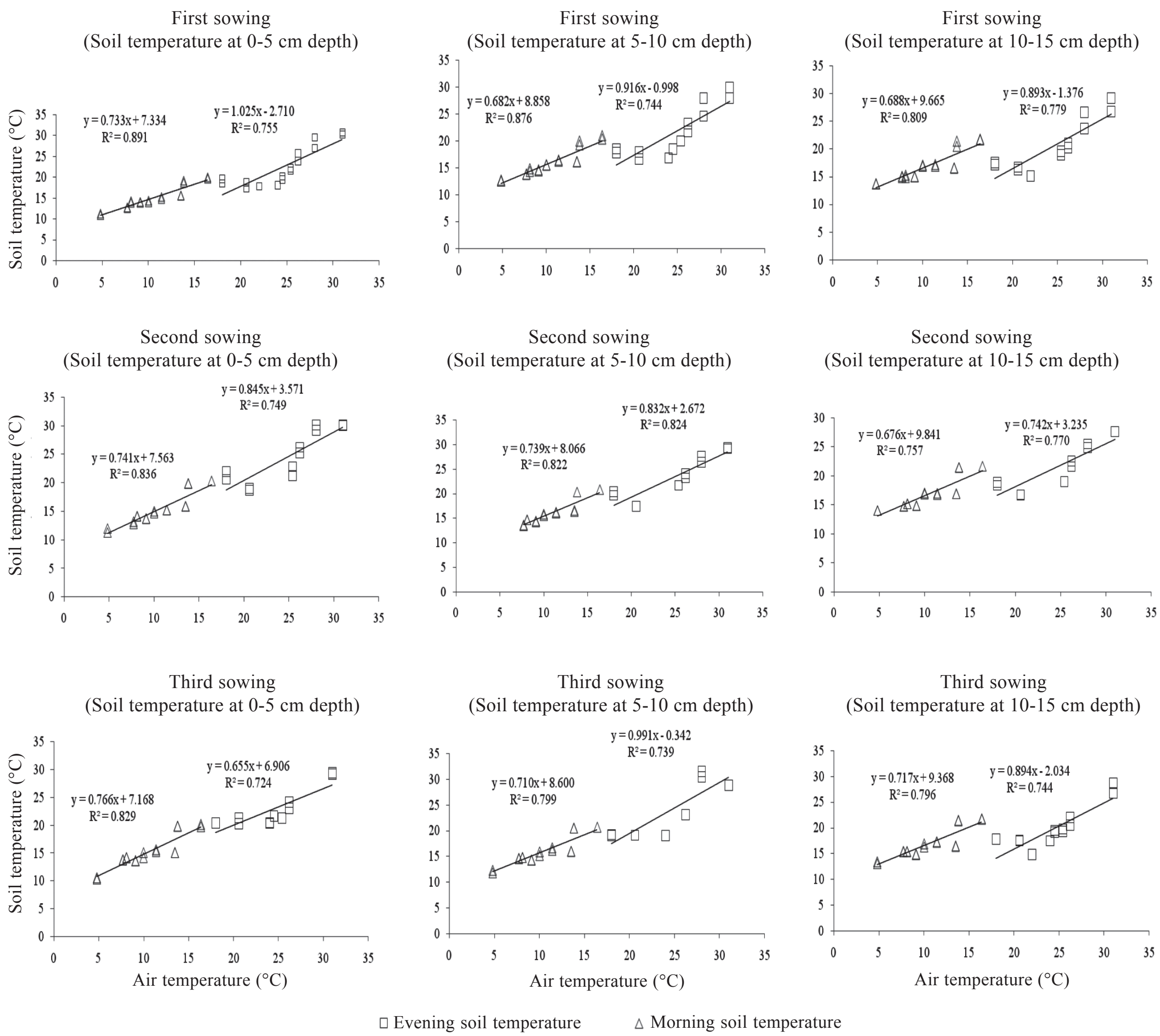

Fig. 1. Relations between air temperature and soil temperature measured at 7.21AM and 2.21PM.

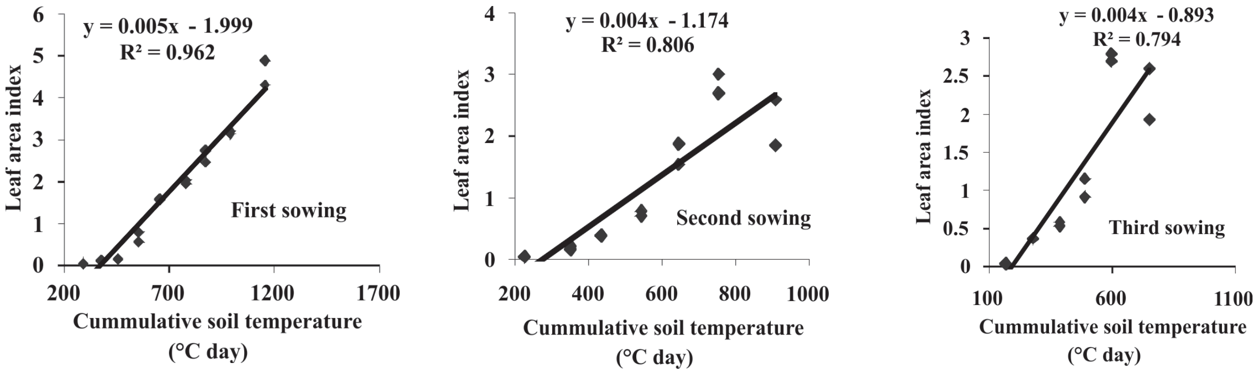

Fig. 2. Relations of Leaf area index with soil temperature

unit increase in ambient temperature would lead to increase in minimum soil temperature by 0.66 to 1.03 units under different weather conditions. This means that the heat capacity of the soil is dependent on the ambient temperature apart from the soil properties and soil intrinsic factors, and in equilibrium under given atmospheric conditions. Over a period of time any change in air temperature would causes increase in soil heat accumulation and hence the soil thermal regimes.

Correlations between biophysical parameters were done. The relationship of soil thermal accumulation and the leaf area index upto peak value was established under different weather conditions through linear regression analysis and shown in the figure 2. Results showed that there is statistically significant and positive correlation. The R^2 value was ranged 0.79 to 0.96 under different weather conditions. This means that heat accumulating in soil over crop growing season could explain around 79 to 96% of the variability in the leaf area index. In order to quantify the dry matter production as a function of soil thermal accumulation it was observed that 87 to 95% variation in dry matter could be explained through differential rate of soil temperature accumulation during the crop growing season (Fig. 3). Adak *et al*. (2011) also found the similar correlation between soil temperature and biological parameters. Linear and non-linear statistical analysis confirmed that there was a positive significant correlation between heat accumulation over its growing period and biophysical parameters (Table 4). This showed that the linear and polynomial regression model developed for wheat variety may be useful for prediction of biophysical parameters such as leaf area index and biomass for other varieties under different weather conditions. This information can be used as input parameters in dynamic crop simulation model for improving the efficiency of the model for estimating the plan biophysical parameters.

Conclusion

From the above studies it was concluded that soil temperature showed a statistically positive

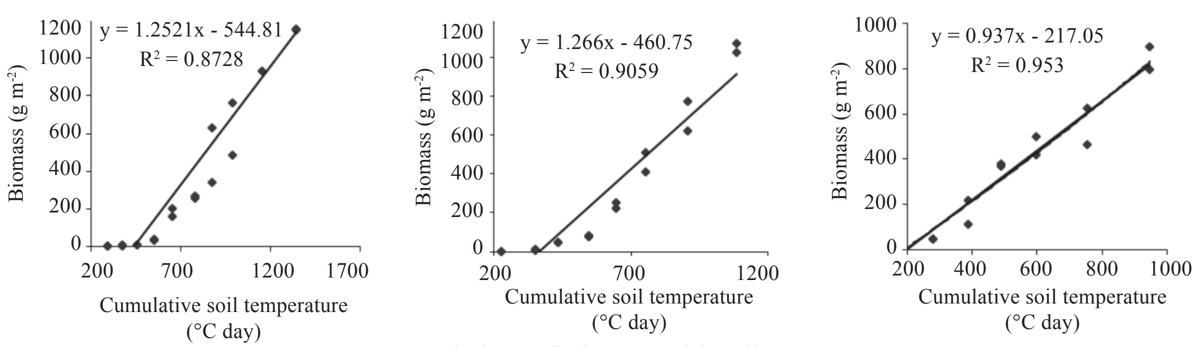

Fig. 3. Relations of Biomass with soil temperature

Table 4. Linear and non-linear regression models for predicting the biomass and leaf area under different weather condition in wheat crop as function of soil temperature

Model	First sowing	Second sowing	Third sowing
		Biomass	
Linear	y = 1.252x - 544.8 R^2 = 0.872	y = 1.266x - 460.7 R^2 = 0.905	y = 1.0937x - 217.05 R2 = 0.953
Exponential	Y = 1.114e0.006x R^2 = 0.879	Y= 1.116e0.007x R^2 = 0.890	Y= 4.968e0.006x R^2 = 0.701
logarithmic	Y=804.8ln(x) - 4849 R^2 = 0.751	Y=639.5ln(x) - 3719 R^2 = 0.742	Y = 478.1ln(x) - 2573 R^2 = 0.875
Polynomial (order 2)	Y = 0.000x2 - 0.076x - 103.3 R^2 = 0.908	Y = 0.001x2 - 0.618x + 49.58 R^2 = 0.983	Y = 0.000x2 + 0.959x - 187.5 R^2 = 0.953
Polynomial (order 3)	Y = -2E-06x3 + 0.006x2 - 4.478x + 829.2 R^2 = 0.932	Y = -1E-06x3 + 0.004x2 - 2.250x + 321.4 R^2 = 0.987	Y = 1E-07x3 - 5E-05x2 + 1.039x - 198.1 R^2 = 0.953
Power	Y = 4E-11x4.375 R^2 = 0.957	Y= 3E-10x4.197 R^2 = 0.980	Y= 2E-07x3.342 R^2 = 0.893
		Leaf area index	
Linear	y = 0.005x - 1.999 R^2 = 0.962	y = 0.004x - 0.893 R^2 = 0.794	y = 0.004x - 0.893 R^2 = 0.794
Exponential	$y = 0.017e^{0.005x}$ R^2 = 0.875	$y = 0.031e^{0.006x}$ R^2 = 0.818	$y = 0.031e^{0.006x}$ R^2 = 0.818
logarithmic	y = 3.225ln(x) - 19.09 R^2 = 0.873	y = 1.741ln(x) - 9.260 R^2 = 0.735	y = 1.741ln(x) - 9.260 R^2 = 0.735
Polynomial (order 2)	$y = 3E\text{-}06x^2 + 0.000x$ - 0.652 R^2 = 0.982	$y = -1E\text{-}07x^2 + 0.004x$ - 0.918 R^2 = 0.794	$y = -1E\text{-}07x^2 + 0.004x$ - 0.918 R^2 = 0.794
Polynomial (order 3)	$y = -3E\text{-}09x^3 + 1E\text{-}05x^2$ - 0.003x + 0.204 R^2 = 0.983	$y = -6E\text{-}08x^3 + 8E\text{-}05x^2$ - 0.028x + 2.948 R^2 = 0.884	$y = -6E\text{-}08x^3 + 8E\text{-}05x^2$ - 0.028x + 2.948 R^2 = 0.884
Power	$y = 5E\text{-}11x^{3.622}$ R^2 = 0.957	$y = 4E\text{-}08x^{2.774}$ R^2 = 0.935	$y = 4E\text{-}08x^{2.774}$ R^2 = 0.935

and strong relationship with the air temperature both at morning (R^2 = 0.76 to 0.89) and afternoon (R^2 = 0.72 to 0.82). This indicates the fact that if air temperature is going to changeover periods, it will have also an impact on soil temperature. Cumulative surface soil temperature could indicate 79 to 96% variationin leaf area index and 87 to 95% in biomass production. Therefore, soil temperature could be used for estimating the biophysical parameters of wheat more accurately and hence can be used as input for dynamic crop simulation model for improving its accuracy.

References

Adak, T., Kumar, G., Sharma, P.K., Srivastava, A.K. and Chakravarty, N.V.K. 2011. Seasonal changes in soil temperature within mustard crop stand. *J. Agrometeorol*. **13**: 72-74.

Azadegan, B. and Massah, J. 2011. New method for soil surface darkening for increasing soil temperature. *Int. Agrophysics* **25**: 109-113.

Gliñski, J. and Walczak, R.T. 1998. Role of agrophysics in the concept of sustainable agriculture. *Int. Agrophysics* **12**: 25-32.

Jacobs, C.M.J., Jacobs, A.F.G., Bosveld, F.C., Hendriks, D.M.D., Hensen, A., Kroon, P., Moors, E.J., Nol, L., Schrier-Uijl, A. and Veenendaal, E.M. 2007. Variability of annual CO_2 exchange from Dutch grasslands. *Biogeosci*. **4**: 803-816.

Karhu, K., Fritze, H., Hämäläinen, K., Vanhala, P., Jungner, H., Oinonen, M., Sonninen, E., Tuomi, M., Spetz, P., Kitunen, V. and Liski, J. 2010. Temperature sensitivity of soil carbonfractions in boreal forest soil. *Ecology* **91**: 370-376.

Kaspar, T.C. and W.L. Bland. 1992. Soil temperature and root growth. *Soil Sci*. **154**: 290-299.

Leifeld, J. and Fuhrer, J. 2005. The temperature response of CO_2 production from bulk soils and soil fractions is related to soil organic matter quality. *Biogeochem*. **75**: 433-453.

Oliveira, J.C.M., Timm, L.C., Tominaga, T.T., Cassaro, F.A.M., Reichardt, K., Bacchi, O.O.S., Dourado-Neto, D. and Camara, G.M. de S. 2001. Soil temperature in a sugarcane crop as a function of the management system. *Plant Soil* **230**: 61- 66.

Vanhala, P., Karhu, K., Tuomi, M., Sonninen, E., Jungner, H., Fritze, H. and Liski, J. 2007. Old soil carbon is more temperature sensitive than young in an agricultural field. *Soil Biol. Biochem*. **39**: 2967-2970.

Verma, B.C., Datta, S.P., Rattan, R.K. and Singh, A.K. 2011. Effect of temperature, moisture and different nitrogen sources on organic Cabon pools and available nutrients in an alluvial soil. *J. Indian Soc. Soil Sci*. **59**: 286-294.

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