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Impact of agro-meteorological indices on growth and productivity of potato (*Solanum tuberosum* L.) in Eastern India

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ABSTRACT

A two year experiment was conducted during the winter seasons of 2010-11 and 2011-12 on potato (Solanum tuberosum L.) (Variety: 'Kufri Jyoti'). The crop was planted on five dates, starting from 15th November at an interval of seven days with two N doses (N_1- 200 kg ha^{-1} and N_2- 150 kg ha^{-1}) in a split plot design with four replications at District Seed Farm, BCKV to study the impact of thermal environment on the growth and productivity of potato. The 15th November planted crop recorded the highest total growing day degree Celsius (GDD) in both the years and it gradually decreased with the delay in planting. 54.8 and 33.0% variation in total dry matter could be attributed to the variation in GDD under two N doses respectively. The yield of the crop significantly reduced with the increment in heliothermal unit beyond 9000 day degree Celsius hour. The mean thermal use efficiency didn't follow a definite trend.

***Keywords*: Dry matter, GDD, HTU, potato, TUE, yield**

Delay in the onset and withdrawal of monsoon creates a hurdle in land preparation for the winter season crop. There is a dire need to find a suitable date of planting under variable climatic scenario. Temperature and bright sunshine hours are the most important environmental factor affecting the yield of potato in West Bengal. Bishnoi *et al*. (1995) suggested to assess the impact of temperature through accumulated heat unit system. Temperature based agro meteorological indices such as growing day degree (GDD), heliothermal unit (HTU) and thermal use efficiency (TUE) are very useful tools for assessing the growth and yield of the crop (Nath *et al*., 1999). Knowledge of accumulated GDD and HTU may be used to project the developmental stages of a crop as well as its approximate date of harvest (Bonhomme, 2000; Wurr *et al*., 2002; Roy *et al*., 2005). West Bengal experiences short and mild winter. The winter crops are highly temperature sensitive and the temperature variability alters the duration of different phenophases (Parya *et al*., 2010). However, no proper documentation is available to assess the impact of temperature and bright sunshine hour on potato. The present experiment has been framed to address this lacuna.

MATERIALS AND METHODS

The experiment was carried out during *Rabi* (November to March) seasons of 2010-11 and 2011-12 at the District Seed Farm, Bidhan Chandra Krishi Viswavidyalaya, (Latitude 22º58′N and Longitude 88º32′E), West Bengal, India. The study site has a flat terrain located at an altitude of 9.75 m above mean sea level (AMSL). The soil is sandy loam with pH of 8.35 and has total Nitrogen-261 kg ha^{-1}, available Phosphorus- 30.22 kg ha^{-1}, available Potassium- 194.88 kg ha^{-1} and 0.48% organic carbon.

The experimental site falls under tropical humid climate having a short and mild winter spanning from November to February with an annual rainfall of 1457 mm, 85% of which is received during June to September. The average monthly temperature ranges from 10 to 37ºC. The potato growing season is marked by low temperature (occasionally mercury reaches below 10ºC), low humidity and little rainfall.

The experiment on potato (*Solanum tuberosum* L.) (Variety: 'Kufri Jyoti') comprising of ten treatment combinations [five dates of planting (DOP) and two nitrogen levels] was laid on a split plot design with four replications. Five DOP (D_1-15th November, D_2 – 22nd November, D_3 – 29th November, D_4 – 6th December and D_5 – 13th December) were allotted to the main plots, whereas two N-levels (N_1-200 kg ha^{-1}, N_2-150 kg ha^{-1}) were administered as sub-plot treatments, in a plot (5 m x 4 m) of 20 m^2 area at a spacing of 50 cm x 20 cm. A uniform dose of phosphate (P_2O_5) and potassium (K_2O) at the rate of 150 kg ha^{-1} was given to all the crops planted on different dates.

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The GDD, HTU and TUE were computed. The data of maximum and minimum temperatures and bright sunshine hours (BSSH) were collected from Automatic Weather Station, BCKV, Kalyani, West Bengal, India.

The growing day °C (GDD) was calculated in accordance with the following formula (Nuttonson, 1955):

$$\text{GDD} = \frac{\text{Maximum temperature} + \text{Minimumte mperature}}{2} - 5^{o}\text{C}$$

Here, 5°C is taken as the base temperature.

Thermal use efficiency (TUE) is the amount of dry matter produced at given time interval per unit degree day. Thermal use efficiency was measured using the following formula (Saha and Khan, 2008):

$$\text{TUE during tuberization (gm}^{-2}\text{ day }^{o}\text{C}^{-1}\text{)} = \frac{\text{Total dry matter accumulation during tuberization (gm}^{-2}\text{)}}{\text{GDD}}$$

$$\text{TUE for yield (gm}^{-2}\text{ day }^{o}\text{C)} = \frac{\text{Yield(gm}^{-2}\text{)}}{\text{GDD}}$$

Heliothermal unit (HTU (day degree Celsius hour)) was measured using the following formula (Nath *et al.*, 1999),

Plants from one meter row were collected from each plot. The leaves, stems and tubers were separated and dried in hot air oven at 60 °C temperature for 48 hours. The summation of the dry weights of stem, leaves and tuber gave total dry matter (TDM) accumulation which was then calculated in terms of g m^{-2}. For yield, the plants were uprooted with the help of a spade and the tubers were separated from the plant. Rotten and diseased tubers were discarded. The yield from each individual plot (5 m x 4 m) was recorded and later it was converted to t ha^{-1}.

The impacts of GDD on TDM production and HTU on yield have been worked out through statistical regression techniques (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

GDD requirement of potato

The GDD requirement of the potato crop (*Solanum tuberosum* L.) differed due to variation in DOP as well as year (Table 1). During planting to emergence, the mean GDD requirement ranged from 146.5 to 153.8 day °C. Among the three DOP, D_2 maximum heat unit which was due to very high maximum and minimum temperatures (Table 2). The D_4 and D_5 recorded a gradual decline in GDD requirement. During emergence to tuber initiation, GDD requirement gradually declined when the planting dates were delayed beyond D_2. However, the GDD requirement during tuber initiation to dehaulming and dehaulming to harvest declined gradually with the delay in planting except in few cases. The two year mean GDD requirement gradually declined with the delayed planting. The tuberization phase is the most critical stage in potato. In the first year, the duration of this phase gradually declined with the delayed planting because of higher maximum temperature experienced by the late planted crops. In the second year, the duration of this phase ranged from 40 to 52 days, highest under D_1 planting and the lowest under D_5 planting. The shorter duration in the first year was due to lower minimum temperature during this phenophase. On an average, the late planted crop was exposed to higher maximum and minimum temperatures throughout the growth phase. This high temperature shortened the duration of the phenophases under late planted condition. Parya *et al.* (2010) also observed that high temperature reduced the length of the phenophase. Basu *et al.* (2012) recorded that high maximum and minimum temperatures reduced the duration of phenophases in wheat in the Gangetic plains of W.B. The decline in the total GDD requirement observed in the present experiment with the delay in planting was due to increased temperature under late sown condition. The year to year variation in GDD requirement was due to wide variation in the atmospheric temperatures in the two experimental years. Nath *et al.* (1999) observed the dissimilarities in GDD requirement because of experimental years.

HTU requirement of potato

As the HTU originates from the product of GDD value with average BSSH, the variation under different DOP was attributed to the variation in BSSH. During planting to emergence, the late planted crop in the second year recorded lower HTU as compared to the first year crop (Table 3). During emergence to tuber initiation, the D_4 and D_5 planted crops in the first year and D_1 planted crop in the second year recorded high HTU. This was due to the exposure of these DOP to higher amount of BSSH (Table 4). During tuber initiation to dehaulming, the mean BSSH was higher under D_4 and D_5 plantings compared to the early DOP. In the second year, experiment the maximum HTU was recorded by D_4 planted crop. This could be attributed to higher temperature as well as BSSH. The total HTU requirement throughout the growth phases

Table 1: GDD (˚C) requirement of potato at different phenophases under different dates of planting

Date of planting	Planting to emergence			Emergence to tuber initiation			Tuber initiation to dehaulming			Dehaulming to harvest			Total		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean
D_1 - 15th Nov	144.0	149.1	146.5	372.0	399.1	385.6	536.8	707.2	622.0	259.2	118.5	188.9	1312.0	1373.9	1342.9
D_2 - 22nd Nov	132.7	175.0	153.8	413.3	380.7	397.0	531.3	623.3	577.3	194.4	134.4	164.4	1271.6	1313.4	1292.5
D_3 - 29th Nov	144.0	156.2	150.1	333.8	368.6	351.2	486.4	658.0	572.2	194.9	170.8	182.9	1159.1	1353.5	1256.3
D_4 - 6th Dec	114.5	123.3	118.9	344.4	355.1	349.7	442.2	727.7	584.9	212.8	124.4	168.6	1113.9	1330.4	1222.1
D_5 - 13th Dec	105.2	95.2	100.2	323.4	332.4	327.9	488.0	618.0	553.0	222.4	124.4	173.4	1139.0	1170.0	1154.5

Table 2: Duration and the thermal regime during different phenophases in potato under different dates of planting

Date of	Planting to emergence						Emergence to tuber initiation						Tuber initiation to dehaulming					
	Duration		Max Temp (ºC)		Min Temp (ºC)		Duration		Max Temp (ºC)		Min Temp (ºC)		Duration		Max Temp (ºC)		Min Temp (ºC)	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
D_1 - 15th Nov	12	11	22.5	24.0	11.5	13.1	24	26	25.9	26.3	15.1	14.4	44	52	24.9	24.5	9.5	12.7
D_2 - 22nd Nov	7	10	30.6	29.2	17.3	15.8	29	27	25.4	25.0	13.1	13.2	42	45	25.3	24.7	10.0	13.0
D_3 - 29th Nov	9	9	26.6	28.8	15.4	15.9	25	27	25.2	24.3	11.5	13.0	38	47	25.4	25.0	10.2	13.0
D_4 - 6th Dec	7	9	24.8	21.4	17.9	16.0	28	27	24.7	23.1	9.9	13.2	33	49	26.2	26.8	10.6	12.9
D_5 - 13th Dec	8	14	24.5	12.9	11.8	10.7	28	24	24.2	23.6	8.9	14.1	32	40	28.1	27.6	12.4	13.3

Table 3: HTU requirement (day degree Celsius hour) during different phenopases of potato

Date of planting	Planting to emergence			Emergence to tuber initiation			Tuber initiation to dehaulming			Dehaulming to harvest			Total		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean
D_1 - 15th Nov	1038.0	997.3	1017.6	2297.1	2684.7	2490.9	4180.9	4546.5	4363.7	2255.0	817.7	1536.4	9771.0	9046.2	9408.6
D_2 - 22nd Nov	1010.0	1410.5	1210.3	2751.7	2394.2	2572.9	4125.2	3999.9	4062.5	1671.8	979.1	1325.5	9558.7	8783.7	9171.2
D_3 - 29th Nov	849.6	1077.4	963.5	2371.0	2058.4	2214.7	3809.3	4425.4	4117.3	1559.2	1632.1	1595.7	8589.0	9193.4	8891.2
D_4 - 6th Dec	686.7	661.7	674.2	2789.6	1591.2	2190.4	3496.1	5932.6	4714.3	1553.4	1164.7	1359.1	8525.8	9350.1	8938.0
D_5 - 13th Dec	853.4	535.2	694.3	2686.5	1516.6	2101.6	4067.2	5236.0	4651.6	1912.6	1164.7	1538.7	9519.7	8452.4	8986.1

Table 4: Mean bright sunshine hours (BSSH) during the experimental years

Date of planting	Planting to emergence		Emergence to tuber initiation		Tuber initiation to dehaulming		Dehaulming to harvest	
	2010-11	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**
D_1 - 15th Nov	7.2	6.7	6.2	6.7	7.8	6.4	8.7	6.9
D_2 - 22nd Nov	7.6	8.1	6.7	6.3	7.8	6.4	8.6	7.3
D_3 - 29th Nov	5.9	6.9	7.1	5.6	7.8	6.7	8.0	9.6
D_4 - 6th Dec	6.0	5.4	8.1	4.5	7.9	8.2	7.3	9.4
D_5 - 13th Dec	8.1	5.6	8.3	4.6	8.3	8.5	8.6	9.4

was maximum under D_1 planting. This was due to the longer duration of the crop under this particular DOP. Nath *et al.* (1999) also observed variation in HTU in different years in sesame.

Dry matter accumulation during tuberization and yield

Maximum TDM accumulation during tuberization phase was observed in case of D_5 planting in the first year, however in the second year, the D_4 planting recorded the highest value. In the first year, the D_1 and D_4, D_2 and D_3 planted crop didn't show any significant variation in relation to TDM accumulation (Table 5). In the second year the D_1 and D_5 planted crops didn't show any significant variation. The pooled mean result showed the highest TDM accumulation in D_4 followed by D_5 planting. The variation in TDM accumulation under different DOP was due to the variation in duration of the phenophase. In the second year, the minimum temperature during this phenophase was very high in case of late planted crop. N application favoured the TDM accumulation

The yield of potato is given in table- 5. In the first year, the tuber yield was maximum when the crop was planted on 13th December. In the second year, the yield was maximum when the crop was planted on 15th November. The tuber yield was almost similar in two years, when the crop was planted on 13th December. The yield increase under D_1, D_2 and D_3 plantings in the second year were 6.82, 7.46 and 5.75 t ha^{-1} respectively as compared to the first year. The yield of tuber depends on the phenophase duration of tuber initiation to dehaulming. Under D_5 planting in both the year, the tuber yield was similar. The first year recorded an increase of 0.98 t ha^{-1}. This was due to similar thermal regime under D_5 planting in both the years. Yield under D_4 planting was lower by 0.73 t ha^{-1} as compared to the D_5 planting in the first year. However in the second year, the reduction was 6.57 t ha^{-1}. If the pooled mean was observed the maximum tuber yield was recorded under D_1 planting. The yield reduction in D_4 planting was 3.65 t ha^{-1} in comparison to D_5 planting. The thermal regime under D_4 planting was almost similar

Table 5: Effect of dates of planting and N-doses on dry matter accumulation during tuberization and yield of potato

Treatments	Total dry matter (g m^{-2}) during tuberization phase			Yield (t ha^{-1})		
	2010-11	**2011-12**	**Pooled**	**2010-11**	**2011-12**	**Pooled**
D_1 - 15th Nov	331.16	359.30	345.23	16.80	23.62	20.21
D_2 - 22nd Nov	351.40	324.93	338.17	14.53	21.99	18.26
D_3 - 29th Nov	363.35	274.73	319.04	16.60	22.35	19.48
D_4 - 6th Dec	324.11	463.00	393.55	17.87	11.65	14.76
D_5 - 13th Dec	403.91	367.42	385.66	18.60	18.22	18.41
SEm (±)	**15.64**	**9.03**	**9.03**	**0.26**	**0.32**	**0.21**
LSD (0.05)	**48.18**	**27.81**	**26.35**	**0.81**	**0.99**	**0.61**
N_1- 200 kg ha^{-1}	399.09	409.74	404.42	18.93	21.12	20.03
N_2- 150 kg ha^{-1}	310.48	306.01	308.25	14.83	18.00	16.42
SEm (±)	**6.31**	**3.36**	**3.58**	**0.21**	**0.15**	**0.13**
LSD (0.05)	**19.03**	**10.14**	**10.33**	**0.63**	**0.45**	**0.37**

in two experimental years. However, the total HTU was higher under D_4 planting thus exposing the crop to higher radiation which led to lower photosynthetic activities because of increased leaf temperature (Chakraborty, 1994).

Impact of GDD on dry matter production

The TDM production in potato was not significantly related to the variation in GDD under different N-doses (Fig. 1). In case of higher N doses, GDD increment beyond 1000 day °C reduced the TDM production sharply. However, a small increment was observed when GDD exceeded 1150 day °C but the relationship wasn't significant. Only 54.8 % variation in TDM could be assigned to the variation in GDD. When lower dose of N was used, sharp reduction in TDM was noted with the increment of GDD. The reduction in TDM production with the increment of GDD was due to increased temperature and photo respiratory loss in the crop. Basu *et al.* (2012) observed that the GDD during tillering to flowering in wheat didn't affect significantly the stem

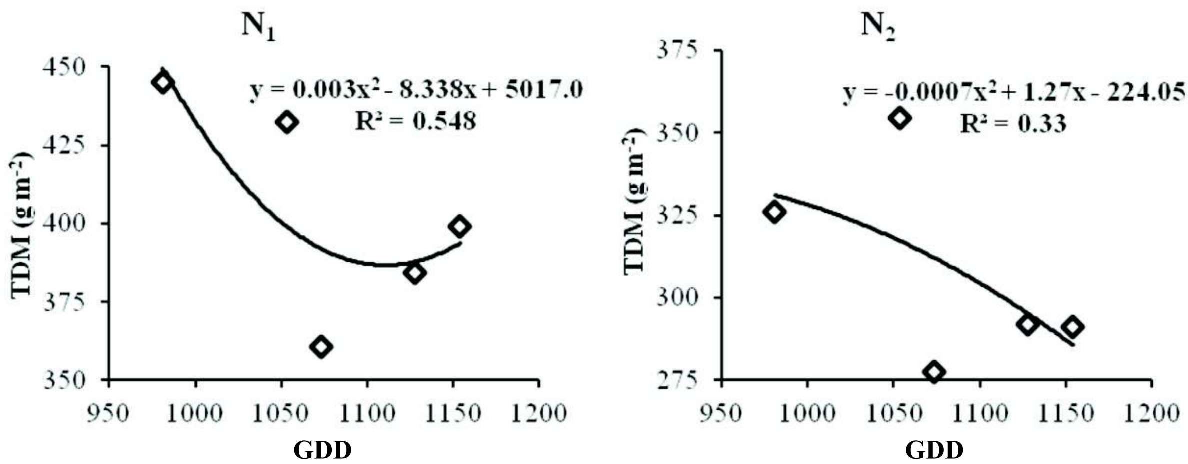

Fig. 1: ***Impact of GDD (°C) on total dry matter production of potato during tuberization at different doses of N (N_1- 200 kg ha^{-1}, N_2- 150 kg ha^{-1})***

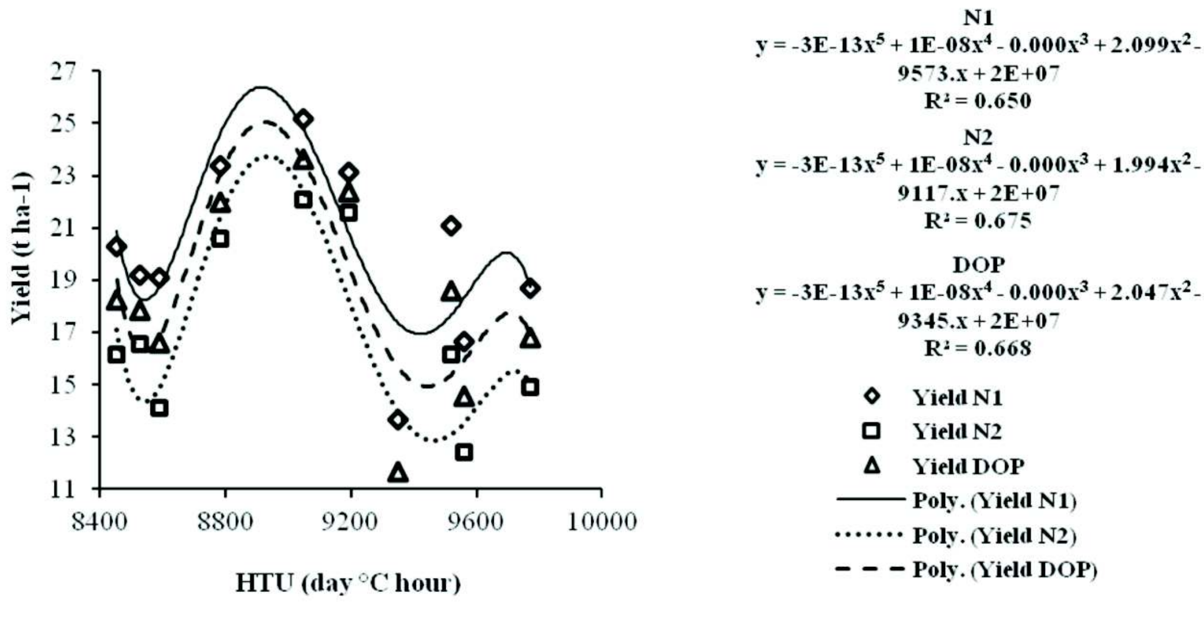

Fig. 2: ***Impact of HTU(day °C hour)) on yield of potato at different N-doses and date of planting, N_1- 200 kg ha^{-1}, N_2- 150 kg ha^{-1})***

weight at the milking stage. They also observed that the increment in GDD reduced both the leaf and stem weight in wheat. Under higher N dose, the small increment in TDM was observed beyond 1150 day °C because of higher canopy volume.

Impact of HTU on yield

The yield of the potato was found to be fifth order polynomial function of HTU irrespective of N doses and DOP. HTU when increased upto 9000 day °C h, the yield was maximum thereafter it declined sharply with the increment of HTU upto 9600 day °C h followed by a marginal increment and then again declined (Fig. 2). 65 % variation in yield under higher N dose could be explained through the variation HTU whereas under lower N dose 67.5 % could be explained through the variation in HTU. In case of DOP, 66.8 % variation in yield could be attributed to the variation HTU. Initial increment in yield due to increment of HTU was due to mild rise of temperature from emergence to tuber initiation phase. Reduction in yield due to increment of HTU beyond 8800 day °C h might be attributed to the steep rise of maximum temperature during the later phase of growth which initiated high leaf temperature, stomatal diffusion resistance leading to the reduction in photosynthetic process (Chakraborty, 1994). Further mild increment might be attributed to the low minimum temperature during the dehaulming phase. The ultimate reduction was due to higher amount of BSSH during the last phase of growth.

TUE of potato

The TUE for TDM production during tuberization phase and yield were higher under high N dose. It also differed due to DOP. The TUE was maximum when the crop was planted under D_5 planting (Table 6). The TUE for yield gradually declined with the delay in planting because of high temperature during tuber initiation to dehaulming under late planted condition. The mean TUE for TDM accumulation during the tuberization phase remained almost similar for the first three DOP thereafter it increased substantially.

This was due to lower duration and higher temperature during this phenophase under late planted condition. In case of yield, the mean TUE was maximum under D_5 planting followed by D_3, D_1, D_2 and D_4. The late planted crop was exposed to higher BSSH which increased the temperature. But the duration was shortened leading to the reduction in total GDD thus increasing the TUE. Saha and Khan (2008) observed that the TUE didn't follow any definite trend in case of mustard. Similar observation was recorded by Sreenivas *et al*. (2008), in aerobic rice. Raghavan *et al.* (2008) also observed similar discrepancy during the early dates of sowing in case of sunflower.

Table 6: Thermal use efficiency (g m^{-2} day °C^{-1}) of potato crop under different DOP and N-doses

	TUE during tuberization			TUE for yield		
	2010-11	**2011-12**	**Mean**	**2010-11**	**2011-12**	**Mean**
D_1N_1	0.36	0.34	0.35	1.42	1.83	1.63
D_1N_2	0.27	0.24	0.25	1.14	1.61	1.37
Mean	**0.31**	**0.29**		**1.28**	**1.72**	
D_2N_1	0.35	0.33	0.34	1.31	1.78	1.55
D_2N_2	0.30	0.22	0.26	0.98	1.57	1.27
Mean	**0.33**	**0.28**		**1.14**	**1.67**	
D_3N_1	0.42	0.26	0.34	1.65	1.71	1.68
D_3N_2	0.33	0.20	0.26	1.22	1.60	1.41
Mean	**0.38**	**0.23**		**1.43**	**1.65**	
D_4N_1	0.39	0.42	0.41	1.72	1.03	1.38
D_4N_2	0.33	0.34	0.34	1.48	0.72	1.10
Mean	**0.36**	**0.38**		**1.60**	**0.88**	
D_5N_1	0.52	0.39	0.46	1.85	1.74	1.79
D_5N_2	0.36	0.31	0.33	1.42	1.38	1.40
Mean	**0.44**	**0.35**		**1.63**	**1.56**	

Note: D_1 - 15th Nov.; D_2 - 22nd Nov.; D_3 - 29th Nov.; D_4 - 6th Dec.; D_5 - 13th Dec. N_1- 200 kg ha^{-1}, N_2- 150 kg ha^{-1}

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