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Leaf Emergence Rate and Temperature in Early and Late Spring Wheat Varieties*

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Abstract : Spring wheat varieties, early Haruyutaka and late Selpek, were grown under field conditions to find the relation between leaf emergence rate and temperature. Fourteen sowings were made at two week intervals from March 17 (S1) to September 13 (S14). Leaf expanding degree (Haun's scale) were measured daily, and shoot apices were checked every day to determine the date double ridge stage (DRS) appeared. Final leaf numbers differed by only one, although the first nine sowings ranged over four months from March (S1) to July (S9). Late variety Selpek always had one more leaf than early variety Haruyutaka for S1～S9, suggesting that the final number of leaves was closely related to the earliness of varieties. Leaf emergence rates with accumulated temperature (AT) were higher before than after DRS, and those before DRS decreased with delay in sowing time. The leaf expanding degree at DRS did not vary greatly among sowing times, but were synchronized with phenology. We established regressions before and after DRS for the relation between leaf expanding degree and AT. The coefficients (a) before DRS were higher than those after DRS for both varieties. In addition, their standard deviation was large so that inclinations of regressions before DRS differed with sowing time. We concluded that leaf emergence rate has a squared relation with mean temperature before DRS and a linear relation with mean temperature after DRS.
Key words : Accumulated temperature, Double ridge stage, Leaf emergence rate, Leaf expanding degree, Regression line, Sowing time, Spring wheat variety.

春播コムギ早晩品種の出葉速度と気温 : 高橋　肇・中世古公男（北海道大学農学部）
要　旨 : 出葉速度と気温との関係を明らかにすることを目的に，春播コムギの早生品種ハルユタカと晩生品種Selpekを圃場条件で栽培した．播種は3月17日(S1)から9月13日(S14)まで2週間間隔で14回行い，連日，出葉展開度（Haun's scale）を測定するとともに生長点の観察から幼穂分化期を決定した．最終的な葉数（止葉まで葉数）は，播種期の違いが3月（S1）から7月（S9）まで4カ月にも及ぶのに対してわずか1葉の違いしかみられなかった．この間，早生品種ハルユタカは晩生品種Selpekに比べ常にほぼ1葉少ないことから，最終的な葉数が品種の早晩性と密接に関係していることが推察された．積算気温に対する出葉速度は，同播種期では幼穂分化期前で高く，それ以降で低く，幼穂分化前では播種期の遅れにともない低下した．幼穂分化期での葉数は播種期の違いによる差が小さく，出葉展開度と生理的齢はほぼ同調しているものと思われた．一方，幼穂分化期を境にその前後について出葉展開度と積期の違いに対して標準偏差が大きかったことから幼穂分化期前で回帰式の傾きが異なることが明らかとなった．出葉速度は，幼穂分化期前では気温に対して相乗的に，幼穂分化期後では気温に対して直線的に反応することが示唆された．
キーワード : 回帰直線，出葉速度，出葉展開度，積算気温，播種期，春播コムギ品種，幼穂分化期．

Wheat produces leaf blades from emergence until the expansion of flag leaves. We observed that the dry matter partitioning to leaf blades was high from emergence to flag leaf primordium initiation (almost the same time as to double ridge stage), and then decreased with culm elongation until flag leaf emergence. The former period was therefore defined as growth phase I and the latter period as growth phase II[16]. Moreover, we found that there was a linear relation between the rate of development and temperature in these two growth phases, and that photoperiod also related linearly[17]. Number of leaves and leaf emergence rate must determine the durations of these two growth phases, because flag leaf emergence is a sign of the end of growth phase II. Although a later leaf like flag leaf is different in its size, function and role from an earlier one like the first leaf to emerge, it is reported that all leaves emerge similarly and that emergence rate is determined by accumulated temperature (AT)[1,4,7,9].

Our objective was to determine the relation between leaf emergence rate and phenology, that is, between leaf emergence rate and temperatuer, in two growth phases : growth phase I and growth phase II. In this experiment, we quantified leaf emergence in the

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main stem of early and late varieties sown 14 times at two week intervals.

Materials and Methods

Spring wheat varieties, semi-dwarf early Haruyutaka and tall late Selpek were used at the Experimental Farm of Hokkaido University 1989. Seeds were set on seeder tapes (Nihon Plant Seeder) every 5 cm and the tapes were planted 2 cm deep with 5 cm intervals (400 plants m^{-2}). Fertilizer was applied just before sowing : N, 90 kg $hectare^{-1}$; P_2O_5, 150 kg ; and K_2O, 75 kg. Fungicide and insecticide were applied a few times to prevent powdery mildew, rust, flies, armyworms and plant louse.

We set up fourteen sowing times at two week intervals from March 17 (S1) to September 13 (S14). S1 emerged on May 31 and S14 on September 19 (Table 1). Each plot had the area of 2 m×3 m with no replications. Haun's scale score[8] was measured on three main stems every day for each sowing time. The score was determined by leaf expanding degree (number of expanding leaves and degree of expanding leaf). In addition, we decided the dates which showed 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0 and 9.0 of Haun's scale from 15 data of five days before and after the dates. Double ridge stage (DRS) was determined by daily observation of the main shoot apex of the three plants using a microscope. Then we decided the dates as similar manner as the leaf expanding degree.

Table 1. Sowing and emergence times.

	Sowing	Emergence
S 1	17 March	31 March
S 2	30 March	11 April
S 3	12 April	25 April
S 4	26 April	7 May
S 5	10 May	20 May
S 6	24 May	1 June
S 7	9 June	16 June
S 8	21 June	28 June
S 9	7 July	11 July
S10	19 July	24 July
S11	2 Aug.	12 Aug.
S12	18 Aug.	23 Aug.
S13	30 Aug.	4 Sep.
S14	13 Sep.	19 Sep.

Results

1. Leaf expanding degree for the 14 sowing times

Figure 1 shows changes in leaf expanding degree of Haruyutaka with accumulated temperature (base temperature is 0°C) for the 14 sowing times. Final leaf numbers, from first leaf to flag leaf of the main stem, were eight in S1～S4 and seven in S5～S9 ; flag leaves had not emerged when winter snow cover began in S10～S14. Leaf expanding degree increased with AT, and the rate of increase before DRS was higher than that after DRS for all 14 sowing times. The rate of increase was particularly high before DRS in S1～S8, but did not differ among sowing times after DRS (see coefficients (a) in Table 3). Figure 2 shows changes in the leaf expanding degree of Selpek with AT for the 14 sowing times. The final number was nine in S1～S4 and S9 and eight in S5～S8, one leaf more than those of Haruyutaka in most sowings. As in Haruyutaka, flag leaves had not emerged in S10～S14. Increase rates before DRS were also higher than those afterwards, and were higher in S1 ～S8 than in S9～S14, similar to Haruyutaka.

2. Days, AT and leaf expanding degree at DRS

DRS has been known as the turning point in the pattern of dry matter partitioning[16]. In this experiment, it also seemed to be a turning point for leaf emergence rate in both varieties. Table 2 shows days and AT from emergence and leaf expanding degree at DRS. We were unable to determine the date of DRS in S9 of Selpek, however, because the plot was not uniform and the plants were varied greatly in their development. Days after emergence became fewer as sowing time was delayed in S1～S8 for both Haruyutaka and Selpek ; it was lowest in S8, then increased with later sowing for S8～S14 in each variety. AT was lowest in S3, S5 and S7 and highest in S10, S11 and S12 for Haruyutaka, and was lowest in S2, S3 and S5 and highest in S10 and S11 for Selpek. The leaf expanding degree did not reach 4.0 in S4～S8 for Haruyutaka, while fifth leaves were emerging in S1～S3 and S9 ～S14. Most Selpek plants had one more leaf than Haruyutaka, because Selpek had five days more after emergence than Haruyutaka

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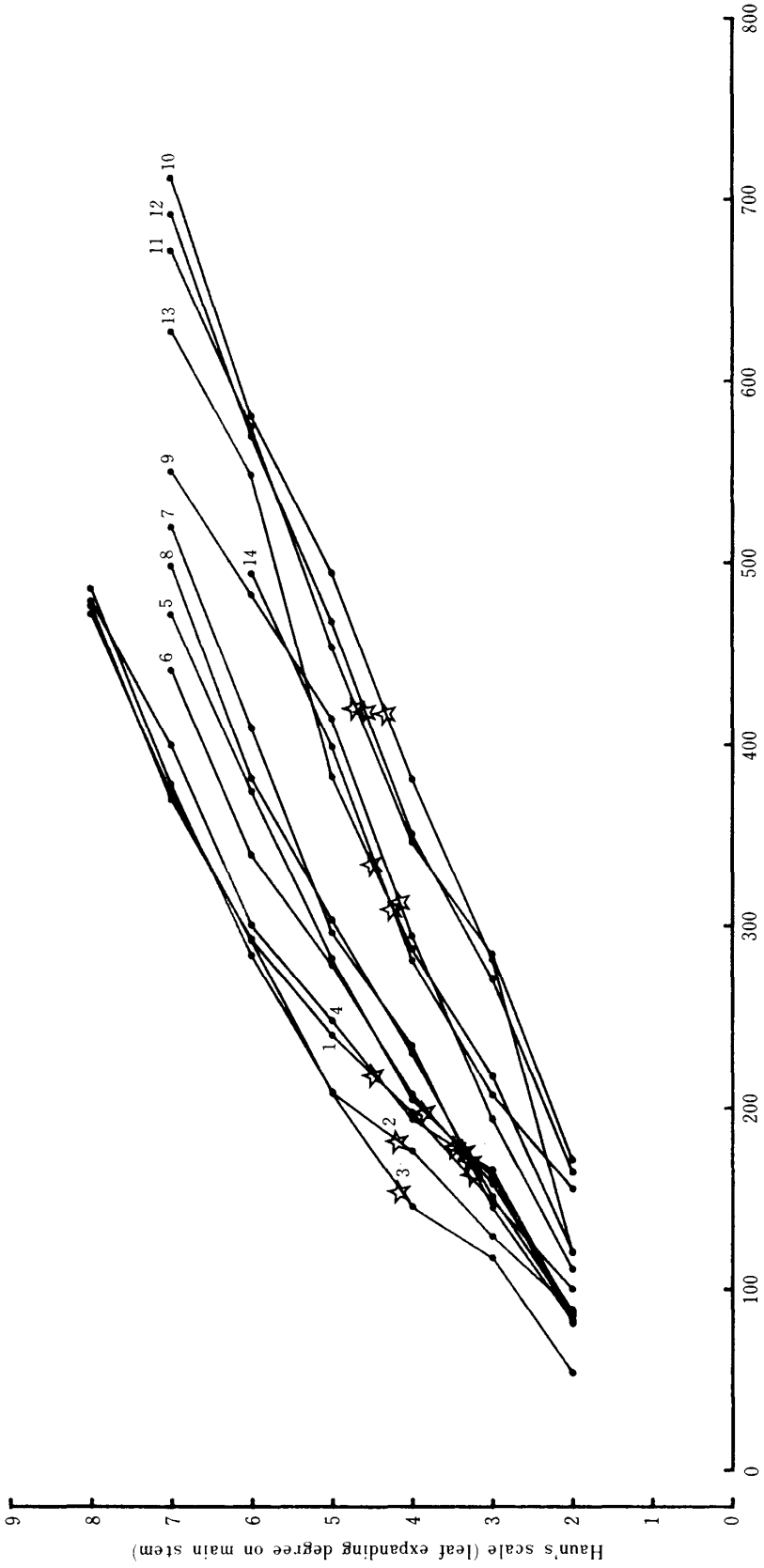


Fig. 1. Relationship between Haun's scale and accumulated temperature for fourteen sowing times in Haruyutaka.
Stars indicate double ridge stage which is the turning point between early two growth phases.

and AT was higher at 71°C day. Leaf emergence rate seemed to synchronize with phenology rather than with time, because the coefficient of variation among sowing times was lower for leaf expanding degree (12%) for both varieties, and was higher for days after emergence and AT (25~41%). Final number of leaves also differed only by one

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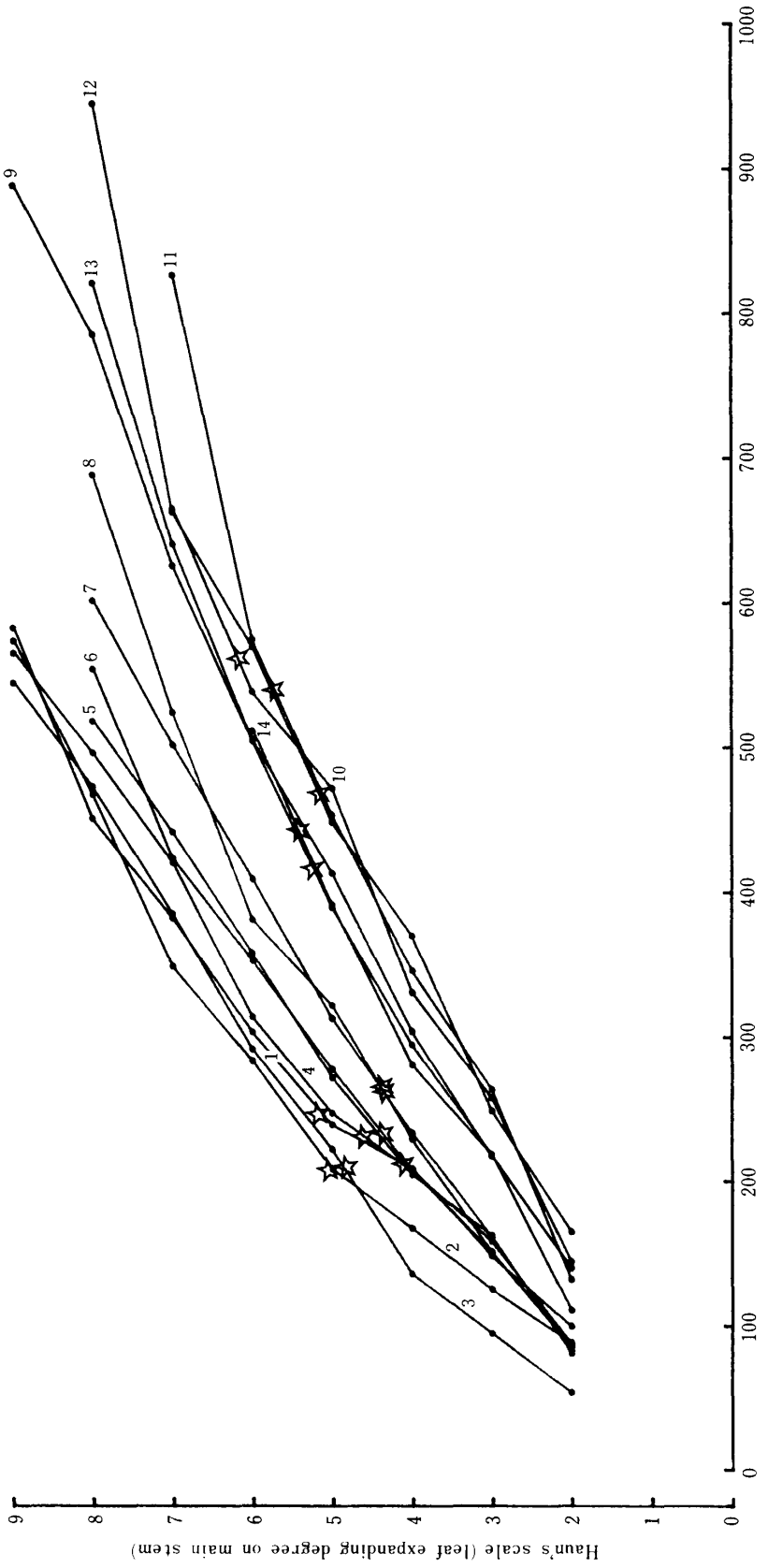


Fig. 2. Relationship between Haun's scale and accumulated temperature for fourteen sowing times in Selpek.
Stars indicate double ridge stage which is the turning point between early two growth phases.

despite time sown, while days after emergence differed considerably.

3. Regression analysis for leaf emergence rate with days and AT

Regression lines were established for relations between AT and leaf expanding degree

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(Haun's scale) at each of the 14 sowing times for the two varieties. Table 3 shows the coefficients (a) and the constants (b) of these regressions. Leaf emergence rates before DRS were higher than those afterwards, so that the coefficients (a) before DRS were higher for both varieties. They were higher for Haruyutaka than for Selpek, especially after DRS. Regression lines before DRS crossed the origin of the coordinate axes because the constants before DRS were almost zero. On the other hand, standard deviations of the coefficients (a) before DRS were higher than those after DRS; thus the regression lines had different inclinations among sowing times before DRS, and the inclinations after DRS were all the same for each sowing time. The coefficient (a) before DRS decreased from S1 to S10 and increased from S10 to S14 for Haruyutaka and decreased from S1 to S11 and increased from S11 to S14 for Selpek, while mean temperature increased from S1 to S10 and decreased from S10 to S14 for both varieties. Thus, it seems that there are negative linear relations between these coefficients (a) before DRS and mean temperature.

We also calculated the regression lines of leaf expanding degree with days after emergence. The coefficients of these regressions, a (days), and the coefficients of regressions for AT, a (AT), were dependent on mean temperature before and after DRS for the two varieties. Table 4 shows correlation coefficients of these relations. The correlation coefficients of relation before DRS between a (days) and mean temperature were significantly negative, higher than 0.60 for both varieties. Those between a (AT) and mean temperature were negative and higher than 0.89. Therefore, leaf emergence rate before DRS might show a squared relation with mean temperature. On the other hand, after DRS, correlation coefficients of the relation between a (days) and mean temperature were significantly negative, 0.82 for Haruyutaka and 0.53 for Selpek. However, those between a (AT) and mean temperature were not significant. Therefore, leaf emergence rate showed a linear relation with mean temperature after DRS. This relation was more significant for Haruyutaka than for Selpek.

Table 2. Days, accumulated temperature from emergence and leaf expanding degree (Haun's scale) at double ridge stage in Haruyutaka and Selpek.

Sowing time	Days after emergence		AT (°C days)		Leaf expanding degree	
	Hy	Sp	Hy	Sp	Hy	Sp
S 1	30	34	209	240	4.4	5.1
S 2	24	27	177	209	4.1	5.0
S 3	19	24	152	208	4.1	4.9
S 4	16	19	180	219	3.5	4.6
S 5	13	16	163	205	3.3	4.2
S 6	14	17	191	239	3.8	4.3
S 7	11	17	162	266	3.2	4.3
S 8	11	15	189	267	3.4	4.3
S 9	14	—	295	—	4.2	—
S10	17	23	405	539	4.3	6.2
S11	19	26	408	555	4.7	5.7
S12	20	23	409	467	4.6	5.2
S13	17	25	320	443	4.2	5.4
S14	24	29	328	392	4.4	5.3
Mean	18	23	256	327	4.0	5.0
C. V.	30	25	39	41	12	12

AT : accumulated temperature (base temperature is 0°C).
Hy : Haruyutaka, Sp : Selpek.
C. V. : Coefficient of variance (%)

Discussion

In general, the development of leaves is known to accelerate linearly with temperature and the leaf emergence rate to be linearly related with AT[1,4,7,9]. In this experiment, there were linear relations between leaf emergence rates and AT for both early and late spring wheat varieties; further, their inclinations were different before and after DRS (Figs. 1 and 2). DRS, ear primordium initiation, is at almost concurrent with the end of leaf primordium initiation. The final number of leaves is, therefore, determined by this stage. The rate of leaf initiation closely governs leaf emergence rate. So, these factors are important in controling development in wheat. While the leaf initiation rate increases with temperature, its rate of increase was reported to accelerate with long daylength[5,6,13,15]. Crops S1～S9 differed

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Table 3. Coefficients (a) and Constants (b) of regression lines ($Y=aX+b$) for the relationship between leaf expanding degree (Haun's scale, $Y\times10^{-2}$) and accumulated temperature (°C days) for Haruyutaka and Selpek.

	Before DRS						After DRS					
	Haruyutaka			Selpek			Haruyutaka			Selpek		
	a	b	M. T.	a	b	M. T.	a	b	M. T.	a	b	M. T
S 1	2.02	− 1	7.0	2.02	− 2	7.1	1.40	158	10.7	1.17	241	11.5
S 2	2.28	0	7.4	2.41	− 4	7.7	1.22	225	11.5	1.08	295	12.2
S 3	2.57	21	8.0	2.21	55	8.7	1.21	238	12.8	1.20	238	13.0
S 4	1.94	9	11.3	1.95	11	11.5	1.36	160	13.0	1.21	204	13.4
S 5	1.85	17	12.5	1.87	16	12.8	1.24	128	14.1	1.25	151	14.3
S 6	1.91	10	13.7	1.89	11	14.0	1.29	141	15.7	1.16	177	15.9
S 7	2.08	8	14.7	1.67	25	15.6	1.07	157	18.0	1.08	156	18.8
S 8	1.73	23	17.2	1.73	23	17.8	1.11	157	20.7	0.86	231	22.3
S 9	1.35	22	21.1	1.25	26	21.9	1.17	41	23.3	0.78	203	22.7
S10	0.99	31	23.8	1.07	23	23.4	0.92	52	22.0	0.78	180	21.4
S11	1.12	0	21.5	1.02	32	21.3	0.91	86	20.3	0.40	373	18.2
S12	1.13	4	20.5	1.09	11	20.3	0.89	89	16.7	0.59	264	13.7
S13	1.36	12	18.8	1.22	18	17.7	0.83	169	13.4	0.72	222	11.5
S14	1.43	− 6	13.7	1.30	12	13.5	0.93	135	11.1	0.82	179	10.2
Mean	1.70	11		1.62	18		1.11	138		0.94	222	
S. D.	0.48	11		0.46	15		0.19	57		0.26	60	

DRS : double ridge stage. M. T. : mean temperature (°C) before DRS (from emergence to DRS) and after DRS (from DRS to final leaf emergence). S. D. : standard deviation.

by only one leaf in final number of leaves, although they were sown ever a range of four months from March to July. This might be resulted by higher temperature and longer photoperiod during early summer. Late variety Selpek always had one more leaf than early variety Haruyutaka, indicating that the final number of leaves might be closely related to the earliness of varieties. Kirby et al.[11] also stated that differences in maturity are associated with reduction in number of leaves in their comparison of 14 wheat varieties. The developmental rate before DRS might be attributable to initiation and emergence rates of leaves rather than to final number of differentiated leaves. Because the leaf expanding degree at DRS did not greatly differ among the 14 sowing times (Table 2), and these rates nearly synchronized with phenology. Mitchell et al.[14] suggested that a crop compensates for a large number of leaf primordia which have not yet emerged, and/or a slow rate of leaf emergence, by ending leaf initiation earlier, thereby ensuring a relatively constant date of flag leaf emergence. Their statement supports and emphasizes our observation.

We calculated linear regressions between leaf expanding degree and AT before and after DRS (Table 3). The leaf emergence rates were higher before DRS for both varieties. This inclination was different among sowing times before DRS because the standard deviation was higher, leading to the conclusion that leaf emergence rate has a squared relation with mean temperature (Table 4). The reason for this squared relation is not known, although effects of temperature, photoperiod or nutrition on leaf emergence rate were found. Leaf emergence rate was reported to be accelerated by long daylength[19] and nitrogen supply[18]. Aspinall and Paleg[2] showed that increasing light intensity increased the rate of primordium production. However, Kirby et al.[11] indicated that the rate of leaf initiation increased with temperature but photoperiod had little effect. Baker and Gallagher[3] found a

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Table 4. Correlation coefficient of relations between coefficients a(days) or a(AT) and mean temperature before and after double ridge stage (DRS) for Haruyutaka and Selpek.

	Before DRS	After DRS
Haruyutaka		
a(days)	−0.617*	−0.824***
a(AT)	−0.899***	−0.345
Selpek		
a(days)	−0.609*	−0.528*
a(AT)	−0.893***	−0.297

a(days) : coefficient of linear regression between leaf expanding degree and days after emergence.
a(AT) : coefficient of linear regression between leaf expanding degree and accumulated temperature after emergence.
*, ***: 5% and 0.1% of significance.

quickening of leaf appearance rate with rising temperature for spring sowing times, while Jones and Allen[10] suggested that rate of leaf emergence was characterized by long periods when leaves emerged linearly with time, despite considerable variation in temperature. Because photoperiod increases and decreases similarly as temperature does, especially we have to assess the independent effect of temperature and photoperiod, respectively. The influence of these various factors on leaf emergence rate and final number of leaves should be assessed in future.

References

1. Amir, J. and T.R. Sinclair 1991. A model of the temperature and solar-radiation effects on spring wheat growth and yield. Field Crop Res. 28 : 47—58.
2. Aspinall, D. and L.G. Paleg 1963. Effects of daylength and light intensity on growth of barley. I. Growth and development of apex with a fluorecent light source. Bot. Gaz. 124 : 429—437.
3. Baker, C.K. and J.N. Gallagher 1983. The development of winter wheat in the field. 1. Relation between apical development and morphology within and between seasons. J. Agric. Sci. 101 : 327—335.
4. Baker, J.T., P.J. Pinter, Jr., R.J. Reginato and E. T. Kanemasu 1986. Effects of temperature on leaf appearance in spring and winter wheat cultivars. Agron. J. 78 : 605—612.
5. Cottrell, J.E., J.E. Dale and B. Jeffcoat 1982. The effects of daylength and treatment with gibberellic acid on spikelet initiation and development in Clipper barley. Ann. Bot. 50 : 57—68.
6. ———— and ———— 1986. The effects of photoperiod and treatment with gibberellic acid on the concentration of soluble carbohydrates in the shoot apex of spring barley. New Phytol. 102 : 365—373.
7. Delecolle, R., R.K.M. Hay, M. Guerif, P. Pluchard and C. Varlet-Grancher 1989. A method of describing the progress of apical development in wheat, based on the time-course of organogenesis. Field Crops Res. 21 : 147—160.
8. Haun, J.R. 1973. Visual quantification of wheat development. Agron. J. 65 : 116—119.
9. Hay, R.K.M. and G.T. Wilson 1982. Leaf appearance and extension in field grown winter wheat plants : the importance of soil temperature during vegetative growth. J. Agric. Sci. 99 : 403—410.
10. Jones, J.L. and E.J. Allen 1986. Development in barley (*Hordeum sativum*). J. Agric. Sci. 107 : 187—213.
11. Kirby, E.J.M., J.R. Porter, W. Day, J.S. Adam, M. Appleyard, S. Ayling, C.K. Baker, R.K. Belford, P.V. Biscoe, A. Chapman, M.P. Fuller, J. Hampson, R.K.M. Hay, S. Matthews, W.J. Thompson, A.H. Weir, V.B.A. Willington and D. W. Wood 1987. An analysis of primordium initiation in Avalon winter wheat crops with different sowing dates and at nine sites in England and Scotland. J. Agric. Sci. 109 : 123—134.
12. ————, K.H.M. Siddique, M.W. Perry, D. Kaesehagen and W.R. Stern 1989. Variation in spikelet initiation and ear development of old and modern Australian wheat varieties. Field Crops Res. 20 : 113—128.
13. Miglietta, F. 1989. Effect of photoperiod and temperature on leaf initiation rates in wheat (*Triticum* spp.). Field Crops Res. 21 : 121—130.
14. Mitchell, R.A.C., E. White and R. Sylvester-Bradley 1991. Prediction of flag-leaf emergence in wheat crops. Field Crops Res. 27 : 119—130.
15. Mohapatra, P.K., D. Aspinall and C.F. Jenner 1982. The growth and development of the wheat apex : the effects of photoperiod on spikelet production and sucrose concentration in the apex. Ann. Bot. 49 : 619—626.
16. Takahashi, T., K. Nakaseko and K. Gotoh 1988. Dry matter partitionings of tall Haruhikari and semi-dwarf 2-47 in spring wheat. Jpn. J. Crop Sci. 57 : 522—526*.
17. ———— and ———— 1992. Influence of temperature and photoperiod on phenological development in early and late spring wheat varieties. Jpn. J. Crop Sci. 61 : 576—582*.

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18. Thorne, G.N., D.W. Wood and H.J. Stevenson 1988. Effects of nitrogen supply and drought on early development of winter wheat in the field in Eastern England. J. Agric. Sci. 110 : 109—117.
19. Wright, D. and LL.G. Hughes 1987. Relationships between time, temperature, daylength and development in spring barley. J. Agric. Sci. 109 : 365—373.

* In Japanese with English abstract.

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