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# Dry Matter Partitioning to Stem at Full Maturity Affects Stem Desiccation and Combine Harvest Maturity in Soybeans

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**Abstract:** Days from full maturity to combine harvest maturity (DFC) is a major concern in combine harvesting of soybeans (*Glycine max* (L.)), especially in northern Japan, which has a short harvesting period. The combine harvest maturity, which was defined as the day at which the moisture content of the stem reached 30%, was analyzed using 7 soybean varieties for 3 yr in Hokkaido. There were significant differences in DFC among varieties (12 to 31 d) and among the 3 yr (16 to 25 d). DFC was closely associated with dry matter partitioning to stem (DMPS) at full maturity, that is, high DMPS increased DFC. The relationship between DMPS and DFC was examined by pod removal experiments conducted for 2 yr. In the soybean plants with high DMPS pod removal increased the stem desiccation period and DFC. These results indicated that DMPS at full maturity is an informative indicator for predicting the harvest maturity in the combine harvesting system.

**Key words:** Combine harvest maturity, Dry matter partitioning, Soybean, Stem desiccation.

Harvest maturity shown by the day at which the moisture content of seed reached 14% (TeKrony et al., 1979) is a major concern in the production of soybeans (*Glycine max* (L.)) because harvest maturity influences seed germination, seed quality, and seed infection (Howell et al., 1959; Wilcox et al., 1974; TeKrony et al., 1984). Before the introduction of combine harvesters, the soybean plants were cut and then left to desiccate in a pile after harvest before threshing. The farmers harvested the soybean plants with a seed and stem moisture content of more than 20% and 50%, respectively. In the combine harvest system, the plants are cut and seeds threshed from the pod simultaneously, requiring desiccation of the whole plant in the field before harvest. Combine harvest before sufficient stem desiccation of the soybean plant increases the risk of adherence of mud and/or dust to the seed coat in the threshing process. This damages the external appearance of the seed and lowers its commercial value. Using the combine harvesting at various conditions in Hokkaido, Hara et al. (2001) concluded that the incidence of soiled soybeans was low when the stem moisture level was below 40%. Kamiya et al. (1977) and Shimonasako (1991) reported a significant increase in the percentage of soiled soybean seeds when the stem moisture level exceeded

30%. Therefore, combine harvest maturity (CHM) in Hokkaido may be redefined as the day at which the stem moisture reached below 30% and this is not the same as the day of full maturity (FM).

Green stem symptom is similar to slow stem desiccation, and is caused by the remaining green and moisture in the stem even though the pods and seeds have reached FM. There are 3 possible causes of green stem system: fungal or viral infection, green stinkbugs and soybean variety (Wright, 2003). Matsumoto et al. (1986) reported that the varietal difference was a factor in delayed stem maturation. Hill et al. (2006) indicated that genetic variability exists among cultivars with regard to green stem sensitivity, and Hajika et al. (2005) also suggested that genetic factors affect green stem symptoms. Furuya et al. (1988) suggested that the cause of green stem is the disorder balance of sink-source organs. However, few attempts have been made on the comparison between dry matter partitioning and stem desiccation in soybean varieties of Hokkaido.

The days from FM to CHM (DFC) is important information for soybean production as it allows combine harvesters to be utilized during the short fall season limited with early snowfall in northern Japan. The information on DFC would be helpful for the practical combine harvesting

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This research was supported in part by a Research Conducted by Special Assignment of the Ministry of Agriculture, Forestry & Fisheries of Japan. **Abbreviations** : CHM, combine harvest maturity; DFC, days from full maturity to combine harvest maturity; DM, dry matter; DMPS, dry matter partitioning to stem; DW, dry weight; FM, full maturity.

of soybeans if CHM could be forecasted before harvesting. Ogiwara and Ishikura (1994) suggested that the analysis of soluble stem protein may be useful in predicting delayed stem maturation. Inoue and Oida (2002) also indicated the possibility of measuring the number of flowers and pods per plant to predict the occurrence of green stem symptoms. However, these studies have not evaluated the effect of varietal or year-to-year variation on the possibility of prediction. Thus, little information exists about the possibility of predicting CHM in northern Japan, especially in Hokkaido.

The objectives of this study were: 1) to characterize the varietal differences and year-to-year variations in DFC, 2) to determine the effect of dry matter partitioning on CHM, and 3) to evaluate possible indicators that could be used to predict the day of CHM.

## Materials and Methods

### 1. Plant materials and culture

From 1988 to 1990, 7 varieties of soybean were sown between 18 May and 21 May. A variety Toyomusume and a breeding line Tokei 907 were used to conduct additional experiments in 1999 and 2000, respectively.

Seedlings were thinned after establishment to provide a plant density of 16.7 m<sup>-2</sup>. In each year, the previous crop was green oats. Each plot consisted of 6 rows, 3 m long and 0.6 m spacing, arranged in a randomized block design with 3 replications. Experiments were conducted in 1988 to 1990, 1999 and 2000 at the Hokkaido Prefectural Tokachi Agricultural Experiment Station (42°55' N, 143°03' E, 95 m above sea level) on a dry andosol soil. The experimental area was fertilized with a synthetic fertilizer (21 N, 175 P<sub>2</sub>O<sub>5</sub>, 91 K<sub>2</sub>O kg ha<sup>-1</sup>) prior to seeding. The experimental area was weeded by hand during plant development. Insect pests were controlled as needed with appropriate chemicals according to the cultural practices recommended by Hokkaido Prefecture.

### 2. Measurements

Ten soybean plants (five hills) were randomly sampled from each plot every 5 to 7 d from FM to the middle of November for 3 yr. After collecting the samples, the fresh weight of pods and stems in each plot was measured. The dry weight (DW) of each part was also measured after drying at 70°C for 72 hr. The samples were collected around midday on several sunny days to exclude the temporal influence of rainfall or diurnal changes. The moisture content of stem was calculated from the fresh weight and DW. The date of FM (R8) was determined as the day at which around 90% of the pod on the main stem reached its mature color (Fehr et al., 1971; Fehr and Caviness, 1977). The data for dry matter partitioning to stem (DMPS) was calculated from the DW at FM using the following equation:  $DMPS (\%) = (Stem\ DW) / (Stem\ DW + Pod\ DW) \times 100$ . Combine harvest maturity (CHM), defined as the day at which the stem moisture content reached 30%, was estimated by the following equation:  $CHM (date) = DB + ((30\% - MB) \times (DA - DB)) / (MA - MB)$ , where, DA and DB are the sampling dates closest to 30% moisture after and before CHM, respectively, and MA and MB are the moisture percentages at DA and DB, respectively.

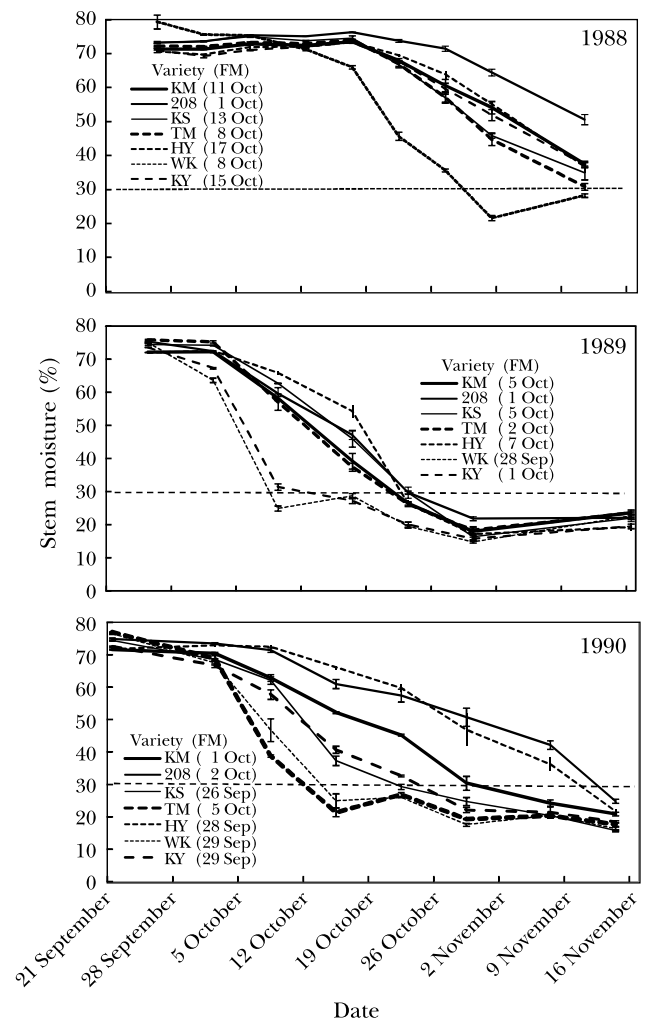


Fig. 1. Changes in soybean stem moisture during desiccating period from 1988 to 1990.

Variety names are as follows: KM, Kitamusume; 208, Toiku 208; KS, Kitamishiro; TM, Toyomusume; HY, Himeyutaka; WK, Wasekogane; KY, Kariyutaka. FM indicates date of full maturity. The horizontal broken line represents stem moisture content of 30% corresponding to that of combine harvest maturity (CHM). The vertical bars show standard errors (n=3).

where, DA and DB are the sampling dates closest to 30% moisture after and before CHM, respectively, and MA and MB are the moisture percentages at DA and DB, respectively.

### 3. Pod removal treatments

To confirm the influence of DMPS on stem desiccation and DFC, we removed 80, 40, 20 and 0% of the pods at the pod-filling stage (R5) from Toyomusume on August 19, 1999 and for Tokei 907 on August 17, 2000. Before

Table 1. The full maturity (FM), combine harvest maturity (CHM), and days from FM to CHM (DFC) in 7 soybean varieties.

Varieties	FM			CHM			DFC		
	1988	1989	1990	1988	1989	1990	1988	1989	1990
Kitamusume	11 October	5 October	1 October	NR	21 October	29 October	>31	16	28
Toiku 208	1 October	1 October	2 October	NR	22 October	11 November	>41	21	40
Kitamishiro	13 October	5 October	26 September	NR	22 October	21 October	>29	17	25
Toyomusume	8 October	2 October	5 October	NR	20 October	11 October	>34	18	6
Himeyutaka	17 October	7 October	28 September	NR	22 October	9 November	>25	15	42
Wasekogane	8 October	28 September	29 September	29 October	8 October	13 October	21	10	14
Kariyutaka	15 October	1 October	29 September	NR	11 October	23 October	>27	10	24
Mean	10 October	2 October	30 September		18 October	25 October	–	16	25

CHM (date): first day when desiccated to 30% of stem moisture, calculated from the following equation:  $CHM = DB + \frac{(30\% - MB) \times (DA - DB)}{MA - MB}$ . DA and DB are the closest date after and before CHM, respectively. MA and MB are the moisture at DA and DB, respectively. DFC (days) = CHM – FM. NR: did not reach CHM until 11 November, 1988.

Table 2. Monthly air temperature and monthly total precipitation during soybean growing period in 3 yr tested.

	Air temperature (°C)					Precipitation (mm)				
	June	July	August	September	October	June	July	August	September	October
1988	15.6	14.8	20.1	15.2	8.7	50	41	169	95	118
1989	12.7	18.8	21.3	16.2	9.6	181	36	209	149	26
1990	16.5	18.3	20.7	16.1	10.1	63	71	166	238	154

Data source: Automated Meteorological Data Acquisition System (AMeDAS) at Memuro station.

removal of pods, the number of pods to be removed per plant in each treatment was calculated according to the average number of pods per plant on each plot. The calculated number of pods per plant on each plot was uniformly thinned from the top node to the bottom node of main stem and branches. The pod removal treatment was conducted on all plants in each plot. The stem moisture content was determined after drying at 85°C for 48 hr. DMPS was determined in the same manner as the previous experiments.

#### 4. Statistical analysis

Data were subjected to analysis of variance using the GLM procedure of SAS (SAS Ins., 1988). Simple linear regression was used to examine the relationship between DMPS and DFC.

### Results

#### 1. Transition of stem desiccation and DFC

Fig. 1 shows changes in the content of stem moisture after FM in the 7 varieties during the experimental period. The desiccation of stem began from about 70% moisture content at FM in most varieties, and it reached 30% (the

content at CHM) before the end of October, except for 1988. The pattern of transition from FM to CHM varied with the variety and the year. In 1989, most varieties reached CHM at the end of October. In 1990, the date of CHM widely varied with the variety: mid October in two varieties, the end of October in three varieties, and mid November in the other two varieties. In 1988, none of the varieties except one reached CHM before the end of October. Therefore, the difference in transition type of stem desiccation is characterized by stem moisture in late October, when a relatively large variation was observed with the variety and year.

For simple comparison of desiccation period, the DFC in each variety was computed as one criterion (Table 1). The DFC ranged widely from 6 to 40 d across the years and varieties. The mean DFC in 1989 and 1990 were 16 and 25 d, respectively. These results showed that DFC varied significantly with the year and variety.

#### 2. Corelation of stem desiccation with the weather condition and plant growth

The monthly air temperature and total precipitation during the soybean growing season in 1988–1990 are

Table 3. Dry weight (DW) and dry matter partitioning to stem (DMPS) at full maturity in 7 soybean varieties.

Varieties	Pod DW (g/plant)				Stem DW (g/plant)				DMPS (%)			
	1988	1989	1990	Mean	1988	1989	1990	Mean	1988	1989	1990	Mean
Kitamusume	17.4 a	26.6 a	31.6 a	25.2	6.7 b	9.1 a	9.9 a	8.6	28.1 bc	23.7 a	23.8 a	25.2
Toiku 208	14.0 b	27.3 a	29.1 a	23.7	9.1 a	8.2 ab	9.2 ab	8.8	39.4 a	23.2 ab	24.1 a	28.9
Kitamishiro	16.3 ab	23.4 a	25.5 a	21.7	6.8 b	6.8 bc	6.6 c	6.7	29.4 bc	22.1 abc	20.6 b	24.0
Toyomusume	16.5 ab	26.6 a	27.1 a	23.4	7.1 b	6.6 bc	5.8 c	6.5	29.6 bc	19.9 c	17.7 c	22.4
Himeyutaka	15.1 b	23.4 a	28.6 a	22.4	8.1 ab	7.8 abc	10.0 a	8.6	35.0 ab	25.0 a	26.0 a	28.7
Wasekogane	19.9 a	24.6 a	29.5 a	24.7	6.5 b	6.1 c	7.4 bc	6.7	24.7 c	19.9 c	20.1 bc	21.6
Kariyutaka	14.4 b	27.4 a	27.8 a	23.2	7.0 b	6.5 bc	6.9 c	6.8	32.7 ab	19.2 c	20.0 bc	24.0
Mean	16.2	25.6	28.5	–	7.3	7.3	8.0	–	31.3	21.9	21.8	–

DMPS percentage was calculated from the following equation:  $DMPS (\%) = (Stem\ DW) / (Stem\ DW + Pod\ DW) \times 100$ . Values followed by the same letter in a column are not significantly different at 5% level using Tukey's HSD test.

Table 4. Correlation coefficients between soybean stem moisture and weather conditions, full maturity (FM), pod dry weight (DW), stem DW, and dry matter partitioning to stem (DMPS).

Date of measurement	1988		1989		1990	
	17 October	1 November	17 October	30 October	15 October	29 October
Weather conditions during desiccating period						
Accumulated Temp.	0.10	0.07	-0.71	-0.15	0.20	0.00
Daylight Hours	0.10	0.06	-0.66	-0.14	0.26	0.07
Precipitation	0.41	0.49	-0.63	-0.46	0.14	-0.16
Rainy days	0.14	0.12	-0.72	-0.30	0.07	-0.13
FM	-0.09	-0.05	0.70	0.11	-0.22	-0.02
Pod DW at FM	-0.86*	-0.88**	-0.30	0.39	0.42	0.18
Stem DW at FM	0.50	0.68	0.58	0.60	0.32	0.23
DMPS at FM	0.72	0.84*	0.87**	0.45	0.95**	0.87*

Each factor of weather conditions was summed from full maturity to the date of measurement in each variety. \* and \*\* indicate significant correlation at 5% level and 1% level, respectively.

summarized in Table 2. Our experiments were conducted under different weather conditions, especially low air temperature in July in 1988 and a small amount of precipitation in October in 1989. Therefore, a significant difference in DW among the varieties was observed, except for the pod DW in 1989 and 1990 (Table 3). DMPS also showed significant differences among the varieties in each year. However, the stem DW did not correlate with the pod DW across 3 yr ( $R^2=0.046$ ,  $df=19$ ).

As shown in Fig. 1, the variation of stem desiccation period across varieties and years could be characterized by stem moisture in late October. Therefore, the correlation was analyzed on stem moisture in late October with FM, pod DW, stem DW, and DMPS (Table 4) were analyzed. Only DMPS showed a significant correlation with stem moisture over 3 yr.

### 3. Effect of DMPS on DFC

Fig. 2 shows the changes in stem moisture in pod removal treatments. In Toyomusume, DMPS increased

from 21 to 42% as the percentage of pod removal increased from 0 to 80%. The same treatment of Tokei 907 in 2000 also increased DMPS from 20 to 59%. According to the increase of DMPS, DFC increased from 20 to over 35 d in 1999 and from 26 to 34 d in 2000, respectively (Table 5). Thus, the pod removal treatments demonstrated that the DMPS at FM greatly affects DFC.

### Discussion

We found drastic differences in stem moisture with the year and variety during the harvesting times in 1988 to 1990 (Fig. 1). In 1989 and 1990, most of the varieties had reached harvest maturity by the latter half of October, but in 1988, only one variety had reached CHM by mid November (Table 1). In July 1988, temperatures a few degrees lower than usual prior to and during the flowering stage were found to induce flower abscission and pod setting failure (Kurosaki and Yumoto, 2003; Shirai and Sasaki, 1988; Tanaka, 1997). Consequently, the pod DW in 1988 decreased markedly to 63% and 57%, compared with



the corresponding values in 1989 and 1990, respectively. Whereas the stem DW in 1988 was 100% and 91%, respectively. In addition, DMPS was higher in 1988 (31%) than in 1989 and 1990 (22%) (Table 3). Inoue (2003)

reported that a high air temperature during the flowering period increased the occurrence of green stem in Fukui Prefecture. In contrast, Mochizuki et al. (2005) reported that temperatures a few degrees higher than usual during the reproductive period inhibited the development of sink organs and suggested that a high temperature was not the primary cause of the occurrence of delayed stem senescence. These opposite conclusions may reflect year-to-year variations of DMPS since the investigations were carried out for only 1 year, and the studies focused on the relationship between the yield components and the occurrence of green stem symptoms, not on DMPS. In our study, DMPS significantly correlated with stem moisture desiccation all 3 yr, while weather factors during the desiccating period were not significantly related to stem moisture (Table 4). These results indicate that DMPS is primarily influenced by weather conditions during growth (i.e., before FM) and affects the stem desiccation after FM.

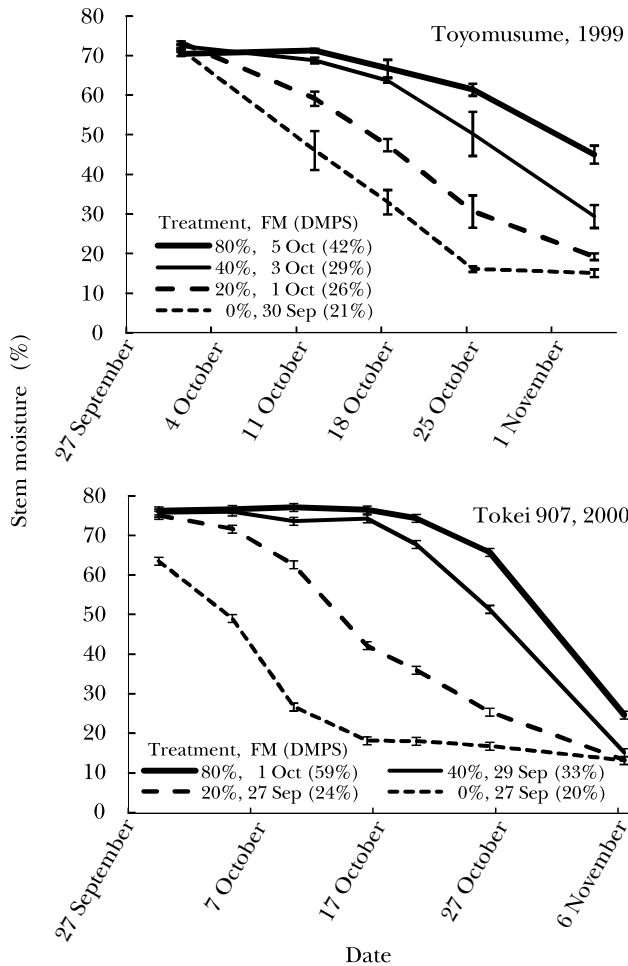


Fig. 2. Effect of soybean pod removal treatments on stem moisture. The variety Toyomusume and breeding line Tokei 907 were subjected to pod removal treatment at R5 (the early stage of pod filling) on August 19, 1999 and August 17, 2000, respectively. The vertical bars show standard errors (n=3). FM indicates date of full maturity. DMPS means dry matter partitioning to stem.

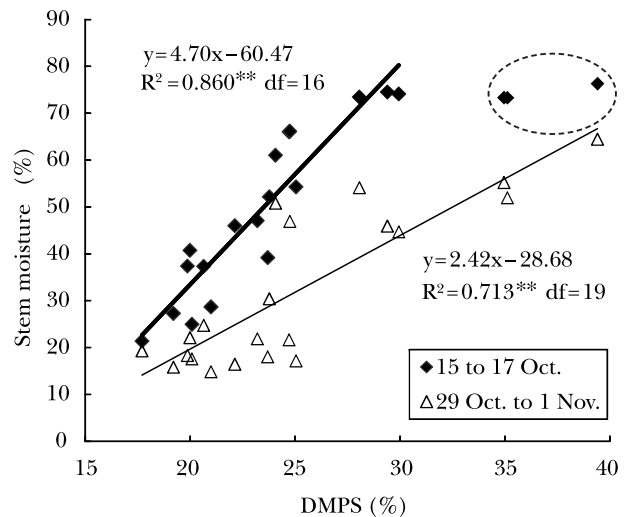


Fig. 3. Relationship between dry matter partitioning to stem (DMPS) and stem moisture in 7 soybean varieties across 3 yr (1988 to 1990). Data for DMPS of over 30% on 15 to 17 October (within the broken line area) were excepted in analyses of correlation and regression. \*\*: significant at 1% level.

Table 5. The dry matter partitioning to stem (DMPS), full maturity (FM), combine harvest maturity (CHM), and days from FM to CHM (DFC) in soybean pod removal treatments.

Pod removal treatment	Toyomusume (1999)				Tokei 907 (2000)			
	DMPS (days)	FM (date)	CHM (date)	DFC (days)	DMPS (days)	FM (date)	CHM (date)	DFC (days)
0%	21	30 Sep	19 Oct	20	20	27 Sep	9 Oct	12
20%	26	1 Oct	25 Oct	24	24	27 Sep	23 Oct	26
40%	29	3 Oct	3 Nov	31	33	29 Sep	1 Nov	33
80%	42	5 Oct	NR	>35	59	1 Oct	4 Nov	34

The DMPS (%) are calculated from the same equation described in Table 3. The CHM (date) and DFC (days) are calculated from the same equation described in Table 2. NR: did not reach CHM until 10 November, 1999.

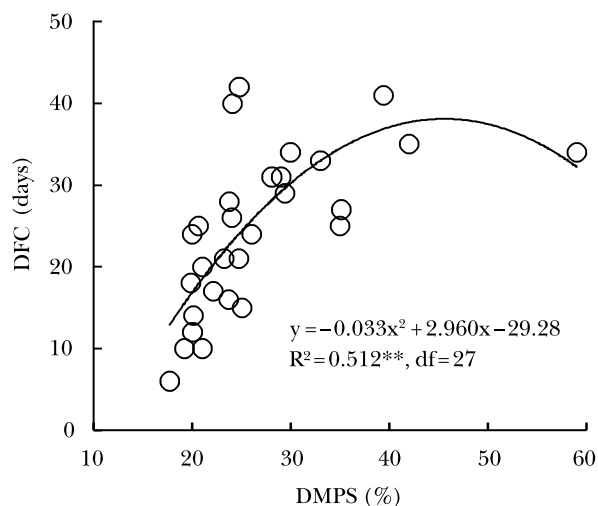


Fig. 4. Relationship between dry matter partitioning to stem (DMPS) and days from full maturity to combine harvest maturity (DFC) in 8 soybean varieties across 5 yr. DMPS and DFC are described in Table 2 and 3 (1988 to 1990) and Table 5 (1999 to 2000). \*\*: significant at 1% level.

DMPS, defined as the ratio of DW of the stem to the DW of the entire mature plant, may be similar to the reversed value of apparent harvest index (HI), defined as the ratio of matured seed weight to whole plant weight. Buzzell and Buttery (1977) and Schapaugh and Wilcox (1980) reported that the HI was negatively correlated with maturity and straw weight. Yumoto et al. (1998) observed that early matured varieties in the Tohoku district seemed to have a higher stem desiccation rate. In this study, we confirmed that the disordered balance (i.e., higher DMPS) between the pod as the sink organ and the stem as the source organ would primarily affect the stem desiccation (Fig. 3) and DFC (Fig. 4). This conclusion was derived from the relationship between DMPS and stem moisture in mid October ( $R^2 = 0.860^{**}$ ,  $df = 16$ ) and at the end of October ( $R^2 = 0.713^{**}$ ,  $df = 19$ ) in the 7 varieties across 3 yr (Fig. 3). This conclusion is supported by the results of pod removal treatment (Fig. 2). With regard to soybean breeding in Hokkaido, the significant varietal differences in DMPS (Table 3) indicate that a variety with higher HI and cold-weather tolerance may not only improve the yield potential but also advance the combine harvest maturity. That is, soybeans with a low DMPS (i.e., high HI) will ensure high-quality seed production and high efficiency for combine harvesting in the short fall season. The early maturing high-yield variety with cold-weather tolerance, “Yukihomare,” which has a high HI of 62%, demonstrated a high stem desiccation rate when compared with that of a later maturing variety, “Toyokomachi” (60%) (Tanaka et al., 2003).

In practical soybean production, the estimation of CHM, the day at which stem moisture reached below 30%,

would be useful information for soybean farmers utilizing combine harvesters during the short fall season in Hokkaido. In this respect, we recognized a close relationship between DMPS and stem moisture by the latter half of October (Fig. 3). Moreover, we found significant regression coefficients in DMPS and DFC (Fig. 4), which suggests the possibility of forecasting combine harvest maturity from DMPS. A DMPS of lower than 20% would result in transition to CHM in mid October (as in Toyomusume in 1990 shown in Fig. 1); soybeans with a DMPS of over 20% to 25% may reach CHM by the end of October (as in Toyomusume in 1989 shown in Fig. 1); and soybeans with a high DMPS of over 30% may show considerably delay CHM to the end of October (as in Toyomusume in 1988 shown in Fig. 1). In particular, when a delay in CHM until the end of October is predicted, DMPS will help the farmers to decide whether they should start the combine harvest before unfavorable weather conditions arrive as well as to prepare for the treatment of soiled soybeans in the worst case. Therefore, DMPS is expected to be an informative indicator for the combine harvesting system in soybean.

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