Differences of Response to Cool Summer Damage and Wet Damage among Upland Crops

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Hokkaido, located in the northernmost part of Japan, is regarded as one of the important food supply areas in Japan. However, the yield stability of upland crops has not yet been attained there due to large yearly fluctuations of climate and widely distributed problem soils such as volcanic ash soils, heavy clay soils and peat soils.

Especially, in Tokachi district, which is located in the eastern Hokkaido, and is the main upland farming area in Hokkaido, yields of upland crops remarkably decrease in cool or wet summer years. It is considered that the most important problem in Tokachi agriculture is how to overcome the influence of adverse meteorological conditions on upland crops.

Therefore, we tried to clarify the relationships between growth and yield of upland crops and meteorological factors in Tokachi district.

Outlines of agriculture, climate and soils in Tokachi district

1) *Agriculture*[2)]

As shown in Table 1, the district has 246,000 ha of cultivated area, 70% of which is planted to many kinds of upland crops. Many of them show a high percentage to the total area of each crop in Hokkaido. Cultivated area per farm there is about two times that of the whole Hokkaido. Thus, Tokachi district is called the main upland farming area in Hokkaido.

2) *Climate*

Hokkaido belongs to the humid sub-frigid zone. Monthly meteorological factors (air temperature, precipitation and duration of sunshine) in Obihiro at the center of Tokachi district and Tokyo are shown in Fig. 1.

Annual mean air temperature (6.1°C) in Obihiro is much lower than that (15.3°C) of Tokyo. Furthermore, the crop cultivation period with monthly mean air temperature higher than 10°C lasts for only 5 months (May to September) in Obihiro. Monthly precipitation in that period is from 80 to 130 mm. Sunshine duration in the months from June to September is shorter than that in other months.

3) *Soils*[3)]

Table 1. Position of Tokachi agriculture in Hokkaido (1981)

	Area*	Cultivated area*	Upland crop area*	Cultivated area per farm (ha)	Soybean*	Azuki bean*	Kidney bean*	Sugar beet*	Potato*	Soiling corn*	Wheat*
Hokkaido	8351	1150	411	9.8	19.0	27.3	23.1	74.0	67.9	51.7	106.0
Tokachi district	1083	246	175	21.3	8.5	9.1	17.1	30.5	24.7	21.7	30.2
Percentage in Hokkaido (%)	13.0	21.4	39.7	—	44.7	33.3	74.0	41.2	36.4	42.0	28.5

* in $\times 10^3$ ha

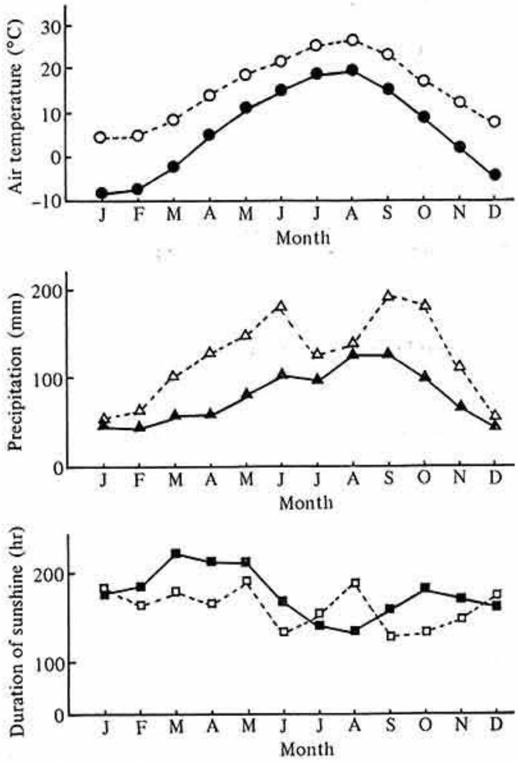

Fig. 1. Climate in Obihiro and Tokyo
●, ▲, ■: Obihiro,
○, △, □: Tokyo

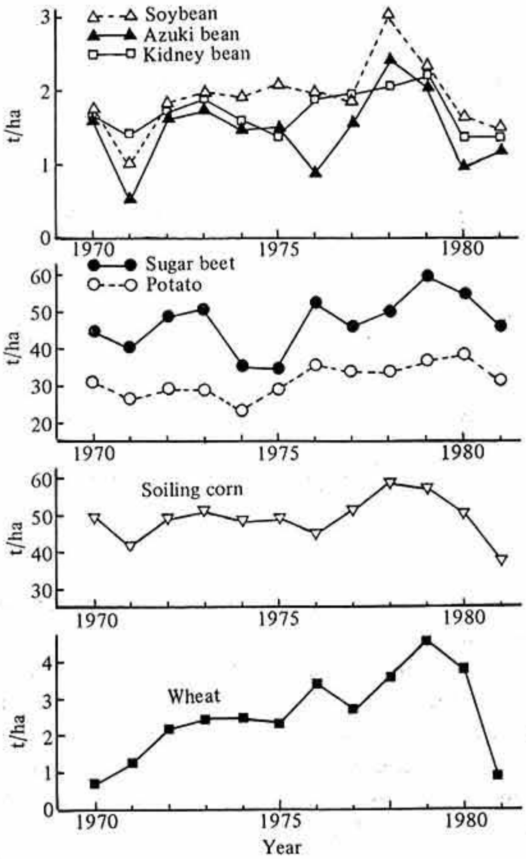

Fig. 2. Transition of yields of upland crops in Tokachi district

In Tokachi district, volcanic ash soils are most widely distributed, namely 51% of the total cultivated area, followed by 36% of alluvial soils, and 4.5% of peat soils. Ill-drained fields occupy 38% of the total cultivated area, and this percentage is higher than any other upland farming area in Hokkaido. Therefore, upland crops are apt to be suffered from wet damages in Tokachi district.

Relationships between yield-index of upland crops and meteorological factors

1) *Transition of yield-index of upland crops and meteorological factors*

Transition of the actual yields[2] of main upland crops (soybean, azuki bean, kidney bean, sugar beet, potato, soiling corn and wheat) from 1970 to 1981 in Tokachi district is shown in Fig. 2.

It is recognized that the yield of each crop has gradually increased in these twelve years although it shows yearly fluctuations. This increasing trend of the yield is considered to be caused by improvement of varieties and cultivation methods. Therefore, it should be more appropriate to use the yield-index than to use the actual yield itself in an attempt to clarify the responses of upland crops to meteorological factors. The yield-index is calculated from the actual yield and the estimated standard yield given by the linear regression equation between actual yields and years using the following formula:

$$\text{Yield-index} = \frac{\text{Actual yield}}{\text{Estimated standard yield}} \times 100$$

The yield-indices are shown in Table 2 in

Table 2. Transition of yield-index of upland crops in Tokachi district

Crops	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Soybean	103	**59**	104	108	103	110	102	96	154	115	**77**	**68**
Azuki bean	118	**37**	117	126	103	100	**59**	107	161	135	**62**	**75**
Kidney bean	102	**85**	103	109	**90**	**85**	119	110	120	127	**78**	**80**
Sugar beet	108	**93**	112	113	**79**	**75**	112	95	101	118	108	**88**
Potato	115	**94**	102	97	**76**	**94**	112	104	102	107	109	**87**
Soiling corn	103	**85**	102	105	99	100	**91**	105	119	116	100	**75**
Wheat	**43**	**70**	113	116	109	95	132	98	121	144	117	**25**

Table 3. Average yield of upland crops and coefficient of variance (C.V.) of yield-index in Tokachi district (1970–1981)

Crops	Soybean	Azuki bean	Kidney bean	Sugar beet	Potato	Soiling corn	Wheat
Average yield t/ha	1.88	1.45	1.69	47.4	31.9	48.9	2.55
C. V. of yield-index (%)	24.5	35.7	16.2	14.1	11.1	11.9	35.6

which bold face indicates years of poor harvest for each crop.

From Fig. 2 and Table 2, average yield of each crop and coefficient of variance of yield-index were obtained and shown in Table 3. The coefficients of variance of yield-index show that the instability of upland crops is in the order of azuki bean, wheat>soybean>kidney bean>sugar beet> soiling corn and potato.

Transition of meteorological factors in the growing season (from June to September) in Obihiro[1] is shown in Fig. 3.

From Table 2 and Fig. 3, it was recognized that yield-indices of soybean, azuki bean and kidney bean were lower than 90 in 1971, 1980 and 1981. Monthly mean air temperature from June to September in these poor harvest years was lower than 16.5°C. In addition, azuki bean showed poor harvest in 1976 and kidney bean in 1974 and 1975.

Yield-indices of sugar beet and potato were lower than 95 in 1971, 1974, 1975 and 1981, and the total precipitation from June to September of these years was higher than 520 mm (average per month: 130 mm).

Soiling corn showed poor harvest in 1971, 1976 and 1981 and wheat in 1970, 1971 and 1981.

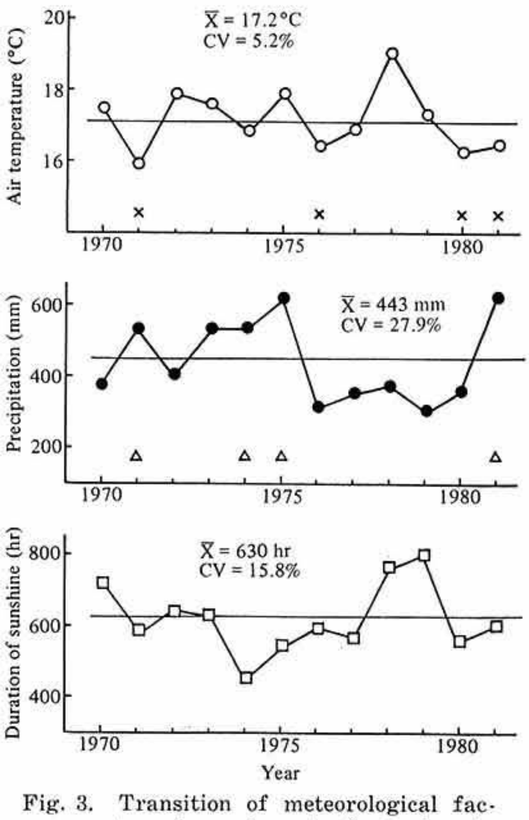

Fig. 3. Transition of meteorological factors from June to September in Tokachi district
△: Wet damage year
×: Cool summer damage year

Table 4. Correlation coefficient between yield-index of upland crops and meteorological factor

Meteorological factor	Soybean	Azuki bean	Kidney been	Sugar beet	Potato	Soiling corn	Wheat
Air temperature	0.882***	0.902***	0.522	0.220	0.118	0.735**	0.302
Precipitation	-0.315	-0.179	-0.652*	-0.764**	-0.791**	-0.498	-0.331
Duration of snnshine	0.506	0.582*	0.688*	0.740**	0.569	0.550	0.179

* 5% significant
** 1% significant
*** 0.1% significant

Table 5. Regression analysis between yield-index of upland crops and meteorological factors

Crops	Regression equation	Correlation coefficient	$x_{y=90}$
Soybean	$y = 24.3x - 318.2$	0.882***	16.8°C
Azuki bean	$y = 35.7x - 515.8$	0.902***	17.0°C
Kidney bean	$y = -0.086x + 137.9$	-0.652*	557 mm
Sugar beet	$y = -0.072x + 137.4$	-0.764**	658 mm
Potato	$y = -0.072x + 131.9$	-0.791**	582 mm
Soiling corn	$y = 9.88x - 70.2$	0.735**	16.2°C

y: yield-index
x: air temperature for soybean, azuki bean and soiling corn
precipitation for kidney bean, sugar beet and potato
$x_{y=90}$: value x corresponding to $y=90$

2) *Correlations between yield-index of upland crops and meteorological factors*

Correlation coefficients between yield-index of upland crops and each meteorological factor in a growing season (sugar beet: May to September, wheat: May to July, and other crops: June to September) are shown in Table 4.

High positive correlations were observed between yield-indices of soybean, azuki bean and soiling corn and mean air temperature during the growing season. High positive correlation was also observed between yield-index of azuki bean and duration of sunshine.

On the other hand, high negative correlations were recognized between yield-indices of kidney bean, sugar beet and potato and precipitations during the growing season of each crop. The yield-indices of these crops also showed fairly high positive correlations with duration of sunshine.

However, no correlations were found between yield-index of wheat and meteorological factors.

Thus, it is thought that soybean, azuki bean and soiling corn are apt to be suffered from cool summer damage, and kidney bean, sugar beet and potato from wet damage (Plate 1–6).

Regression analysis between yield-index of upland crops and meteorological factors is shown in Table 5. Mean air temperature or precipitation which caused the yield-index of each upland crop to decrease to 90 (an indicator for poor harvest year) is shown in the right column of the table.

Thermosensitivity of azuki bean is the highest, as the crop shows the greatest coefficient of regression equation and the highest air temperature for yield-index 90. It is followed by soybean, and then soiling corn which is the lowest of these three crops.

Average per month of precipitation during a growing season which caused decrease of yield-index to 90 was 132 mm (for sugar

Plate 1. Difference of cool summer damage between sugar beet (left) and azuki bean (right)

Plate 2. Zink defficiency of soiling corn caused by low temperature

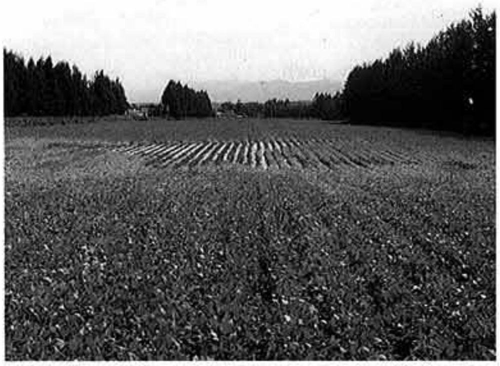

Plate 3. Wet damage of kidney bean on alluvial soils

Plate 4. Difference of wet damage between soybean (left) and kidney bean (right)

Plate 5. Root rot of sugar beet (wet damage) caused by wet climate

Plate 6. Aerial infrared photograph showing wet damage of crops

Table 6. Correlation coefficient between yield-index of upland crops and monthly meteorological factors

Month	Soybean	Azuki bean	Kidney bean	Sugar beet	Potato	Soiling corn
May	——	——	——	-0.582*	——	——
June	0.612*	0.601*	-0.436	-0.714**	-0.699*	0.822***
July	0.628*	0.558	-0.366	-0.623*	-0.177	0.269
August	0.665*	0.751**	-0.384	-0.312	-0.438	0.412
September	0.428	0.493	0.056	0.367	-0.024	0.446

Meteorological factors: air temperature for soybean, azuki bean and soiling corn
precipitation for kidney bean, sugar beet and potato

Table 7. Multiple regression analysis between yield-index and meteorological factors

Crops	Multiple regression equation	Multiple regression coefficient R	Contribution percentage $R^2 \times 100(\%)$
Soybean	I = 26.266***T − 0.0678 P − 0.0408 S − 296.995*	0.930***	86.5
Azuki bean	I = 34.461** T − 0.0297 P + 0.0254 S − 496.717**	0.913***	83.3
Kidney bean	I = 6.466 T − 0.0676 P + 0.0424 S − 8.207	0.837**	70.0
Sugar beet	I = −0.644 T − 0.0484* P + 0.0707 S + 75.374	0.867**	75.2
Potato	I = −1.110 T − 0.0585* P + 0.0358 S + 122.487*	0.828**	68.5
Soiling corn	I = 10.166** T − 0.0483* P − 0.0104 S − 47.280	0.870**	75.6

I: Yield-index, T: Air temperature, P: Precipitation, S: Duration of sunshine

beet), 139 mm (kidney bean) and 146 mm (potato). For this result, it is considered that sugar beet and kidney bean are easily suffered from wet damage and potato follows these crops.

3) Correlations between yield-index of upland crops and meteorological factors of each month

To clarify in which month the cool summer damage and wet damage occur, correlation coefficients between yield-index of upland crops and monthly meteorological factors were calculated (Table 6).

Soybean and azuki bean are affected mainly by the air temperature from June to July (early growth stage) and the temperature of August (flowering stage). Soiling corn is also affected mainly by the temperature of June (early growth stage).

Sugar beet is affected mainly by the precipitation from May to July (early growth stage and subsequent stage for growing leaves and stems), and potato is affected mainly by the precipitation of June (early growth stage).

With the kidney bean, however, no significant correlation is found between yield-index and monthly precipitation.

4) Multiple regression analysis between yield-index and meteorological factors

As a matter of fact, the meteorological factors are inter-correlated, so that the multiple regression analysis between yield-index of upland crops and meteorological factors was made (Table 7). With soybean and azuki bean, multiple regression coefficients are higher than 0.9 with the contribution percentage higher than 80%. Therefore, values of the yield-indices of these beans can mostly be explained by air temperature, precipitation and duration of sunshine in a growing season. Multiple coefficients of the other crops are from 0.83 to 0.87, with contribution percentages from 70% to 75%.

Consequently, it is thought that yield-index of upland crops can be forecasted by using multiple regression equations in Table 7 from meteorological data in each growing season.

Summary

Although Tokachi district is an important upland-farming area of Hokkaido, upland crop production is very unstable due to large yearly fluctuation of humid, sub-frigid climate and wide distribution of volcanic acid soils in the district. Therefore, relationships between meteorological factors (air temperature, precipitation, and duration of sunshine) during the growing season and crop yields were analyzed, by using yield-index instead of actual yield. The yield-index is the percentage of the actual yield to the estimated standard yield, which is given by the linear regression equation between yearly yields and years.

1) The instability of upland crops is in the order of azuki bean, wheat>soybean>kidney bean>sugar beet>soiling corn, potato.

2) Soybean, azuki bean and soiling corn are apt to be suffered from cool summer damage, while kidney bean, sugar beet and potato from wet damage. Mean air temperature in the growing season was lower than 16.5°C in cool summer damage years, and average per month of precipitation was higher than 130 mm in wet damage years.

Furthermore, soybean and azuki bean were affected mainly by air temperature from June to August (early growth stage and flowering stage) and soiling corn was also affected mainly by temperature of June (early growth stage). Sugar beet was affected mainly by precipitation from May to July (early growth stage and leaf-stem growing stage), and potato by precipitation of June (early growth stage).

3) Multiple regression coefficients between yield-index and meteorological factors were from 0.83 to 0.91, and contribution percentages were from 70% to 83%. Consequently, it is thought that yield-index of upland crops can be forecasted by using the multiple regression equation from meteorological data in the growing season of each crop.

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