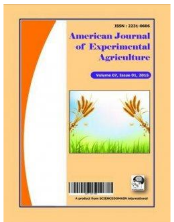

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Growth and Yield of Fall-sown Cereals in the Kanto Region – In the Context of Multipurpose Production

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SI and KIY designed the study. Authors SI and KY performed the field experiments. Author SI performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The possibilities of running a bio-ethanol plant from rice straw in the Kanto region in Japan have been assessed in a project named "Development of Technologies for Biofuel Production Systems in Rural Areas (2012-2015)" funded by MAFF. Aims of the present study are to estimate yielding ability of fall-sown cereals especially triticale and oat on upland fields in the context of multipurpose production.

Study Design: Randomized block design of two treatments (crops and seasons) with three replicates.

Place and Duration of Study: Central Region Agricultural Research Center, NARO (Tsukuba, Japan), three years.

Methodology: (1) Sampling of planted crops, (2) Analysis of meteorological data.

Results: Significant interactions between crops by seasons were observed with height ($P < 0.001$), effective tillers per area ($P < 0.01$), percentage of effective tillers in fresh weight ($P = 0.05$) and

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above-ground dry matter yield ($P < 0.001$). Above-ground dry matter yield of rye did not differ between three seasons, while that of two-row barley, triticale and oat significantly differed between seasons. For example, triticale produced the greatest (1538 g m^{-2}) and the lowest yield (394 g m^{-2}) in 2014/2015 and 2012/2013, respectively. Similarly oat yield in Kannondai was the lowest in 2012/2013 when soil temperature at 5 cm depth recorded at or below 1°C for as many as 135 hours compared with 20 hours and 26 hours in 2013/2014 and in 2014/2015, respectively.

Conclusion: A hypothesis was suggested that fluctuations in above-ground dry matter yield observed between three seasons with two-row barley, triticale and oat produced on upland fields could be explained at least partly from the low soil temperature records observed in 2012/2013.

Keywords: Triticale; oat; bioethanol; soil temperature.

1. INTRODUCTION

Bioethanol production from cultivated crops has been the theme studied under various projects funded by MAFF [1] and NEDO [2] since the government made a Cabinet decision on a “Biomass Nippon Strategy” in 2002. In these projects and related studies, attention was chiefly paid to high yielding energy crops of *gramineae* such as sugarcane [3], sorghum, *Miscanthus* [4], *Erianthus* and napiergrass, while less attention was paid to cereals and their residues except for rice straw [1]. Chen et al. [5], in attempts to diversify and explore alternative feedstocks other than corn in the United States, conducted experiments to produce bioethanol from agricultural residues and hays of cereal crops such as wheat, barley and triticale. As to Japan, Koga [6] calculated an energy balance of winter wheat along with sugar beet and other rotational crops in the context of fuel ethanol production in the Tokachi region in Hokkaido. In his study, the employed value of dry matter yield of above-ground part of winter wheat was 8.06 Mg ha^{-1}, leading to his speculation that quality-oriented fertilization, *i.e.* limited nitrogen application to this crop of noodle-making usage could be lowering the yield. Actually in Hokkaido, above-ground part of dry matter yield as high as 21.81 Mg ha^{-1} has been reported for winter wheat [7], a similar yield to those reported from Europe [8-9] implying a possibility to regard winter wheat as a feedstock for bioethanol production in this region.

In the Kanto region, it is rice straw that could be a feasible feedstock to make bioethanol from [1,10]. However, cultivating rice in paddy fields is not sufficient for one to run a bioethanol plant in a sustainable manner. It is vital to secure several types of feedstocks to rely on rather than leaving the fate of the plant to a single feedstock. These feedstocks are preferred to have various usages such as livestock feed along with feedstock usage, conceptually similar to dual-purpose wheat utilized in different parts of the world [11-12] as well as sugarcane in Brazil where mills are known to alter the ratio of production of ethanol to sugar in accordance with the demand [13].

In the present study, we focus on fall-sown cereal crops which are often grown after rice on paddies under various cropping systems [14-15]. However, we would cultivate these crops on upland fields and not on paddies, as bioenergy crops are often intended to grow on ‘marginal lands’ to avoid competition with food crops [16]. The objective of the present study was therefore to assess yielding ability of fall-sown cereal crops on upland fields that could be achieved in the Kanto region.

2. MATERIALS AND METHODS

2.1 Field Experiments

Three field experiments of rye, two-row barley, oat and triticale were conducted in a field of NARO - Agricultural Research Center (36°02’N, 140°10’E) (3-1-1, Kannondai, Tsukuba, Ibaraki, 305-8666, Japan) in three seasons of 2012/2013, 2013/2014 and 2014/2015. Seeds of rye, barley, triticale and oat cultivars were sown manually (Table 1). Furrow spacing was 0.18 m. pH(H_2O), total nitrogen, available phosphoric acid, exchangeable potassium and humus content in the soil sampled in 2013 were 6.5, 0.35%, 1.5 mg/100 g, 65.3 mg/100 g and 6.8%, respectively. Nitrogen, phosphorus, and potassium were applied at the rate of 6 g m^{-2}. Randomized block design with three replicates was applied. The size of each plot was 3 m by 10 m. Dates of sowing and harvest are presented in Table 1. In three seasons, sorghum was planted prior to fall-sown cereals from the middle of May until the end of September. Data of air temperature, soil temperature, precipitation and solar radiation in Kannondai were obtained from the Weather Data Acquisition System of National Institute for Agro-

Environmental Sciences [17], while data in Yawara were obtained from the meteorological observatory at the Yawara Lowland Field of National Agricultural Research Center.

2.2 Sampling and Analysis

Above-ground part of the plants of known area, i.e. 0.54 m^2 in 2012/2013 and 0.36 m^2 in 2013/2014 and 2014/2015, was harvested in mid to end of April in 2012/2013 and at heading stage of each crop in 2013/2014 and 2014/2015 (Table 1). A part of each sample was taken as a sub-sample and dried at 80°C in an oven to constant weight and dry matter weight was then determined. Another part of each sample was taken to determine leaf area index (LAI) using an automatic area meter, AAM-8 (Hayashi Denko co ltd., Tokyo).

2.3 Statistical Analysis

Analysis of variance (ANOVA) followed by multiple comparisons by Bonferroni's test as well as regression analysis were performed using an SPSS program (IBM Japan, Ltd., Tokyo).

3. RESULTS AND DISCUSSION

3.1 Growth and Yield

3.1.1 Growth and yield

Mean daily temperature, total rainfall and total solar radiation during the experiments are presented in Table 2.

Harvest results are presented for crops (Table 3a) and cultivars (Table 3b). Significant interactions between crops by seasons were observed with all the components except for LAI. Height of rye did not significantly differ between seasons, while that of two-row barley, triticale and oat differed. It was shorter in 2012/2013 than in the other two seasons for triticale and oat. As for two-row barley, greater height was observed in 2014/2015 than in the other two seasons. Similar interactions were observed with above-ground dry matter yield of rye, two-row barley and oat. Above-ground dry matter yield of triticale significantly differed between seasons with 2014/2015 and 2012/2013 showing the greatest and the lowest yield, respectively. Significant difference between seasons was observed with effective tillers per area of two-row barley and triticale, while there was no significant difference with that of rye. In 2012/2013, rye yielded significantly better than triticale and oat. Triticale yielded well in 2013/2014 and 2014/2015. Especially in 2014/2015, the greatest above-ground dry matter yield was observed with triticale compared with the other three crops. Effective tillers per area of two-row barley was significantly smaller in 2012/2013 than in the other two seasons, while that of triticale in 2012/2013 was smaller than in 2013/2014. Significant difference in percentage of effective tillers in fresh weight between seasons was observed for rye, while there was no difference for two-row barley and triticale. LAI of two-row barley was significantly smaller than that of rye and oat. Overall LAI was smaller in 2012/2013 than in the other two seasons. Except in 2012/2013, triticale cultivars yielded well achieving the above-ground dry matter yields over 1,000 g m^{-2}. Among oat cultivars, Major performed well in 2013/2014 and 2014/2015, although it hardly yielded in 2012/2013. Mean biomass yields for different oat cultivars reported from Mediterranean environments are roughly comparable to the values of aboveground dry matter yield observed in the present study except for one cultivar which was reported to have yielded as high as 1717.0 g m^{-2} [18]. As to triticale, the reported biomass values from Mediterranean environments [19] were greater in two out of three years than the aboveground dry matter yield values observed in the present study.

3.1.2 Soil temperature

Unlike the oat crop that hardly yielded in Kannondai, the yield exceeding 10 Mg ha^{-1} was obtained on paddies in Yawara in 2012/2013 (Morio Matsuzaki, personal communication, February 2016) located within 10 km of Kannondai. In order to identify factors that possibly differentiated the fate of oat between the two locations, soil temperature measurements at 5 cm and 10 cm depths as well as air temperature measurements were compared in November, December, January, February and March over three seasons (Fig. 1). Overall soil temperature measurements both at 5 cm and 10 cm depths in Kannondai (upland) were lower than those observed in Yawara (paddy) during night time, while air temperature measurements of the two locations were similar. The results in January are presented in Fig. 1 as an example. In Table 4, the number of hours and the number of longest consecutive hours are presented when soil temperature at 5 cm depth recorded at or below 1°C. In 2012/2013, soil temperature at 5 cm depth in Kannondai was at or below 1°C for 135 hours compared with 20 hours and 26 hours in 2013/2014 and in 2014/2015, respectively. It should be noted here that the soil temperature in Yawara never dropped to or below 1°C. Similar trends were observed both in 2013/2014 and 2014/2015. Taking these into consideration, the low soil temperature records observed in Kannondai in 2012/2013 might explain at least partly the yield reduction in this particular season. Little difference in air temperature between two locations might suggest that choosing the right crops/cultivars of fall-sown cereals to cultivate requires not only the measurements of air temperature but also of soil temperature.

Yoshihira et al. [20] compared growth and yield of rye, wheat and triticale in Hokkaido over 5 seasons. Above-ground dry matter yield was similar between rye and triticale with the mean yield over 5 years being 1780 g m^{-2} and 1742 g m^{-2}, respectively. The yields observed by Yoshihira et al. [20] and in the present study are not comparable considering that growth conditions such as the time of sowing and that of harvest are different. However, yield stability observed with rye and triticale between seasons in Yoshihira et al. [20] was a good contrast to the present study where yield fluctuated greatly between seasons both for rye and triticale. Rye yielded better than triticale in 2012/2013 and it was the other way around in 2014/2015. There was no significant difference between the two crops in 2013/2014. Triticale yield was particularly low in 2012/2013 when soil temperature dropped to or below 1°C for 135 hours. Meteorological data recorded at NARO Hokkaido Agricultural Research Center [21] where Yoshihira et al. [20] conducted their field experiments with triticale indicated that soil temperature at 5 cm depth did not drop below 0°C during winter when the soil was covered with snow. It was, however, below 1°C for as many as several months. Triticale cultivars Yoshihira et al. [20] tested in their study were bred in Poland and their cold tolerance might have been superior to the cultivars that were commercially obtainable in Japan and therefore were sown in the present study. As to oat, Livingston III and Elwinger pointed out that winter hardiness of both average and elite oat entries has been improved in the period from 1935 to 1992 in USA, and that the rate of improvement slowed down after the mid1970s possibly attributable to lack of funding and/or exhaustion of genetic potential [22].

Table 1. Date of sowing and harvest in three seasons

Crop	Cultivar	2012/2013		2013/2014		2014/2015	
		Sowing	**Harvest**	**Sowing**	**Harvest**	**Sowing**	**Harvest**
Rye	Haru-ichiban	9, Nov.	16-23, Apr.	11-12, Nov.	22, Apr.	27-28, Oct.	20, Apr.
Barley	Wasedori-nijyo	9, Nov.	16-23, Apr.	11-12, Nov.	16, Apr.	27-28, Oct.	15, Apr.
Triticale	Kairyo-ryecorn	9, Nov.	16-23, Apr.	11-12, Nov.	8, May	27-28, Oct.	8, May
	RYekokko II	9, Nov.	16-23, Apr.	11-12, Nov.	8, May	-	-
	Ryekokko III	-	-	-	-	27-28, Oct.	25, Apr.
	Ryedax	9, Nov.	16-23, Apr.	-	-	-	-
	Rye-star	-	-	11-12, Nov.	8, May	27-28, Oct.	7, May
Oat	Kyushu 14	9, Nov.	16-23, Apr.	11-12, Nov.	30, Apr.	27-28, Oct.	22, Apr.
	Tsubame	9, Nov.	16-23, Apr.	11-12, Nov.	30, Apr.	27-28, Oct.	23, Apr.
	Idaten	9, Nov.	16-23, Apr.	11-12, Nov.	30, Apr.	27-28, Oct.	24, Apr.
	Major	9, Nov.	16-23, Apr.	11-12, Nov.	15, May	27-28, Oct.	15, May

3.2 Simple Estimation of Above-ground Dry Matter Yield

LAI (Fig. 2a) and height (Fig. 2b) were regressed against above-ground dry matter yield, respectively. Simple estimation of above-ground dry matter yield was attempted by regressing LAI-Height index (product of LAI and Height divided by 100) against above-ground dry matter yield (Fig. 2c). Results of regression analysis are presented in Table 5. LAI-Height index explained above-ground dry matter yield better than LAI or height for rye, two-row barley and triticale, while coefficient of determination was similar between LAI and LAI-Height index for oat. There have been attempts of estimating crop yield from height [23-24] in the literature.

Table 2. Mean daily temperature, total rainfall and total solar radiation over the two seasons of the experiments

Month	2012/2013			2013/2014			2014/2015		
	Temp. (°C)	Rain. (mm)	Sol. Rad. (MJ)	Temp. (°C)	Rain. (mm)	Sol. Rad. (MJ)	Temp. (°C)	Rain. (mm)	Sol. Rad. (MJ)
Oct.	17.3	131	375	18.1	429	311	16.9	263	339
Nov.	9.9	84	271	10.2	16	294	11.6	50	246
Dec.	4.2	56	248	5.0	47	272	4.4	45	263
Jan.	2.4	30	324	3.0	25	324	4.1	51	297
Feb.	3.7	19	341	3.6	136	321	4.0	41	319
Mar.	10.0	35	431	8.4	79	464	8.8	87	465
Apr.	13.0	150	542	12.9	133	576	13.3	78	459
May	17.5	49	686	18.5	103	650	19.7	90	681
Mean	9.8	69	402	10.0	121	402	10.4	88	384

Temp: Temperature; Rain: Rainfall; Sol. Rad.; Solar Radiation

Table 3a. Harvest data of fall-sown cereal crops sown in three seasons

Year	Crop	Height (cm)	ETA (m^{-2})	PET (%)	LAI	Above-ground DMY (g m^{-2})
2012/2013	Rye	104.8	622	95.8	4.15	778
	Two-row barley	63.8	444	95.7	2.27	375
	Triticale	57.6	460	91.3	3.34	394
	Oat	33.9	-	-	-	129
2013/2014	Rye	110.0	864	88.9	8.10	1039
	Two-row barley	64.9	914	93.5	4.13	649
	Triticale	110.2	693	95.5	5.66	1285
	Oat	80.0	823	94.1	6.01	940
2014/2015	Rye	116.3	558	78.6	5.64	875
	Two-row barley	98.4	1166	93.7	4.94	1110
	Triticale	120.5	613	92.8	6.31	1538
	Oat	80.0	589	73.6	5.32	754
	d.f.					
Year (Y)	2	***	***	***	***	***
Crop (C)	3	***	**	***	*	***
Y x C	6	***	**	***	ns	***

ETA: Effective tillers per area; PET: Percentage of effective tillers in fresh weight
d.f.: Degrees of freedom
****P < .001; **P = .01; *P = .05; ns: Not significant*

Table 3b. Harvest data of fall-sown cereal crop cultivars sown in three seasons (Mean ± S.D.*)

Year	Crop	Cultivar	Height (cm)	ETA (m^{-2})	PET (%)	LAI	Above-ground DMY (g m^{-2})
2012/2013	Rye	Haru-ichiban	105 ± 20	622 ± 27	95.8 ± 0.8	4.15 ± 0.25	778 ± 203
	Two-row barley	Wasedori-nijyo	64 ± 9	444 ± 131	95.7 ± 0.6	2.27 ± 0.27	375 ± 54
	Triticale	Kairyo-ryecorn	58 ± 6	448 ± 74	94.2 ± 1.5	3.34 ± 0.91	374 ± 104
		Ryekokko II	61 ± 10	534 ± 50	94.1 ± 1.3	3.86 ± 0.21	467 ± 91
		Ryedax	54 ± 5	398 ± 85	85.5 ± 5.9	2.81 ± 0.80	342 ± 122
	Oat	Kyushu 14	27 ± 25	-	-	-	62 ± 69
		Tsubame	39 ± 18	-	-	-	209 ± 273
		Idaten	36 ± 3	-	-	-	117 ± 57
		Major	-	-	-	-	-
2013/2014	Rye	Haru-ichiban	110 ± 2	864 ± 13	88.9 ± 2.1	8.10 ± 0.96	1039 ± 57
	Two-row barley	Wasedori-nijyo	65 ± 9	914 ± 246	93.5 ± 1.2	4.13 ± 1.56	649 ± 210
	Triticale	Kairyo-ryecorn	100 ± 2	728 ± 21	93.0 ± 0.5	6.98 ± 0.79	1392 ± 222
		Ryekokko II	116 ± 3	688 ± 151	96.9 ± 0.4	4.85 ± 1.58	1197 ± 211
		Rye-star	115 ± 6	663 ± 110	96.6 ± 0.7	5.15 ± 1.63	1267 ± 255
	Oat	Kyushu 14	69 ± 9	778 ± 114	93.7 ± 2.7	4.52 ± 0.44	736 ± 23
		Tsubame	74 ± 10	961 ± 153	94.0 ± 3.7	6.59 ± 0.50	937 ± 135
		Idaten	70 ± 2	984 ± 158	91.6 ± 4.7	4.97 ± 1.27	853 ± 93
		Major	107 ± 9	570 ± 195	97.1 ± 1.2	8.00 ± 2.74	1235 ± 296
2014/2015	Rye	Haru-ichiban	116 ± 2	558 ± 54	78.6 ± 13.4	5.64 ± 1.80	875 ± 189
	Two-row barley	Wasedori-nijyo	98 ± 4	1166 ± 18	93.7± 2.1	4.94 ± 0.89	1110 ± 139
	Triticale	Kairyo-ryecorn	118 ± 2	542 ± 85	95.1 ± 1.2	5.96 ± 0.60	1485 ± 264
		Ryekokko III	107 ± 4	711 ± 116	89.1 ± 4.6	7.59 ± 0.57	1683 ± 262
		Rye-star	137 ± 2	587 ± 113	94.2 ± 5.0	5.39 ± 0.67	1446 ± 294
	Oat	Kyushu 14	68 ± 8	621 ± 223	83.3 ± 4.5	3.64 ± 0.78	576 ± 154
		Tsubame	72 ± 4	728 ± 36	74.6 ± 5.5	4.82 ± 0.47	637 ± 68
		Idaten	79 ± 2	761 ± 178	70.5 ± 9.3	5.23 ± 0.50	802 ± 75
		Major	102 ± 15	246 ± 68	66.2 ± 3.3	7.59 ± 1.78	1001 ± 320

**standard deviation; ETA: Effective tillers per area; PET: Percentage of effective tillers in fresh weight*

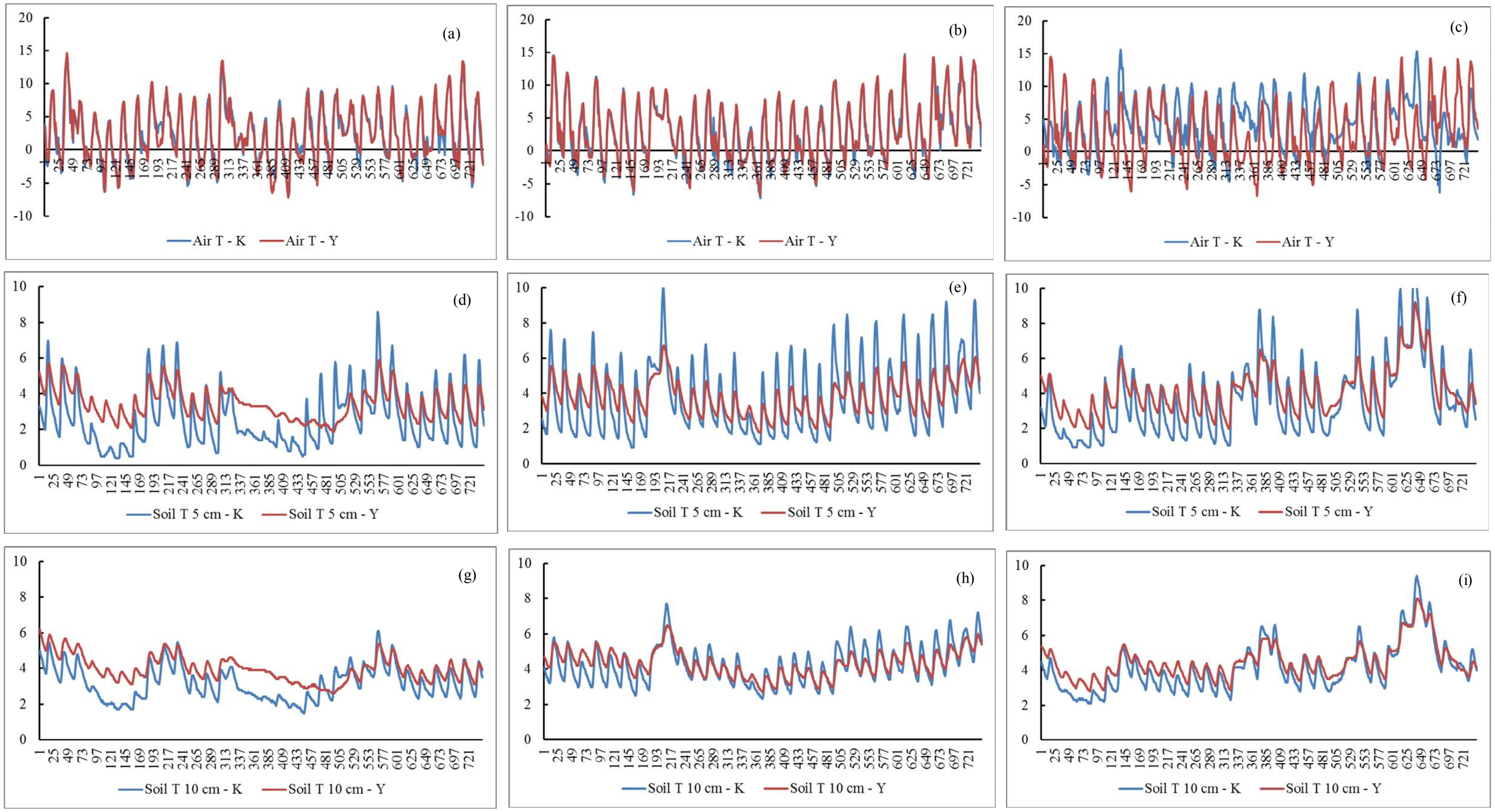

Fig. 1. Hourly change in air temperature and soil temperature at 5 cm and 10 cm depth at Kannondai (K: upland) and Yawara (Y: paddy) in January, 2013, 2014 and 2015

X axis: hour; Y axis: temperature

air temperature in 2013 (a), 2014 (b), 2015 (c); soil temperature at 5 cm depth in 2013 (d), 2014 (e), 2015 (f); soil temperature at 10 cm depth in 2013 (g), 2014 (h), 2015 (i)

Table 4. The number of hours and longest consecutive hours when soil temperature at 5 cm depth recorded at or below 1°C

Year	Location	Observation	Nov.	Dec.	Jan.	Feb.	Mar.
2012/2013	Kannondai	Total hours	0	29	91	15	0
		Longest consecutive hours	0	18	18	6	0
	Yawara	Total hours	0	0	0	0	0
		Longest consecutive hours	0	0	0	0	0
2013/2014	Kannondai	Total hours	0	0	5	15	0
		Longest consecutive hours	0	0	5	11	0
	Yawara	Total hours	0	0	0	4	0
		Longest consecutive hours	0	0	0	4	0
2014/2015	Kannondai	Total hours	0	7	26	0	0
		Longest consecutive hours	0	7	9	0	0
	Yawara	Total hours	0	2	0	0	0
		Longest consecutive hours	0	2	0	0	0

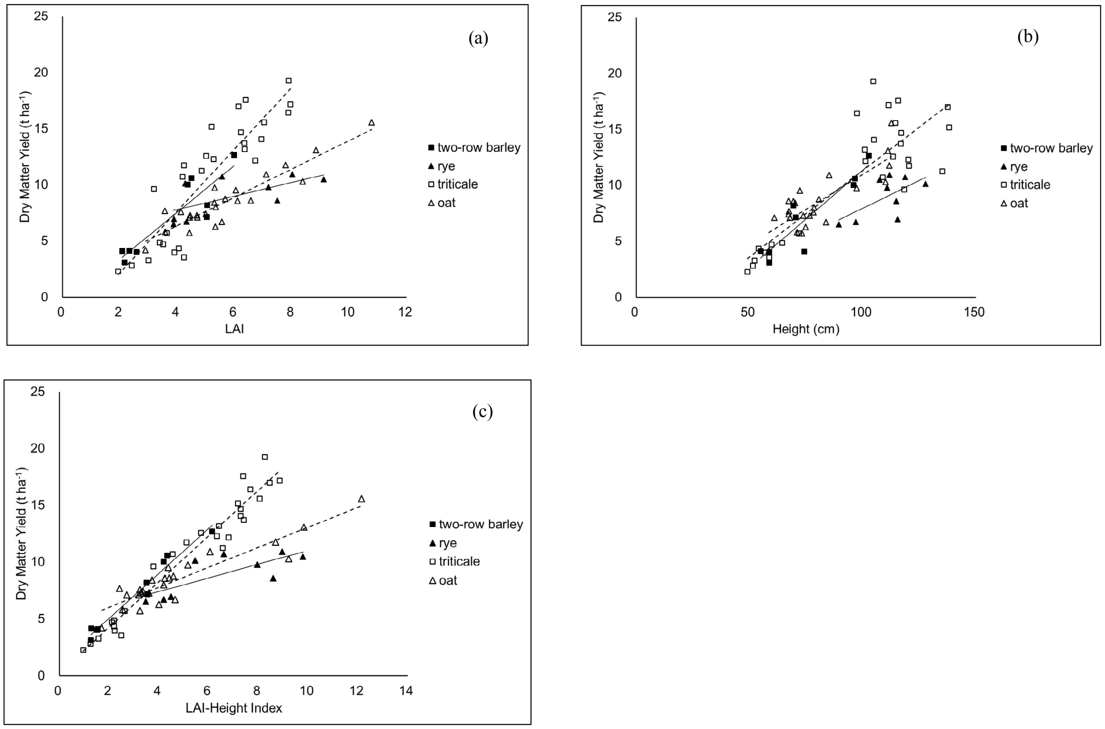

Fig. 2. Regression analysis of (a) LAI, (b) Height, and (c) LAI-Height index, against above-ground dry matter yield

3.3 Implications for Bioethanol Production

It was shown that above-ground dry matter yield could be roughly estimated by the LAI-Height index for oat and triticale. As there are devices that aid simple estimation of LAI on field without needing to damage the canopy, one might find the LAI-Height index useful at the scene of feedstock production for bioethanol purpose.

As to the conversion rate to ethanol, in a study presenting ethanol yield from various crops and residues [25], ethanol yields in the range of 0.26 - 0.41 L and of 0.26 - 0.31 L would be theoretically produced from 1 kg of dry grains and dry straws respectively of barley, oat and wheat. Beres et al. [26] reported the production of 1008 - 2659 L ha^{-1} of ethanol from 2.89 - 5.84 Mg ha^{-1} of grain yield of spring triticale in six agroecological zones and provinces across

Table 5. Coefficients of linear regression analysis of LAI, Height and LAI-Height Index against above-ground dry matter yield

Explanatory variable	Crop	*n*	Coefficient (t pr.)	Constant (t pr.)	*P*	R^2
LAI	Two-row barley	9	2.09 (= .001)	ns	= .001	0.79
	Rye	9	0.61 (= .05)	5.4 (= .05)	= .05	0.37
	Triticale	27	2.76 (< .001)	-3.3 (= .05)	< .001	0.78
	Oat	24	1.26 (< .001)	ns	< .001	0.85
Height	Two-row barley	9	0.17 (= .001)	-6.0 (= .05)	= .001	0.81
	Rye	9	ns	ns	ns	-
	Triticale	27	0.15 (< .001)	-4.1 (= .05)	< .001	0.72
	Oat	24	0.13 (< .001)	ns	< .001	0.66
LAI-Height Index	Two-row barley	9	1.98 (< .001)	1.1 (= .05)	< .001	0.96
	Rye	9	0.60 (= .05)	5.0 (= .01)	= .05	0.53
	Triticale	27	2.01 (< .001)	ns	< .001	0.95
	Oat	24	0.88 (< .001)	4.3 (< .001)	< .001	0.83

ns: Not significant

Canada. In their study, ethanol yield produced per kg of dry grains falls between 0.40 - 0.53 L, a greater range compared with that calculated by Kim and Dale [25] for barley, oat and wheat grains. Wang et al. [27] reported ethanol yields of 0.44 L and 0.41 L produced from 1 kg of dry grains of triticale and rye, respectively. Supposing 0.30 L as the producible ethanol yield per kg of dry grains and straws, the crops cultivated in the presented study would have produced ethanol in the range of 387 L ha^{-1} (oat in 2012/2013) - 4620 L ha^{-1} (triticale in 2014/2015). The highest part of this range implies that quite a large amount of ethanol could be producible from fall-sown cereals, although it should be noted that compositions of the harvested grains and straws were neither analyzed nor considered in the present study.

Closing down of two bioethanol plants in Hokkaido in 2015, however, has shown difficulty of operating bioethanol business based on cultivated crops. Learning from the report that these plants were facing difficulty in obtaining sufficient feedstocks from the planned sources [28] gives us an impression that there is still much to do at the side of agronomy. Yield stabilization between seasons by means of both breeding and agronomy would be the first priority.

4. CONCLUSION

Yield of two-row barley, oat and triticale grown on upland field fluctuated greatly between three seasons showing the lowest yield in 2012/2013. Soil temperature at 5 cm depth was at or below 1°C for 135 hours compared with 20 hours and 26 hours in 2013/2014 and in 2014/2015, respectively. An observation of high yielding oat was made on paddies within 10 km of the upland field where the present study was conducted. Little difference existed in air temperature between two locations, while soil temperature tended to drop on the upland field than on the paddies at night. This might suggest that choosing the right crops/cultivars of fall-sown cereals to cultivate requires not only the measurements of air temperature but also of soil temperature.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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