ABSTRACT

A case study on the effect of Japanese larch (Larix kaempferi Carr.) arable land windbreaks on the reduction of wind damage in Kamioribe District, Shihoro Town, eastern Hokkaido, Japan, is reported. Wind damage occurred on May 8, 2016. Buds of larches were supposed to be just opened, and the leaves on short shoots were still extending at that time. The percentage of severe damage was high on arable lands outside sheltered areas. In contrast, it was low on lands within areas 15 to 20 times the heights of windbreaks leeward to Japanese larch arable land windbreaks. These differences were statistically significant. The results of this study indicate that Japanese larch arable land windbreaks are effective for the reduction of wind damage during the early spring cultivation season, regardless of if its buds are closed or its leaves are not fully extended.

Keywords: arable land windbreak, Japanese larch, spring cultivation season, Tokachi spring wind, wind shielding effect

INTRODUCTION

Historically, the Tokachi Plain in Tokachi Subprefecture (eastern Hokkaido) was covered with primeval forests of daimyo oak trees (Quercus dentata Thunb.). These forests have since been cleared as the land has been converted for cultivation. The soil in the plain is an Andosol composed of volcanic ash. Strong western or northwestern winds blow across the plain from late autumn to late spring. By mid-April, the snow melts and the soil dries. Volcanic ash soils of the Tokachi Plain are prone to wind erosion caused by strong western foehn winds (called the Tokachi spring wind), which end in mid-June (Shikaoichoushihensan-iinkai, 1994; Otofukechoushihensan-iinkai, 2002; Shimizuchoushihensan-iinkai, 2005).

Planting stocks of sugar beets are planted — or its seeds are sown — from late April to early May (Shimizuchoushihensan-iinkai, 2005). Newly planted stocks and small seedlings are prone to wind damage due to being hit by small particles of soil blown by the wind, strong winds pulling young plants from the soil, or the removal of soil from around plant roots.

On the Tokachi Plain, arable land windbreaks are often planted to protect the cultivation fields. These arable land windbreaks consist of one to several rows of trees to reduce wind velocity. Japanese larch (Larix kaempferi Carr.) accounts for about 78% of the planted species and is chosen for use in arable land windbreaks because it is rapid-growing (Tsuji et al., 2005).

Larch buds on the Tokachi Plain start to open in early May (Ohshima et al., 2002), and it takes about three weeks from the bud opening for the full extension of leaves on short shoots (Hirakawa and Suzuki, 2006). During half of the high risk period of wind damage, larch buds are either not open or open, but do not have fully extended leaves (Tsuji et al., 2005; Tsuji et al., 2007). Thus, Torita et al. (2003) suggested that Japanese larch arable land windbreaks were insufficiently effective in spring because the wind velocity reduction effect of a trunk line windbreak of deciduous Manchurian ash (Fraxinus mandshurica var. japonica Maxim.) was much lower in winter than in summer. They (Torita et al., 2003) stated that "Presence of leaves would be very important in arable land windbreaks which are planted in about one to three rows." They also stated that "It is difficult to find a tree species which open buds just after melting of snow in April. Thus, evergreen trees are candidates for species with high wind shielding effects in spring cultivation season" (Torita et al., 2003). Tsuji et al. (2005) described the disadvantage of larch trees: "The main disadvantage is that the growth of this tree between the end of April and the beginning of May, the period with high risk of wind erosion in this area, is not sufficient to provide maximum wind shielding effects." Tsuji et al. (2007) suggested that Japanese larch arable land windbreaks were insufficiently

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effective in spring because the buds were closed or the leaves on short shoots were still extending, and proposed changing the species of arable land windbreaks to evergreen trees such as Sakhalin fir (Abies sachalinensis [F.Schmidt] Mast.) and Sakhalin spruce (Picea glehnii Masters). Akama et al. (2007) posted a photograph of either a Sakhalin fir or Sakhalin spruce arable land windbreak and gave the following caption: "Conifers which are effective for Tokachi wind in spring." In contrast to the reports of Torita et al. (2003), Tsuji et al. (2005, 2007), and Akama et al. (2007), it was reported that snow banks of similar sizes formed leeward to deciduous Japanese larch and evergreen Sakhalin fir arable land windbreaks in winter, suggesting that the wind velocity reduction effects of these two types of windbreak are similar (Ohshima et al., 2003; Hokkaido Forestry Research Institute, 2005). Thus, it is necessary to resolve this contradiction. This study was conducted to clarify the relationship between Japanese larch arable land windbreaks and the reduction of wind damage during the early spring cultivation season.

Table 1 Daily maximum wind speed on May 4-12, 2016 at Kamishihoro, the nearest weather station to Shihoro Town, Hokkaido

| Date  | Wind direction | Wind speed (m/s) |
|-------|----------------|-----------------|
| May 4 | West           | 5.7             |
| May 5 | West-southwest | 7.7             |
| May 6 | West-southwest | 5.4             |
| May 7 | West-southwest | 6.8             |
| May 8 | West-northwest | 10.1            |
| May 9 | West-southwest | 6.2             |
| May 10| South-southwest| 3.1             |
| May 11| North-northeast| 3.7             |
| May 12| West           | 6.7             |

(Japan Meteorological Agency, 2016)

Fig. 1 Location of Kamioribe, Shihoro Town, Hokkaido.

Fig. 2 Proportion of wind (exceeding 10 m/s) direction on May 8, 2016 in Shihoro Town, Hokkaido (measured by Shihoro Town Office).

MATERIALS AND METHODS

Study Site

The study was conducted in Kamioribe District, Shihoro Town, Tokachi Subprefecture, eastern Hokkaido (Fig. 1) (43° 9’ 23”–43° 39” N, 143° 16’ 23”–43° 22’ 13” E). Kamioribe District is essentially a flat area of arable land. The soil in this area is Andosol consisting of volcanic ash (National Land Agency, 1977). In Shihoro, 540 × 540 m townships were created; these lie in the east-southeastern to west-northwestern and north-northeastern to south-southwestern directions. On May 8, 2016, a strong wind blew across the Tokachi Plain (Table 1, Japan Meteorological Agency, 2016). The main wind direction was west-northwest and was therefore exactly perpendicular and parallel to the orientation of the townships (Fig. 2). Wind damage to sugar beets was caused by this Tokachi spring wind. A summary of the damage survey carried out by the Shimizu Sugar Factory, Hokuren Group, is shown in Table 2. The damage was severe in Kamioribe (10.6% of the area damaged) and Sakura (12.2%) districts in Shihoro Town, and the damaged area was the greatest in Kamioribe. Therefore, Kamioribe was chosen for this case study.

A summary of arable land windbreaks (one to six rows of trees planted by farmers on arable land) is shown in Table 3, and that for trunk line windbreaks (most of them are 40–70 m wide and owned by Shihoro Town) is shown in Table 4. The main direction of arable land windbreaks was north-northeast to south-southwest, just perpendicular to the main direction of the strong wind that occurred on May 8. The main directions of trunk line windbreaks were north-northeast to south-southwest, and east-southeast to west-northwest. The main species for both types of windbreaks was Japanese larch.
Methods

The four main crops cultivated on the Tokachi Plain are sugar beets, potatoes, beans, and wheat. From late April, the planting or sowing of sugar beets and planting of potato tubers start, then the sowing of soybeans, red beans, and kidney beans continue from mid-May (Shimizuchoushihensan-inkai, 2005). Thus, by May 8, 2016, almost all sugar beets were either planted or sown. Figure 3 is a photograph taken in Shihoro Town on May 13, 2016, showing a slightly green larch stand. Wind damage occurred on May 8, five days before the photograph was taken. Thus, it can be deduced that either the buds of larches had been closed, or had just opened, and its leaves on short shoots had just started to extend on May 8, 2016. Therefore, the year 2016 was suitable for this study.

A map showing the degree of wind damage to sugar beet for Kamioribe District was provided by the Shimizu Sugar Factory (Hokuren Group) (part of which is shown in Fig. 4). Fields in which sugar beets were cultivated in 2016 were colored on the map. There were five categories on the map: no damage, replanting some stocks, replanting all stocks, re-sowing all seeds, and abandoning sugar beets and cultivating other plants. Sugar beet fields were classified into three groups: no damage, mild damage (replanting some stocks), and severe damage (replanting all stocks, re-sowing all seeds, or abandoning sugar beets and cultivating other plants). The map covers a total of 236 fields; one field was excluded from this study because it was on the leeward side of a barn; 205 fields showed no damage, 5 had mild damage, and 25 had severe damage.

The tree species and visually estimated diameter at breast height (DBH) of arable land windbreaks and trunk line windbreaks were recorded in Kamioribe District in the autumn of 2016. The representative height of dominant and codominant trees was measured for each windbreak using a Vertex IV height measuring instrument (Haglöf Sweden AB) in the fall of 2017, setting the transponder of the Vertex IV on a road adjacent to each windbreak. However, for arable land windbreaks that were not adjacent to roads, the representative heights were visually estimated. A visual estimation of the DBH and height was necessary, as it was impossible to gain access to the arable land windbreaks because of the potential risk of soil-borne disease.

Windbreaks were categorized as arable land windbreaks of larch, trunk line windbreak of larch, arable land windbreak other than larch, and trunk line windbreak other than larch.

Table 2. Wind damage to sugar beets in Shihoro town, Hokkaido on May 8, 2016

| District      | Number of farmers who planted sugar beets | Number of farmers who suffered wind damage | Area of sugar beets planted or sown (ha) | Area of sugar beets with wind damage (ha) |
|---------------|------------------------------------------|-------------------------------------------|----------------------------------------|-----------------------------------------|
| Nakaishiho    | 19                                       | 3                                         | 192                                    | 8.5                                     |
| Shihorominami | 52                                       | 8                                         | 469                                    | 31.5                                    |
| Shihorokita   | 36                                       | 5                                         | 298                                    | 19.1                                    |
| Sakura        | 16                                       | 4                                         | 120                                    | 14.6                                    |
| Kamioribe     | 78                                       | 21                                        | 613                                    | 65.1                                    |
| Shimooribe    | 19                                       | 1                                         | 165                                    | 1.7                                     |
| Nakaotofuke   | 9                                        | 1                                         | 79                                     | 6.0                                     |
| Nitta         | 3                                        | 1                                         | 34                                     | 2.0                                     |
| Nishikami     | 13                                       | 1                                         | 194                                    | 6.0                                     |
| Total         | 245                                      | 45                                        | 2,164                                  | 154.5                                   |

Statistical Analyses

The 5 × 3 contingency tables were constructed for the \( \chi^2 \) analyses. If there are many expected values less than 5.0, the calculated \( \chi^2 \) could be biased (Quinn and Keough, 2002; Zar, 2010). In this case, "A secure practice is to have the mean expected frequency be at least 6.0 when testing \( \alpha \) with as small as 0.05" (\( \alpha \) being the significance level) (Zar, 2010). Since there were 231–235 samples, \( \chi^2 \) analyses were performed with a 5 × 3 contingency table.

However, other statisticians recommend a different method: "Another solution to small observed frequencies is to collapse or combine some categories", so that "no more than 20% of the categories have expected frequencies less than about five" (Quinn and Keough, 2002). To assure objective analyses, the recom-
mendation of Quinn and Keough (2002) was also employed. To achieve this, two steps were necessary. First, windbreak categories were collapsed into three types: sheltered by arable land windbreaks of larch, sheltered by trunk line windbreaks of larch, and outside a sheltered area. Arable lands sheltered by windbreaks other than larch were excluded from the analyses because their sample sizes were small and the main interest in this study was the effectiveness of arable land windbreaks of larch in the early spring cultivation season. Second, damage groups were either collapsed or combined to make them into two categories. To avoid biases, all possible contingency tables were considered. Thus, three types of $3 \times 2$ contingency tables were reconstructed for each multiple number of windbreak heights. In the first type of table, the mild damage category was combined with no damage category to form the no or mild damage category, and in the second type of table, the mild damage category was collapsed, both to test the hypothesis "the severe wind damages occur independent of the windbreak category." In the third type of table, the mild damage category was combined with the severe damage category to form the mild or severe damage category, to test the hypothesis "the wind damages, both mild and severe, occur independent of the windbreak category." The $\chi^2$ test was used for all tables.

RESULTS

The $5 \times 3$ contingency tables for the windbreak categories and wind damage to sugar beets are shown in Table 5. For cases in which 15 and 20 times windbreak heights were defined as...
Table 5  Contingency table (5 × 3) for windbreak categories and wind damage to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016

(a) The area 10 times that of windbreak height was defined as the sheltered area

| Windbreak category | No damage | Mild damage | Severe damage |
|--------------------|-----------|-------------|--------------|
| Sheltered by arable land windbreaks of *Larix* | 39 (92.9%) | 2 (4.8%) | 1 (2.4%) |
| Sheltered by trunk line windbreaks of *Larix* | 34 (94.4%) | 0 (0.0%) | 2 (5.6%) |
| Sheltered by arable land windbreaks other than *Larix* | 7 (77.8%) | 0 (0.0%) | 2 (22.2%) |
| Sheltered by trunk line windbreaks other than *Larix* | 2 (100.0%) | 0 (0.0%) | 0 (0.0%) |
| Outside a sheltered area | 122 (84.1%) | 3 (2.1%) | 20 (13.8%) |

(b) The area 15 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage | Mild damage | Severe damage |
|--------------------|-----------|-------------|--------------|
| Sheltered by arable land windbreaks of *Larix* | 54 (91.5%) | 4 (6.8%) | 1 (1.7%) |
| Sheltered by trunk line windbreaks of *Larix* | 45 (91.8%) | 0 (0.0%) | 4 (8.2%) |
| Sheltered by arable land windbreaks other than *Larix* | 9 (90.0%) | 0 (0.0%) | 1 (10.0%) |
| Sheltered by trunk line windbreaks other than *Larix* | 3 (100.0%) | 0 (0.0%) | 0 (0.0%) |
| Outside a sheltered area | 92 (83.6%) | 1 (0.9%) | 17 (15.5%) |

(c) The area 20 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage | Mild damage | Severe damage |
|--------------------|-----------|-------------|--------------|
| Sheltered by arable land windbreaks of *Larix* | 57 (91.9%) | 4 (6.5%)** | 1 (1.6%)** |
| Sheltered by trunk line windbreaks of *Larix* | 51 (91.1%) | 0 (0.0%) | 5 (8.9%) |
| Sheltered by arable land windbreaks other than *Larix* | 11 (78.6%) | 0 (0.0%) | 3 (21.4%) |
| Sheltered by trunk line windbreaks other than *Larix* | 5 (83.3%) | 0 (0.0%) | 1 (16.7%) |
| Outside a sheltered area | 80 (83.3%) | 1 (1.0%) | 15 (15.6%)* |

(d) The area 30 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage | Mild damage | Severe damage |
|--------------------|-----------|-------------|--------------|
| Sheltered by arable land windbreaks of *Larix* | 65 (91.5%) | 4 (5.6%) | 2 (2.8%) |
| Sheltered by trunk line windbreaks of *Larix* | 55 (85.9%) | 0 (0.0%) | 9 (14.1%) |
| Sheltered by arable land windbreaks other than *Larix* | 12 (80.0%) | 0 (0.0%) | 3 (20.0%) |
| Sheltered by trunk line windbreaks other than *Larix* | 9 (90.0%) | 0 (0.0%) | 1 (10.0%) |
| Outside a sheltered area | 64 (85.3%) | 1 (1.3%) | 10 (13.3%) |

Note: * and ** denote statistically significant differences by residual analysis at significance levels of 0.05 and 0.01, respectively.

sheltered areas, the occurrence of wind damage was significantly different (0.01 < p < 0.05) depending on the windbreak category (Table 5b and c). The percentage of severe wind damage to sugar beets was significantly higher in arable lands outside a sheltered area (residual analysis, p < 0.01 for 15 times and p < 0.05 for 20 times) (Table 5b and c). In contrast, it was significantly lower in fields sheltered by arable land windbreaks of larch (residual analysis, 0.01 < p < 0.05 for 15 times and p < 0.01 for 20 times) (Table 5b and c). The percentage of mild wind damage was significantly higher in fields sheltered by arable land windbreaks of larch (residual analysis, 0.01 < p < 0.05 for 15 times and p < 0.01 for 20 times) (Table 5b and c). For cases in which 10 and 30 times windbreak heights were defined as sheltered areas, the occurrences of wind damage were not significantly different (0.25 < p < 0.5 for 10 times and 0.1 < p < 0.25 for 30 times) depending on the windbreak category (Table 5a and d).

The 3 × 2 contingency tables for windbreak categories and the reduction of wind damage (no and mild damages were grouped) are shown in Table 6. For cases in which 15, 20, and 30 times windbreak heights were defined as sheltered areas, the occurrence of severe wind damage was significantly different (0.01 < p < 0.05 for 15, 20, and 30 times) depending on the windbreak category (Table 6b, c, and d). The percentage of severe wind damage to sugar beets was significantly higher in arable lands outside of a sheltered area (residual analysis, p < 0.01 for 15 and 20 times) (Table 6b and c). In contrast, it was significantly lower in fields sheltered by arable land windbreaks of larch (residual analysis, 0.01 < p < 0.05 for 15, 20, and 30 times) (Table 6b, c, and d). For cases in which 10 times windbreak height was defined as a sheltered area, the occurrence of severe wind damage was not significantly different (0.05 < p < 0.1) depending on the windbreak category (Table 6a).

The 3 × 2 contingency tables for windbreak categories and wind damage reduction (mild damage collapsed) are shown in Table 7. For cases in which 15 and 20 times windbreak heights were defined as sheltered areas, the reduction in wind damage was significantly different (0.01 < p < 0.05 for both) depending on the windbreak category (Table 7b and c). The percentage of
severe wind damage to sugar beets was significantly higher in arable lands outside a sheltered area (residual analysis, \( p < 0.01 \) for 15 times and \( 0.01 < p < 0.05 \) for 20 times) (Table 7b and c). In contrast, it was significantly lower in fields sheltered by arable land windbreaks of larch (residual analysis, \( 0.01 < p < 0.05 \) for 15 and 20 times) (Table 7b and c). For cases in which 10 and 30 times windbreak heights were defined as sheltered areas, reductions in wind damage were not significantly different (\( 0.05 < p < 0.1 \) for both) depending on the windbreak category (Table 7a and d).

The 3 \( \times \) 2 contingency tables for windbreak categories and the elimination of wind damage (mild and severe damage groups) are shown in Table 8. The elimination of all degrees of wind damage was not significantly different (\( 0.1 < p < 0.25 \) for 10, 15, and 20 times, \( 0.25 < p < 0.5 \) for 30 times) depending on the windbreak category.

**DISCUSSION**

Concerning the appropriate number of times windbreak heights effective for reducing wind damage on the leeward side to windbreaks, the results of this study suggest that areas 15 and 20 times the windbreak heights are the most appropriate (Tables 5b, 5c, 6b, 6c, 7b, and 7c, statistically significant differences in all tables), whereas 30 times are much less appropriate (Tables 5d, 6d, and 7d, significant differences only in Table 6d), and 10 times is not appropriate (Tables 5a, 6a, 7a, no significant differences). Onodera et al. (1955) reported that wind velocity was reduced within 15 times leeward to the Japanese larch windbreak height in the Tokachi Plain. Torita et al. (2003) reported that wind speed was reduced by 18 to 20 times leeward to the windbreak height. The results of this study are consistent with these reports.

Although trunk line windbreaks consist of more than 10 rows of trees, the results of this study failed to demonstrate the effectiveness of Japanese larch trunk line windbreaks in the early spring cultivation season (Tables 5b, 5c, 6b, 6c, 7b, and 7c). The reason for the high effectiveness of larch arable land windbreaks was demonstrated, whereas that of larch trunk line windbreaks was not could not be made clear from this study. One of the possible reasons for this is that most trees in the larch trunk line windbreaks had lost lower branches because of crowding. The other possible reason is that larch trees standing adjacent to cultivation fields in trunk line windbreaks were heavily pruned because the fallen leaves and branches of larches are hated by farmers. The relationship between forest management and the effect of Japanese larch trunk line windbreaks on the reduction of wind damage in the spring cultivation season needs to be studied.

The results of this study suggest that Japanese larch arable land windbreaks are effective for reducing (Tables 5b, 5c, 6b, 6c, 7b, and 7c), but not eliminating (Table 8) wind damage on arable lands leeward to windbreaks during the early spring cultivation season. These results support those reported by Ohshima et al. (2003) and Hokkaido Forestry Research Institute (2005), but were contradictory to Torita et al. (2003), Tsuji et al.
Japanese Larch Arable Land Windbreaks are Highly Effective for Reducing Wind Damage in Early Spring

Table 7  Contingency table (3 × 2) for windbreak categories and reduction of wind damage (mild damage collapsed) to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016

| Windbreak category                          | No damage | Severe damage |
|---------------------------------------------|-----------|---------------|
| Sheltered by arable land windbreaks of Larix| 39 (97.5%)| 1 (2.5%)      |
| Sheltered by trunk line windbreaks of Larix | 34 (94.4%)| 2 (5.6%)      |
| Outside a sheltered area                    | 122 (85.9%) | 20 (14.1%) |

Table 7 (b) The area 15 times that of the windbreak height was defined as the sheltered area

| Windbreak category                          | No damage | Severe damage |
|---------------------------------------------|-----------|---------------|
| Sheltered by arable land windbreaks of Larix| 54 (98.2%)* | 1 (1.8%)*    |
| Sheltered by trunk line windbreaks of Larix | 45 (91.8%)| 4 (8.2%)      |
| Outside a sheltered area                    | 92 (84.4%)* | 17 (15.6%)*  |

Table 7 (c) The area 20 times that of the windbreak height was defined as the sheltered area

| Windbreak category                          | No damage | Severe damage |
|---------------------------------------------|-----------|---------------|
| Sheltered by arable land windbreaks of Larix| 57 (98.3%)* | 1 (1.7%)*    |
| Sheltered by trunk line windbreaks of Larix | 51 (91.1%)| 5 (8.9%)      |
| Outside a sheltered area                    | 80 (84.2%)* | 15 (15.8%)*  |

Table 7 (d) The area 30 times that of the windbreak height was defined as the sheltered area

| Windbreak category                          | No damage | Severe damage |
|---------------------------------------------|-----------|---------------|
| Sheltered by arable land windbreaks of Larix| 65 (97.0%)| 2 (3.0%)      |
| Sheltered by trunk line windbreaks of Larix | 55 (85.9%)| 9 (14.1%)     |
| Outside a sheltered area                    | 64 (86.5%)| 10 (13.5%)    |

Note: * and ** denote statistically significant differences by residual analysis at significance levels of 0.05 and 0.01, respectively.

(2005, 2007), and Akama et al. (2007).

None of the literature against the high effectiveness of Japanese larch arable land windbreaks in the spring cultivation season is based on data. Torita et al. (2003) measured the wind velocity leeward to Manchurian ash trunk line windbreaks but not around Japanese larch arable land windbreaks. They surveyed wind damage to red beans, but the Tokachi spring wind blew on June 9 and 10 in the year they surveyed, so leaves on the short shoots of larches were supposed to have been fully extended by then (Ohshima et al., 2002; Hirokawa and Suzuki, 2006). Tsuji et al. (2007) analyzed the relationship between the densities of arable land windbreaks and the rate of wind damage and showed that the relationship was statistically non-significant. They did not state the names of the crops being investigated, nor the date when wind damage occurred. They also did not investigate the relationship between the species planted in arable land windbreaks and the extent of wind damage. Thus, their study did not examine the effectiveness of Japanese larch arable land windbreaks on the reduction of wind damage during the early spring cultivation season. The publication by Akama et al. (2007) was a pamphlet, not a scientific study.

Tsuji et al. (2005) studied wind damage to sugar beets and reported that "On the survey on wind erosion had confirmed that wind erosion damage occurs in areas outside the windbreaks, and not in the sheltered areas." They also reported that "The wind erosion damage ratio increased with the density of the windbreak networks becoming less in Otofuke. And, it was proven that there was a negative correlation between the density of the windbreak networks and the wind erosion damage ratio in Otofuke" (Tsuji et al., 2005). These reports are consistent with the results of this study. Tsuji and Saho (2006) also reported that most wind damage to sugar beet crops in 2001 occurred in arable lands outside a sheltered area, which is consistent with the results of this study. However, Tsuji et al. (2005) and Tsuji and Saho (2006) did not report the date when the wind damage occurred, and thus, it is impossible to deduce whether the leaves on short shoots of larch had been fully extended or not. If wind damage occurred in late May or early June, then the damage cannot be attributed to the deciduous nature of larch, as the leaves on short shoots would have been fully extended by then. Both reports did not analyze the relationship between the species in the arable land windbreak and the extent of wind damage. Thus, it is impossible to judge the effectiveness of Japanese larch arable land windbreaks in the spring cultivation season from these studies. In addition, a statement contradictory to the above-quoted statement is found in Tsuji et al. (2005), causing confusion: "On the other hand, erosion damage occurred near the windbreaks." Furthermore, the same first author (Tsuji et al., 2005, 2007) denies the high effectiveness of larch arable land windbreaks against wind damage caused by the Tokachi spring wind, causing further confusion.

Several studies have shown that farmers support the high effectiveness of Japanese larch arable land windbreaks in the

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Table 7 Contingency table (3 × 2) for windbreak categories and reduction of wind damage (mild damage collapsed) to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016
spring cultivation season. In questionnaire surveys carried out on the Tokachi Plain, 94%–98% (Nonokawa, 1991) and 86% (Torita et al., 2004) of farmers answered that arable land windbreaks were effective in preventing wind damage. Ueno (2003) developed an analytic hierarchy process model for the maintenance and management of arable land windbreaks based on the responses of farmers on the Tokachi Plain, and the prevention of soil erosion was assigned as the most important merit of windbreaks. Furthermore, Nakagawa (2018a) reviewed 156 local history chronicles from the Tokachi Plain and found deciduous larch arable land windbreaks that reduced wind damage during the spring cultivation season had been evaluated as highly effective by 31 literatures, whereas there were no negative statements regarding the use of this tree species in arable land windbreaks. Nakagawa (2018b) carried out a similar review of local history chronicles on the Shari plain, another major area prone to wind damage during the spring cultivation season in Hokkaido, and again found only positive conclusions from seven reports. Nakagawa (2018c) also found that Japanese larch arable land windbreaks during the spring cultivation season were evaluated to be highly effective in a pamphlet issued by the Forestry Department of Tokachi Subprefecture, Hokkaido Government.

From the results of this study and the above literature review, it can be concluded that arable land windbreaks of Japanese larch are effective at reducing wind damage in cultivation fields during the early spring cultivation season, even if larch buds are not open or the leaves on short shoots are not fully extended.

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Table 8 Contingency table (3 × 2) for windbreak categories and elimination of wind damage (mild and severe damages were grouped) to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016

(a) The area 10 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage (92.9%) | Mild or severe damage (7.1%) |
|--------------------|-------------------|-----------------------------|
| Sheltered by arable land windbreaks of Larix | 39                | 3                           |
| Sheltered by trunk line windbreaks of Larix  | 34 (94.4%)        | 2 (5.6%)                    |
| Outside a sheltered area                   | 122 (84.1%)       | 23 (15.9%)                  |

Table 8 (b) The area 15 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage (91.5%) | Mild or severe damage (8.5%) |
|--------------------|-------------------|-----------------------------|
| Sheltered by arable land windbreaks of Larix | 54                | 5                           |
| Sheltered by trunk line windbreaks of Larix  | 45 (91.8%)        | 4 (8.2%)                    |
| Outside a sheltered area                   | 92 (83.6%)        | 18 (16.4%)                  |

Table 8 (c) The area 20 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage (91.9%) | Mild or severe damage (8.1%) |
|--------------------|-------------------|-----------------------------|
| Sheltered by arable land windbreaks of Larix | 57                | 5                           |
| Sheltered by trunk line windbreaks of Larix  | 51 (91.1%)        | 5 (8.9%)                    |
| Outside a sheltered area                   | 80 (83.3%)        | 16 (16.7%)                  |

Table 8 (d) The area 30 times that of the windbreak height was defined as the sheltered area

| Windbreak category | No damage (91.5%) | Mild or severe damage (8.5%) |
|--------------------|-------------------|-----------------------------|
| Sheltered by arable land windbreaks of Larix | 65                | 6                           |
| Sheltered by trunk line windbreaks of Larix  | 55 (85.9%)        | 9 (14.1%)                   |
| Outside a sheltered area                   | 64 (85.3%)        | 11 (14.7%)                  |
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