http:/ap.fftc.org.tw/e-journal
The FFTC Journal of Agricultural Policy

Understanding the Role of Farmers, Scientists, and Extension Staff in Developing Climate Change Adaptation Technologies in Tokachi and Okhotsk, Hokkaido, Japan

Tomoyoshi Hirota[1*] and Kazuhiko Kobayashi [2]
[1]Faculty of Agriculture, Kyushu University, Fukuoka, Japan
[2]Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo, Japan
*Corresponding e-mail: hirota@agr.kyushu-u.ac.jps

Received March 8, 2023; Accepted November 24, 2023

ABSTRACT

In Tokachi region of Hokkaido, Japan, the soil's freezing depth has become shallower since mid-1980s resulting in the proliferation of volunteer potatoes in the fields, where remaining potato tubers after harvesting survive the winter and grow as weeds to the following crops. To eradicate the volunteer potatoes, the farmers adopted soil frost enhancement by snow removal in winter, a practice that a farmer had invented before. The adopters, however, sometimes encountered undesired outcomes due to insufficient or excessive soil frost. An extension agronomist brought this problem to the attention of a scientist, who then combined the farmers' practice with a soil temperature model and thereby established the soil frost control (SFC) technology. With SFC, soil frost depth is optimized for controlling volunteer potatoes without the excessive freezing. The SFC technology was implemented in a web-based decision support system, which facilitated the wide adoption of the technology by the farmers. After the SFC was transferred to Okhotsk region of Hokkaido, the agronomists at regional institutions extended the use of the technology to the improvements of soil physical properties and crop growth. The extended application of SFC enlarged its user base beyond potato growers. In Okhotsk also, the SFC was implemented in a web-based information system and was widely adopted by the farmers. We attribute the wide adoption of the SFC technology to the involvement of farmers and local agronomists at the early stages of technology development and the involvement of regional agronomic institutions at later stages of technology development and dissemination.

Keywords: innovation, soil frost, snow, volunteer potatoes, crop growth, soil tilth

INTRODUCTION

Climate change driven by human activities is currently underway and is expected to intensify further into the future. Agriculture is one of the societal sectors that are most vulnerable to the climate change. Facing the challenges of the ongoing climate change, it is necessary not only to curb the greenhouse gas emissions (mitigation), but also to reduce the risks and, if possible, turn them into opportunities (adaptation). In agriculture, the farms are where the adaptation to climate change takes place, and therefore it is imperative that the agricultural technology for adaptation to climate change is adopted by most farmers and farming organizations across the region of concern.

The obvious importance of farmers' adoption of the adaptation technology leads to a critical question: What determines the adoption (or rejection) of a new technology by the users? This is the very question that has been addressed in the paradigm of diffusion of innovations (*the diffusion*, hereafter) (Rogers, 2003). In *the diffusion* paradigm, an innovation is defined as an idea, practice, or object that is perceived as new by an individual. Objective newness, let alone usefulness, is not a requirement for innovation. If an idea or a practice seems new to an individual, it is an innovation (Rogers, 2003). An innovation diffuses among the members of a social system through certain channels of communication over time. Adoption or rejection of the innovation by the members is an outcome of the diffusion process. It follows that the elements of diffusion process: innovation, social system, communication channels, and time are the major determinants of adoption of the innovation. The involvement of the latter three elements explains the fact that advantages of an innovation seldom warrant its successful adoption (Rogers, 2003). This holds true in adaptation of agriculture to climate change. We need not only to focus on the advantages of an adaptation technology but also to address the other elements of *the diffusion* for wide adoption of the adaptation measure.

In this article, we take up soil frost control (SFC) as a technology for adaptation in agriculture to climate change. It was first developed in Tokachi region of Hokkaido, Japan under the climate-induced shallowing of soil frost, which caused proliferation of *volunteer potatoes* in the field (Hirota and Kobayashi, 2019). The volunteer potatoes refer to unharvested potato tubers that overwinter and grow as weeds to the following crops (more details given later) (Rahman, 1980). The SFC effectively suppressed volunteer potatoes and was widely adopted by the farmers in Tokachi (Hirota and Kobayashi, 2019). SFC was further developed after being transferred to another major cropping region: Okhotsk of Hokkaido, where SFC was applied to improve soil physical property and increase crop yield. With the expanded advantages beyond the control of volunteer potatoes, SFC was adopted by more farmers than potato growers in Okhotsk.

We analyzed the development of SFC technology and its adoption by farmers in Tokachi followed by those in Okhotsk as a connected series of *the diffusion* processes. We tracked the temporal evolution of the technology and the roles of major actors in the development and adoption of the technology. The major actors included farmers, extension staffs, scientists as well as the relevant institutions such as agricultural cooperatives and extension centers. We also addressed communications between the actors. We thereby addressed the major determinants of diffusion of innovation: time, communication, and the members of social systems in addition to the technology itself (Rogers, 2003).

Agriculture in eastern Hokkaido and the change of climate therein

Hokkaido is Japan's dominant producer of various upland crops like potatoes, onion and wheat, and our study regions: Tokachi and Okhotsk in Eastern Hokkaido, are the major crop producers of Hokkaido. Agriculture in these regions has long been constrained by the freezing of soils under very low temperature in winter. Since mid-1980s, however, the soil freezing depth has become gradually shallower in Tokachi. It was not because of the warming of the winter climate, but of the earlier snow fall. The snow depth of 20 cm was reached earlier in more recent years and the snow insulated the soil surface from the falling air temperature earlier than before, which resulted in the shallowing trend of soil frost (Hirota *et al*., 2006).

The earlier snowfall in Tokachi turned out to be a part of climate change across northern Japan. Decreasing snow depth along the coast of Japan Sea, reduced drift ice in the coast of Okhotsk Sea, and the earlier snowfall in Tokachi. All these changes started in the mid-1980s. They were caused by the weakening of typical pattern of winter climate that brings deep snow to regions in Japan-Sea side, and cold and dry weather in the Pacific side like Tokachi (Hirota *et al*., 2006).

Temporal evolution of soil frost control for volunteer potatoes management

As the soil frost became shallower, many changes took place in agriculture. In the past, the soil had been frozen deeply, and crops like alfalfa and autumn-sown wheat could not survive the winter. As the soil frost became shallower, these crops could overwinter, and the farmers and agronomists now try to grow them in Eastern Hokkaido (The Science Council of Japan, 2023).

The shallower soil frost also brought to the farmers undesired changes in their fields. Small tubers of potatoes left in the soil after harvesting had been killed by freezing before but can now survive the winter and become weeds to the following crops (Figure 1). They are called volunteer potatoes (VP, hereafter), which must be controlled to prevent them from competing with the crop for soil nutrients and accommodating soil-born pests like nematodes (Rahman, 1980). As spraying herbicides did not control VP effectively, the farmers had to remove the volunteer potatoes plants by hands, which costed them much time and labor in the middle of busy farming season (Hirota and Kobayashi, 2019). Some farmers even dropped potatoes from the crop rotation.

Figure 1. Volunteer potatoes growing in a field in Tokachi, Hokkaido, Japan.

In 1990, some farmers started plowing snow in the field in the middle of winter (Figure 2). The practice proceeded in 3 steps (Hirota *et al.*, 2010; Yazaki *et al*., 2013). At the first step, snow is plowed to expose the soil surface to cold air while the plowed snow is piled up as ridges alongside the stripes of the soil surface. After the exposed soil is frozen deeply enough, the farmer plows the snow ridges to expose the soil beneath them and pile up the snow over the now frozen soil, which does not undergo further freezing. This is the second step. For the third step, after the exposed soil is frozen to sufficient depth, the snow is moved from the ridges to cover the soil surface and thereby the entire field is frozen to the depth to prevent the remaining potato tubers from overwintering.

Figure 2. Snowplowing, or Yukiwari in Japanese, practiced at a field in Tokachi, Hokkaido, Japan.

The snow removal against VP had been invented in 1980 by Mr. Yutaka Yoshida, a farmer in Tokachi (Hirota *et al*., 2021). He encountered the problem of VP earlier than the other farmers and observed that the tubers at the soil surface were killed by freezing while those left deep in soil survived. The observation led him to the idea of snow removal for enhancing soil freezing and thereby suppressing VP. At that time, he removed the snow by pushing a bucket attached to the front of his tractor, which was not an efficient work. As the practice of snow removal diffused among the farmers, the snow-pushing evolved into snowplowing for higher efficiency. They called the practice of snowplowing as *Yukiwari* in Japanese or snow-breaking when it is literally translated into English.

A problem of *Yukiwari* had emerged, however. While it enhanced the soil frost, too deep freezing delayed the snow melt in spring, which delayed the start of the cultivation and eventually hindered the harvest. Shallower freezing, on the other hand, brought them proliferation of VP in the fields. The problem was that the farmers had no ways to know the soil's frost depth which varied year by year and had to depend on intuition and fortune for the decision making on timing and frequency of the *Yukiwari* (Hirota and Kobayashi, 2019). An extension agronomist at Tokachi Agricultural Extension Center (TAEC) recognized the problem of *Yukiwari* and brought it to the attention of T. Hirota at Hokkaido Agricultural Research Center (HARC) of NARO (National Agricultural Research Organization) in the year 2005.

At that time, Hirota had developed a simple but physics-based model of soil temperature across a vertical profile (Hirota *et al.*, 2002), and had been conducting intensive observations on atmosphere / snow layer / soil frost layer interactions (Hirota *et al*., 2005). These experiences facilitated him to formulate the challenge of *Yukiwari* as an optimization of soil frost depth to attain two conflicting targets:

1) to attain soil freezing deep enough to kill all the remaining tubers, and
2) to keep soil frost depth shallow enough to avoid excessive delay in waiting for the soil to melt in the next spring.

The SFC was developed for the optimization of soil frost using the soil temperature model (Hirota et al., 2002). The development of SFC at HARC was facilitated by the cooperation with Tokachi Federation of Agricultural Cooperatives (TFAC) along with the individual agricultural cooperatives. For example, the scientists at HARC collected the records of soil frost and snow depth at 60 sites across the region observed by the agricultural cooperatives. The scientists also conducted a field survey of VP in 30 farmers' fields. These undertakings were supported by TFAC and the agricultural cooperatives (Hirota and Kobayashi, 2019). The observation data were used to establish the relationship between the occurrence of VP and the soil frost depth (Maezuka 2008) and to verify and improve the soil frost model. The scientists also started the development of web-based system for farmers to make decisions on *Yukiwari* with SFC.

In 2010, the cooperation of the scientists at HARC with TFAC developed to a collaborative project that involved the regional research and development organizations: Tokachi Agricultural Experiment Station (TAES) and Tokachi Agricultural Extension Center (TAEC) (Hirota and Kobayashi, 2019). The soil frost model was further elaborated, and the user-interface in the decision-support system with SFC was improved through this project. SFC was implemented to the web-based information system run by TFAC. The farmers in this region can now make the decision by themselves on the timing and frequency of *Yukiwari* with SFC technology instead of intuition or expert advises. According to an estimation by TFAC, about 60-70% of the farmers use the information system and conduct SFC at about 5,300 ha of potato fields in the region.

The SFC prevented VP almost completely (Yazaki *et al*., 2013), and with the very efficient machine operation during the off-season of winter without additional costs for chemical agents. Control of VP has generally been conducted by means of mechanical or chemical treatments, but none of the methods are completely effective (Rahman, 1980). It has been known that low temperature kills remaining tubers, which, however, has not been used as a means of controlling VP. The SFC appears to be the first that controls the VP by means of controlling soil frost.

Roles of the major actors in the diffusion of soil frost control in Tokachi region

We analyzed the involvement of major actors in the diffusion of SFC in Tokachi. As noted above, Mr. Yoshida of Tokachi invented the snow removal to control VP in 1980. This practice was adopted by progressive farmers in Tokachi since 1990s when soil frost became shallower and VP proliferated greatly. The diffusion of the practice was initiated by the network of farmers' wives, who had born the burdens of manually removing VP from the fields. While the farmers themselves were not strongly motivated to adopt the snowplowing idea, they possibly adopted it being prodded by their wives. It was easy for them to adopt the practice: they simply watched the operation by the earlier adopter nearby. They then tried it by themselves in their own fields without needing any detailed information on the operation. The results were obvious in the next spring for themselves as well as the others around who had not adopted it yet (Hirota and Kobayashi, 2019). These features: simplicity, trialability, and observability of the snow removal are known to be conducive to more rapid diffusion of the innovation than the other innovations (Rogers, 2003).

During this early phase of the diffusion among the farmers, the practice was improved for higher efficiency and acquired the name: *Yukiwari*. The adoption was, however, limited to the progressive farmers because of the uncertainty of the soil frost depth attained by the practice. The agronomist at the extension center of the region played the critical role to present this issue of *Yukiwari* to T. Hirota at HARC, where the farmers' practice was turned into the control technology as noted earlier.

Hirota and Kobayashi (2019) listed the following features of the SFC technology as the major contributors to its wide adoption by the farmers in Tokachi:

1. As a farmer-originated innovation that was initially diffused among farmers, it had traits that are conducive to the rapid and sustained adoption by farmers,
2. SFC had technical advantages over other options like herbicide spray in suppressing VP for its high efficacy and low cost, and
3. The problem of farmers' practices dependent on their experiences and intuition was solved by turning it into a control technology based on scientific understanding.

The farmers' contribution to the development of SFC is evident in the features 1 and 2, whereas the feature 3 owes to the scientists' expertise. The extension staff at TAEC contributed to the development of SFC by offering the link between the two groups of people: scientists and farmers, that are seldom connected directly with each other. The extension staff was well connected with the scientists as a member of the Hokkaido Branch of the Society of Agricultural Meteorology of Japan (Hirota and Kobayashi, 2019).

The agricultural institutions also contributed to both development and dissemination of the technology. The federation of agricultural cooperatives of the region (TFAC) contributed to the development of SFC far beyond the support for the scientists to collect the climatic records and make observation in farmers' fields. When T. Hirota was connected to TFAC, he was urged to elaborate the farmers' practice of *Yukiwari* with scientific expertise (Hirota and Kobayashi, 2019). TFAC also proposed the scientists at HARC to develop a decision-making system based on SFC for farmers. The implementation of SFC to the web-based information system that had been run by TFAC greatly facilitated the wide adoption of SFC technology by the farmers. Without the existing information system at TFAC, development of the decision-support system on SFC would have cost much more.

It must be noted that the web-based system was not the only means of dissemination of SFC to the farmers. TFAC conducted the demonstration of SFC in districts where it had been little adopted. It made the SFC more observable and triable for the farmers around the demonstration sites. Dissemination of SFC was also facilitated by the collaborations on its development with the experiment station (TAES) and the extension center (TAEC). The farmers involved in the field evaluation of SFC by TAEC later served as a change agent, who disseminated SFC technology among the neighboring farmers. Experiences of the field evaluation and accumulation of scientific understandings among the TAES staffs facilitated the compilation of technical manual and guidelines for SFC applications. These documents greatly facilitated the technology transfer of SFC to Okhotsk region as follows.

Transfer and further development of SFC technology in the Okhotsk region

The successful diffusion of SFC technology among farmers in Tokachi was followed by its transfer to Okhotsk region, another major producer of upland crops, which took place in 2012. In the technology transfer from Tokachi to Okhotsk, the extension centers in both regions played the major role. Within the provincial government of Hokkaido, the extension centers in different regions are well connected with each other. The manuals and other documents were transferred from Tokachi to Okhotsk, and also there were transfer of the extension staffs between the regions. After the technology transfer to control VP, the technology was transformed in adaption to the local environment and agricultural production in Okhotsk.

Snow compaction (*Yukifumi* in Japanese) (Figure 3) rather than snowplowing (*Yukiwari*) was adopted more widely in Okhotsk. They preferred *Yukifumi* to *Yukiwari* for reasons like ease of adoption because of the low costs. For example, used tires could be adapted to snow compaction (Figure 3). The shallower snow depth than Tokachi allowed the farmers in Okhotsk to apply *Yukihumi* widely. Farmers in this region played the major roles in the improvements of *Yukifumi* in adaptation to the local conditions.

Figure 3. Snow compaction, or Yukifumi in Japanese, practiced at a field in Okhotsk, Hokkaido, Japan.

With the soil frost, the farmers found that the soil became more porous and the tillage became much easier and quicker. Local agronomists at the extension center and the agricultural cooperative of the region found that crop growth was improved by the soil frost in 2013. Scientists at the prefectural experiment station confirmed these beneficial effects of soil frost in the field experiments with onion conducted from 2015 to 2017 (Onodera *et al*., 2022). With SFC in the field, more nitrogen was retained in soil, which increased the crop growth and yield while reducing nitrogen leached to the ground water. Target of SFC thus extended from VP to soil tilth and crop yield in a very short period. Finding of the beneficial effects on crops took place only one year after the introduction of SFC for VP managements in 2012, which suggests the diffusion of SFC to this region before the technology transfer via the regional extension centers. The rapid development of SFC for the new targets was facilitated by the communication among the farmers, local agronomists, and scientists at prefectural experiment station as well as at HARC.

Since Okhotsk is Japan's largest producing region of onion, the novel use of SFC for higher yield of the crop prompted its adoption by more farmers than potato growers and expanded the area of the technology application. Farmers can now have access to SFC on the climatic information system of the agricultural cooperative in this region. Like in Tokachi, the implementation of SFC to the decision-support system on the web greatly contributed to the wide adoption of the technology among the farmers in this region. The area of SFC in the Okhotsk region has reached more than 3,600 ha at present as estimated by the agricultural cooperative.

CONCLUSION

In both Tokachi and Okhotsk regions, the wide adoption of the SFC technology by farmers was attributed to the involvement of farmers and local agronomists on the interpersonal networks at the initial stages of the technology development prior to its dissemination to farmers by agronomic institutions such as agricultural cooperatives and extension services. Inclusion of the local actors in technology development and communications should be critical for the adaptation of agriculture to changing climate as a series of the diffusion of innovations.

REFERENCES

Hirota T, Pomeroy JW, Granger RJ, Maule CP (2002). An extension of the force-restore method to estimating soil temperature at depth and evaluation for frozen soils under snow. *J Geophys Res* 107, D24, ACL 11-1 to 10, (4767, 10. 1029/2001JD001280).

Hirota T, Iwata Y, Hamasaki T, Sameshima R, Hayashi M (2005). Micrometeorological conditions and the thermal and moisture characteristics of seasonally frozen soil in Eastern Hokkaido: New comprehensive hydrometeorological observation system for atmosphere-snow-frozen soil interaction. *J Agric Meteorol* 60: 673–676.

Hirota T, Iwata Y, Hayashi M, Suzuki S, Hamasaki T, Sameshima R, Takayabu I (2006). Decreasing soil-frost depth and its relation to climate change in Tokachi, Hokkaido, Japan. *J Meteorol Soc Jpn* 84:821−833.

Hirota T, Usuki K, Hayashi M, Nemoto M, Iwata Y, Yanai Y, Yazaki T, Inoue S (2011). Soil frost control: Agricultural adaptation to climate variability in a cold region of Japan. Mitig Adapt Strateg Glob Change 16: 791–802. DOI 10.1007/s11027-011-9296-8.

Hirota T, Kobayashi K (2019). The Roles of farmers, scientists, and extension staff in technology development for soil frost control as an adaptation to climate change in Tokachi, Hokkaido, Japan. In *Adaptation to Climate Change in Agriculture: Research and Practices*. Eds. T. Iizumi, R. Hirata, and R. Matsuda, pp. 211-228. Springer Nature Singapore, Singapore.

Hiorta T, Nakatsuji T, Kominami Y (2021). *Advancements of Agricultural Meteorology in Hokkaido*, 222 pages. Dairyman, Sapporo (in Japanese).

Maezuka K (2008). The volunteer potatoes problems and its managements by snow removal. *J Agric Meteorol Hokkaido* 60: 39−44 (in Japanese).

Onodera M, Nakatsuji T, Hirota T (2022). Controlling soil frost depth in winter soil to improve physical soil properties, suppress nitrogen leaching, and improve onion field productivity in cold regions. *Jpn J Soil Sci Plant Nutr*, 93: 121–130 (in Japanese with English abstract).

Rahman A (1980). Biology and control of volunteer potatoes—a review. *NZ J Exp Agric*, 8: 313-319.

Rogers EM (2003). *Diffusion of Innovations*, 5th ed, 551 pages. Free Press, New York.

The Science Council of Japan (2023). Role of Agro-Environmental Engineering for Agricultural Adaptation and Stable Food Supply under Climate Change in Japan. https://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-25-k230926-15.pdf (in Japanese)

Yazaki T, Hirota T, Iwata Y, Inoue S, Usuki K, Suzuki T, Shirahata M, Iwasaki A, Kajiyama T, Araki K, Takamiya Y, Maezuka K (2013). Effective killing of volunteer potato (*Solanum tuberosum L.*) tubers by soil frost control using agrometeorological information: An adaptive countermeasure to climate change in a cold region. *Agric For Meteorol*, 182–183: 91–100.

ACKNOWLEDGEMENTS

We appreciate the cooperation of the farmers in Tokachi, particularly Mr. Y. Yoshida, Mr. K. Bitou, Mr. M. Kaji, and Mr. H. Fujimori as well as the farmers in Okhotsk, particularly Mr. R. Mizutome, Mr. T. Saito and Mr. T. Sakamoto. Our appreciation also goes to Mr. M. Shirahata (formerly at Tokachi Agricultural Extension Center), Mr. M. Suzuki, Mr. K Araki, Dr. N. Miki, Dr. T. Nakatsuji and Mr. M. Onodera of the Hokkaido Research Organization, Mr. K. Maezuka, Mr. T. Kaji, Mr. A. Sawasaki, and Mr. T. Taraba of Tokachi, Federation of Agricultural Cooperatives, Mr. T. Shoji and Mr. S. Hatakeyama of Kitamirai Agricultural Cooperatives for their cooperation. This research was supported by the Project of the NARO Bio-oriented Technology Research Advancement Institution(research program on development of innovative technology [29017C]) and J.S.P.S. KAKENHI Grant Numbers JP 19H00963).

AUTHORS' CONTRIBUTIONS

Tomoyoshi Hirota: Conceptualization, Investigation, Methodology, Writing - Original Draft. Kazuhiko Kobayashi, Conceptualization, Writing – review & editing.

COMPETING INTERESTS

The authors declare no competing financial interests.