SEED SOURCE EFFECTS ON GERMINATION, GROWTH, AND YIELD OF CARROTS UNDER NATURAL FARMING

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ABSTRACT

Natural farming is a type of low-input sustainable agricultural system that is characterized by the avoidance of the use of any animal materials. Production of self-produced seeds by farmers is recommended under natural farming environments, with an expectation of improved crop growth and yield. However, there have been no scientific studies that investigated the performance of self-produced seeds under natural farming. This study investigated the germination rate, growth, and yield of carrots (*Daucus carota* L.) from different seed sources under natural farming. The main experimental factor was the cultivation method: CT – control; CF – conventional farming; NF1 – natural farming with tillage and compost input; and NF2 – natural farming without tillage and compost, and the subfactor was the seed source: OPN – open-pollinated seeds self-produced under natural farming; OPC – open-pollinated seeds produced under conventional farming; and HB – hybrid seeds. The germination rate of OPN seeds was higher than that of other seeds. In addition, root fresh weight and other root parameters of OPN were as high as for HB seeds. This suggests that using self-produced seeds by farmers improves crop performance in a natural farming system.

Key words: epigenetic variation, maternal environment effect, natural farming, no-tillage system, seed germination

INTRODUCTION

Natural farming (“Shizen-noho” or “Shizen-no” in Japanese) is a type of organic farming that is widely perceived in Japan to be a method of sustainable cultivation. Since the development of theories and methodologies in the 1930–1940s, natural farming has spread not only in Japan but also throughout the world (Fukuoka 2004; Sawanobori & Komatsuzaki 2019). The most distinguishing feature of natural farming from organic farming is that it does not use any materials derived from animals, including manure (Sawanobori & Komatsuzaki 2019). Some of the natural farming groups do not even till or weed to avoid disturbing the soil surface. These methods often result in lower yields; the amount of soil nutrients readily available to plants is generally lower than other farming methods, and weeds compete with crop growth. Despite the disadvantage of low yield, natural farming continues to attract many people (Kawaguchi et al. 2014; Mitra et al. 2017).

This is because natural farming is considered to be more compatible with nature and more sustainable than organic farming (Fukuda 2018).

Since no survey has been conducted on the current status of natural farming, it is not possible to provide figures on the area under natural farming cultivation or the number of natural farming practitioners. However, the following data provided by Japan’s Ministry of Agriculture, Forestry, and Fisheries (MAFF 2017) may help in understanding the current state of agriculture in Japan. The number of agricultural management entities was approximately 1.38 million in 2015, of which 1.34 million were family-owned entities, accounting for 98% of the total agricultural management entities. Of these agricultural management entities, 52.8% operate less than 1 ha and 91.2% less than 5 ha (Fukasawa 2020). The area of Japanese Agricultural Standard – JAS-certified organic farming – was only 0.5% of the total agricultural land in Japan in 2017 (Sawanobori & Komatsuzaki 2019).

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Due to the high cost of obtaining JAS organic certification, in fact, the percentage of farmland without JAS certification has increased by about 19% from 2009 to 2017 (MAFF 2019), and the number of organic farmers without JAS certification is about double that of certified organic farmers (Sawanobori & Komatsuzaki 2019).

For a long time, Japan relied on imports of chemical fertilizers, agricultural chemicals, and even organic fertilizers. These materials can be used at a low cost in the short term, but in the long run, there is a risk of increased costs, both economically and environmentally. Researching and practicing natural farming methods from a long-term perspective will be effective as one way to guarantee sustainable production of agricultural products in the future. In natural farming, many changes observed are long-term, occurring slowly over time (Takahashi 2010). Production of on-farm seeds adapting to a natural farming environment across generations has been positioned as one of the important technologies in natural farming (Sawanobori & Komatsuzaki 2019). Phenotypic plasticity through epigenetic mechanisms may be an important contributor to the adaptation of plant species to different environments (Bräutigam et al. 2013; Balao et al. 2018). Studies have indicated that the ancestral environmental conditions of plants can influence the progeny phenotype through epigenetic mechanisms (Boyko & Kovalchuk 2008). Therefore, producing self-produced seeds across generations may potentially promote seed germination, growth, and yield of vegetables under natural farming conditions.

Although hybrid seeds often have higher yields compared to open-pollinated seeds (Kutka 2011), they can perform well only under high-input agricultural management (Macharia et al. 2010; Omondi et al. 2014). Conversely, open-pollinated seeds can be produced by farmers. This means that self-produced seeds adapted to local soil conditions can potentially result in higher crop yields compared to hybrid seeds. However, to the best of the authors' knowledge, there have been no scientific studies that investigated and compared the performance of self-produced seeds under natural farming to other types of seeds. This paper reports the findings of a field experiment investigating the crop performance from different seed sources under natural farming conditions.

A root vegetable was selected because the root-to-shoot (R : S) ratio has been shown to be altered by the nutritional conditions of the maternal plant (Verhoeven & van Gurp 2012). Open-pollinated seeds of carrots (*Daucus carota* L.) produced on the farm under natural farming were compared with seeds of the same cultivar produced under conventional farming and with seeds of a hybrid cultivar used commonly in conventional farming. The germination rate, growth, and yield of carrots from each type of seed were studied under four different cultivation methods, including two different natural farming methods.

MATERIALS AND METHODS

Experimental site

The field experiment took place at the Institute for Agriculture, Medicine, and the Environment, Izunokuni, Shizuoka, Japan (139°1' E, 35°3' N) during the growing seasons of 2017 and 2018. The field had been left fallow for 3 years before the experiment. The soil of the field was Light Colored Andosol (Tabuchi et al. 2008), and the soil properties of the experimental site at the beginning of the experiment are shown in Table 1. The daily temperature and precipitation values at the field site during the growing seasons are shown in Figure 1.

Experimental design

The experimental design was a split-plot, with cultivation methods assigned to the main plots and seed sources assigned to subplots. The experiment had three replications. The cultivation methods were: CT – control; CF – conventional farming; NF1 – natural farming with tillage and compost input; and NF2 – natural farming without tillage and compost. The seed sources were OPN – open-pollinated seeds produced under natural farming; OPC – open-pollinated seeds produced by a seed company under conventional farming; and HB – hybrid seed produced under conventional farming and obtained from a seed company. The main plot measured 4 m × 5 m, within which three subplot ridges, 1 m wide and 3 m long, were formed.

CT plots were given tillage without any fertilization. The CF plots were tilled, and chemical fertilizer was applied (Table 2). The NF1 method was adapted from a method used by the Natural Farming Academy of the Mokichi Okada Association; it comprised tillage and application of plant material compost. Considering the mineralization rate of nitrogen

(11% of the total nitrogen applied), we applied grass compost with concentrations of N, P₂O₅, and K₂O of $2.50\% \pm 0.70$, $2.82\% \pm 0.14$, and $4.94\% \pm 0.27$ (mean $\pm$ SD), respectively. The NF2 method was adapted from a method used by Akame Natural Farming School (Akame Shizennō Juku), Sakurai, Nara, Japan (Fukuda 2018); it was a no-tillage system, without application of compost, and weeds were cut at the soil surface and spread as mulch.

The open-pollinated seed cultivar for the 2017 autumn cultivation was ‘Kuroda-gosun’, but the cultivar for the 2018 spring and autumn cultivations was changed to ‘Chikumano-gosun’ due to

the unavailability of seeds for 2018. Both OPN seeds were obtained from the same institute where the experiment was carried out. ‘Kuroda-gosun’ had been self-produced for more than 10 generations under natural farming conditions, and ‘Chikumano-gosun’ had been self-produced for two generations. The OPC seeds of ‘Kuroda-gosun’ were purchased from the Noguchi Seed Co. (Saitama, Japan), and the OPC seeds of ‘Chikumano-gosun’ were purchased from the International Nature Farming Research Center (Nagano, Japan). The hybrid seed cultivar was ‘Kouyounigou’, and it was purchased from Takii & Co. (Kyoto, Japan) (Table 3).

Fig. 1. Daily temperature and precipitation during the three growing seasons (data from the Institute for Agriculture, Medicine, and the Environment)

Table 1. Soil properties of the field

pH	Electric conductivity (mS·cm ⁻¹)	Cation exchange capacity (cmolc·kg ⁻¹)	Total C (%)	Total N (%)	C/N	Phosphate absorption coefficient (g·kg ⁻¹)	Available phosphate (mg·kg ⁻¹)	Exchangeable cations (g·kg ⁻¹)		
								K ₂ O	CaO	MgO
6.22	0.032	27.0	2.78	0.34	8.1	20.7	6.6	0.77	1.33	0.40

Table 2. Fertilizer input under CF treatment

Type of fertilizer	Application date			Components (kg·ha ⁻¹)		
	2017	2018	2018	N	P ₂ O ₅	K ₂ O
Compound fertilizer (CDU555)	July 11	Feb. 28	July 11	40	40	40
Magnesium multi-phosphate (Kudo-Jyusho-Rin)	July 11	Feb. 28	July 11	0	40	0
Compound fertilizer (NH-Kasei-2)	Sept. 8	May 10	Sept. 12	40	0	40

Table 3. Names of the cultivar and seed supply

Year	2017 autumn		2018 spring and autumn		
Seed source	Cultivar	Seed supply	Cultivar	Seed supply	
HB	‘Kouyounigou’	Takii & Co.	‘Kouyounigou’	Takii & Co.	
OPC	‘Kuroda-gosun’	Noguchi Seed Co.	‘Chikumano-gosun’	International Nature Farming Research Center	
OPN	‘Kuroda-gosun’	Institute for Agriculture, Medicine, and the Environment	‘Chikumano-gosun’	Institute for Agriculture, Medicine, and the Environment	

Carrot cultivation

The soil was tilled to a depth of 0.15 m before sowing carrot seed in the CT, CF, and NF1 plots. In the NF2 plots, the soil was left undisturbed, apart from scraping the soil surface to remove weeds before sowing. The seeds were sown manually, using a dibbling method, in two lines per ridge with 0.6 m between rows. Six seeds were sown per hill at 6-cm intervals. In autumn 2017, under NF2, seeds were strip seeded in two lines per ridge, with an interval of approximately 5 mm between seeds. The number of seeds sown under NF2 in autumn 2017 was estimated using the weight of the seed sown and the average weight of OPC. After thinning, the plant density was 36 plants per m². Sowing, thinning, and data collection were carried out on the same dates for all treatments (Table 4). No pesticides or herbicides were applied during the experiment. Weeds were removed manually in CT, CF, and NF1 and were left as mulch in NF2.

Sampling procedure

Germination was monitored after sowing, and the germinated seedlings were counted when approximately half of the seeds had germinated in a plot; this was at 21, 10, and 7 days after sowing in autumn 2017, spring 2018, and autumn 2018, respectively. Leaf length was monitored as an index of plant growth. The longest leaf of each plant was measured on 36 plants per plot three times at 2-week intervals. Final sampling was performed using the same 36 plants per plot. The carrots were harvested and separated into leaf and root components. Measurements noted were root weight, root length, maximum root diameter, and leaf weight, and the number of leaves was also recorded. The R : S ratio was also calculated from the root and shoot fresh weights.

Statistical analysis

Analysis of variance (ANOVA) was performed on all the data using R (Microsoft R Open 4.0.2 for Windows from Microsoft Corporation) with a split-plot function of the “agricolae” package (version 1.3-3). Logit transformation was performed for the germination data, and log transformation was performed for other data when required to ensure normal distribution. When significant differences were found among treatments, multiple comparisons were performed using the Bonferroni method.

RESULTS

Germination rate

In autumn 2017, the effects of cultivation method and seed source on the germination rate and their interaction were determined (Table 5). The interaction effect indicated that the effect of seed was not consistent across the four cultivation methods. The germination rate for OPN was higher than the rates for HB and OPC only under NF2, while no such trend was observed under CT, CF, and NF1 (Table 6). In spring and autumn 2018, only a seed source effect was detected (Table 5). The germination rate for OPN was higher than the rates for OPC and HB in spring 2018, and the rates for OPN and OPC were higher than that for HB in autumn 2018.

Leaf length

The leaf length, which was measured as an index of plant growth, differed significantly among the cultivation methods throughout the growing season but not among the seed sources in autumn 2017 (Table 7). In general, the leaves were significantly longer for CF and NF1 than the ones under NF2. In spring and autumn 2018, in addition to the effect of cultivation methods, an effect of seed source was detected. In the final growth survey, the leaves of plants from OPN and OPC seeds were significantly longer than that for HB seeds in spring 2018, and the leaf length for plants from OPC seeds was significantly more than that for plants from HB seeds in autumn 2018.

Yield parameters

Among the parameters measured at harvest, seed source effect was determined for root fresh weight, root length, and root maximum diameter in autumn 2017 (Table 8). These values were higher for HB seeds than OPC seeds, while no significant difference was found between HB and OPN seeds. On the other hand, in autumn 2018, the root maximum diameter of OPN was lower than that of HB. Except for these trends, all parameters reflected the trend found for plant leaf length during the growth period (Tables 8 and 9). There were significant differences in R : S among the cultivation methods in spring 2018 and among the seed sources in both spring and autumn 2018 (Table 9). When comparing this ratio among the cultivation methods, the values under CF and NF1 were higher than those under NF2 in spring 2018. Among the seed sources, the values for OPN and OPC seeds were lower than those for HB seeds in both spring and autumn 2018.

Table 4. Cultivation and sampling schedule

	2017 autumn	2018 spring	2018 autumn
Sowing date	July 26–27	Mar. 16–17	July 20–21
Germination survey date	Aug. 16	Mar. 27	July 27
Thinning date	1st Sept. 1	1st Apr. 30	1st Aug. 28
	2nd Sept. 27	2nd May 10	2nd Sept. 23
	3rd Oct. 10	3rd May 25	3rd Oct. 6
Growth survey date	1st Sept. 29	1st May 29	1st Sept. 23
	2nd Oct. 13	2nd June 11	2nd Oct. 7
	3rd Oct. 27	3rd June 25	3rd Oct. 21
Yield survey date	Nov. 8–10	June 28–30	Nov. 2–4

Table 5. Effects of cultivation methods and seed sources on germination rate (%)

Treatment	2017 autumn	2017 spring	2018 autumn
Method (M)			
CT	42.65 ± 14.47a	14.30 ± 12.39a	29.20 ± 20.68a
CF	36.59 ± 12.69a	20.85 ± 22.61a	44.76 ± 32.21a
NF1	34.09 ± 8.09a	20.59 ± 20.46a	32.61 ± 26.93a
NF2	3.37 ± 5.18b	11.65 ± 13.14a	27.40 ± 19.41a
Significance	***	ns	ns
Seed source (S)			
HB	29.97 ± 23.37b	0.38 ± 0.36c	3.97 ± 4.83b
OPC	26.17 ± 17.73b	15.55 ± 8.36b	44.06 ± 15.80a
OPN	31.39 ± 14.78a	34.62 ± 15.91a	52.45 ± 16.72a
Significance	***	***	***
M × S interactions	***	ns	ns

The values are the average ± standard deviation. Means followed by the same letter do not differ significantly according to Bonferroni procedure at $p = 0.05$. ns – not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

CT – control; CF – chemical fertilizer; NF1 – natural farming with tillage and compost input; NF2 – natural farming without tillage and compost

Table 6. Effects of cultivation methods and seed sources on germination rate (%) in autumn 2017

	Method (M)			
	CT	CF	NF1	NF2
Seed source (S)				
HB	48.78 ± 22.84a	39.11 ± 20.51a	30.94 ± 12.13a	1.05 ± 1.55b
OPC	37.72 ± 14.52a	34.44 ± 11.72a	32.39 ± 0.98a	0.11 ± 0.09b
OPN	41.44 ± 3.26a	36.22 ± 8.32a	38.94 ± 7.71a	8.94 ± 5.86a

Note: See Table 5

Table 7. Effects of cultivation methods and seed sources on leaf length during the growth period

Treatment	2017 autumn			2018 spring			2018 autumn		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Method (M)									
CT	19.38±6.95ab	22.77±8.69ab	22.61±9.80a	7.84±2.91b	11.60±5.19b	19.94±7.92bc	21.13±4.71ab	22.98±6.04ab	23.50±6.76ab
CF	23.85±6.74a	29.65±8.33a	30.45±8.98a	20.92±4.55a	31.98±6.00a	44.71±6.24a	33.61±6.53a	38.07±6.74a	39.03±6.19a
NF1	27.90±5.44a	33.98±5.46a	34.76±6.05a	16.64±4.18a	26.50±6.60a	37.15±6.61ab	30.63±3.12a	34.26±3.76ab	34.98±3.45ab
NF2	7.66±3.93b	8.64±4.17b	9.53±4.67a	6.17±1.67b	8.11±3.11b	12.97±6.00c	15.72±4.28b	17.77±5.17b	17.67±5.77b
Signifi- cance	**	**	*	**	***	**	**	*	*
Seed source (S)									
HB	21.35±7.11a	25.20±9.03a	24.91±9.75a	11.92±5.53a	17.76±8.74a	25.50±11.40b	24.44±7.82a	26.94±8.74a	27.05±9.26b
OPC	19.55±10.16a	24.25±12.90a	24.61±13.97a	13.34±7.92a	20.70±13.05a	30.42±16.43a	27.09±9.58a	30.26±11.17a	30.75±11.65a
OPN	20.32±10.80a	24.52±12.98a	27.53±12.05a	13.42±7.95a	20.18±12.53a	30.16±15.77a	24.28±8.84a	27.62±10.12a	28.58±10.31ab
Signifi- cance	ns	ns	ns	ns	ns	*	ns	ns	*
M × S interactions	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: See Table 5

Table 8. Effects of cultivation methods and seed sources on belowground parameters including root fresh weight, root length, and root maximum diameter

Treatment	Root fresh weight (g per plant)			Root length (cm)			Root maximum diameter (mm)		
	2017 autumn	2018 spring	2018 autumn	2017 autumn	2018 spring	2018 autumn	2017 autumn	2018 spring	2018 autumn
Method (M)									
CT	46.67±35.70a	9.20±8.47b	38.07±21.61ab	10.06±2.82a	7.40±2.90ab	10.21±2.84a	25.77±10.28a	13.40±5.36b	24.31±6.90a
CF	72.11±38.02a	61.63±19.13a	97.05±30.99a	11.98±2.46a	13.32±2.44a	13.46±1.28a	32.20±9.58a	33.13±5.13a	37.02±5.70a
NF1	90.43±26.80a	39.80±13.54a	81.10±20.79a	12.14±1.63a	10.96±1.78a	12.18±1.39a	37.57±5.88a	27.63±4.60a	35.75±3.74a
NF2	6.42±7.07a	1.82±2.12b	18.60±18.94b	4.77±2.12a	3.49±2.03b	7.27±2.22a	11.76±5.55a	6.78±3.76b	17.64±8.95a
Signifi- cance	*	***	**	*	**	*	*	***	*
Seed source (S)									
HB	70.57±44.51a	27.65±25.20a	66.95±42.79a	10.88±3.69a	9.63±4.93a	11.15±3.04a	32.28±11.82a	20.66±11.51a	31.79±10.57a
OPC	46.62±43.12b	29.74±31.29a	59.82±41.22a	9.21±3.59b	8.41±4.30a	10.75±3.49a	24.10±12.52b	20.40±12.38a	28.03±10.86ab
OPN	57.49±38.16ab	26.94±26.93a	49.35±34.50a	10.48±3.38ab	8.34±4.13a	10.45±2.87a	28.21±11.34ab	19.66±12.11a	26.22±9.62b
Signifi- cance	**	ns	ns	*	ns	ns	**	ns	**
M × S interactions	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: See Table 5

Table 9. Effects of cultivation methods and seed sources on aboveground parameters including leaf fresh weight, leaf count, and R : S

Treatment	Leaf fresh weight (g per plant)			Leaf count			R : S ratio (g·g ⁻¹)		
	2017 autumn	2018 spring	2018 autumn	2017 autumn	2018 spring	2018 autumn	2017 autumn	2018 spring	2018 autumn
Method (M)									
CT	-	7.48±5.42bc	10.10±6.81a	7.31±1.21a	6.70±1.44bc	5.24±1.37a	-	1.12±0.60ab	4.18±1.86a
CF	-	48.60±22.60a	28.83±12.41a	7.92±0.84a	9.43±1.20a	6.48±0.94a	-	1.43±0.61a	3.72±1.67a
NF1	-	27.02±12.22ab	21.11±9.68a	7.98±0.54a	8.29±1.12ab	6.02±1.04a	-	1.59±0.50a	4.38±1.88a
NF2	-	2.45±2.53c	5.64±4.12a	5.66±1.18a	5.00±0.92c	5.35±0.67a	-	0.61±0.32b	2.79±1.57a
Significance	-	**	*	ns	**	ns	-	**	ns
Seed source (S)									
HB	-	12.84±10.94b	10.97±6.84b	7.03±1.20a	6.69±1.57b	5.02±0.70b	-	1.74±0.69a	5.78±1.58a
OPC	-	25.79±27.56a	20.44±15.40a	7.26±1.38a	7.29±2.31ab	6.09±1.27a	-	0.96±0.36b	2.84±0.74b
OPN	-	25.54±24.31a	17.85±12.72a	7.80±1.16a	8.08±2.08a	6.21±0.95a	-	0.86±0.36b	2.69±0.69b
Significance	-	**	**	ns	**	**	-	***	***
M × S interactions	-	ns	ns	ns	ns	ns	-	ns	ns

Note: See Table 5

- no data; R : S – root-to-shoot ratio

DISCUSSION

Self-produced seeds showed positive effects under natural farming conditions in improving crop performance compared to other seeds. In autumn 2017, the germination rate of OPN seeds was higher than that of other seeds under the NF2 regime. NF2 did not involve tillage, so the soil temperature was likely lower than that with other methods using tillage. The temperature of the soil, when covered with grass mulch without plowing, can be up to 5 °C lower than that under conventional farming (Jelonkiewicz & Borowy 2009). As OPN was self-produced under the natural farming system method, the supply of nutrients in the maternal environment was generally low. Luzuriaga et al. (2006) showed that when the maternal environment was nutrient-rich, the germination rate was slow. Although further tests are required to verify our findings, nutrient conditions may have affected the seed germination rate, making the OPN seeds germinate well even at lower temperatures.

The higher germination of OPN compared to HB and OPC seeds in spring 2018 was also in line with this phenomenon. The average temperature during the germination period in spring 2018 was 8.5 °C, which was below the optimum temperature (15–25 °C) for carrot germination (Corbineau et al. 1994; Rubatzky et al. 1999). The higher germination rate at low temperatures may result in a longer growth period, which is often necessary to obtain sufficient yield under natural farming (Takahashi 2010).

Similar to the results of germination rate, the results for root fresh weight also indicated the potential superiority of self-produced seeds. In autumn 2017, root fresh weight and other root parameters of OPC were significantly lower than for HB seeds, as expected, since hybrid seeds generally have higher yield than open-pollinated seeds due to heterosis (Golmirzaie et al. 1998). On the other hand, the root parameters for OPN were as high as for HB seeds, suggesting that the self-produced seeds may enable farmers to obtain open-pollinated seeds that have

a yield potential similar to that of hybrid seeds. However, in spring and autumn 2018, no such differences were found, and the values for OPN were actually the lowest among the three seed sources. This discrepancy among different cultivation seasons could be due to the difference in years invested in seed self-production. The seed type used for OPN in autumn 2017 was ‘Kuroda-gosun’, which had been self-produced for more than 10 generations. On the other hand, the seed type used in spring and autumn 2018 was ‘Chikumano-gosun’, which had been self-produced for only two generations. The possibility of different genotype responses to natural growing conditions should also be taken into account. In contrast to the previous study that showed changes in the R : S ratio with the maternal nutrient conditions (Verhoeven & van Gurp 2012), no R : S differences between OPN and OPC seeds were detected, and the only difference detected was between HB seeds and others. Since the difference in R : S ratio among the contrasting cultivars is similar across the environmental gradient (Xu et al. 2018), the difference between cultivars in our study may have masked any responses to the maternal environment for R : S in open-pollinated seeds. It was difficult to detect the difference between means on seed sources compared to cultivation methods because the alpha levels are adjusted for the multiple comparisons. Furthermore, the R : S ratio under NF2 was lower than that under CT and NF1 in this study, probably due to the increased soil strength under no-tillage, which in turn inhibits root growth (Howeler et al. 1993).

Compared to other cultivation methods, the yield of NF2 was much lower. This is not surprising, considering that this is only the result of the first or second year. One of the well-known leaders of this farming method stated that it took 10 years to get a reasonable yield because it takes time for the soil to become suitable (Kawaguchi & Tsuji 2011). In Japan, the main soils, called andosols, can fix large amounts of organic matter (Sawanobori & Komatsuzaki 2019). In the field experiments conducted in Japanese soils, soil organic carbon has been shown to increase when cover crop residues and weed residues are combined with no-till systems (Arai et al. 2014; Higashi et al. 2014).

A meta-analysis of the relationship between soil carbon and crop yield has shown that crop yield increases with increasing carbon concentration (Oldfield et al. 2019). In addition to increasing carbon concentration, no-till systems also contribute to the diversity of soil microbiology and animal communities (Komatsuzaki & Ohta 2007; Kaneko et al. 2018; Sawanobori & Komatsuzaki 2019). Filser et al. (2016) found that soil microbiological and animal activity has direct and indirect effects on carbon sequestration and nutrient supply. No-till cultivation represented relatively lower yields in the first 1–2 years, but after 4–5 years the yields were comparable, and after 6 years the yields were higher in no-till cultivation (Pittelkow et al. 2015). Hence, it is expected that in NF2, crop yields will gradually increase with increasing carbon concentration over time, although yields will decrease initially.

Natural farming is not an established field of research, but it is the one that should be expanded in the future. In fact, to the best of our knowledge, there are no previous studies similar to the present study at this time. A long-term trial with NF2 may reveal the effects of seed self-production.

CONCLUSION

In this study, the germination rate of self-produced seeds was higher than that of other seeds. In addition, the root fresh weight and other root parameters of self-produced seeds for more than 10 generations were as high as for hybrid seeds. This suggests that using self-produced seeds by farmers improves crop performance in a natural farming system. Our research results also provided the implication that not only does soil preparation take years, but also seed self-cultivation may be effective only after years of repeated practice. It is necessary to develop technology to shorten the time it takes to secure the yield in a natural farming system.

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