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Comparison of Soil Nutrition, Tree Performance, and Insect and Disease Occurrence between Organic and Conventional Asian Pear Orchards

HYUN-SUG CHOI[1], KYEONG-HO LIM[2], MENGMENG GU[3], WOL-SOO KIM[4], DO-IK KIM[5], KYEONG-JU CHOI[5] AND HAN-CHAN LEE[2]

Abstract

A conventional and an organic orchard each with 12-year-old 'Niitaka' pear (*Pyrus pyriforia* Nakai) trees were compared in terms of soil nutrition, tree performance, and insect and disease occurrence in the warm, humid environment of South Korea from 2008 to 2010. The organic orchard management system had higher weed species diversity compared to that of the conventional system. The conventional orchard had higher soil pH, organic matter, [T-N], [P_2O_5], [K_2O], [MgO], and CEC than the organic orchard on average over the three years but this did not result in higher foliar [T-N], [P], and [Ca]. Overall fruit shape index, soluble solids concentration, and color were similar under both management systems, but individual fruit size and fruit yield were both higher and fruit firmness was lower in the conventional orchard. Fruit from the organic trees were more damaged by diseases and insects. Estimated fruit production income was not significantly different between the two management systems in the first two years, but income was 69% higher for the conventional system in year 3 than for the organic system as a consequence of yield loss from severe pest problems due to an extended period of precipitation in that summer production season.

Demand for organic fruit has increased in developed countries during recent decades due to perceived health benefits, taste, food safety, environmental concerns, and government regulations relating to the use of pesticides (14). Asian pear (*Pyrus pyriforia* Nakai), which is grown mainly for fresh consumption, ranks second amongst fruit species in terms of production volume and cultivated area in South Korea (11). Although the price of organic pears has been two or three times higher than that of conventional fruit, organic pear production in South Korea is relatively low due to high insect and disease pressures in the warm and humid weather conditions in production areas, and because of the limited scientific information that is available on organic production. Regionally-specific research is needed, therefore, to help increase organic pear production to meet consumer demand.

Most eco-agricultural pear research in South Korea has been conducted for only a short period of time (one or two years). Compost treated-pear trees have been shown to have increased soluble sugar concentration, increased phenolic compounds, and reduced titratable acidity in fruit, which advanced fruit harvesting dates compared to chemically fertilized trees (2, 8, 12, 13). However, application of chitin-decomposable agents and Bordeaux mixture in an organic pear orchard did not reduce scab (*Venturia nashicola* Tanaka et Yamamoto) occurrence in leaves or improve fruit quality compared to conventional pear orchard management (5). Weather conditions which vary from year to year may cause different results in conventional and particularly in organic orchards.

[1] Organic Agriculture Division, National Academy of Agricultural Science, Suwon, Gyeonggi-do 441-707, Repulic of Korea
[2] Pear Research Station, National Institute of Horticultural & Herbal Science, Naju, 520-821, Republic of Korea
[3] Texas AgriLife Extension Service, Department of Horticultural Sciences, Texas A&M University, College Station, TX 77843, USA
[4] Department of Horticulture, Chonnam National University, Gwangju, 500-757, Republic of Korea
[5] Jeonnam Agricultural Research & Extension Services, Naju, 520-715, Republic of Korea
[2] To whom requests should be addressed. Email address: koholim@korea.kr

Most research for organic fruit nutrition or orchard floor management systems has been conducted in arid production areas (1, 17, 19, 21, 23, 24) or in the cooler northeastern US (16) and little in the warm and humid southern US (3, 4). No long-term research has been conducted in warm and humid regions such as those that occur in East Asia. This study was, therefore, conducted to investigate the differences in soil nutrition, tree performance, and insect and disease occurrence between a conventional and an organic Asian pear orchard over three years in the warm, humid environment of South Korea.

Materials and Methods

Plant materials and treatment applications

The study was conducted on 12-year-old 'Niitaka' pear (*Pyrus pyriforia* Nakai) trees in adjacent 1-ha conventional and 1-ha organic orchards in Boseong (Latitude: 34˚N; Longitude; 127˚E), Chonnam, South Korea from 2008 to 2010. The region has a humid and warm East Asian monsoonal climate, with the rainy season occurring primarily from early summer to autumn. Annual precipitation was 960 mm in 2008, 1,247 mm in 2009, and 2,083 mm in 2010, and the average daily temperature was 14.5°C in 2008, 14.6°C in 2009, and 12.2°C in 2010 (9). Both orchards had a loam top soil (<30 cm) with clay loam in the deeper layers. This soil had low to moderate natural fertility levels, optimum organic matter (OM) content (3-4%), and low to neutral pH (5.7-5.9). The planting distance was 4.5 m between trees and 6 m between rows for a density of 370 trees per ha for both orchards. Trees were trained as a 3.0 m tall Y shape with a 2-wire trellis system for tree support and training. Between 2005 and 2007, chemical fertilizer (15N-9P-10K, Dongbu Co., Korea) and cattle manure compost (N: 0.9%, P: 1.2%, and K: 1.1%) were applied annually in the conventional orchard, while rice bran compost (N: 2.1%, P: 3.8%, and K: 1.4%) was applied annually to the organic orchard. Consequently, the conventional orchard had been applied annually with 16.1 kg ha^{-1} N, 8.1 kg ha^{-1} P, and 9.5 kg ha^{-1} K while the organic orchard had been applied with 1.6 kg ha^{-1} N, 1.2 kg ha^{-1} P, and 0.9 kg ha^{-1} K annually from 2005 to 2007. Hence the N, P, and K applied to the organic orchard was only 10, 15 and 9%, respectively, of that applied to the conventional orchard. From 2008 to 2010, annual nutrient applications within each system were made in April at rates equivalent to approximately 50 g of actual N per year of tree age for each tree, in order to supply the same N content to each tree in both systems. Pest control within the conventional orchard was achieved using standard products as recommended in this growing region (Table 1). Certified organic materials used for pest management, included lime sulfur, clay+sulfur, cooking oil, plant extract, ginkgo pyroligneous extract, and lactobacillus (Table 1). The plant extract was comprised of extracts from leaves and seeds of different kinds of plants, flowers, and fruits. The pyroligneous extract was produced by destructive distillation of wood but the tar in the liquid was excluded due to its toxic nature. The distillate contains vinegar and phenolic compounds which effectively control disease incidence. It is widely used in East Asian countries. In both management systems, under-tree vegetation was mown two to three times per year and irrigation was applied when needed during the growing season. Young fruit were enclosed in double bags at 45 days after full bloom in both management systems to prevent scab, and infestation by mites and other insects (Fig. 1). Use of both inner and outer bags effectively controls light exposure of the fruit, so improving fruit surface brightness and preventing the fruit surface from turning dark brown.

Vegetation samples, within a 3 m^2 area centered on the tree trunk, were collected from each treatment system in April, 2009 and evaluated for species composition and then dried at 70°C for three days to measure dry weight. Weed dominance index was defined as the order of the predominant weed species around sample trees, where 1 was assigned to the most predominant species, 2 was assigned

Table 1. Summary of insect and disease protection program in the conventional and organic pear orchards from 2008 to 2010.

Date	Active ingredient	No of applications	Target
Conventional	Lime sulfur (20 L)	1	Scab
March to April[1]	Difenoconazole (100 mL)	1	Scab
	Myclobutanil (130 g)	1	Scab, rust
	Lambda-cyhalothrin (200 g)	1	Oriental fruit moth, pear phylloxera, comstock mealybug, aphid
May to June[2]	Fenarimol (26 mL)	1	Rust, scab
	Imidacloprid (200 g)	3	Oriental fruit moth, aphid, pear phylloxera, leaf roller, pear sucker
	Hexaconazole (400 mL)	1	Scab
	Thiamethoxam (200 g)	1	Aphid, mite, pear phylloxera
July to September[2]	Chlorothalonil (400 g)	4	Black rot
	Fenazaquin (26 mL)	4	Leaf roller, mite, oriental fruit moth, pear phylloxera, comstock mealybug, aphid
Organic	Lime sulfur (20 L)	1	Scab, rust, oriental fruit moth
April[3]	Clay+sulfur (1L) + lime sulfur (1 L)	1	Scab, rust, aphid, pear sucker
May to June[3]	Plant extract (5 L) + ginkgo pyroligneous liquid (2 L)	1	Scab, rust, pear phylloxera, leaf roller
	Clay+sulfur (2 L) + lime sulfur (0.5 L) + cooking oil (1 L)	1	Scab, oriental fruit moth, aphid, mite
	Clay+sulfur (2 L) + lime sulfur (1 L) + cooking oil (1 L)	2	Scab, oriental fruit moth, comstock, mealybug, leaf roller
	Clay+sulfur (1.5 L) + lime sulfur (0.5 L)	1	Scab, roller, pear phylloxera, comstock mealybug, aphid
July to August[3]	Plant extract (5 L) + lactobacillus (1 L)	1	Canker, Oriental fruit moth, comstock mealybug, aphid, mite

[1] Dose rates in conventional system from March to April are expressed in 200 L of tank volume per hectare.
[2] Dose rates in conventional system from May to September are expressed in 350 L to 400 L of tank volume per hectare.
[3] Dose rates in organic system are expressed in 500 L of tank volume per hectare.

to the second most predominant species, 3 was assigned to the third most predominant species, and so on.

Nutrient analysis. Soil samples around the sample trees were taken with a 2-cm diameter soil probe at a depth of 0-30 cm in July of both 2009 and 2010. The soil samples were air-dried and sieved through a 2 mm mesh screen for nutrient analyses following the protocol from the NIAST (18). Soil pH was measured with a 1:5 (vol:vol) soil:water ratio, and soil organic matter (OM) was determined using the Tyurin method (10). The total soil nitrogen concentration, [T-N], was analyzed using a N-analyzer (LECO Co., St. Joseph, USA), and available [P_2O_5] in the soil was determined by the Lancaster method (6). Soil was extracted with 1N-NH_4OAC (pH 7.0) buffer solution and then analyzed with an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP, Leeman, USA) to determine [K_2O], [CaO], and [MgO].

Twenty leaves from five randomly-selected trees in each of three center rows of each orchard were taken from the mid section of current year's shoots at approximately 100 days after flowering in 2008, 2009 and 2010. Leaves were dried for three days at 70°C, ground, and digested using the micro-Kjeldahl extraction method. [T-N] was determined

Fig. 1. Paper-bagged 'Niitaka' pear fruits at 45 days after full bloom (left) and following bag removal at pre-harvest (right) in an organic orchard.

using a combustion N analyzer (Buchi Co., Flawil, Switzerland) and leaf [P] was determined using a UV spectrometer (Shimadzu, UV-1601, Japan). The ground leaf samples were also extracted using the Mehlich 3 method (15), and then analyzed for [K], [Ca], and [Mg] using an ICP.

Fruit quality and insect and disease analyses. All fruit from the 15 sampled trees in each system were harvested in mid-October, weighed, and counted to determine fruit yield. Twenty fruit per tree were then randomly sampled to measure the following fruit characteristics: fruit shape index was evaluated from the ratio of fruit width and length; fruit soluble solids concentration (SSC) and firmness were determined using a hand-held refractometer (N1 Atago, Japan) and a hand-held penetrometer with 5-mm diameter plunger (Japan), respectively; and fruit skin color was assessed using a fruit Hunter color meter with a high grade spectrum color sensor (CR 301 Minolta, Japan) where higher values of L^*, a^*, and b^* represent greater brightness, greater redness, and greater yellowness, respectively. Unlike apples where a^* and b^* values are critical, in Asian pear the L^* value is the most important parameter for defining fruit color. Production income from each treatment system was estimated each year by multiplying the total yield of marketable fruit by the current market price as applicable to either conventional or organic fruit.

The most serious insects and diseases in both orchard systems were visually evaluated using samples of 50 mature leaves and 50 fruit from the outer canopy of each of the 15 sampled trees immediately prior to harvest.

The experiment was analyzed as a repeated measure design. Five trees of similar size in 2008 from each of the three center rows (15 trees = 5 trees/row x 3 rows) located in a level area within each orchard (most orchards are slightly sloped in South Korea) were selected for the comparisons. The same fifteen trees were sampled in each of the three years of the study (2008, 2009 and 2010). Statistical analyses were performed using SAS software (SAS Institute version 8.2, Cary, USA).

Results

The diversity of weed species was higher in the organically managed orchard (Table 2). Weed dry weight was also significantly greater in the organic orchard (526 $g \cdot m^{-2}$) than in the conventional orchard (296 $g \cdot m^{-2}$). *Stellaria media* and *Lolium multiflorum,* respectively, were the most dominant species in the conventional and in the organic orchard systems.

The average soil pH in both orchards over two years was slightly lower than the recommended level for commercial pear production in South Korea (20) (Table 3). The average OM and [T-N] values at a depth of 0-30 cm in the organic orchard were 3.44% and 0.14%, respectively, which were 60-70% lower than

Table 2. Weed species, dry matter, and index of weed dominance observed in the conventional and organic pear orchards in April, 2009.

Orchard	No. of species	Dry matter ($g \cdot m^{-2}$)	Index of weed dominance						
			1	2	3	4	5	6	7
Conventional	9	296	*Stellaria media* Villars	*Duchesnea indica* (Andr.) Focke	*Clematis apiifolia* DC	*Elymus tsukushiensis* Honda	*Galium spurium* var. *echinospermon* (Wallr.) Hayek	*Artemisia princeps* var. *orientalis* (Pampan.) Hara	*Veronica persica* Plir.
Organic	18	526	*Lolium multiflorum* Lam.	*Carex neurocarpa* Max.	*Vicia tetrasperma* (L.) Schreb.	*Vicia hirsuta* (L.) Gray	*Chelidonium majus* var. *asiaticum* (Hara) Ohwi	*Vicia angustifolia* var. *segetilis* (Thuill.) K. Koch.	*Galium spurium* var. *echinospermon* (Wallr.) Hayek

those within the conventional orchard (Table 3). Soil [P_2O_5] in the conventional orchard was higher than that within the organic orchard, but below the recommended concentration for commercial pear orchards in South Korea (20). Soil [K_2O], [MgO], and CEC were higher in the conventional orchard than in the organic orchard but, in each instance, were above recommended values (20).

Average foliar [N], [K], and [Ca] in each of the three years of the study were higher in the conventional orchard than in the organic orchard, but the latter had greater foliar [P] and [Mg] (Table 4). Foliar [K] in both orchards, despite the soil [K_2O] being slightly high, were overall lower than the optimal nutrient range (20).

The average fruit weight over the three-years of the study from the organic orchard was 483 g, which was 74% of that from the conventional orchard (Table 5). Conventionally managed fruit had an average SSC of 11.2˚Brix which was only 0.3˚Brix higher than that of the organic fruit and the difference was non-significant. Firmness of the smaller fruit from the organic orchard was 21% higher than for the fruit from the conventional orchard. Hunter a^* value of conventional fruit was greater than that of organic fruit, and fruit yield was also markedly greater from conventional trees.

Leaf scab and rust (*Gymnosporangium asiaticum*), the most severe foliar diseases in Asian pear production, had consistently higher occurrences in the organic orchard (Table 6). The conventional orchard had higher foliar damage due to pear suckers (*Psylla pyricola*) while the organic orchard had a greater number of beetles (*Melolonhta incana*) on the leaves, a greater incidence of pear bark miner (*Acrocerops astaureta*) in/on the bark, and a higher density of aphids (*Aphis citricola*) on the bark. Conventional trees had, on average, 20.4% of scab damage to fruit while there was 57.2% damage to the organic fruit (Table 6). Damage from comstock mealybug (*Pseudococcus comstocki*) and stink bug (*Halyomorpha halys*) to organic fruit over three years averaged 23.6 and 13.1%, respectively, but these insects were absent in the conventional orchard.

In the first two years of the study, production income was similar for both the conventional and the organic systems with values ranging from $30,000

Table 3. Soil pH, OM (organic matter), [T-N], [P2O5], [K2O], [CaO], [MgO], and CEC (cation exchange capacity) at the depth of 0-30 cm in the conventional and organic pear orchards in July, averaged over two years (2009 and 2010).

Orchard	pH	OM	[T-N]	[P_2O_5]	Ex. Cation ($cmol^{+}\cdot kg^{-1}$)			CEC
	(1:5)	(%)	(%)	($mg\cdot kg^{-1}$)	[K_2O]	[CaO]	[MgO]	($cmol^{+}\cdot kg^{-1}$)
Conventional	5.94	4.92	0.23	372	2.97	5.43	3.05	19.8
Organic	5.87	3.44	0.14	140	1.08	5.80	2.03	16.9
Significance	*	***	**	***	***	*	**	**
Desired level[1]	6.0-6.5	2.5-3.0	-[2]	200-300	0.3-0.6	5.0-6.0	1.5-2.0	10-15

[1] Adapted from RDA (20).
[2] RDA (20) does not specify a desired level for [T-N], and OM can substitute for [T-N].
*, **, *** Significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 4. Foliar macro nutrient concentrations in the conventional and organic pear orchards in August, averaged over three years (2008, 2009 and 2010).

Orchard	Foliar nutrients (%)				
	[T-N]	[P]	[K]	[Ca]	[Mg]
Conventional	1.90	0.30	1.42	1.53	0.26
Organic	1.66	0.33	1.06	1.37	0.39
Significance	NS	NS	**	NS	*
Desired level[1]	1.8-2.5	0.10-0.17	1.5-2.3	1.2-1.7	0.25-0.33

[1]Adapted from RDA (20).
NS, *, ** Nonsignificant or significant at $P < 0.05$ and 0.01, respectively.

ha^{-1} to \$50,000 ha^{-1}, but income was considerably higher in the conventional orchard in 2010 (Fig. 2).

Discussion

The conventional orchard tended to have more broadleaf weeds such as *Stellaria media* and *Duchesnea indica*, which are typically observed under fertile conditions. In contrast, the organic system had more leguminous species such as *Vicia tetrasperma*, *V. hirsute* and *V. angustifolia* var. *segetilis*, possibly because of the lower N supply from the applied organic manures. Various weed species and a greater dry matter of herbage in organic orchards have been observed in previous studies (7), and conventional dryland winter cereal crops favored more nitrophilous species and fewer legume weeds than occurred in organic crops (22). This could indicate that conservation and greater promotion of biodiversity occurs in organic orchard systems, although the weeds were also

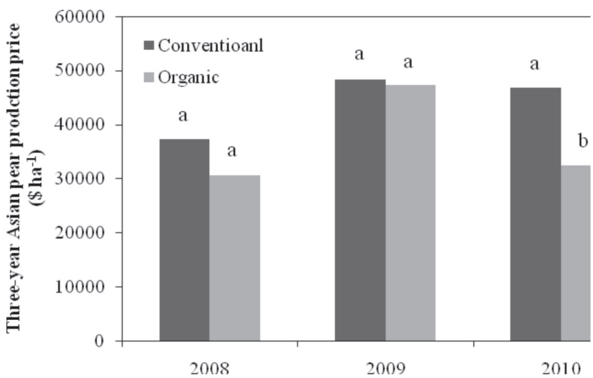

Fig. 2. Estimated fruit production income from the conventional and organic pear systems in 2008, 2009 and 2010. Columns indicated by the same letter were not significantly different according to Duncan's multiple ranged test at 5% level.

Table 5. Fruit fresh weight, shape index (ratio of width and length), SSC (total soluble solids concentration), fruit color, yield, and harvest date in the conventional and organic pear orchards in October, averaged over three years (2008, 2009 and 2010).

Orchard	Fruit characteristics									
	Fresh wt. (g)	Shape index	SSC (°Brix)	Firmness (N)	Color L*	Color a*	Color b*	Number (no. •tree^{-1})	Yield (tonne •ha^{-1})	Harvest date
Conventional	674	1.12	11.2	21.8	60	6.26	35	131	34.7	Sep 27
Organic	483	1.14	10.9	26.2	59	5.08	35	113	14.2	Oct. 5
Significance	***	NS	NS	*	NS	*	NS	***	***	-

NS, *, *** Nonsignificant or significant at $P < 0.05$ and 0.001, respectively.

competing with trees for water and nutrients, so they became a management challenge.

In South Korea, farmers of conventional orchard systems typically apply large amounts of nutrients through compost, sometimes at higher than recommended amounts for pear production, to increase fruit quality and yield. Such high amounts, however, could increase nutrient leaching potential after the end of the fruit growing season when nutrient uptake by fruit trees is reduced (4). In addition to potential leaching, the compost could also have contributed to the increase in weeds found in the conventional system since sod-culture was used instead of the application of herbicides for controlling weed occurrence (Table 2). High inputs of compost and chemical fertilizer from 2005 to 2007 before the study was initiated would have also increased levels of soil macro nutrients in the conventional system. Although lower OM, [T-N], [K_2O], [CaO], and [MgO] were found in the soil and lower [T-N], [K], and [Ca] were found in leaves from the organic orchard, the values were not considered to be deficient overall compared to current soil and foliar nutrient recommendations for commercial orchards (20).

There were no significant differences between the organic and the conventional orchard systems for fruit shape index, SSC, and fruit color, which is similar to results reported for both 'Galaxy Gala' (19) and 'Starking Delicious' apples (23). As observed in other conventional orchards in South Korea, where gibberellins were applied on the pedicels of all fruit on a tree to increase fruit size at 30 days before fruit harvest, there was a heavier mean fruit weight (674 g per fruit) and a corresponding and expected lower fruit firmness (21.8 N) for fruit from the conventional system. L*, the critical hue value for determining the color of 'Niitaka' pear fruit, ranged from 60 to 65 and was not significantly different from values reported for conventional and organic pear orchards in other regions of South Korea (8). It was expected that the conventional fruit would have had a higher L* value than the organic fruit, as the conventional system had received higher levels of fertilization before the initiation of the experiment (2005-2007), but this did not occur. The higher amount of clay+sulfur and lime+sulfur applied in the organic system (Table 1) would normally have reduced light penetration and decreased fruit surface color but these impacts were negated by bagging the fruit.

The most significant disease of Asian pears, scab of leaves and fruit, was higher in 2010 compared with the previous two years (data not presented), and the incidence was dramatically higher on trees in the organically managed system. Rain lasted for 28 days and two typhoons occurred in August (565 mm) of 2010, and the pear orchard received approximately double the amount of precipitation compared to the previous years, which would have affected the spread of scab on both leaves and fruit. In the organic farming

Table 6. Incidence of disease and insect damage to leaf, bark, and fruit in the conventional and organic pear orchards in September, averaged over three years (2008, 2009 and 2010).

Orchard	Disease (%)		Insect (%)					Disease and Insect (%)		
	Leaf		Leaf			Bark		Fruit		
	Scab (*Venturia nashicola* Tanaka et Yamamoto	Rust *Gymnosporangium asiaticum* Miyabe et Yamad)	Pear sucker (*Psylla pyricola* Foerster)	Beetle (*Melolonhta incana* Motschulsky)	Kuwana pear aphid (*Procipolus kuwanai* Monzen)	Bark miner (*Acrocercops astaureta* Meyrick	Bark aphid (*Aphis citricola* Van der Goot)	Scab (*Verturia nashicola* Tanaka et Yamamoto)	Comstock mealybug (*Pseudococcus comstocki* Kuwana)	Stink bug (*Halyomorpha halys* Stål)
Conventional	3.9	3.0	22.0	0.0	0.0	1.3	0.7	20.4	0.0	0.0
Organic	24.6	16.1	0.0	18.4	0.1	80.6	12.6	57.2	23.6	13.1
Significance	***	*	***	***	NS	***	***	***	***	***

NS, *, *** Nonsignificant or significant at $P < 0.05$ and 0.001, respectively.

system, control of the scab occurrence in 2010 was insufficient to produce an economic yield of marketable fruit.

Pear sucker, one of the most serious pests on Asian pears, is frequently found on leaves in conventional orchards in South Korea but, in this study, was rarely seen in the organic management system in any of the three years of observations (Table 6). This is typical in other organic orchards in South Korea perhaps because the pesticides used favor beneficial insects and natural enemies of the pear sucker. Pear fruit were bagged approximately 45 days after full bloom for preventing insect attack and for improving fruit surface color. However, the insect damage to fruit in the organic system was significant (Table 6) and exceeded the economic threshold of 10%. Earlier bagging of fruit would likely have prevented comstock mealybug and stink bug from damaging young fruit in May and June.

The conventional orchard over the three years of the study had 17% higher net income than the organic orchard due to higher yields of marketable fruit (Fig. 2). In order to reduce disease occurrence, organically managed trees required heavy pruning to increase light penetration into and ventilation of the inside of the tree canopy. This practice decreases fruit yield and increases labor costs in the orchard. A new approach for managing insect and disease control in organic orchards is required and might include the selection of more suitable cultivars, methods for controlling ground-cover competition, and enhanced nutrient management techniques to allow farmers to achieve higher yields.

Conclusions

Although the conventional orchard had considerably higher nutrients in the soil, the organic orchard had soil and foliar nutrients within the optimal range as well as a higher degree of biodiversity in the understorey vegetation. Fruit production in the organic orchard was particularly reduced in year 3 when there was a prolonged wet period in the summer leading to a higher fruit disease and insect pest incidence. It is not surprising that the conventional system had higher yields than the organic system as the conventional orchard received higher nutrient inputs, less weed competition, and gibberellins had been applied to increase fruit size. Development of effective organic control methods for specific insects and diseases is required in order to increase the commercial viability of organic pear fruit orchards in South Korea. Use of the unmarketable fruit, which is produced in small-scale organic farming systems, could be achieved through the development of processed fruit products. Ongoing scientific research for organic pear production is expected to resolve a number of the issues raised in this research.

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