

## Effect of Chemical Fertilizer and Compost on Soil Physicochemical Properties, Leaf Mineral Content, Yield and Fruit Quality of Red Pepper (*Capsicum annuum* L.) in Open Field

Seong Eun Lee\*, Jin Myeon Park, Young Eun Park, and Tae Jun Lim

Horticultural & Herbal Crop Environment Division, National Institute of Horticultural & Herbal Science, Wanju 55365, Korea

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Nowadays, sustainable and environment-friendly agriculture has become an important issue all around the world, and repeated applications of mineral and/or organic fertilizer will probably affect mineral nutrient dynamics in soil in the long term but only a limited number of observations are available. This study was carried out to investigate whether there is any influence of different fertilizer management for red pepper (*Capsicum annuum* L.) cultivation on soil physicochemical properties, leaf mineral content, yield and fruit quality in the aspect of long-term practice in open field condition. NPK, NPK+compost, compost only, and unfertilized control plot were included in the treatments. The application of chemical fertilizer and/or compost repeated annually for 17 years from 1994 to 2011. Soil organic matter content was higher in compost treatments than in no-manure treatments. Available phosphate and the yield of red pepper were highest in NPK+compost treatment followed by NPK (chemical fertilizer), compost, and control. The results indicate that in the long term, nitrogen supply is still needed for increasing red pepper yield, but reduction in the use of chemical fertilizer could be also possible with the proper application of compost.

**Key words:** Organic matter, Exchangeable cation, Available phosphate, Bulk density

### Effect of chemical fertilizer and compost on fruit quality and yield of red pepper.

Treatment	Yield	Capsaicin	Dihydro-capsaicin	Carotenoid
	kg 10a <sup>-1</sup>	----- mg g <sup>-1</sup>	D.W. -----	ASTA <sup>†</sup> value
Control	256.2 d <sup>‡</sup>	2.36 a	1.95 a	94.67 a
NPK	1183.1 b	0.58 b	0.31 b	73.00 a
NPK + compost	1481.2 a	0.13 b	0.00 b	74.33 a
Compost	827.0 c	1.67 a	1.45 a	77.67 a

<sup>†</sup>ASTA: American Spice Trade Association.

<sup>‡</sup>Mean separation within columns by LSD at  $P=0.05$ .

\*Corresponding author: Phone: +82632386342, Fax: +82632386305, E-mail: pplm96@korea.kr

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## Introduction

Sustainable and organic farming is largely based on INM (Integrated Nutrient Management). For this reason, appropriate soil management is required to improve soil fertility and crop production while minimizing nutrient losses. It becomes more apparent in long-term experiments because permanent agricultural use of soil decreases nutrient and soil organic matter contents (Chan et al. 2002), and long-term intensive cultivation can cause considerable changes in soil pH, cation exchange capacity and exchangeable cation contents, mainly by fertilizer additions (Schjøning et al., 1994; Hera, 1996; Blake et al., 1999; Ellmer et al., 2000; Noble et al., 2000; Pernes-Debuyser and Tessier, 2004).

Organic farming systems mainly rely on organic fertilizers such as compost, slurry, and animal and green manure to maintain nitrogen (N) nutrition of the crops. Soil organic carbon is closely associated with a wide range of physical, chemical and biological properties of soil, and its content has been recognized as a key component of soil quality (Reeves, 1997). Several studies have demonstrated that repeated manure applications over many years significantly increase gross N mineralization (Müller et al., 2011). Gibbs and Barraclough (1998) reported that the addition of labile organic matter to soil did not affect gross N mineralization, but markedly increased N immobilization in short-term. It is one of the key challenges of organic farming to match N release from organic fertilizers and crop demand for N.

Soil organic carbon (SOC) is fundamental to the maintenance of soil fertility and function, and has been identified as a key indicator of soil quality, which influences a wide range of soil physical, chemical and biological properties. Besides this, conversion of organic residues such as sewage sludge, green cut, organic wastes or animal manure into useable composts reduces the amount of waste deposited into landfill sites, thereby improving the cycling of matter. However, to maintain plant nutrient contents, in most cases, mineral fertilizers are used, whilst the role of soil organic matter as an essential determinant of soil fertility and stability is often underestimated (Ros et al., 2006).

Red pepper is a popular spice and one of the major vegetable crops in Korea. Continuous cropping of red pepper is widespread because many farmers prefer monoculture for several reasons such as technical convenience. For these reasons, NIHHS (National Institute of Horticultural and Herbal Science)' long-term application experiment for nutrient management in red pepper started in 1994. The aim of this work was to evaluate the long-term effects of chemical fertilizer and compost on the soil physical and chemical properties, leaf mineral content, yield and fruit quality of red pepper, to ascertain the advantage of organic matter on the crop and soil, and to look for the possibility of reducing the use of chemical fertilizer by gaining precious information through long-term experiment of various soil management practices on red pepper.

## Materials and Methods

### Red pepper cultivation and fertilizer management

Red pepper (*Capsicum annuum* cv. Geumtap) plants were grown in long-term application plots filled with sandy loam from 1994 to 2011 in Suwon. The area of each experimental plot was 10.8 m<sup>2</sup> (3.0 × 3.6 m), and the seedlings were planted at a spacing of 0.75 × 0.45 m in early-May and grown until early-October every year. They were grown in open field condition in a randomized block design with three replicates. The treatments were NPK, NPK+compost, compost only, and control (no-fertilizer treatment). In this experiment, 20 Mg ha<sup>-1</sup> of compost made from rice straw and cattle manure was given in compost treatments every year, and the annual application rate of N (urea), P<sub>2</sub>O<sub>5</sub> (superphosphate) and K<sub>2</sub>O (potassium sulfate) were 190, 112, and 149 kg ha<sup>-1</sup>, respectively. Split application rate of nitrogen and potash was 55 (basal): 15:15:15 (three times additional)%. Lime was applied by ORD method to maintain appropriate soil pH for red pepper cultivation except control. Soil samples for chemical analysis were collected by soil auger, and soil samples for physical analysis were collected by 100 cm<sup>3</sup> cylindrical core in the depth of 5 ~ 15 cm at pre-planting stage. Fertilizer treatment designed for this long-term experiment is presented on Table 1.

**Table 1. Fertilizer treatments used in this experiment.**

Treatment	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	CaO	Compost
	----- kg ha <sup>-1</sup> -----				Mg ha <sup>-1</sup>
Control	-	-	-	-	-
NPK	190	112	149	LR	-
NPK + compost	190	112	149	LR	20
Compost	-	-	-	LR	20

<sup>1</sup>LR: Lime requirement to bring the soil to pH 6.5.

**Soil and plant analysis** Chemical analysis for determination of the mineral content of each sample was conducted according to 『Methods of soil chemical analysis』 (NIAST, 2000). For the determination of soil pH, air-dried soil samples were mixed with deionized water with a ratio of 1 : 5 (soil : water), and the pH of the clear supernatant was measured by pH electrode (Orion VERSA STAR, Thermo fisher scientific, US). And then, soil electrical conductivity (EC) was measured by electrical conductivity meter (CM-30R, DKK-TOA, Japan). Soil available phosphate was determined according to the method of Lancaster. For determination of soil exchangeable cation (K, Ca, and Mg), air-dried soil samples were extracted with 1 N ammonium acetate (soil : solution ratio was 1 : 10) for 30 minutes, and concentration of the extract was determined by ICP-OES (SDS-720, GBC, Australia). Soil moisture content of each treatment, as an indicator linked to soil-water and pore space relation, was measured by obtaining samples with a 2.54 cm cylindrical coring tube.

Quantitative analysis of plant N followed Kjeldahl method. About 3 g catalyst mixture ( $K_2SO_4$  :  $CuSO_4$  = 9 : 1) and 10 mL concentrated sulfuric acid were added to 0.5 g of dry plant samples for digestion, and then the distillate obtained by Kjeldahl apparatus (Kjeltec 8400, Foss, Sweden) was titrated with standardized 0.1 N HCl. Plant P was measured by ammonium vanadate method, and K, Ca, and Mg were determined by ICP-OES (SDS-720, GBC, Australia) after wet digestion with a mixture of  $HNO_3$  and  $HClO_4$  (85/15, v/v).

Capsaicin and dihydrocapsaicin content of red pepper fruit were analyzed by UPLC (Acquity, Waters, America) method (Table 2). 1 g of red pepper powder, dried at 60°C, was extracted with 10 mL acetone for 5 hours.

After that, 1 mL of supernatant was mixed with 4 mL methanol, and filtered by 0.2  $\mu$ m membrane filter. A 20  $\mu$ L aliquot was used for each UPLC injection, and the analysis of carotenoid was followed ASTA (American Spice Trade Association) method (AOAC, 1990).

**Statistical analysis** Multiple comparison tests using LSD range test were conducted in this experiment. Statistical analysis was carried out by SAS statistical package (version 9.2, SAS Institute, Cary, NC).

## Results and Discussion

**Soil physical and chemical properties** The long-term application of compost increased the liquid and gaseous phase of soil. As a result, the bulk density of soil near root zone showed significant decrease in this experiment (Table 3). Regular addition of organic residues, particularly the composted ones, increased soil physical fertility, mainly by improving aggregate stability and decreasing soil bulk density (Diacono et al., 2010).

Soil chemical properties sampled at 5~15 cm and 15~25 cm from the surface are presented in Table 4 and 5, respectively. Soil organic matter was higher in compost treatments than in other treatments. Numerous studies in both temperate and tropical regions have shown that large increases in soil organic matter content can be achieved by adding organic manures and wastes to soils (Haynes et al., 1998; Khaleel et al., 1981). Electrical conductivity and exchangeable magnesium were higher in chemical fertilizer treatments than in control or compost treatment. Exchangeable Ca was higher in NPK than in NPK+compost treatment. Available phosphate in soil at 5~15

**Table 2. HPLC condition for capsaicin and dihydrocapsaicin analysis used in this experiment.**

Parameter	Condition
Column	$\mu$ Bondapak C18, 3.9 $\times$ 300 mm, 10 $\mu$ m
Mobile phase	Methanol : 1% Acetic acid = 7 : 3
Flow rate	1.0 mL min <sup>-1</sup>
Temperature	Ambient
Injection volume	10 $\mu$ L

**Table 3. Effect of chemical fertilizer and compost on soil physical properties at pre-planting stage (Mar. 27, 2011).**

Treatment	Bulk density	Solid phase	Liquid phase	Gaseous phase
	g cm <sup>-3</sup>	-----	%, v/v	-----
Control	1.30 a <sup>†</sup>	49 a	28 a	23 a
NPK	1.31 a	49 a	28 a	23 a
NPK + compost	1.20 b	45 b	30 a	25 a
Compost	1.19 b	45 b	29 a	26 a

<sup>†</sup>Mean separation within columns by LSD at  $P=0.05$ .

**Table 4. Effect of chemical fertilizer and compost on soil chemical properties at 5~15 cm depth (Mar. 28, 2011).**

Treatment	pH	EC	OM	Av.P <sub>2</sub> O <sub>5</sub>	Ex. cation		
					K	Ca	Mg
	1:5	dS m <sup>-1</sup>	g kg <sup>-1</sup>	mg kg <sup>-1</sup>	cmol kg <sup>-1</sup>		
Control	6.2 a <sup>†</sup>	0.21 c	6.6 b	30 d	1.67 a	3.58 b	1.40 b
NPK	7.7 a	0.41 ab	9.0 b	273 b	1.65 a	6.05 a	3.17 a
NPK + compost	7.4 a	0.56 a	19.4 a	453 a	2.99 a	4.98 ab	2.82 a
Compost	7.3 a	0.28 bc	16.1 a	178 c	0.67 a	4.90 ab	1.48 b

<sup>†</sup>Mean separation within columns by LSD at P=0.05.

**Table 5. Effect of chemical fertilizer and compost on soil chemical properties at 15~25 cm depth (Mar. 28, 2011).**

Treatment	pH	EC	OM	Av.P <sub>2</sub> O <sub>5</sub>	Ex.cation		
					K	Ca	Mg
	1:5	dS m <sup>-1</sup>	g kg <sup>-1</sup>	mg kg <sup>-1</sup>	cmol kg <sup>-1</sup>		
Control	6.3 a <sup>†</sup>	0.19 b	4.1 a	23 c	1.30 a	3.22 c	1.32 b
NPK	7.6 a	0.34 a	4.8 a	104 b	3.32 a	4.40 ab	2.50 a
NPK + compost	7.5 a	0.39 a	7.5 a	222 a	1.27 a	5.13 a	2.44 a
Compost	7.4 a	0.22 b	7.9 a	110 b	0.83 a	3.87 bc	1.27 b

<sup>†</sup>Mean separation within columns by LSD at P=0.05.

**Table 6. Effect of chemical fertilizer and compost on leaf mineral content of red pepper at growing stage (Jun. 20, 2011).**

Treatment	T-N	P	K	Ca	Mg
	g kg <sup>-1</sup>				
Control	36.6 b <sup>†</sup>	2.31 c	46.4 a	24.6 a	9.86 a
NPK	43.2 a	4.41 b	50.2 a	19.4 a	11.39 a
NPK + compost	46.1 a	5.24 a	54.0 a	16.5 a	8.42 a
Compost	43.1 a	4.05 b	51.0 a	20.2 a	7.07 a

<sup>†</sup>Mean separation within columns by LSD at P=0.05.

**Table 7. Effect of chemical fertilizer and compost on leaf mineral content of red pepper at harvesting stage (Oct. 26, 2011).**

Treatment	T-N	P	K	Ca	Mg
	g kg <sup>-1</sup>				
Control	12.7 a <sup>†</sup>	2.07 b	23.0 a	11.5 a	2.87 b
NPK	14.0 a	2.51 b	19.7 a	12.9 a	4.99 a
NPK + compost	15.3 a	2.09 b	20.9 a	14.2 a	4.38 a
Compost	12.4 a	3.36 a	22.4 a	14.4 a	3.19 b

<sup>†</sup>Mean separation within columns by LSD at P=0.05.

cm was highest in NPK+compost treatment followed by NPK (chemical fertilizer), compost, and control. Available P concentrations were greater with manure application than without manure (Eghball et al., 1996). Long-term applications of large amounts of P fertilizer and animal manures caused an accumulation of inorganic P, resulting in an increase of the potential risk related to mobilization of inorganic P in the top 5 cm of soil (Koopmans et al., 2003).

**Leaf mineral content, yield and fruit quality of red pepper** Leaf N and P content of NPK and those of compost were not significantly different at growing stage (Table 6) because of substantial supply of mineral nutrients from compost (Bartiono and Mokwunye, 1991; Padwick, 1983). Leaf N content of red pepper was lowest in control at growing stage, though it caught up with other treatments at harvesting stage (Table 6 and 7). The gross yield was greatly affected by this low nitrogen content by affecting the initial yield of red pepper (Table 8). Leaf K content

**Table 8. Effect of chemical fertilizer and compost on fruit quality and yield of red pepper (2011).**

Treatment	Yield	Capsaicin	Dihydro-capsaicin	Carotenoid
	kg 10a <sup>-1</sup>	----- mg g <sup>-1</sup> D.W. -----		ASTA <sup>†</sup> value
Control	256.2 d <sup>‡</sup>	2.36 a	1.95 a	94.67 a
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<sup>†</sup>ASTA: American Spice Trade Association.

<sup>‡</sup>Mean separation within columns by LSD at  $P=0.05$ .

was not significantly different between the treatments, attributed to the mineralogy of granite (Park et al., 2009). The application of compost increased the P uptake by 40% in NPK+compost treatment at growing stage, compared with NPK treatment. The yield of red pepper was highest in NPK+compost treatment followed by NPK (chemical fertilizer), compost, and control. Productive and sustainable production systems require mineral fertilizers in combination with management of crop residues and manure to maintain soil organic matter levels and nutrient supply (Pinitpaitoon et al., 2011). Substances determining acidity, containing capsaicin and dihydrocapsaicin, were low in NPK and NPK+compost treatments, while carotenoid was not significantly different between the treatments. Rahman and Inden (2012) reported that high temperature and nutrient solution formulation have important effects on capsaicin contents.

## Conclusion

In our study, annually-repeated application of each fertilizer treatment for red pepper cultivation in open field did not cause any nutrient accumulation and related problem. Long-term application of livestock manure increased soil organic matter content and retention capacity of mineral nutrients essential for red pepper cultivation, and the difference was marked in surface soil region. Bulk density of soil decreased in compost treatments significantly. The yield of red pepper was highest in NPK+compost treatment followed by NPK (chemical fertilizer), compost, and control. The gross yield was greatly affected by leaf nitrogen content affecting the initial yield of red pepper.

## References

- AOAC. 1990. Official Methods of Analysis. Association of Official Agricultural Chemists.
- Bationo, A. and A.U. Mokwunye. 1991. Role of manure and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. In *alleviating soil fertility constraints to increased crop production in West Africa*, ed. A.U. Mokwunye, 217-225. Dordrecht, Netherlands: Kluwer Academic Publishers.
- Blake, L., K.W.T. Goulding, C.J.B. Mott, and A.E. Johnston. 1999. Changes in soil chemistry accompanying acidification over more than 100 years under woodland and grass at Rothamsted Experimental Station, UK. *Eur. J. Soil Sci.* 50(3):401-412.
- Chan, K.Y., D.P. Heenan, and A. Oates. 2002. Soil carbon fractions and relationship to soil quality under different tillage and stubble management. *Soil Till. Res.* 63(3-4): 133-139.
- Diacono, M. and F. Montemurro. 2010. Long-term effects of organic amendments on soil fertility. A review. *Agron. Sustainable Dev.* 30(2):401-422.
- Eghball, B., G.D. Binford, and D.D. Baltensperger. 1996. Phosphorus movement and adsorption in a soil receiving long-term manure and fertilizer application. *J. Environ. Qual.* 25:1339-1343.
- Ellmer, F., H. Peschke, W. Kohn, F.M. Chmielewski, and M. Baumecker. 2000. Tillage and fertilizing effects on sandy soils. Review and selected results of long-term experiments at Humboldt-University Berlin. *J. Plant Nutr. Soil Sci.* 163(3):267-272.
- Gibbs, P. and D. Barraclough. 1998. Gross mineralisation of nitrogen during the decomposition of leaf protein I (ribulose 1,5-diphosphate carboxylase) in the presence or absence of sucrose. *Soil Biol. Biochem.* 30(13):1821-1827.
- Haynes, R.J. and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutr. Cycl. Agroecosys.* 51(2):123-137.
- Hera, C. 1996. The role of inorganic fertilizers and their management practices. *Fert. Res.* 43(1-3):63-81.
- Innerebner, G., B. Knapp, T. Vasara, M. Romantschuk, and H. Insam. 2006. Traceability of ammonia-oxidizing bacteria in compost-treated soils. *Soil Biol. Biochem.* 38(5):1092-1100.
- Khaleel, R., K.R. Reddy, and M.R. Overcash. 1981. Changes in soil physical properties due to organic waste applications: A review. *J. Environ. Qual.* 10:133-141.

- Koopmans, G.F., W.J. Chardon, J. Dolfing, O. Oenema, P. van der Meer, and W.H. van Riemsdijk. 2003. Wet chemical and phosphorus-31 nuclear magnetic resonance analysis of phosphorus speciation in a sandy soil receiving long-term fertilizer or animal manure applications. *J. Environ. Qual.* 32:287-295.
- Mueller, C., R.J. Laughlin, P. Christie, and C.J. Watson. 2011. Effects of repeated fertilizer and cattle slurry applications over 38 years on N dynamics in a temperate grassland soil. *Soil Biol. Biochem.* 43(6):1362-1371.
- Nett, L., S. Aversch, S. Ruppel, J. Rühlmann, C. Feller, E. George, and M. Fink. 2010. Does long-term farmyard manure fertilization affect short-term nitrogen mineralization from farmyard manure? *Biol. Fert. Soils* 46(2):159-167.
- NIAST. 2000. Methods of soil chemical analysis. National Institute of Agricultural Science and Technology, RDA, Suwon, Korea.
- Noble, A.D., G.P. Gillman, and S. Ruaysoongnern. 2000. A cation exchange index for assessing degradation of acid soil by further acidification under permanent agriculture in the tropics. *Eur. J. Soil Sci.* 51(2):233-243.
- Padwick, G.W. 1983. The maintenance of soil fertility in tropical Africa: A review. *Exp. Agr.* 19:293-310.
- Park, J.M., I.B. Lee, Y.I. Kang, and K.S. Hwang. 2009. Effects of Mineral and Organic Fertilizations on Yield of Hot Pepper and Changes in Chemical Properties of Upland Soil. *Kor. J. Hort. Sci. Technol.* 27(1):24-29.
- Pernes-Debuyser, A. and D. Tessier. 2004. Soil physical properties affected by long-term fertilization. *Eur. J. Soil Sci.* 55(3):505-512.
- Pinitpaitoon, S., R.W. Bell, and A. Suwanarit. 2011. The significance of available nutrient fluxes in N and P budgets for maize cropping on a Rhodic Kandistox: a study with compost, NP fertilizer and stubble removal. *Nutr. Cycl. Agroecosys.* 89(2):199-217.
- Rahman, M.J. and H. Inden. 2012. Effect of nutrient solution and temperature on capsaicin content and yield contributing characteristics in six sweet pepper (*Capsicum annuum* L.) cultivars. *J. Food Agr. Environ.* 10(1):524-529.
- Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Till. Res.* 43(1-2):131-167.
- Ros, M., S. Klammer, B. Knapp, K. Aichberger, and H. Insam. 2006. Long-term effects of compost amendment of soil on functional and structural diversity and microbial activity. *Soil Use Manage.* 22(2):209-218.
- Schjonning, P., B.T. Christensen, and B. Carstensen. 1994. Physical and chemical-properties of a sandy loam receiving animal manure, mineral fertilizer or no fertilizer for 90 years. *Eur. J. Soil Sci.* 45(3):257-268.