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Review article

Organic plant production is not the best: Considering produce cost, plant pest problems, plant nutritional and sensory qualities, environmental effects and consumer protection

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Abstract

Discussion based on research evidence highlighted the superiority of toxic, chemical-free plant production (TCFP) to organic plant production (OPP) from various aspects. The results of research have demonstrated that TCFP not only offers toxic, chemical-free plant produce but also is superior to OPP in having a lower produce cost, less plant pest problems, superior nutritional and sensory qualities of produce, lower detrimental environmental effects, lower nitrate contamination in plant produce and better conservation or improvement of soil or both. In addition, it is deduced that OPP imposts consumer protection problems while TCFP does not. Therefore, TCFP should be practiced instead of OPP without toxic plant-pest-control chemicals. However, in most agricultural areas it is not possible to produce plants without using toxic plant-pest-control chemicals. Plant production based on good agricultural practice should be applied, which allows appropriate uses of toxic plant-pest-control chemicals and of chemical fertilizer in combination with organic fertilizer and bio-fertilizer suitable to each soil and each kind of plant. It was also deduced that OPP imposes a problem in consumer protection. Examples were presented with discussion of the research methodology and how misinterpretation of the research results may lead to mistaken support for OPP.

Introduction

Globally, including in Thailand, there has been a belief that organic plant production (OPP) is the best plant production in many aspects, including lower produce cost, less plant pest problems, superior nutritional and sensory qualities of produce, lower detrimental environmental effects, lower nitrate contamination in plant produce, lower soil compaction and hardness, and overall soil improvement as compared to other plant production systems. Broadly speaking, OPP is a plant production system that uses no synthetic inputs, including no synthetic pesticide and no chemical fertilizer (Kuepper and Gegner, 2004). However, chemical fertilizers, which can be produced with very large variation in their contents of plant nutrient elements and with high solubility, in fact, can enhance broader adjustment of plant nutrient supply to meet plant demand and to create desirable soil conditions. The extent of adjustment can be varied to a greater degree than with organic fertilizers to suit the nature of the plant as well as the soil nutrient status so that desirable outputs in different aspects are attained. Accordingly, it is conceivable that chemical fertilizers can help enhance plant production systems that are superior to OPP in the afore-mentioned aspects. This paper highlights some of the research results that have shown the superiority of plant production systems that consider the uses of chemical fertilizers in combinations with organic and bio-fertilizers compared to OPP. Articles with similar contents, including highlights as cartoons, have been published in Thai in forms of booklets (Suwanarit, 2014; 2017).

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Costs of plant yields obtained with organic fertilizers compared to those obtained with chemical fertilizers

When applied to the same soil and for the same kind of plant with the same amount, organic fertilizers give much lower plant yields than chemical fertilizers do. For example, field experiments with paddy rice and field crops in Thailand led to conclusions that they must be applied at the rates that were 8–70 times of those of chemical fertilizers, depending on the kind and source of organic fertilizers, to produce crop yields comparable to those obtained with chemical fertilizers (Table 1). Though the figures were from the first cropping after fertilizer application (and thus taking no account of the residual effects of the fertilizers), Suwanarit (2005) deduced that organic and chemical fertilizers at the rates that produce comparable crop yields had comparable residual effects on crop yields. In addition, the results of an experiment, using a loamy soil in relatively large pots (10 kg soil/pot) on *Telfairia occidentalis* (a leaf vegetable) by Okubena-Dipeolu et al. (2015) showed that 25 kg cow dung and 12.5 kg poultry manure were comparable to 1 kg of 15-15-15 chemical fertilizer in shoot dry weight production. Moreover, the results of the experiments of Pinitpaitoon et al. (2011) with five consecutive annual applications of chemical fertilizers to soil for maize crops showed that on average, 88 kg of the commercial compost was needed to attain a maize yield comparable to that obtained with 1 kg of a 23-23-0 chemical fertilizer. These estimates are either comparable to or higher than those shown in Table 1. The figures in Table 1 imply that to obtain produce cost comparable to that obtained with chemical fertilizer, organic fertilizer prices must not exceed 12.5%, 8.33%, 7.14%, 5.56%, 5.5% and 2.27% of the prices of the chemical fertilizers (the percentage is referred to hereafter as the critical percentage relative to chemical fertilizer price for organic fertilizers, %CCP) in cases of guano, chicken manure, duck manure, pig manure, cow manure and compost, respectively. However, prices of organic fertilizers relative to chemical fertilizer prices are higher than these %CCPs. In Thailand, the lowest prices of chicken manure and compost are about USD 36/t and USD 130/t, respectively (www.kokomax.com/webboart-th-53407-1074973, 22/02/25018; www.thaifertilizer.com/fertilizer-price, 22/02/25018), whereas the prices of chemical fertilizers that produce crop yields comparable to those obtained with the organic fertilizers are USD 144/t and USD 158/t, respectively (based on prices of urea, di-ammonium phosphate and potassium chloride and the rates per ha of applied N, available P_2O_5 and soluble K_2O from chemical fertilizer). Accordingly, the prices of chicken manure and compost are 25.0% and 82.2% of those of chemical fertilizers, respectively, which are much higher than the %CCPs for chicken manure (8.33%) and compost (2.27%). The crop yield cost discussed above actually takes no account of transportation and application costs which are higher in the case of organic fertilizers. Therefore, with the exception of green manure, it is clear that costs per unit weight of crop yields produced with organic fertilizers are higher than those with chemical fertilizers.

In some cases, organic fertilizers increase plant growth but do not increase the desired yields while chemical fertilizers increase both plant growth and the desired yield. These are the worst unfavorable cases for organic fertilizers because the increased growth may mislead farmers into believing that they will get increased desired yields with the application of the organic fertilizer if they take it for granted from examination of growth of the plants and the results of the experiment shown in Table 2 demonstrate a case of this, showing that pig manure increased the weight of the vegetative parts but not of the tubers of cassava whereas chemical fertilizer (where the kind and rate of application were based on chemical analysis of the soil) increased the vegetative parts and tubers by similar extents. Accordingly, in this case, pig manure increased the cost per unit weight of tubers while chemical fertilizer reduced it, resulting in a higher cost per unit weight of tubers obtained with pig manure compared to that obtained with chemical fertilizer.

Table 1 Amounts of farmyard manures and compost that produce a crop yield comparable to that produced by 1 kg of chemical fertilizer (Suwanarit 2005, 2007)[a]

Kind of fertilizer	Amount (kg) of organic manure producing crop yield[a] comparable to that produced by 1 kg chemical fertilizer
Bat guano	8
Chicken manure	12
Duck manure	14
Pig manure	18
Cow manure	20
Compost	44–70

[a] chemical fertilizers applied based on soil chemical analysis to obtain maximum profits expressed as the rate giving a yield of 95% of the maximum yield.

Table 2 Effects of pig manure and chemical fertilizer on fresh weight of leaves plus stems and of tubers of cassava (Narkviroj et al., 1990)

Applied fertilizer	Weight of leaves plus stems (t/ha)[a]	Weight of tubers (t/ha)[a]
Chemical fertilizer		
No application	15.8[b]	14.4[b]
Applied at 625 kg/ha (12-8-8 grade fertilizer)	23.1[a]	20.5[a]
Pig manure		
No application	20.3[b]	17.6[a]
Applied at 6.25 t/ha	22.3[a]	18.0[a]
Coefficient of variation (%)	6.3	13.2

[a] values in the same column with different lowercase superscript letters are different at $p \leq 0.05$.

Effects of organic and chemical fertilizers on crop pest incidence

Most organic fertilizers increase plant disease and insect incidence. For example, among common organic fertilizers, bat guano, which is normally high in phosphorus content, is the only organic fertilizer that can be expected to decrease crop pest incidence, though no supporting research results is available. In contrast, a conclusion could be drawn from research results that chemical fertilizers with high contents of phosphorus or potassium or both but not too high a content of N decrease crop pest incidence. This provides the possibility for farmers to reduce crop pest problems by using chemical fertilizers appropriate to each kind of plant and each soil that can be done with soil chemical analysis. The following are examples of research findings that support this generalization.

1. NPK fertilizers with high N content and chemical fertilizers with N only increase both plant insect and disease incidence (Chau and Heong, 2005; Zhong-xian et al., 2007).

Chau and Heong (2005) conducted a field experiment to examine the effects of: 1) different rates of manure compost (0.8 %N and 0.4% P_2O_5) and of an organic fertilizer (23.5% organic matter, 3.2% P_2O_5); and 2) an NPK chemical fertilizer (100 kg N, 40 kg available P_2O_5 and 30 kg soluble K_2O per ha) on both insect and plant disease incidence in paddy rice grown on a soil with 0.19% N, 0.02% P and

1.5%K. No significant effects on damage from stem borers, numbers of brown hoppers and numbers of leaf folder larvae and incidence of both rice blast and sheet blight were observed among different rates and different kinds of organic fertilizers. Moreover, no significant differences in paddy yields were observed among all the experimental treatments, including chemical fertilizer. Since no control treatment (without any fertilizer application) was included in the experiment, justifiable conclusion on the effects of the tested organic manure cannot be drawn. However, the chemical fertilizer, relatively very high in N, resulted in higher figures in all the parameters than the tested organic fertilizers regardless of the kind and rate of application; this implied that the chemical fertilizer, with relatively very high N, enhanced damage from stem borers, numbers of brown hoppers and numbers of leaf folder larvae and the incidence of both rice blast and sheet blight. This was a case in which an NPK fertilizer that was relatively high in N enhanced both insect pest and disease incidence in a crop.

Zhong-xian et al. (2007), from an intensive literature review, concluded that the application of N fertilizer increased insect pest damage in rice through increasing the feeding preference, food consumption, survival, growth, reproduction and population density of the pests.

2. Organic fertilizers, which mostly have higher N than P and K, increase both plant disease and insect incidence as shown by the research results in Table 3. The results were from a field experiment on a low fertility soil (0.08% total N, 2.9 mg/kg available P and 0.78 mg/kg exchangeable K) with a poultry manure high in N (2.2%) but with very low P (0.05 mg/kg) and K (9.4 mg/kg). The results showed that poultry manure application: 1) increased the numbers of aphids, grasshoppers and bugs; 2) resulted in consistent trends of increases in the numbers of flea beetles and white flies; and 3) increased the incidence of symptoms and severity of pepper veinal mottle virus on chilli pepper (*Capsicum annum*). This was a case in which an organic fertilizer high in N enhanced both disease and insect incidence on a crop grown on a soil low in N, P and K.

3. Research on the effects of chemical P fertilizer on the pest incidence of a crop is lacking. Nevertheless, available research results (Table 4) showed that P-fertilizer reduced brown blotch disease for cowpea (*Vigna unguiculata* [L.] Walp). The results were from a field experiment with three consecutive cropping events with cowpea on a soil very poor in N, P and K (0.07% N, 0.87 mg/kg available P and 5.5 mg/kg exchangeable K). Only P fertilizer at different rates, as the experimental treatments, was applied either to the soil prior to each of the three consecutive annual cowpea cropping events or as a foliar application at 4 wk after planting. The results showed marked depressive effects of fertilizer P on the incidence and severity of brown blotch disease. This was a case in which the depressive effects of P fertilizer were observed on a crop receiving low supplies of N, P and K in the soil.

4. K fertilizers reduce both disease and insect pest incidence even when applied to soils already sufficient in K as shown by the research results in Table 5 from a field experiment with soybean on Vertisols, with low N and P but sufficient K status (180 kg/ha available N, 8.4 kg/ha available P and 302 kg/ha available K) for growth and yield production of this crop. The aim was to examine the effects of K fertilizer on the yield and on both insect pest and disease incidence of soybean. Blanket N fertilizer and P fertilizer, based on soil tests, were applied to the soil at planting in all experimental treatments. The results showed that K fertilizer markedly decreased: 1) numbers of blue beetles, stem flies and defoliators and 2) both collar rod disease and leaf spot disease incidence on the plants. This was a case, in which the depressive effects of K fertilizers were observed on a crop receiving sufficient supplies of N, P and K.

Table 3 Effects of poultry manure on insect and disease incidence (number per plant) for chilli- pepper (*Capsicum sp.*) (Echezona and Nganwuchu, 2006)

Pest name	Poultry manure rate (t/ha)[a]		
	0	20	40
Aphids (*Myzus persicae* Sulzer and *Aphis gossypii* Glov.)	1.4[a]	1.4[a]	3.1[b]
Grasshopper (*Zonocerus variegates* L.)	0.9[a]	1.6[b]	1.8[c]
Bugs (*Helopeltes schoutedni* Reuter)	1.0[a]	2.6[ab]	3.8[b]
Flea beetles (*Pedagrica sjostedti* Jacoby and *P. uniforma* Jacoby)	0.8[a]	1.0[b]	0.9[ab]
White flies (*Bemisia tabaci* Genn.),	4.9[a]	6.2[a]	7.9[a]
Pepper veinal mottle virus			
Incidence of symptom (%)	31.1[a]	45.8[b]	47.3[b]
Severity of symptom (%)	31.1[a]	45.8[b]	41.5[b]

[a] values with a common lower case letter in the same line are not different at $p \leq 0.05$.

Table 4 Effects of phosphorus fertilizer on brown blotch disease of cowpea (Owolade et al., 2006)

Phosphorus fertilizer (kg P_2O_5/ha)	Number of infected plants (%)[a]	Disease severity[a,b]	Plant yield (kg/ha)[a]
0	80[c]	4.2[c]	648[c]
30	66[b]	3.5[b]	994[b]
60	26[a]	2.8[b]	1,455[a]
90	25[a]	1.0[a]	1,450[a]

[a] values with different lowercase superscript letters in the same column are different at $p \leq 0.05$.

[b] a higher value represents greater severity.

Table 5 Effects of potassium fertilizer on yield and disease and insect pest incidence on soybean (International Potash Institute, 2007)

K fertilizer (K_2O/ha)	Soybean yield (kg/ha)[a]	Blue beetle (number/1 m of row)[b]	Stem fly (% of tunneled plants)[b]	Defoliators (number/1 m of row)[b]
0	1,510[b]	5.9	13.9	1.3
25	1,807[a]	2.0	3.9	1.0
50	1,983[a]	1.8	2.9	0.8
75	1,983[a]	1.3	0.0	0.7

[a] values with different lowercase superscript letters in the same column are different at $p \leq 0.05$;[b] results of statistical comparison of values not reported

Table 5 (cont'd)

K fertilizer (K_2O/ha)	Collar rot incidence (% plant mortality)[b]	Leaf spot incidence (% infected plants)[b]
0	9.17	38.6
25	6.07	28.5
50	4.61	22.6
75	2.22	25.4

[b] results of statistical comparison of values not reported

Furthermore, the results of work by Akhtar et al. (2010) supported the above finding. In their field experiment conducted on a loam soil that had low available N and available P but very high available K (31 mg/kg extractable NO_3, 9.7 mg/kg available P, 214 mg/kg available K), They compared the effects of sulfate of potash and muriate of potash applied at various rates on tomatoes. Nitrogen (200 kg N/ha) and phosphorus (65 kg available P/ha) fertilizers were applied to all experimental treatments. The results showed that K fertilizers statistically decreased fruit borer damage and leaf blight *Septoria* disease incidence on the tomato fruit and increased the fruit yield. Since the K status of the soil was much higher than the sufficient level for plant yield production, it was considered that the increase in the fruit yield was due to the suppressive effects of K fertilizers on both insect pest and disease incidence. This was a case in which K fertilizer decreased both insect pest and disease incidence on a crop grown on a soil with sufficient in K.

5. NPK fertilizers containing not too high N decrease both disease and insect pest incidence on crops. The following are examples.

5.1 Chemical fertilizer (15-15-15 grade) decreased both disease and insect pest incidence on groundnut (Table 6) based on the results of the field experiment on a sandy clay loan soil with relatively low N and P status (1.5% organic matter (OM), 7.84 mg/kg available P; no K analysis was reported). The results clearly showed that increased rates of the NPK fertilizer decreased: 1) the severity of seedling blight, leaf spot and rust; and 2) insect damage of the groundnut. This was a case in which the depressive effects were observed of an NPK fertilizer (1:1:1 ratio) on pest insects and diseases of a crop grown on a soil which was low in N and P.

5.2 Chemical fertilizers (15-15-15 grade) decreased both disease and insect pest incidence on cassava (Table 7) based on an experiment in polyethylene bags using a sandy loam soil (fertility status was not described). The results showed that the applied 15-15-15 chemical fertilizer: 1) decreased both spider mite and mealy bug incidence; and 2) decreased African cassava mosaic disease incidence and showed consistent trends of a decrease in leaf spot infection. This was a case in which the depressive effects were observed of an NPK-fertilizer (1:1:1 ratio) on pest insects and diseases on a crop.

Table 6 Effects of chemical fertilizer (15-15-15 grade) on yield and disease and insect pest incidence on groundnut (Ihejirika et al., 2006)

Chemical fertilizer (kg/ha)[a]	Score for leaf spot[b]	Score for rust[b]	Score for seedling blight[b]	Insect damage[c]	Groundnut kernel (kg/ha)
0	2.08	1.46	1.32	4.87	314
40	1.17	1.22	1.20	4.45	546
80	0.96	1.15	1.16	3.77	563
130	0.96	1.00	1.10	3.28	570
$Lsd_{0.05}$	0.518	0.208	0.204	nr	2.41

nr not reported
[a] chemical fertilizer (15-15-15 grade)
[b] higher score represents higher disease or insect pest incidence
[c] numbers of pots damaged by insects as percentage of the total number of pots

Table 7 Effects of chemical fertilizer (15-15-15 grade) disease and insect pest incidence on cassava plants and cassava plant growth (Omorusi and Ayanru, 2011)

Chemical fertilizer (kg/ha)[a]	Spider mite score[b]	Mealybug score[b]	Mosaic disease score[b]	Leaf spot score[b]	Plant height (cm)
0	2.36	2.04	1.72	8.81	26.8
10	1.80	0.81	1.75	4.21	31.3
100	1.38	0.75	1.15	4.08	36.5
p-value[c]	< 0.01	< 0.01	< 0.05	> 0.05	< 0.01

[a] chemical fertilizer (15-15-15 grade)
[b] higher score represents higher disease or insect pest incidence
[c] only overall *p*-values for experimental treatments reported

Effects of different types of fertilizers on nutritional qualities of plants

The available research results showed no clear differences in the effects of organic and chemical fertilizers on plant nutritional quality. However, they did show that: 1) combinations of organic and chemical fertilizers that were appropriate for the soil properties and the kind of plant were superior to either organic fertilizer or chemical fertilizer alone; and 2) combinations of organic fertilizers, chemical fertilizers and bio-fertilizers appropriate for the soil properties and the kind of plant were superior to using only one type or combinations of two types of fertilizers. The following are examples.

1. Cabbages and cucumbers produced using chemical fertilizer, compost or farmyard manure were not different in total antioxidant capacities (Table 8) based on field experiments in two consecutive years with cabbage and cucumber. All the experimental treatments, except for the control (no fertilizer), were fertilized to the same levels of nutrients according to soil analysis to attain a supposed yield (assuming that the nutrient uptake of 1 t of cabbage was 3.57 kg N, 0.57 kg P and 3.57 kg K and the nutrient uptake of 1 t of cucumber was 1.67 kg N, 0.70 kg P and 2.33 kg K)**.** Corrections were made depending on the organic fertilizers and the content of nutrients in the soil based on referenced recommendations. Plant yields per unit area were not reported. The results showed that chemical fertilizer, compost and manure produced cabbages and cucumbers that were comparable in total antioxidant capacities in both years.

2. Tomato fruits from organic production and GAP (good agricultural practices) production were similar in fruit quality, contents of antioxidants (lycopene, beta-carotene, ascorbic acid and phenolic substances) and antioxidant capacities as concluded by Lumpkin (2005). The author drew this conclusion from the results of a field investigation comparing five organic farms to five matched nearby conventional farms that were generally similar in soil type, environmental conditions and other relevant factors (except management practices) for each pair of organic and conventional farms.

3. Tomato fruits obtained with appropriate combinations of organic manure and mineral fertilizer were higher in nutritional quality than those obtained with either organic manure or mineral fertilizer alone. Heeb (2005) conducted three greenhouse experiments on sand to compare the effects of organic and mineral fertilizers on tomato. The organic fertilizers used were: 1) chicken manure and 2) fresh cut grass and clover mulch, whilst mineral fertilizer was in nutrient solution. The parameters used for the comparison were: 1) taste, 2) contents of ascorbic acid, lycopene and soluble phenolic substances and 3) the total antioxidant capacity of tomato fruits. From the results of the experiments, the author concluded that organic or mineral fertilizers were not important for yield and quality and to achieve a resource saving and balanced nutrient supply and high-quality tomato yield, a combination of organic and mineral fertilizers should be considered.

4. Chemical fertilizer produced higher concentrations of polyphenol and carotenoid and higher antioxidant capacity of sweet potatoes than organic manure, while a combination of chemical fertilizer and organic manure produced the highest values of the three properties (Koala et al., 2013). Koala et al. (2013) conducted a field experiment to examine the effects of well-composed livestock manure (as organic manure) and of mineral fertilizers (applied as single N, P and K-fertilizers) on sweet potato. No description of the soil properties for the experiment was provided. The treatments were combinations of three rates of organic manure and NPK fertilizers using nine N/P/K ratios. The results showed that combinations of organic and chemical fertilizers had higher antioxidant capacities and concentrations of polyphenols and total carotenoids in the product tubers than either the organic fertilizer or chemical fertilizers alone. The organic fertilizer at 20 t/ha applied annually in combinations with 15–30 kg N/ha, 30 kg available P/ha and 45–90 kg K/ha and the organic fertilizer at 20 t/ha applied every two years in combinations with 0–30 kg N/ha, 0-30 kg P/ha and 90–100 kg K/ha had comparable total antioxidant capacities that were higher than all the other combinations. This was a case in which NPK chemical fertilizers with relatively low N in combination with an organic fertilizer enhanced higher concentrations of the phytochemicals than either one of the two types of fertilizers alone.

5. Spinach (*Spinacia oleracea* L.) grown with a combination of chemical fertilizer, organic manure and bio-fertilizer had higher contents of chlorophyll A, chlorophyll B, carotenoid, carbohydrate, vitamin C and vitamin B9 than that grown with any one alone of the three types of fertilizers. Additionally, spinach grown with a combination of two of the three types of fertilizer was either higher than or comparable to that grown with only one types of fertilizer, as shown by research results in Table 9. The results were from a greenhouse experiment using a sandy soil with 0.23% OM (P and K status were not reported). The experimental treatments were: 1) C: application of chemical fertilizer, 2) O: application of organic compost, with 0.60% N and 84.5 parts per million P; (3) B: application of biofertilizer; and (4) C + O; 5) C+B; 6) O + B; and 7) C + O + B.

Table 8 Effects of different types of fertilizers on total antioxidant capacity (milligrams gallic acid equivalent/100 g) of cabbage head and cucumber fruits (Pavla and Pokluda, 2008)

Fertilizer[a]	Cabbage[b]		Cucumber[b]	
	2005	2006	2005	2006
No fertilizer	233±32[a]	299±27[a]	108±14[a]	184±1[a]
Chemical fertilizer	186±73[a]	281±5[a]	117±43[a]	53±33[b]
Compost	201±34[a]	284±22[a]	133±10[a]	60±38[b]
Farmyard manure	211±65[a]	296±32[a]	129±32[a]	62±12[b]

[a] all fertilizers applied according to soil analysis, supposed yield and average NPK uptake of crops (cabbage: 3.57 kg N/t, 0.57 kg P/t, 3.57 kg K/t; cucumber: 1.67 kg N/t; 0.70 kg P/t; 2.33 kg K/t)

[b] values (mean ± SD) in the same column with the same lowercase superscript letter are not different at $p \leq 0.05$ (Tukey's honest significant difference test).

Table 9 Effects of different types of fertilizer on dry weight of aerial parts, concentration of chlorophyll A, chlorophyll B and carotenoid, carbohydrate in tissue and vitamin C and vitamin B9 in leaves of spinach (Alderfast et al., 2010)[a]

Fertilizer	Dry weight (g/pot)	Chlorophyll A (mg/0.10 m^2)	Chlorophyll B (mg/0.10 m^2)	Carotenoid (mg/0.10 m^2)
Chemical fertilizer (C)	12.9^{a}	2.23^{cd}	1.57^{ab}	0.82^{a}
Organic manure (O)	3.4^{e}	1.75^{de}	1.11^{bc}	0.67^{b}
Bio-fertilizer (B)	4.2^{e}	1.55^{f}	0.76^{c}	0.56^{b}
C + O	7.8^{c}	2.88^{b}	1.77^{a}	0.91^{a}
C + B	11.1^{b}	2.55^{bc}	1.67^{a}	0.74^{ab}
O + B	3.1^{c}	2.04^{de}	1.14^{bc}	0.81^{a}
C + O + B	5.6^{d}	3.77^{a}	2.18^{a}	0.88^{a}

C: comparable to 12-12-40 fertilizer at 4.5 g/pot containing 7 kg of soil; O: 14 g/pot compost (0.60% N); B: *Azotobacter* sp., *Azospirillum* sp. and phosphate solubilizing bacteria

[a] values with a common lowercase superscript letter in the same column are not different at $p \leq 0.05$

Table 9 (cont'd)

Fertilizer	Carbohydrate (%)	Vitamin C (mg/10g)	Vitamin B9 (mg/10g)
Chemical fertilizer (C)	13.3^{cd}	42.7^{b}	85.0^{de}
Organic manure (O)	12.0^{de}	28.4^{d}	55.0^{de}
Bio-fertilizer (B)	11.6^{e}	29.0^{cd}	40.0^{e}
C + O	15.0^{b}	44.7^{ab}	125.0^{b}
C + B	14.0^{bc}	41.1^{b}	100.0^{bc}
O + B	13.5^{c}	38.0^{ab}	65.0^{de}
C + O + B	21.0^{a}	52.2^{a}	155.0^{a}

Effects of different types of fertilizers on sensory qualities of plants

Generally, mineral N fertilizers and most organic fertilizers decrease the aroma or softness of aromatic rice or both. In soils that have P lower than the level that gives the maximum paddy yield, adding P fertilizer at the rate that produces the maximum paddy yield results in the highest softness. For soils that have K at the level lower than that for the maximum paddy yield, adding K fertilizer, up to the rate that is higher than the rate for maximum paddy yield so that the yield is decreased to around 80% of the maximum yield, enhances the aroma of rice. With the application of an organic fertilizer to aromatic rice, consideration of P and K fertilizers to be applied along with it is necessary to offset the negative effects of the organic fertilizer on the aroma and softness. The following research findings provide supporting evidence.

1. Most organic fertilizers, which mostly have higher N than P and K, and mineral N fertilizers decrease the aroma and softness of Kaw Dauk Mali-105 aromatic rice and Suphan Buri-1 aromatic rice, except in the case that the soil had very low N. For soils with very low N, adding N fertilizers at the rates that produce paddy yields at 30% or less of the maximum yields increased the two qualities (Tables 10 and 11).

The results in Table 10 are from a pot experiment using clay soil, with medium total N (0.13%N), high available P (31 mg/kg P by Bray-II method) and very high exchangeable K (122 mg/kg K), to examine the effects of an organic fertilizer on the aroma of Suphan Buri-1 aromatic rice. The tested organic fertilizer, prepared from composting soybean meal with cow dung, had 60.6% organic matter, 7.9 C/N ratio, 4.4% total N, 4.0% total P and 3.0% total K. The results showed that the lowest rate of applied organic fertilizer increased the aroma, while higher rates produced increased negative effects on the aroma, which indicated a parabolic relationship between the rates of applied organic fertilizer and the aroma, with the lowest rate being the rate that produced rice grains with the highest aroma. The results in Table 11 were obtained from a field experiment on clay soil (1.3% OM, 8 mg/kg Bray-II available P, 50 mg/kg extractable K) to examine the effects of mineral N fertilizer on the cooking qualities of Kaw Dok Mali-105 aromatic rice. The obtained effects of mineral N fertilizers on the aroma was appreciably similar to that of the organic fertilizer shown in Table 10 and, in addition, the softness of the cooked rice was decreased by increased rates of the chemical N-fertilizer. Additionally, Gu et al. (2015) reported that the application of mineral N fertilizer decreased grain quality, especially in terms of eating and cooking quality.

Table 10 Effects of organic fertilizer on yield and aroma of Suphan Buri-1 aromatic rice (Poomipan et al., 2017)

Amount of N in applied organic fertilizer (kg N/ha)[a]	Paddy yield (kg/ha)[b]	Concentration of aromatic substance (2-AP) in grain (ppm)[b]
0.0	1,769^{d}	1.59^{b}
78.1	2,844^{c}	1.77^{a}
156.3	3,900^{b}	1.43^{c}
312.5	5,581^{a}	1.15^{d}
% CV	12.4	9.1

ppm = parts per million

[a] organic fertilizer with 4.3% N, 4.0% P and 3.05% K

[b] values in the same column with different lowercase superscript letters are different at $p \leq 0.05$.

Table 11 Effects of nitrogen from chemical fertilizer on paddy yield, aroma and softness of grain of Kaw Dok Mali-105 aromatic rice (Suwanarit et al., 1996)[a]

Amount of N in applied chemical fertilizer (kg N/ha)	Paddy yield (kg/ha)	Aroma score[b]	Softness score[b]
0.0	3,163[c]	6.60[a]	7.30[a]
31.3	4,513[b]	6.65[a]	6.95[ab]
93.8	5,450[a]	6.20[b]	6.55[b]
281.3	2,644[c]	5.10[c]	5.50[c]

[a] values in the same column with a common lowercase superscript letter are not different at $p \le 0.05$.

[b] higher score represents higher quality

2. The softness of Kaw Dauk Mali-105 rice was highest at the rate of P fertilizer that produced around the maximum paddy yield as reported by Suwanarit at al. (1997). This group of authors conducted six pot experiments to examine the effects of the rate of chemical P fertilizer on the sensory qualities of cooked Kaw Dauk Mali-105 aromatic rice. Six soils with different N, P and K status were used but blanket chemical N and K fertilizers were applied to all the experimental treatments so that the N and K supply levels of each soil were at the levels that enhanced the maximum growth of rice plants. The results showed significant parabolic relationships among the relative softness of cooked rice grains and relative paddy yields and relative shoot dry matter weight, with the softness of cooked rice being highest at the rate of P fertilizer that produced 99.5% of the maximum paddy yield.

3. The aroma of Kaw Dauk Mali-105 rice was highest at the K fertilizer rate that was higher than that produced the maximum yield as found by Suwanarit et al. (1997a). This group of authors conducted eight pot experiments to examine the effects of the rate of chemical K fertilizer on the sensory qualities of cooked Kaw Dauk Mali-105 aromatic rice. Eight soils with different N, P and K status were used but blanket mineral N and P-fertilizers were applied to all the experimental treatments so that N and P supply levels of each soil were at the levels that enhanced maximum growth of rice plants. The results showed highly significant parabolic relationships among the relative aroma of cooked rice grains and relative paddy yields, with the aroma of cooked rice being highest at the rate of K fertilizer that was so high that the paddy yield was reduced to 82% of the maximum paddy yield.

Contamination of nitrate in plant produce

In application of fertilizers to the same soil type to obtain comparable plant yields, plants produced using organic fertilizer have a greater nitrate concentration than those produced using chemical N fertilizer. The results shown in Table 12 support this statement and are from a 2 yr field experiment to compare the effects of different fertilizers on cabbage. The tested fertilizers included farmyard manure (0.97% N, 0.61% P and 1.04% K; applied at 55 t/ha), compost (0.57% N, 0.09% P and 0.21% K; applied at 30 t/ha) and mineral fertilizer (analysis and application rate were not reported). The application rates were calculated based on: 1) soil analysis; 2) a target cabbage yield of 50t/ha assuming that to produce 1 t of cabbage required 3.57 kg N, 0.57 kg P and 3.57 kg K; and 3) corrections according to referenced literature. The results (the averages obtained in two years) showed that the farmyard manure and the chemical fertilizer increased both the cabbage yield and nitrate concentration in the cabbages, but the compost did not affect these two parameters. The farmyard manure, which produced a cabbage yield comparable to that from using chemical fertilizer, produced cabbages with a nitrate level that was 1.7 times that found in cabbages grown using the chemical fertilizer. Though the compost resulted in a lower nitrate concentration in the cabbages than from using chemical fertilizer, the cabbage yield using compost was much lower than that of cabbage grown using the chemical fertilizer. Accordingly, a comparison of the nitrate concentration in cabbages grown using the compost and in cabbages grown using the chemical fertilizer would undoubtedly result in a misleading conclusion.

Effects of different types of fertilizers on compaction and hardness of soil

Similar to organic fertilizers, chemical fertilizers (generally containing no organic substances) help reduce the bulk density and hardness of soils if *in situ* plant stubble is plowed into the soil instead of being taken away or being burned. The research results shown in Tables 13 and 14 support this statement; which is contrary to the belief or misperception of some people that mineral fertilizers increase the bulk density and hardness of soil (Suanchokwichian, 2016).

Specifically, the results in Table 13 are from a long-term experiment in a paddy field, with a clay loam soil, to compare the effects of different rates of a rice straw compost (with 2.16% N, 0.28% P, 0.50% K, 13.2 C/N ratio) and of 8-4-4 mineral fertilizer and combinations of these two types of fertilizer when applied annually for paddy rice production on rice yields and soil properties. In all the experimental treatments, the rice stubble was left on the soil surface until 20 d before the annual rice planting at which time it was mowed and plowed into the soil, whereas the compost was applied using broadcasting followed by plowing into the soil at the same time as the stubble management. The results, obtained after the 11th annual planting, showed similar effects of the compost and mineral fertilizers on the bulk density and hardness of the soil.

Table 12 Effects of compost, farmyard manure and chemical fertilizer on yield and nitrate concentration in cabbage (Zahradnik and Petrikova, 2007)

Fertilizer[a]	Weight of cabbage head[b] (kg/m^2)	Nitrate concentration in cabbage head[b] (mg/kg)
No fertilizer	6.40[a]	40[a]
Compost	5.79[a]	49[a]
Farmyard manure	8.06[b]	121[c]
Chemical fertilizer	7.86[b]	71[b]

[a] rates adapted to a target yield of 50 t/ha, assuming that the rates of nutrients required to produce 1 t of cabbage are 3.57 kg N, 0.57 kg P and 3.57 kg K
[b] values in the same column with different lowercase superscript letters are different at $p \le 0.05$.

Table 13 Effects of chemical fertilizer and compost annually applied to soil for paddy rice cultivation for 11 yr (with incorporation of the left-over stubble in land preparation before the following annual cropping) on bulk density and hardness of the soil (Songmuaeng et al., 1986)

Fertilizer	Bulk density of soil at 4–10 cm depth (g/m^3)[c,d]	Hardness of the surface layer[a,d]
No fertilizer	1.67[b]	24.7[b]
Chemical fertilizer[b]	1.60[a]	19.6[ab]
Compost[c]	1.60[a]	17.2[a]

[a] higher value indicates higher hardness.
[b] equivalent to 16-8-8 fertilizer at 312.5 kg/ha/yr.
[c] 6.25 t/ha/yr.
[d] values in the same column with a common lowercase superscript letter are not different at $p \leq 0.05$.

The results in Table 14 were from a long-term field experiment on a clay loam soil to examine the effects of NP fertilizer (N:P = 1:1) applied to soil for annual maize cropping on the properties of the soil. Maize stubble was left on the soil surface after annual harvest and was mowed and plowed into the soil as a part of the land preparation about 1 mth before annual cropping. The results, obtained after the 10th annual cropping, showed that the application of NP fertilizer decreased the bulk densities of the soils at depths of 2–8 cm and 12–18 cm.

Table 14 Effects of chemical fertilizer applied to soil for annual maize cropping for 10 years on bulk density of the soil (Tattao, 1987)[a].

Fertilizer	Bulk density of soil (g/m^3)[c]	
	At 2–8 cm depth	At 12–18 depth
No application	1.17[b]	1.48[b]
Chemical fertilizer[b]	1.04[a]	1.23[a]

[a] maize stubble left on soil surface and plowed into the soil in land preparation for following cropping.
[b] equivalent to 10-10-0 fertilizer at 312.5 kg/ha/yr.
[c] values in same column with different lowercase superscript letters are different at $p \leq 0.05$.

Effects of different types of fertilizers on the environment

OPP, which uses organic fertilizers and bio-fertilizers, causes more detrimental environmental effects than from plant production that considers appropriate use of chemical fertilizers along with organic fertilizers and bio-fertilizers. The detrimental effects include: 1) nitrate leaching from the soil; 2) emission of greenhouse gases; 3) accumulation of heavy metals in the soil; and 4) soil deterioration. The following are examples of research results that support these statements.

1. Torstensen et al. (2006), who conducted long-term field experiments on soils with fine, medium and coarse textures for 10 yr or more, concluded that to produce one unit weight of plant produce, OPP released nitrate from the soils by an amount that was more than twice that released by crop production using organic manure, bio-fertilizer and mineral fertilizer in combinations that were appropriate to the soil and plant requirements. The main reason for higher nitrate leaching in OPP was the lack of synchrony between the N release from organic N sources and the crop demand.

2. Organic fertilizers enhanced the emissions of methane (CH_4) and nitrous oxide (N_2O) from soils compared to mineral fertilizers, both under submerged and upland conditions (Stevens and Laughlin, 2001; Meng et al., 2005; Ma et al., 2007; Jin et al., 2010; Yang et al., 2010). These gases have Global Warming Potentials that are 28–36 and 265–298 times, respectively, of that of CO_2 based on a 100-year timescale (Environmental Protection Authority, 2018). Accordingly, it seems that the application of organic manure to soils with the aim of delaying conversion of the organic C to CO_2 is undesirable, especially in the case where the soil properties and the environment are favorable to the emission of these two gases.

3. Organic fertilizers have a greater risk of the accumulation of heavy metals in soils to harmful levels than chemical fertilizers, as suggested by the results of study shown in Table 15 where the amounts of the studied heavy metals, except cadmium (Cd), annually brought into the agricultural soils of England and Wales from the use of organic fertilizers were much higher than those arising from chemical fertilizers and agricultural limes: the amounts were more than 11.3, 3.2 and 2.0 times of those brought in by chemical fertilizers and limes in the cases of lead (Pb), arsenic (As) and mercury (Hg), respectively, and 4.3 times of that brought in by chemical fertilizers and limes in the case of chromium (Cr).

Table 15 Amounts (t/yr) of heavy metals brought in by organic manures and by chemical fertilizers and lime to agricultural soils in England and Wales (Nicohlson et al, 1998)

Material	Pb	Cd	Cr	As [a]	Hg
Organic manures					
Household waste	95	2	98	nd	2
Farmyard manure	52	4	39	16	<1
Industrial waste	<1	<1	210	<1	<1
Total	>147	>6	347	>16	>2
Chemical fertilizers and lime	13	8	81	5	<1

nd = no data available.

Organic farmers' experience of soil deterioration

Though the percentage of farmland in Europe that is organic had been increasing in the past (reaching nearly 6% in 2014), the percentage of organic farmland in Scotland has been decreasing (Scottish Government, 2016). In 2002, almost 8% of agricultural land in Scotland was organic, almost double the rate in the UK. But this fell sharply thereafter and by 2007 the rate was about 4%, matching that across the UK, and since then Scotland had been below the rest of the UK. In 2015, the total area was equivalent to 2.3% of agricultural land in Scotland, compared to 3.0% in the UK as a whole. From interviewing farmers across the UK who had made the change over the past few years, Rustin (2015) found a variety of reasons for the change, with one of them being soil deterioration.

Soil deterioration after a certain time of organic plant production should be expected because the supplies of the fertilizer elements (N, P and K) in the soil change with the length of time of land utilization. After a certain period of time, supplies of some of the elements in the soil will become too high while that of the others will be too low for normal plant growth and development due to: (1) imbalance (which may be positive in the case of one element but negative in the case of another element) between the nutrient input to the soil through organic fertilization and the nutrient taken away from the soil through harvesting plant produce; and 2) characteristically too little variation in the N, P and K contents of different organic fertilizers. Variation in the contents of N, P and K is so small that changes of the kind or source of organic fertilizer, if done by the farmer, will not help adjust the supplies of these elements to the suitable ones; this is unlike chemical fertilizer which can be produced to have large variation in its N, P and K contents and can be used in such a way that the maintenance or improvement of balance as well as increased levels of nutrient elements are attained. Accordingly, after a certain time of OPP the soil will not be as productive as it was at the beginning of the land utilization or, in other words, the soil deteriorates in its fertility.

Plant production superior to OPP

From the above-mentioned research results, it is clear that plant production involving the use of chemical fertilizers in appropriate combinations with other types of fertilizers, (organic fertilizers and bio-fertilizers), is superior to OPP which does not allow chemical fertilizer use, in enhancing lower produce cost, fewer plant pest problems, superior nutritional and sensory qualities of produce, lower detrimental environmental effects, lower nitrate contamination in plant produce and better conservation or improvement in soil productivity or both. However, OPP has the advantage of resulting in plant produce that is free from toxic plant-pest-control chemicals. Therefore, plant production that uses no toxic-plant-pest-control chemicals and considers uses of chemical fertilizers in appropriate combinations with organic fertilizers and bio-fertilizers shall not only produce toxic chemical-free plant produce but also it will be superior to organic plant production in enhancing lower produce cost, less plant pest problems, superior nutritional and sensory qualities of produce, lower detrimental environmental effects, lower nitrate contamination in plant produce and better conservation and/or improvement of soil. Such a plant production system is hereafter called "Toxic Chemical-Free Production" or TCFP.

However, TCFP cannot be practiced in most areas of plant production, especially in Thailand, due to intensive plant pest occurrence. In this case, plant production employing good agricultural practices (GAP) that allows appropriate uses of chemical fertilizers to enhance the superiority of appropriate combinations of chemical fertilizers, organic fertilizers and bio-fertilizers in the above-discussed aspects along with use of plant pest control chemicals by the recommended practices, shall be more suitable in these areas compared to OPP and accordingly should be practiced by farmers.

Consumer protection problem imposed by OPP

In addition to the inferiority based on all aspects deduced in the preceding section compared to TCFP, OPP has another serious drawback, as there is no way to check whether a plant produce that claims to be organic has in fact been grown with or without chemical fertilizers, whereas those products attributed as produce from TCFP and GAP can be checked using chemical analysis of the toxic substances in the produce. Therefore, the certification of organic produce has no appeal in terms of consumer protection because TCFP produce which can be obtained using chemical fertilizers, for example, may be claimed as organic. From the above discussion, it would appear that only TCFR and GAP produce and not organic produce, can be certified with reliability. Certification based on the production process as is done by some organizations should not be used to certify plant produce, since it is not a reliable way of certifying plant produce and, accordingly, in protecting consumers.

Examples of research methodology or misinterpretation of research results or both that may lead to a mistaken belief or misperception of OPP

The following are examples of research work in which the methodology or misinterpretation of the results (or both) may lead to a mistaken belief in OPP.

Research work of Zahradnik and Petrikova (2007)

Some results of this work are given Table 12. The methodology of this work was described in Section 6. The results showed that the farmyard manure and the chemical fertilizer increased both the cabbage yield as well as the nitrate concentration in the cabbages but the compost did not affect these two parameters, though effort was made to design the experimental treatments so that all of them would produce the same target yield. The farmyard manure produced cabbages with a nitrate concentration that was 1.7 times higher than that found in cabbages produced using chemical fertilizer. Though the compost produced cabbages that were lower (by 0.69 times) in nitrate concentration than that of cabbages grown using the chemical fertilizer, this did not increase the cabbage yield. Accordingly, comparison of the observed nitrate concentration in these two cases was unjustifiable. Mistakenly, if one took it for granted from a comparison of the actual nitrate contents, the conclusion should be drawn that using chemical fertilizer produced cabbage that contained a higher nitrate level than the cabbages produced with the compost and this would lead to a mistaken belief that OPP had this advantage over TCFR.

Research work of Poomipan et al. (2016)

Some results of this work are given in Table 16. The results were from a pot experiment using a clay soil with moderate N status (0.13% total N), high P status (31 mg/kg Bray-II available P) and very high K status (122 mg/kg exchangeable K) to compare the effects of an organic fertilizer (4.43% total N, 3.99% total P, 3.04% total K) and a chemical fertilizer on the yields and aroma of Suphan Buri-1 aromatic rice. Both the organic and chemical fertilizers were applied at rates that provided N at the rate of 78 kg total N/ha and the organic fertilizer was equally applied at 10 d after transplanting and at the panicle initiation (PI) stage, whereas the chemical fertilizers were applied as a 16-20-0 fertilizer at the rate that provided 34.3 kg N/ha at 10 d after transplanting and as urea at the rate that provided 43.7 kg N/ha at PI. The results showed that rice grains produced using the organic fertilizer had a higher aroma value than those produced using packaged chemical fertilizers. Though the experimental treatments were designed so that the same amount of N fertilizer was applied, the organic fertilizer produced a lower paddy yield and a lower total N uptake than from using chemical fertilizers, indicating a lower N supply from the former fertilizer than from the latter. Since a higher N supply produced a lower aroma value for the rice grain, as shown in Table 15, it is not valid to draw the conclusion from a comparison of the observed aroma levels and, accordingly, if one took it for granted from a comparison of the observed aromas, the conclusion would be invalid that the organic fertilizer produced rice with a higher aroma than that of rice grown using chemical fertilizers and this could lead to the mistaken belief that OPP has this advantage over TCFR.

Table 16 Effects of organic and chemical fertilizers on paddy yield and the aroma of Suphan Buri-1 aromatic rice (Poomipan et al., 2016)

Treatment	Paddy yield (kg/ha)[b]	Total N uptake (kg/ha)[b]	Concentration of aromatic substance (2-AP) in de-husked grain (ppm)[b]
Control	1,769[c]	22.4[c]	1.59[ab]
Organic fertilizer[a]	2,844[b]	29.9[b]	1.77[a]
Chemical fertilizer[a]	3,325[a]	48.4[a]	1.46[b]
% CV	14.3	13.5	5.2

ppm = parts per million

[a] applied at rate equal to 78 kg total N/ha

[b] values in the same column with a common lowercase superscript letter are not different at $p \leq 0.05$

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