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Original Paper

An Evaluation Method for Various Recycled Organic Materials Using a Self-Organizing Map

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自己組織化マップを用いた多様な有機性資源化物の評価法の検討

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1. Introduction

Various kinds of organic wastes like sewage sludge, food scraps and kitchen garbage, in addition to animal manure and food processing residue have recently been promoted for recycling. In the recovery treatment of these organic wastes, some new methods such as carbonization, gasification and thermal decomposition have been developed. Although the variety of applications for produced recycling materials have also gradually increased, the main use is expected to be in agriculture as fertilizer and soil amendment.

In the fertilizer control act in Japan, the composted and dried sludge of sewage is classified as normal fertilizer, whereas compost from livestock excrement has been classified as special fertilizer. Manufacturers have an obligation to express the chemical and nutrient component of the produced material. For fertilizers from sewage sludge, they also have a duty to assay the injuries when they are used with young plants. In general, the rate of application of fertilizers for recycled organic materials is indicated by the content of nitrogen, phosphorus and potassium, and with C/N ratio or pH. It is difficult to actually estimate the quantity of effective nutrients which will be obtained in the field since the degradation and mineralization rates of the recycled organic materials are influenced by the soil and the weather conditions. The fertilizer nutrient remaining in the field will change with the absorption rate of the nutrient by the cultivated crops. It has been indicated that the effects of the organic fertilizer cannot be discussed with only the results of a single year cultivation test. For example, Kuboi *et al.* (1995) reported that long-term continuous test under crop cultivation is indispensable for judging the effectiveness of sewage sludge. Yasuda *et al.* (2003) asserted that compost application of 20 t/ha every planting is necessary for soil productivity maintenance. Since

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so many years and costs are necessary to produce results of continuous cultivation tests, it is hoped that features of the recycled organic materials can be shown by more convenient tests.

The evaluation methods for recycled organic materials have been examined by many researchers. Some typical methods of evaluation for recycled organic materials are supposed, such as the concentration of nutrient components, the ripeness of humus, young plant tests and so on (Matsunaka, 2003). Excess amounts of recycled organic materials are often applied to fields because decomposition and mineralization go on very slowly and little effect appears in the nutriment for crops. It also causes environmental problems. There are reports which show environmental influence such as changes in ammonia volatilization (Misselbrook *et al.,* 2001) and in quantities of effluent and leaching from spread compost in a field (Couillard and Li, 1993).

What kind of view point should be important for the evaluation of recycled organic materials in reconstructing the recycling society? How should communications between the manufacturer and the user of the recycled organic materials be framed? Especially, the users of the recycled organic materials have strong interests in the qualities of recycled organic materials and aspire to understand not only their component data but also their effect on fields and on crop growth. Evaluation of the fertilizers' components in the crop and the components which remain behind in the soil is necessary for comprehending their effect on cultivation. Results obtained by a cultivation test are reported in tables and figures to describe agronomic properties of the recycled organic materials. The method of principal component analysis (PCA) is a powerful statistical method to understand such multi-dimensional information as mentioned above. A map of the principal component score calculated by PCA can show the total characteristic of individual recycled organic material visually. The principal component score, however, is likely to be the same value and the materials can not be distinguished adequately.

The Self-Organizing Map (SOM) is a visualization technology for multidimensional information systematized by Kohonen (1995), and since improved by many researchers. SOM uses the similar way as PCA in the local process of sorting. In SOM, an individual material is expressed by a unit and illustrated by a small circle or a honeycomb cell in two dimensional map. The unit cells which have similar data will be gathered in neighboring area through the learning process. We used SOM in this paper to describe the agronomical properties after crop cultivation test. Comprehensive evaluation and notation methods for various recycled organic materials will be discussed in this paper by using PCA and SOM.

2. Cultivation tests using the recycled organic materials

2.1 Materials and method

As test fertilizers for recycled organic materials, cattle excrement compost, sludge compost and sludge pyrolysate were used in comparison with ordinary chemical fertilizer. The cattle excrement compost was produced from the manure of dairy cattle raised on the university farm of Tokyo University of Agriculture and Technology. Surplus sludge from human waste treatment was supplied to make sludge compost and sludge pyrolysate roasted at about 200℃. Components and features of the test materials as fertilizer and soil are shown in Table 1.

As test crops for the cultivation tests, komatsuna (*Brassica rapa* L. var. *peruviridis*) and radishes (*Raphanus.sativus* L. var. *radicula*) were cultivated. In respect of the nutrient rate of application in the cultivation test plots, 1 times to 4 times the rate of total nitrogen were set for each test fertilizer on the standard basis of chemical fertilizer used in the Kanto district considering the degradation rate and the ferti-

Table 1 Chemical properties of test recycled organic materials and soils

	T-N (%DM)	P_2O_5 (%DM)	K_2O (%DM)	Mg (%DM)	Ca (%DM)	C/N (−)	EC (mS/cm)	pH (−)
Chemical fertilizer	7.06	5.39	1.99	0.42	4.61	0.08	55.30	4.92
Cattle excrement compost	2.77	1.18	4.57	1.27	0.00	4.73	1.361	8.50
Sludge compost	4.38	10.82	1.59	2.14	0.02	5.49	1.972	7.96
Sludge pyrolysate	4.70	7.23	1.76	2.07	0.02	6.12	1.935	6.89
Red soil	0.13	0.01	0.22	0.30	0.02	13.61	0.107	5.59
Black soil	0.47	0.03	0.14	0.20	0.06	13.58	0.285	5.45

lizer effect. The test plots combining two optional fertilizers were designed similarly at 1 times to 4 times the standard nitrogen. Two optional fertilizers were weighed to make total nitrogen of each fertilizer equivalent. Two kinds of soil which have no nutrient were blended as growth media in the ratio of 1 : 1 by volume. Soil was added with the test fertilizers as N : P : K = 15 : 7 : 12 (kg/10 a) for komatsuna and N : P : K = 19 : 11 : 15 (kg/10 a) for radish. On the test plot with partial fertilizer component, calcium superphosphate and potassium sulfate were added, while on the plot of surplus fertilizer component was remained. Test crops were cultivated with a plastic growth pot of 14 cm diameter, 12 cm depth and 0.8 kg DM soil, in the net roof room of the university farm (Fuchu, Tokyo). Five individuals were grown with five growth pots in each test plot. The cultivation period was from 24th October to 15th December, 2004. Atmospheric temperature and rain fall during the cultivation period were illustrated in Figure 1. The places of growth pots were changed weekly so as to avoid the effect of solar radiation incident upon the net roof room. The crops were watered properly, considering the surface condition of the growth soil and the amount of rainfall.

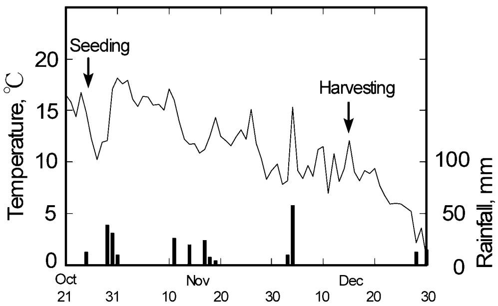

Fig. 1 Atmospheric temperature and rainfall during cultivation period.

2.2 Chemical analysis of nutrient components

The nutrient components of harvested crops and remaining growth soils were analyzed with a standard chemical method as follows. Three big individuals from five growth pots were selected as analysis samples along with three growth soil samples from which the root was carefully removed. The results of cultivation tests were described with an average of three selected samples. The concentration of nitric acid included in the harvested crop was measured with the colorimetric method using salicylic acid (Cataldo method). The concentration of phosphorus was calculated from the concentration of phosphoric acid measured with the colorimetric method using vanadmolybdate acid after pre-treatment by a wet resolving method. The concentration of potassium, magnesium and calcium were analyzed by atomic absorption spectrophotometer after pre-treatment by a wet resolving method. The nutrient components of the growth soil were analyzed by the same method as that used for the crop except for the concentration of total nitrogen which was measured by a dry combustion method.

2.3　Test result

(1) Growth result

The test plot was shown by the symbol for the trial fertilizer : a : chemical fertilizer, b : cattle excrement compost, c : sludge compost, d : sludge pyrolysate, e : non fertilizer. For example, a combination of chemical fertilizer and cattle compost is shown as “ab”. In addition, each test plot was labeled with a numeral in the range 1–4, according to the amount of fertilizer. Yield of komatsuna for each test plot is shown as fresh mass in Figure 2. Fresh mass is shown on the vertical axis with test plot shown horizontally. The growth of crops in single uses of the trial fertilizer increased in proportion to rate of application. The growth in cases where chemical fertilizer was used was the best generally. Growth was retarded on the cattle compost plots.

In the cases where a combination of fertilizers was used, the plots containing chemical fertilizer and sludge compost produced the greatest yield and the next highest yield was produced by the plots in which chemical fertilizer and sludge pyrolysate were used. The fresh mass of chemical fertilizer and cattle compost combined was more than that of only cattle compost. The test results of the radish cultivation are not shown here. Lamina of radish in the test plots increased in proportion to the rate of application, while its root did not. Takebe *et al.* (1995) showed the similar growth results for komatsuna using three times the nitrogen standard with sewage sludge. Both nitrogen uptake and fresh mass were half of the controls obtained using the standard chemical fertilizer.

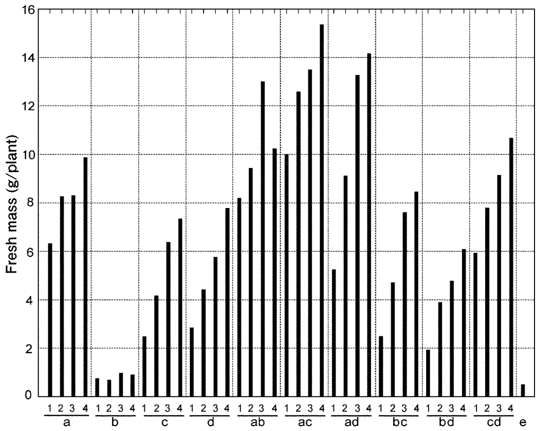

Fig. 2　Fresh mass of komatsuna in the harvest. Symbol means the test fertilizer ; a : chemical fertilizer, b : cattle excrement compost, c : sludge compost, d : sludge pyrolysate, e : non fertilizer. ab : combination of chemical fertilizer and cattle compost. Number means amount of fertilizer ranged from 1 times to 4 times standard level.

(2) Nutrient analysis results

The concentration of nitric acid in lamina was shown in Figure 3. Its concentration in lamina was less than that in petiole but the necessary mass of petiole could not be secured in all plots because the petioles were thin. The concentration of nitric acid in the lamina was high in the chemical fertilizer plots and sludge compost plots, and the concentration increased in proportion to rate of application. The changes in the content rate of calcium, magnesium, potassium and phosphoric acid are shown in Figure 4. Phosphoric acid and potassium tended to increase approximately in proportion to rate of application. However, the content rate of potassium was significantly lower in the cattle compost plots. The content of magnesium and calcium in the lamina tended to be lower as the

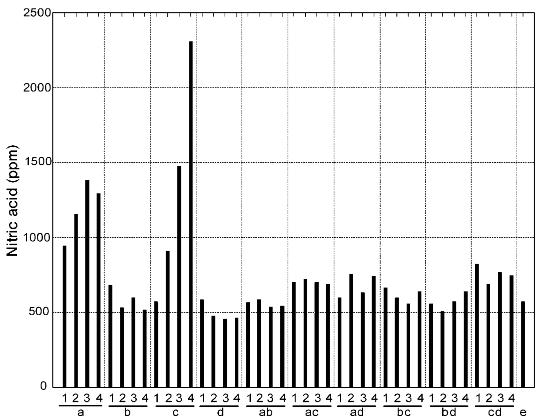

Fig. 3　Concentration of nitric acid contained in komatsuna lamina.

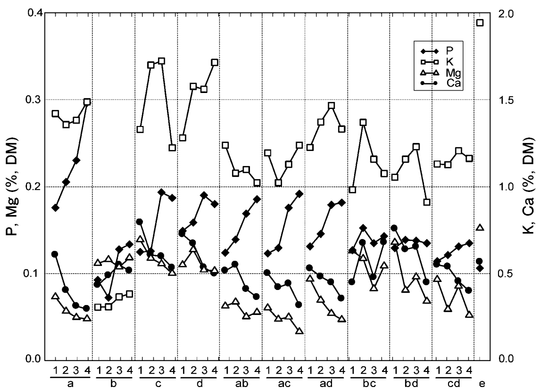

Fig. 4 Content rate of phosphorous, potassium, calcium and magnesium in komatsuna lamina.
◆ ; phosphorous, □ ; potassium, ● ; calcium, △ ; magnesium.

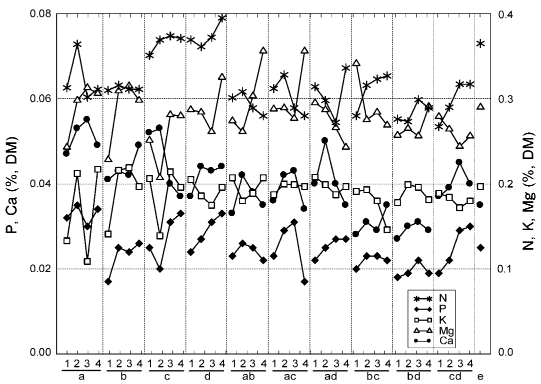

Fig. 5 Soil component after the cultivation, the content rate of nitrogen, phosphorous, potassium, calcium and magnesium.
＊ ; nitrogen, ◆ ; phosphorous, □ ; potassium, ● ; calcium, △ ; magnesium.

amount of application increased, except for the cattle compost plots. The relation between the content rate and fertilizer level in the combination plots of the cattle compost and other fertilizer was complex.

In relation to the soil component after the cultivation, the content rate of total nitrogen, phosphoric acid, potassium, magnesium and calcium are shown in Figure 5. The content of total nitrogen decreased in comparison with the initial content of the test plot for the chemical plot and the cattle excrement plot, while it increased in both the sludge compost and sludge pyrolysate plots. Total nitrogen content in the combination test plots which contained chemical fertilizer and sludge compost or sludge pyrolysate did not increase compared to the original level before the test.

Nishio *et al.* (2004) reported nitrogen dynamics in a cultivation experiment using a combination of chemical fertilizer and cattle excrement compost or pig excrement compost. In the result for the pig excrement compost, remaining nitrogen in the soil was more than the input nitrogen. However, the result was on to the contrary for the cattle excrement compost. It was confirmed that nitrogen dynamics differed according to the organic substances combining chemical fertilizer when they were applied to the soil. In our experiment, nitrogen dynamics in the combination plots of chemical fertilizer and sludge compost or sludge pyrolysate differ from that in the plots of sole sludge compost or sole sludge pyrolysate.

Except for total nitrogen, the concentration of the soil components being considered decreased after cultivation. Though for phosphorus and magnesium the concentration of components in the soil was higher in proportion to the rate of application, for potassium and calcium the relation between the rate of application and the concentration after cultivation was not clear. By subtracting the component remaining after cultivation and the component absorbed by the crop from the component before cultivation, we obtain the amount escaping to outside the pot. We refer to this as the "environment runoff". The sludge compost plots had a high environment runoff rate for phosphorous, and the next highest rate was in the sludge pyrolysate plots. The environmental runoff rate also increased with higher fertilizer levels.

3. Principal component analysis of test result and self-organizing map

3.1 Method of principal component analysis

The data used for analysis were yield of crop, concentration of each of total nitrogen, phosphorus, potassium, magnesium and calcium in the crops, and concentration of residual phosphorus in the growth soil for all test fertilizers. The standardized data was used in the analysis because the units are different in the original data. All data can be confidently explained in terms of the first principal component and second principal component by PCA in which the eigenvalues of first principal component and second principal component were greater than 1 and the contribution ratio also exceeded 70%.

3.2 Presentation by PCA

The eigenvector of first and second principal components in PCA is shown in Table 2. As indices which could be used to synthetically evaluate crop yield and quality in the cultivation experiment, it became clear that fresh mass and phosphorus concentration of crop are equivalently important from the eigenvector of the first principal component. From the eigenvector of the second principal component, the concentration of calcium, magnesium, potassium is taken here to be an index to the "quality" of crop cultivation. The first principal component in PCA presents the total growth of crops and second principal component shows the degree of crop absorption and soil residue, and the effect on the quality.

The principal component score from the viewpoint of the first and second principal component was shown in Figure 6, which presents the effect of the trial fertilizer on the cultivation experiment result. Type of fertilizer and fertilizer level are shown by the character in the figure. The fluctuation of crop yield and quality in the cultivation result were illustrated compactly together in two-dimensional information. This figure helps to understand features of the trial fertilizers. For example, it is confirmed that chemical fertilizer has properties which cause not only the yield but the quality to be kept high when fertilizer level is changed. It is shown that the sludge compost affects the yield and the quality of the crops, and that the degree of the effect on the quality is greater for fertilizer levels of 3 times and 4 times. The effect on yield through increase in fertilizer level for sludge pyrolysate is not big as with chemical fertilizer, while the quality is equivalently stable with the chemical fertilizer. For the cattle excrement compost, the effect on the quality was large, though the effect on the yield was small.

When two kinds of fertilizers were applied mixed, the effect of the fertilizer level on the yield was between that of the two fertilizers.

Table 2　Eigenvector of first and second principal component in principal component analysis

	First principal component	Second principal component
Fresh mass	0.4530	−0.2675
Phosphorous	0.4513	0.2435
Potassium	0.2067	0.4941
Magnesium	−0.4368	0.4170
Calcium	−0.3897	0.3958
Nitric acid	0.2852	0.3702
Phosphorous in soil	0.3527	0.3968

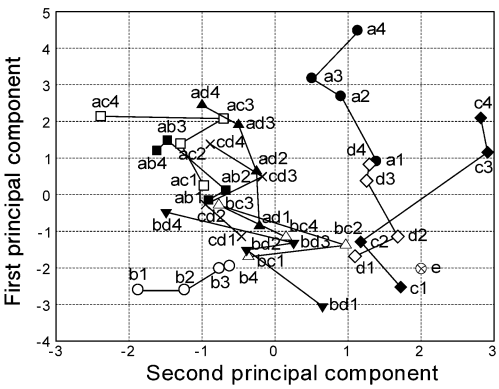

Fig. 6　Principal component score of each cultivation test result.

For example, the figure shows that the effect on the quality and the yield also increased when fertilizer level was increased for a combination of chemical and sludge pyrolysate.

3.3 Composition of self-organizing map

The self-organizing map is generally composed of a two layer network as shown in Figure 7. The first layer is the input layer and the second layer is the output layer where units are typically arranged two-dimensionally. To describe the self-organizing process : the postulated information processing in the brain was imitated and expressed with equation (1) by Kohonen. He established the learning algorithm in which the units of the output layer similar to the input signal are organized in the vicinity.

$$m_i(t+1)=m_i(t)+h_{ci}(t)[x(t)-m_i(t)] \quad (1)$$

where $m_i(t)$: is the reference vector of unit i at time t, $h_{ci}(t)$: is a vicinity function of unit i at time t, $x(t)$: is the input vector of unit i at time t. The learning algorithm is as follows ; a winner unit $m_c(t)$ is found to minimize the distance of the input vector and the reference vector at time t according to the equation (2).

$$|x(t)-m_c(t)|=|x(t)-m_i(t)| \quad (2)$$

A vicinity defined by the vicinity function $h_{ci}(t)$ is formed around a winner unit. All units of the vicinity are learned slightly with equation (1). Number of units in the vicinity is reduced by the vicinity function $h_{ci}(t)$ of which range is made narrower along with time. The following vicinity function was used in the experiment.

$$h_{ci}(t)=\alpha_0(1-t/T) \quad (3)$$

where α_0 is initial value (=0.5), and T is total learning times.

The same data used in the principal component analysis was used as the input layer for SOM. The units of 50 × 41 in the output layer learned with a Gaussian vicinity function.

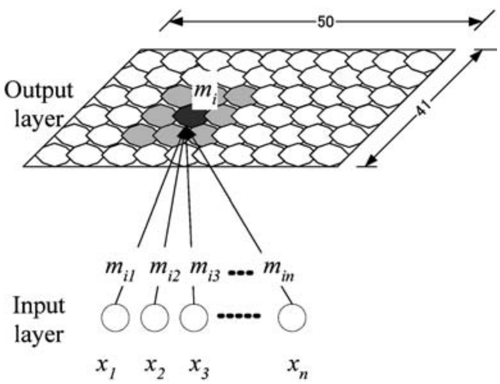

Fig. 7 Two layers network for self-organizing map.

3.4 Presentation by SOM

(1) Component map

Cultivation results of komatsuna according to the self-organizing map are shown in Figure 8. The similarities between the synthetic data are expressed at the distance between units which show the test plots denoted alphabetically and numerically. The color of the units shows the grade of the component data, in which red, green and blue express high, middle and low, respectively. The map shows that the sludge compost is similar totally to the chemical fertilizer, and that sludge compost of 3 times and 4 times standard concentration cause synthetically similar results to the chemical fertilizer of 1 times standard concentration. Synthetic evaluation of the effect of utilizing combinations of recycled organic materials was also shown in the map. For example, it is shown that the combination of sludge compost and sludge pyrolysate is similar to chemical fertilizer.

Comparing the color pattern of 'Mg' with that of 'Mass', we notice that it is in reverse. This means that concentration of magnesium decreased as komatsuna grew larger. It is remarkable that sludge compost of 1 times standard concentration caused higher magnesium concentration. The color pattern of calcium is similar to that of magnesium while it is not shown here. The map of 'NO3' shows that

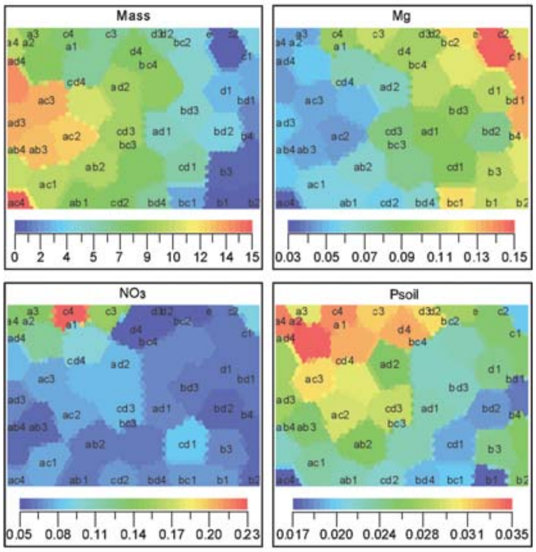

Fig. 8　Features of each cultivation test results obtained by self-organizing map. Mg : magnesium in komatsuna (%, DM), NO_3 : nitric acid in komatsuna (μg/100 mg-fresh mass), Mass : fresh mass of komatsuna (g), Psoil : residual phosphorous in soil (%, DM).

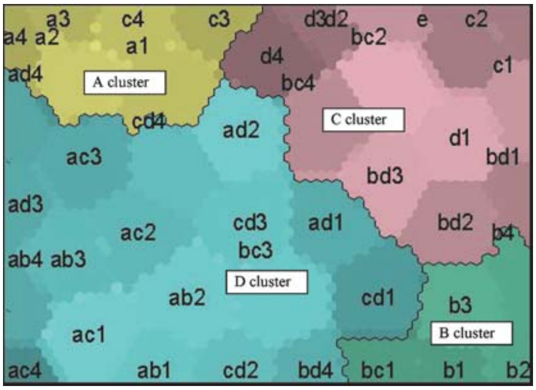

Fig. 9　Clustering map of cultivation test results.

sludge compost 4 times standard caused highest concentration of nitric acid. The self-organizing map indicates that sludge compost is a characteristic fertilizer in organic materials and it induces cautions visually.

(2) Cluster map

Clustering by the Ward system, the result of dividing into 4 groups was shown in Figure 9. Chemical fertilizer and sludge compost of 3–4 times were classified as belonging to cluster A. Cattle excrement compost was classified as belonging to cluster B which confronted cluster A. Chemical fertilizer and cattle excrement compost are located respectively in diagonal position of the map. This means that synthetic character of chemical fertilizer and cattle excrement compost differs contrastingly in the effect on crop cultivation.

Sludge pyrolysate and sludge compost of 1–2 times were classified as belonging to cluster C and the combinations of trial fertilizers were assigned roughly into cluster D. Cluster C is located in the middle of cluster A and B. This means that sludge pyrolysate affects crops in the level between chemical fertilizer and cattle excrement compost. Sludge compost also affects as well as sludge pyrolysate, while its effects on crop cultivation depend upon the amount of application. Sludge compost affects crops as intensely as chemical fertilizer if its application is 3–4 times standard of chemical fertilizer. Though this result is estimated from principal component score distribution by PCA, the users of recycled organic materials can easily understand these properties and characteristics when they watch the self-organizing map. Disadvantage of SOM should be discussed with the merits. The scale of the self-organizing map is not same as the principal component score distribution. The distance between two units shows similarity of two materials, however, the scale of distance is not precisely same on the any points of the map. This should be known as a disadvantage of the self-organizing map.

A compost and manure utilization promotion network system in Chiba Prefecture uses the quality chart developed by Ushio *et al.* (2004). This chart shows the fertilizer component by “radar” graphs and in tables, and the standard of compost utilization, but it is difficult to compare features and to know the similarity. SOM is an excellent visualizing method to illustrate the multiple features, which can provide a communication tool between users and producers of the recycled organic materials to avoid the mismatch of demand and supply.

4. Summary

An evaluation method for recycled organic materials was examined by a simple pot culture test to understand the effect on crop cultivation and environmental loading in their use because resource recycling from various organic wastes has been increasing recently. The test plots used fertilizer levels of from 1 times to 4 times the standard level for three kinds of organic material, cattle excrement compost, sludge compost and sludge pyrolysate, as well as for chemical fertilizer, and for various combinations of use. Through the cultivation experiment using komatsuna and radish, data such as crop yield, ionic components in the crop and residual components in cultivated soil were acquired. The utilization of a Self-Organizing Map (SOM) was examined as a representation of the test results in comparison with principal component analysis (PCA) to summarize and express the multi-dimensional data. The following points are summarized from the results and discussion.

(1) For the use of single trial fertilizer, crop yield on harvesting was in proportion to the rate of fertilizer application. However it was not always proportional to rate of application where a combination of fertilizers such as chemical fertilizer applied jointly with the recycled organic materials was used.

(2) Nitrate ion concentration of komatsuna lamina was high in the chemical fertilizer plots and sludge compost plots, and the concentration increased in proportion to rate of application. The concentration of phosphorus and potassium increased in approximate proportion to rate of application, while the concentration of magnesium and calcium tended to be lower as the rate of application is increased. In combination use, the relation between content rate of components and fertilizer level became a complex.

(3) By the principal component analysis, the first principal component and the second principal component show the effect of the crop yield and the quality respectively. Describing the test data by the principal component score in two-dimensional information can provide potential for understanding crop yield of the trial fertilizer and the degree of the effect of quality on the fluctuation.

(4) Utilization of a self-organizing map helped to visually represent the similarities and tendencies of recycled organic materials on the effect of crop cultivation and environmental loading. The self-organizing map is useful as a communication tool between manufacturers and users of recycled organic materials because overall evaluation can be easily performed and the effect of combination utilization of recycled organic materials can be easily comprehended with such a map.

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Abstract

Recently there has been promotion of the recycling of various kinds of organic wastes after their recovery. Excess amounts of recycled organic materials are often applied to fields because the decomposition and mineralization go on very slowly and little effect appears in terms of nutrients for crops. In this paper, for various recycled organic materials, an evaluation and representation method are described to show comprehensively, through crop cultivation tests and the analysis of components, the features and properties obtained. As recycled organic material test fertilizers, cattle excrement compost, sludge compost and sludge pyrolysate were compared with ordinary chemical fertilizer. In terms of nutrient rate of application in the cultivation test plots, 1 times to 4 times the rate of nitrogen were set for each test fertilizer, on the standard basis of chemical fertilizers of Kanto district, considering the degradation rate and the fertilizer effect. The nutrient components of harvested crops and remaining growth soil were analyzed with a standard chemical method. The map of principal component scores by principal component analysis shows the effect of the trial fertilizer. Utilization of the self-organizing map presented more visually the similarities and tendencies of the recycled organic materials on crop cultivation and environmental loading.

Key Words

organic waste, crop cultivation test, recovery treatment, self-organizing map

要旨

近年，多様な有機性廃棄物を再資源化してリサイクルすることが進められている．このような有機性資源化物は分解や無機化が遅く，作物に対する栄養素としての効果が現れにくいことから，時には過剰な量が圃場に施用されている．本論文では，作物栽培試験と成分分析試験によって得られたデータを基に，有機性資源化物の特色と性質を総合的に理解するための評価法とその表示法について検討した．有機性資源化物の肥料として，牛糞堆肥，屎尿汚泥堆肥，屎尿汚泥熱分解物を供試して，化成肥料と比較試験を行った．栽培試験では，有機物の分解率と肥効率を考慮して，関東地区の窒素標準施肥量を基に，その 1 倍から 4 倍までの施用量の試験区を設定した．収穫した作物および栽培後の土壌の養分は標準分析法に従って分析した．データの主成分分析から得られる主成分得点によって，供試肥料の特徴を示すことができた．さらに，自己組織化マップを用いることにより，有機性再資源化物を施用した場合の作物への影響や環境負荷の類似性や傾向を，一層視覚的に表現できることを示した．

キーワード

有機性廃棄物，作物栽培試験，再資源化，自己組織化マップ