Advance Journal of Food Science and Technology 4(3): 177-181, 2012
ISSN: 2042- 4876

Submitted: May 08, 2012 Accepted: May 29, 2012 Published: June 25, 2012

An Ecological Balanced Fertilization Model Based on Chemical and Microbial Compound Fertilization

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Abstract: This study proposed an Ecological Balanced Fertilization Model (EBFM) based on microbial compound fertilizer. We selected nine evaluating factors as Minimum Data Set (MDS). This MDS includes nutrition and microorganisms. According to the composition of chemistry nutrients to soil, microbial fertilizer and the level of effective fertilizer nutrient supply, we use the EBFM of the specific crops to develop the ratio of various elements. Finally, the Weighted Fuzzy Clustering Algorithm (WFCA) is used to evaluate the soil nutrient spatial changes of proposed EBFM after fertilizer operations comprehensively. The experiment shows that by using the proposed EBFM three years the spatial differences of soil nutrient has become narrowed. The overall fertility of soil has been increased.

Keywords: Compound fertilizer, Ecological Balanced Fertilization Model (EBFM), Minimum Data Set (MDS), Weighted Fuzzy Clustering Algorithm (WFCA)

INTRODUCTION

Besides favorable light and moisture conditions, crops need adequate Nitrogen, Phosphorus, Potassium and other nutrients to grow healthily. In China, chemical fertilizers are widely used for improved productivity in an economic and sustainable manner. However, (Humne *et al*., 2008) studied the long-term effect of different treatments of fertilizers and found that 100% recommended dose of chemical fertilizer have bad effects on hydraulic conductivity, particle density, infiltration rate, porosity and maximum water holding capacity. Lawrence *et al*. (2008) showed that excessive nitrogen caused less blossom and lower fruit-setting rate because of high speed of plant growth. Owing to a strong impact of excessive phosphorus and potassium fertilization on the photosynthetic active radiation transmission, its effect was also determined on the content level of nitrogen in green matter of oats. Therefore, appropriate fertilization is very important for healthy agriculture. Based on these literatures, the contents of chemical nutrition in fertilizer, either excessive or insufficient, should be taken into consideration in the soil fertilization.

With the development of soil microbiology, environ-mental microbial fertilizer has become the focus of the ecological agriculture research. Paul and Sundara (1971) isolated several strains of *bacillus* sp from the root of leguminous plant. The *bacillus* sp can dissolve 19% of $Ca_3(PO_4)_2$ in soils. Enkh-Amgalan *et al*. (2006) improved azotobacter's activity and the ability of fixing nitrogen by promoting the nif genes in azotobacter. Nonetheless, all these researches are limited to the efficiency of microbial fertilizer, while few of them have studied on the applying methods for microbial fertilizers. The contribution of this study is that we build an EBFM based on chemical and microbial compound fertilizer. The EBFM is able to reduce the spatial variability of soil nutrients, increase the comprehensive soil quality and improve the ecological environment.

EBFM AND FERTILIZATION FEATURE PARAMETER

The EBFM is described as:

$$W_I = W_O - \Delta W - T_n \tag{1}$$

W_I is the amount of available nutrients in fertilizer (mg/kg). W_O is the optimal amount of nutrients absorbed by wheat during its growth, which can be obtained through expert experience or tests in the laboratory. T_n is the content of available nutrients in current topsoil and, here, it is one of the chemical nutrients in MDS. ΔW is the fertilization feature parameter of the current season, defined as:

$$\Delta W = W_1+W_2+W_3+W_4-W_5 \tag{2}$$

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The variables in the right-hand side of the equation refer to the content of five available nutrients in soils. They are the available nutrient that mineralized and released by topsoil involved in the circulation of cinnamon soil, which carried by water or dust, transformed by soil microorganism and fixed by soils, respectively. In other words, ΔW includes all the available nutrients in and out of the cropland ecosystem except the changeable parameters such as “fertilizer utilization efficiency” and “coefficient of soil available nutrients” of general fertilization model. Therefore ΔW is an important parameter for EBFM. However, W_4 (the content of the available nutrient transformed by soil microorganisms) is easily affected by the environment, while the other four are comparatively constant and can be extracted through the cropland experiments. Thus, it is necessary to discuss the determination of W_4.

In MDS, the associative azotobacter and phosphobacteria have main impact on W_4. Let $W_{4\mathrm{A}}$ be the quantification of nitrogen fixed by associative azotobacter and W_{4B} be the quantification of available phosphorus transformed by phosphobacteria, then we have $W_{4\mathrm{A}} = W_{4\mathrm{A}} + W_{4B}$.

- $W_{4\mathrm{A}} = W_{4a} \times N_a$, where W_{4a} is the quantification of nitrogen fixed by one associative azotobacter and N_a refers to the number of associative azotobacter in the cropland. Since the connection between associative azotobacter and the root of wheat is not compact, the nitrogen fixation is instable and easily affected by the surrounding environments. Due to its complicate mechanism, the nitrogen fixation for wheat rarely has an acceptable theory to utilize. Consequently, the fixation rates of associative azotobacter are estimated through cropland experiment so that the proportion of nitrogen in W_4 can be determined. A ^{15}N isotope dilution method is employed to estimate the nitrogen fixation ability of associative azotobacter (Malik and Bilal, 1997). The percentage of the nitrogen fixed, $\%N$ and the quantification of nitrogen fixed, N_f, are defined as:

$$\%N = (1 - {}^{15}N_{\mathrm{fs}} / {}^{15}N_{\mathrm{nfs}}) \times 100\% \tag{3}$$

$$N_{\mathrm{f}} = N_{\mathrm{t}} \times \%N \tag{4}$$

where, $^{15}N_{nfs}$ is the proportion of ^{15}N in the original samples, while $^{15}N_{fs}$ is the percentage of ^{15}N in the control samples and N_t is the quantification of total nitrogen fixed.

Malik and Bilal (1997) proposed a method of testing the distribution of associative azotobacter in the wheat rhizosphere in natural state. The experimental result indicated that most of associative azotobacter distributed in three areas of the soil: one centimeter away from Root Surface (NRS), near (<1 cm) the Root Surface (RS) and on the Root surface (RP). The MPN approach is used for bacteria counting. The distributions of associative azotobacter in the three areas are 1.8×10^4 cells per gram in NRS, 4.2×10^4 cells per gram in RS and 7.5×10^6 cells per gram in RP, respectively. Then the nitrogen fixing efficiency can be calculated as:

$$W_{4\mathrm{a}} = N_{\mathrm{f}} / (N_{\mathrm{NRS}} + N_{\mathrm{RS}} + N_{\mathrm{RP}}) \tag{5}$$

where, N_f is the quantification of nitrogen fixed by one single stalk of wheat. N_{NRS}, N_{RS} and N_{RP} refer to the numbers of associative azotobacter in NRS, RS and RP, respectively.

- $W_{4\mathrm{B}}$ can be calculated by utilizing the dynamic characteristic and the conservation principle of phosphate. The solubization kinetics of P was studied by (Shi *et al*., 2008) using calcium phosphate as the medium. By analyzing the relationship between the content of insoluble phosphate and that of available phosphorus, he obtained the dynamic model of the phosphate:

$$Y = a\mathrm{Log}x + b \tag{6}$$

where, Y represents the quantification of phosphate solubization and x refers to the concentration of phosphobacteria. Two parameters a and b are transformation constant and characteristic constant respectively. Through numerical analysis, we have the dynamic model of insoluble phosphorus solubization as follows:

$$Y = 4.54\mathrm{Log}\, x + 11.23 \tag{7}$$

COMPREHENSIVE FORMULA FOR THE CHEMICAL AND MICROBIAL COMPOUND FERTILIZER

Traditional proportioning formula is only for the compound fertilizer mixed with nitrogen, phosphorus, potassium or other chemical nutrients, however, such chemical compound fertilizers is not a good way to improve the soil fertility. Therefore, combining chemical nutrients with microbial fertilizers with a certain proportion is one possible way that can maintains the healthy and fertile condition of the soils. Since the two factors of associative azotobacter and phosphobacteria have great influence on the nitrogen and phosphorus supplying of wheat in the experimental cropland, we designed the mixing formula for compound nitrogen and phosphorus fertilizer.

Mixing formula for compound nitrogen fertilizer: Chen *et al*. (2008) demonstrated that the wheat absorbed nitrogen more easily from the soils than from the chemical fertilizers. When the amount of chemical nitrogen application is up to 15 g/m, the wheat will reach the highest productivity. However the more chemical nitrogen application will cause production reduction and environmental pollution. Asis *et al*. (2000) indicated that the nitrogen fixation effect of associative azotobacter was best under the condition of chemical nitrogen half applying and the maximal production could reach 10~12%. So on the basis of these research, we obtained the formula for the expert compound nitrogen fertilizer as follows:

$$W_{NC}=W_{IN}/(2\times\xi) \quad (8)$$

$$W_{NW}=W_{IN}/(2\times W_{4a}\times\gamma) \quad (9)$$

where, W_{NC} is the amount of chemical nitrogen fertilizer demand for mixing (mg/kg); W_{IN} is the total nitrogen demand for present soil; ξ is the nitrogen concentration of the chemical nitrogen fertilizer; W_{NW} is the amount of associative azotobacter fertilizer demand for fixing; γ is the nitrogen fixation efficiency of associative azotobacter.

Mixing formula for compound phosphorus fertilizer: The form of phosphorus in soil was composed of available phosphorus and insoluble phosphate. The phosphobacteria represented by bacillus megaterium can change the insoluble phosphate into the phosphorus available for crops. According to the dynamic model of Eq. (6), the expert compound phosphorus fertilizer formula could be obtained as follows:

$$W_{PC}=W_{IP}-(u_4-u_2)\times\eta \quad (10)$$

$$W_{PM}=10^{(u4-u2-b)/a}/\mu \quad (11)$$

where, W_{PC} is the amount of chemical phosphorus fertilizer demand for mixing (mg/kg) and W_{IP} is the total phosphorus demand for present soil. u_4 is the content of total phosphorus in present soil and u_2 is the content of available phosphorus in present soil. η is the phosphorus concentration of the chemical phosphorus fertilizer. W_{PM} ($\times 10^{12}$ kg^{-1}) is the amount of phosphobacteria fertilizer demand for fixing; a is transformation constant; b is characteristic constant. μ is the nitrogen fixation efficiency of associative azotobacter. If $W_{IP} > (u_4-u_2)\times\eta$, the compound phosphorus fertilizer would be obtained according to the Eq. (10) and (11); otherwise, only the phosphobacteria fertilizer provides phosphorus for wheat by Eq. (11).

The quantity of other fertilizer can be determined by:

$$W_{ui} = W_1/\sigma \ (i = 1, 3, 7)$$

where,

W_{ui} is the gross amount of certain fertilizer (kg)
σ is the available content of the whole fertilizer (%)

The compound fertilizer formula combining chemical nutrients with microbial fertilizers should comply with the following three rules:

- Avoid the influence of the pH and the salt concentration on the microbial fertilizers during the process of mixing microbial fertilizers with chemical fertilizers.
- Mix the microbial fertilizers after being fermented respectively in the assurance of no antagonism happens while mixing two or more microbial fertilizers.
- Chemical fertilizers and microbial fertilizers for mixing must conform to the state standards or industrial standards and the labeled value of nutrition must be consistent with the actual value and bacteria concentration of the compound fertilizer must reach a fairly high level.

EXPERIMENTS AND RESULTS

Site description: The cropland in this study, which is about 1 ha, is located in an experimental cropland in Jiangsu University (32°17′15″N, 119°53′19″E, Elevation 286 m). The average annual frost-free period is 240 days and the average annual sunshine duration is 265811 h. The cropland is partitioned into 25 blocks, each of which is 20×20 m and is positioned by GPS. We selected nine factors as Minimum Data Set (MDS). They are available potassium, available phosphorus, calcium carbonate, total phosphorus, total nitrogen, total potassium, organic matter, associative azotobacter and phosphobacteria.

Data acquisition: We designed an information-optimized sampling method to save time and cost

Table 1: The data reflecting the distribution of the evaluation indicators in MDS

Evaluation factor	Graduation	Min	Max	Mean	SD	Variation coefficient (%)	Weight
Available potassium (mg/kg)	76.09	37.36	113.45	62.35	54.21	34.33	0.092
Available phosphorus (mg/kg)	42.34	26.78	69.12	45.21	8.2	18.92	0.102
Calcium carbonate (%)	7.88	4.98	12.86	8.65	1.93	20.36	0.091
Total phosphorus (mg/kg)	166.36	103.76	270.12	195.34	86.36	36.36	0.146
Total nitrogen (g/kg)	3.18	0.75	3.93	2.63	0.98	40.36	0.135
Total potassium (g/kg)	17.38	3.85	21.23	15.87	3.65	12.01	0.128
Organic matter (g/kg)	8.67	6.69	15.36	8.23	2.96	19.31	0.136
Associative azotobacter (10^6 g^{-1})	8.60	2.12	10.72	9.52	1.63	25.84	0.089
Phosphobacteria (10^5 g^{-1})	32.50	18.36	50.86	37.23	8.75	31.35	0.081

Table 2: Result of weighted fuzzy clustering algorithm

	2009			2010			2011	
μ	CN	F-value	μ	CN	F-value	μ	CN	f-value
0.999	120	0.435	0.999	125	0.321	0.999	128	0.395
0.997	109	0.874	0.997	114	0.701	0.997	117	0.546
0.995	100	1.575	0.995	103	1.365	0.995	105	0.656
0.993	92	2.584	0.993	93	1.684	0.993	94	0.895
0.991	84	3.415	0.991	84	2.035	0.991	83	1.025
0.988	77	4.586	0.988	75	3.145	0.988	73	1.365
0.985	70	4.904	0.985	67	4.263	0.985	65	2.364
0.982	63	5.356	0.982	60	5.876	0.982	58	3.125
0.978	57	5.412	0.978	53	6.324	0.978	52	3.325
0.974	51	5.537	0.974	47	6.764	0.974	47	3.836
0.970	46	5.026	0.970	41	6.321	0.970	42	3.547
0.965	41	4.935	0.966	36	6.021	0.966	37	3.125
0.960	36	3.254	0.962	31	5.698	0.963	32	2.985
0.955	31	2.125	0.958	26	5.046	0.960	27	2.752
0.950	27	1.861	0.955	22	4.364	0.958	22	2.368
0.945	23	1.825	0.951	18	3.785	0.955	16	1.869
0.940	19	1.156	0.948	15	2.368	0.952	11	1.452
0.935	16	1.114	0.945	12	1.698	0.950	6	1.265
0.930	13	0.952	0.941	9	1.425	0.948	2	1.035
0.925	10	1.230	0.938	7	1.254	0.946	1	1.000
0.920	8	1.254	0.934	5	1.154			
0.915	6	1.112	0.931	3	1.025			
0.910	4	1.253	0.927	2	0.957			
0.905	3	1.036	0.923	1	1.000			
0.900	2	1.045						
0.895	1	1.000						

during data extraction. The sampling number *n* of every block is determined by a soil variation factor Δh_i, i.e., n = k. Δh_i, where, *k* is an empirically determined parameter. Since *k* is a constant in this study, *n* is mainly determined by Δh_i.

The nine nutrients in MDS are referred as $U = \{u_1, u_2, \ldots, u_9\}$, which are analyzed through the chemical and physical test equipments. Table 1 shows the data reflecting the distribution of the evaluation indicators in MDS.

Feasibility of EBFM validated by using Weighted Fuzzy Clustering Algorithm (WFCA): As a high-efficiency classification method, Fuzzy Clustering Algorithm (FCA) finds its wide use in soil quality assessment. However, the traditional FCA has no regard that the indicators have different contribution to the results. So in this study, we used the Weighted Fuzzy Clustering Algorithm (WFCA) to improve the accuracy of the assessment.

The results validated by WFCA: The indicators in MDS are measured in 2009, 2010 and 2011, respectively. The EBFM formula fertilization has been carried out from 2009. The result of weighted fuzzy clustering algorithm to all indicators is shown in Table 2. In the table, μ reflects the similarity degree among the data. Class Number (CN) corresponds to the μ. F-value is calculated out by using F distribution in probability statistics. The bigger F-value shows greater distance between among the classes, which indicates the better cluster result.

The experimental results of the three yeas indicate that:

- After 3 years ecological balanced fertilization, the range of μ becomes smaller and the similarity degree among the data aggregates gradually, which indicate that the spatial differences has become smaller.
- When the data are classed as one group, the μ has increased continuously from 0.895 to 0.946, which indicate that the comprehensive similarity of every indicators is improving year by year.
- When μ = 0.974, the F values are very great, which indicates a good classification.

Meanwhile, the class number of 2010 and 2011 are less than it of 2009, which indicates the spatial differences of soil nutrient in 2010 and 2011 have become smaller. While the class number in 2010 equal to the class number in 2011, the F value in 2011 are less than the F value in 2010, Which indicates the differences among the classes are getting smaller and smaller. Therefore, it can be seen easily from the experiment that the EBFM formula fertilization has decreased the spatial differences of soil nutrient, which improves the overall ability of the soil in experimental field.

CONCLUSION AND RECOMMENDATIONS

EBFM works out the optimal compound formula of microbial fertilizer and chemical fertilizer according to the distribution of chemical composition in soil. Thus, the crops can be provided adequate nutrition and the invalid chemical composition can be transformed into valid nutrition by microorganism. The experimental result analyzed by WFCA indicates that the spatial differences of soil nutrient have been narrowed in the past 3 year ecological balanced fertilization, which demonstrates that the comprehensive fertility and ecological environment of soil have been improved by EBFM.

The effect of ecological balanced fertilization is a time function. Although the data is from 3 year experiment, the study of the effect of ecological balanced fertilization is only a beginning. The continuing research should be done to evaluate the long-term economic and ecological benefit provided by ecological balanced fertilization.

ACKNOWLEDGMENT

This study was supported the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

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