한국유기농업학회지 제15권 2호
KOREAN JOURNAL OF ORGANIC AGRICULTURE
Volume 15, Number 2: 219-228, June 2007.

Soil Management Practices Affected Nutrient Use Efficiency on Chinese Cabbage (*Braccica campestris*) in the Alpine Region of Korea

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시비 방법이 고랭지 배추와 토양 환경에 미치는 영향

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강원도 고랭지는 채소 재배지로 그 이용 면적이 매년 급속히 증가하고 있다. 급한 경사와 집중적으로 발생하는 장마철의 폭우는 토양 유실은 물론이고 토양 비옥도의 심각한 저하를 초래할 위험이 경작의 강도와 범위가 넓어짐에 따라 더욱더 증가하고 있다. 또한 험한 지형에 따른 기계화 영농의 어려움과 이에 수반하는 노동력의 낭비로 문제점을 제기한다. 채소 작물 재배를 위해 많이 사용하는 요소 비료, 황산암모늄 비료와 함께 특별히 수지(resin)를 피막 처리한 복합비료를 가지고 배추의 생장과 토양에 미치는 영향을 조사하였다. 수지 피막처리는 각각 7, 10, 15%의 비율로 혼합했다. 배추의 수량은 실험에 사용된 비료간에 큰 차이가 없었다. 요소와 황산암모늄은 기본 시비와 함께 2차례 추비를 하였고 수지 피막 복합 비료는 단 한번 초기에 시비하였다. 따라서 이 경우 노동력 절감과 토양 환경 교란의 최소화를 달성할 수 있었으므로 완효성의 수지 피막 처리 비료가 바람직한 것으로 나타났다. 토양에 미치는 효과는 비료의 종류간에 별다른 차이가 없었으나 인산(P_2O_5)의 토양내 축적 현상이 t지 피막 처리 복합 비료 시용 구에서 뚜렷하게 조사되었다. 일반적으로 화학 비료의 시용은 토양 반응(pH)의 저하를 초래하였다.

요약어 : 고냉지토양, 배추, 토양 비옥도, 토양관리, 수지를 이용한 혼합비료, 요소, 황산암모늄

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Ⅰ. Introduction

The high altitude cool region of Northeastern part of South Korea has been intensively cultivated in recent decades for highland vegetable cash crops (MAF, 2006; Lee, 1998). This area is 600 m or high from the sea level and the terrain is very rough with steep slopes which render any easy access very difficult (Kangwon Do, 1995; Lee et al., 1973). Cool summer and cold winter represent the typical climate pattern of this region. The long and cold winter is usually characterized by a great amount of snowfall, early seasonal freezing and late thawing of ground. The annual average temperature in this region is about 6~8℃, much lower than in the land down below (KRMO, 2006). The wet summer monsoon accompanying concentrated heavy rainfalls makes the surface of the land exposed to severe hazard of soil erosion (Cho, 1999; Kim and Park, 1994). High humidity and cloudiness prevent evaporation of water from the soil. Cold damages occur frequently in early spring and pest control becomes urgent problem in summer (Park et al., 2004). Utilization of farm machinery encounters unexpected limitations.

The development and growth of several vegetable crops, however, favors the cool summer of this area. Chinese cabbage and Chinese radish, in particular, have been and will be the ones among the most profitable cash crops in this region, which are the two vegetable crops Kimchi is made of. Kimchi is an internationally recognized Korean food and the population consuming it is on the way of rapid increase all over the world (Ham, 1997). The wide net work of road systematically constructed under national development policy now renders it possible to reach this area by various means of vehicles which may also be used for agricultural purposes. It is well anticipated that reclamation of alpine soils in this region will be more intensified in the near future.

In recent years it has been observed that the deterioration of soil fertility and crop quality grown on the soil is advancing very fast. There are a few research activity and papers available for the time being concerning these problems. The present investigation is one a series of field experiment performed for the conservation and improvement of the in this area.

Ⅱ. Materials and Methods

1. Soil and crop

An alpine soil, Deogcheon series of coarse loamy over sandy-skeletal, mixed mesic Typic

Udifluvents, was used. The chemophysical characteristics of the selected soil were determined using standard methods (NIAST, 1998) shown in Table 1. A variety of summer Chinese cabbage was cultivated on the field plot. The seeds were germinated on a nursery pan, and then transplanted to the field after germination.

Table 1. Physical and chemical properties of the soil (Deogcheon Series. coarse loamy over sandy skeletal, mixed, mesic Typic Udifluvents).

Texture	pH	Organic matter	P_2O_5	K^+	Ca^{2+}	Mg^{2+}	CEC
	(1:5)	%	mg kg^{-1}	——— cmol$_{(+)}$ kg^{-1} ———			
Sandy loam	5.7	2.10	329	0.14	2.38	0.76	8.60

2. Nutrient materials and application methods

Various kinds and application rates of fertilizer materials added to the soil may result in changes of growth and yield of crops as well as changes of soil fertility status. The changes were monitored for consecutive 3 years in the field. Urea, ammonium sulfate, and commercial mixed fertilizer (N-P_2O_5-K_2O = 320-200-270kg ha^{-1}) were applied to the soil. The mixed fertilizer was put under procedure to be coated with resin. Resin-coating was considered to make it slow releasing fertilizers. The rates of resin coated were 7, 10, and 15% of the mixed fertilizer, respectively. Urea and ammonium sulfate fertilizers were divided into even three portions, and added to the filed plot three times following split application method. The time of application of these materials were just before transplant, 15 d after transplant, and 30 d after transplant, respectively. A single fertilization at the time just before transplantation was given for the resin-coated mixed nutrient materials.

Ⅲ. Results and Discussion

1. Growth and development of Chinese cabbage

At the middle season of development, 15 d after transplant just before the 1st supplementary split application of fertilizer was done, there were no significant differences observed among leaf number, leaf length, leaf width, cabbage weight, and root weight despite the differences of the kinds of applied fertilizer materials as shown in Table 2. The development of cabbage grown on the plots treated with urea or ammonium sulfate was a little superior in terms of leaf length, leaf width, and bulb weight to those with other fertilizer treatment in early stage of growth. Ammonium sulfate was better than urea. But there were no significant differences measured for growth parameters among all fertilizer treatment, when it approached the time of harvest. In the middle stage of development conventional fertilization with urea and ammonium sulfate resulted in better growth of above-ground part of the crop, while after this stage resin-coated mixed fertilizers were proven to have better effects on plant growth. In the early stage of plant development, resin-coated fertilizers stimulated faster growth of roots than conventional urea or ammonium sulfate fertilizers. Better growth of root in early stage of development is an obvious benefit for heavier and better bulb formation in the later stage (Cho, 1999). This is one of

Table 2. Growth parameters of Chinese cabbage.

Fertilization	Fertilizer	Leaf number per plant	Leaf length	Leaf width	Plant weight	Dw/Fw§	Root weight
			cm	cm	g	%	g
15 d after transplant	Urea	29	20.7	16.9	410	4.63	3.8
	$(NH_4)_2SO_4$	29	21.9	16.9	421	4.52	3.9
	MF-7% resin‡	28	19.6	15.8	396	4.72	4.2
	MF-10% resin	28	20.3	16.0	410	4.81	4.3
	MF-15% resin	28	20.0	16.1	410	4.79	4.1
LSD†			2.05	1.25	18.86	0.29	0.41
Bulbing stage	Urea	39	30.7	23.4	710	6.53	6.1
	$(NH_4)_2SO_4$	39	30.4	23.3	709	6.01	5.9
	MF-7% resin	38	29.7	22.7	670	5.70	3.9
	MF-10% resin	39	30.7	22.9	750	5.48	5.5
	MF-15% resin	38	30.2	23.0	716	5.51	4.0
LSD			1.00	0.73	59.82	0.32	0.49

†LSD stands for least standard deviation at $P<0.05$.

‡MF-7% resin, MF-10% resin, and MF-15% resin are commercial mixed fertilizers (N-P_2O_5-K_2O = 320-200-270kg ha^{-1}) coated with resin by 7, 10, and 15%, respectively.

§Dw/Fw(%) = (Dry weight of cabbage/Fresh weight of cabbage) × 100 Root advantages expected from slow releasing fertilizers. The positive effects of slow releasing resin-coated mixed fertilizers shown in Table 2 clearly demonstrated that there was no need of multiple applications of these fertilizers more than a single addition to the soil. The weight of a harvested cabbage was heavier when the plant was grown on the plot fertilized with resin-coated materials than that with urea or ammonium sulfate. In particular the heavier total inner leaf weight is very important factor, because the inner leaves are in fact the edible part of the crop.

Table 3. Yield parameters of Chinese cabbage.

Fertilizer	Plant weight	Yield index§	Total inner leaf weight	Inner leaf number (A)	Outer leaf number (B)	B/A
	g per plant		g			%
Urea	980.1	100.0	597.5	38.8	11.8	30.4
$(NH_4)_2SO_4$	979.8	96.0	582.6	38.4	11.6	60.2
MF -7% resin†	1102.1	109.8	646.2	39.6	11.5	29.0
MF -10% resin	1025.9	100.5	612.7	35.7	12.5	35.0
MF -15% resin	1100.6	107.9	631.1	37.2	12.1	32.5
LSD‡	236.40		23.30	3.50	3.80	12.50

†MF-7% resin, MF-10% resin, and MF-15% resin are commercial mixed fertilizers (N-P_2O_5-K_2O = 320-200-270kg ha^{-1}) coated with resin by 7, 10, and 15%, respectively.
‡LSD stands for least standard deviation at $P<0.05$.
§Yield index = (average yield of each fertilizer / average yield of urea)×100

2. Absorption and contents of nutrients of the crop

There were not significant differences among the contents of P_2O_5, K_2O, CaO, and MgO in the leaves of the crop grown on plots treated with various fertilizer materials, as shown in Table 4. The nitrogen content (N), however, in the leaf as well as in root was a little higher than others when the crop was grown on the plot treated with urea fertilizer. Higher contents of K_2O and MgO were found in the crop grown on plots treated with 7% resin coated mixed fertilizer. The contents of N and P_2O_5 in roots were remarkably lower than those in the above-ground parts.

Table 4. Nutrient contents of harvested Chinese cabbage (g per plant).

	Fertilizer	N	P2O5	K_2O	CaO	MgO
Leaf	Urea	1.97	0.53	1.64	0.16	0.13
	$(NH_4)_2SO_4$	1.82	0.48	1.91	0.20	0.13
	MF -7% resin†	1.83	0.49	2.41	0.21	0.15
	MF -10% resin	1.69	0.46	1.68	0.17	0.11
	MF -15% resin	1.71	0.47	1.72	2.20	0.12
Root	Urea	0.82	0.29	0.77	0.17	0.13
	$(NH_4)_2SO_4$	0.80	0.28	0.81	0.17	0.12
	MF -7% resin	0.70	0.27	1.29	0.15	0.12
	MF -10% resin	0.78	0.29	1.47	0.19	0.13
	MF -15% resin	0.77	0.28	1.30	0.18	0.13

†MF-7% resin, MF-10% resin, and MF-15% resin are commercial mixed fertilizers (N-P_2O_5-K_2O = 320-200-270kg ha^{-1}) coated with resin by 7, 10, and 15%, respectively.

3. Fertilizer utilization efficiency(UE)

The highest utilization efficiency of N was observed with application of mixed fertilizer of 7% resin, followed by urea treatment, utilization efficiencies being 13.7 and 12.7%, respectively. The crop harvested from the plot received 7% resin coated mixed fertilizer application was the one where the contents of P_2O_5 and K_2O were the highest. In general the contents and utilization efficiency of K_2O were higher with the application of resin-coated mixed fertilizers Table 5.

Table 5. Fertilizer utilization efficiency(UE).

Fertilizer	N		P_2O_5		K_2O	
	Uptake	UE‡	Uptake	UE	Uptake	UE
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
Urea	109.7	12.7	29.4	6.4	88.3	12.8
$(NH_4)_2SO_4$	102.4	10.4	28.1	5.8	86.9	12.3
MF -7% resin†	113.0	13.7	30.4	6.9	151.5	35.8
MF -10% resin	102.5	10.4	27.9	5.7	99.0	16.7

Fertilizer	N		P_2O_5		K_2O	
	Uptake	UE‡	Uptake	UE	Uptake	UE
MF-15% resin	106.7	11.8	27.3	5.4	97.8	16.3
No fertilizer	69.1		16.6		53.8	

†MF-7% resin, MF-10% resin, and MF-15% resin are commercial mixed fertilizers ($N-P_2O_5-K_2O$ = 320-200-270kg ha) coated with resin by 7, 10, and 15%, respectively.
‡UE(utilization efficiency) % = [(uptake in fertilized plant - uptake in no fertilizer)/input N]×100

4. Yield increase

As shown in Table 6, the fertilization for consecutive 3 years with a variety of the nutrient materials was closely related to increases in annual yield. For example, the yield of the third year was 276% of the first year in case of 105 resin coated mixed fertilizer application. In the meanwhile, there were not found any significant differences in yield increases among applications of various fertilizer materials for a given year.

Table 6. Yield increase for 3 years.

Fertilizer	Yield			Average	Yield index‡
	1st year	2nd year	3rd year		
	——— kg ha^{-1} ———				
Urea	29,040	42,050	70,080	47,060	100.0
$(NH_4)_2SO_4$	30,210	41,130	69,210	46,850	99.5
MF-7% resin†	32,650	39,060	71,780	47,830	101.6
MF-10% resin	30,390	33,600	83,770	42,950	104.7
MF-15% resin	-	-	71,830	71,830	102.5

†MF-7% resin, MF-10% resin, and MF-15% resin are commercial mixed fertilizers ($N-P_2O_5-K_2O$ = 320-200-270kg ha^{-1}) coated with resin by 7, 10, and 15%, respectively.
‡Yield index = (average yield of each fertilizer / average yield of urea)×100

5. Changes in soil nutrient contents

Nutrient contents of the soil were monitored along with the changes of chemical properties such as pH and OM (Table 7). Due presumably to the solubilization from resin coated fertilizers by 10% and 15%, the pHs of the plots treated with these materials were lower than the others when analyzed at the time 15 days after transplantation just before the first supplementary fertilization of urea and ammonium sulfate to the soil. Resin-coating of the mixed fertilizer might have retarded releases of K, Ca, and Mg. Increase in the content of P_2O_5 was remarkable, which is in accordance with the result of Yang et al. (2001). Effects of fertilizations on soil pH were not defined very well among various fertilizer treatments, but it is obvious that the nutrient sources in general had an effect of lowering soil pH. The NO_3-N concentration of the soil had patterns which were unique according to the kinds of fertilizers (Fig. 1). There were distinctive fluctuations in cases of urea and ammonium applications, while slow but steady increases occurred in cases of resin-coated mixed fertilizers treatments. The NO_3-N release in excessive amount from fertilizers may be the loss of nutrient and contribute to the environmental pollution of ground water. The release of NO3-N from resin-coated mixed fertilizers was a function of the amount of resin treated, the more the resin, the less the amount of NO_3-N released into the soil.

Table 7. Changes of soil chemical properties.

Days	Fertilizer	pH	Organic matter	Available P_2O_5	K^+	Ca^{2+}	Mg^{2+}
		(1:5)	%	mg kg^{-1}	— $cmol_{(+)}$ kg^{-1} —		
15 d after transplant	Urea	6.6	1.5	688	0.57	4.06	1.51
	$(NH_4)_2SO_4$	6.4	1.5	690	0.55	3.96	1.50
	MF-7% resin†	6.3	1.8	699	0.16	3.05	0.95
	MF-10% resin	5.7	1.7	747	0.37	2.38	0.78
	MF-15% resin	5.8	1.7	706	0.42	3.11	0.82
LSD‡		0.33	0.16	225	0.04	0.23	0.25
30 d after transplant	Urea	5.5	1.6	644	0.30	3.55	1.33
	$(NH_4)_2SO_4$	5.4	1.6	648	0.29	3.57	1.22
	MF-7% resin	5.2	1.7	869	0.32	4.71	1.11
	MF-10% resin	5.2	1.7	854	0.32	3.29	0.77
	MF-15% resin	5.2	1.7	861	0.31	3.36	1.13
LSD		0.20	0.32	185	0.07	0.67	0.23

Days	Fertilizer	pH	Organic matter	Available P_2O_5	K^+	Ca^{2+}	Mg^{2+}
Harvest	Urea	4.6	2.5	567	1.93	2.92	1.29
	$(NH_4)_2SO_4$	4.6	1.8	578	1.29	2.78	1.17
	MF -7% resin	4.6	1.8	809	0.67	5.30	0.93
	MF -10% resin	4.5	1.9	826	0.51	5.16	0.91
	MF -15% resin	4.6	1.8	822	0.66	5.19	0.92
LSD		0.38	0.27	200	0.46	1.21	0.22

† MF-7% resin, MF-10% resin, and MF-15% resin are commercial mixed fertilizers (N-P_2O_5-K_2O = 320-200-270kg ha^{-1}) coated with resin by 7, 10, and 15%, respectively.

‡ LSD stands for least standard deviation at $P<0.05$.

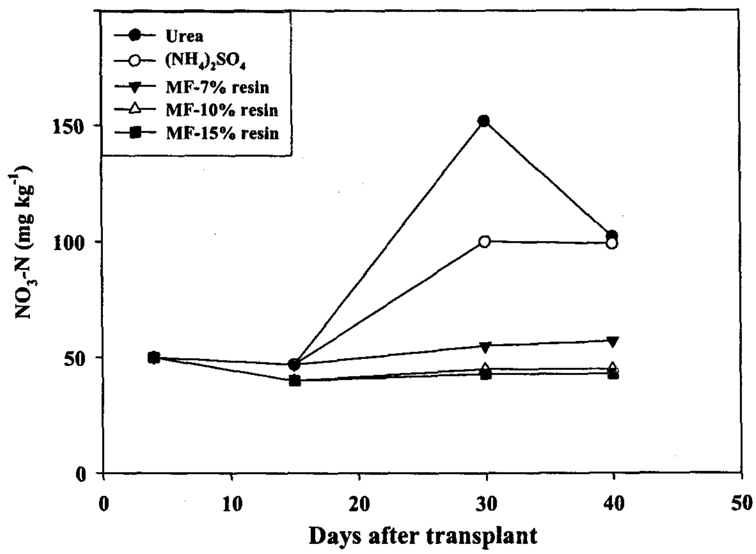

Fig. 1. Changes in the contents of NO_3-N in the soil.

[논문접수일 : 2007. 3. 9. 최종논문접수일 : 2007. 4. 30.]

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