Response of Dent Corn and Sweet Corn to Two Different Forms of Co-situs Application Methods of Controlled Release Fertilizer in Upland Field of a Volcanic Ash Soil

Tohoku Journal of Agricultural Research
Vol. 54 No. 1-2, November 2003
Printed in Japan

Response of Dent Corn and Sweet Corn to Two Different Forms of *Co-situs* Application Methods of Controlled Release Fertilizer in Upland Field of a Volcanic Ash Soil

Xiaohong TIAN and Masahiko SAIGUSA

Laboratory of Environmental Crop Science, Graduate School of Agricultural Science, Tohoku University, Kawatabi, Naruko, Tamatsukuri, Miyagi prefecture 989-6711, Japan

(Received, August, 2003)

Summary

Polyolefin coated fertilizer as a new type of controlled release fertilizer (CRF) has began to be used in upland crops in Japan due to its high N recovery rate and environmental friendly characteristics under humid climate. The objective of this paper lies in investigating the response and adaptability of dent corn (*Zea mays* L. var. *indentata* Sturt.) and sweet corn (*Zea mays* L. var. *saccharata* Sturt.) to two forms of *co-situs* application methods (*co-situs* band application and *co-situs* spot application) of CRF in upland field of a volcanic ash soil (Alic Pachi Mellanudand) under humid climate conditions. The results obtained showed that, compared to the conventional side-band application of urea, for sweet corn and dent corn, in *co-situs* spot application of LP70 (polyolefin coated urea, 70 day type), the mean germination percentage at each sowing point greatly decreased by 66.7% and 50%, respectively ; In *co-situs* band application of LP70, the germination percentage decreased by 26.7% and 10.0%, respectively ; under the condition of *co-situs* band application of urea, nearly all the seeds of two corns did not germinate and the germinating power was inhibited completely ; The weather conditions with less rainfall and higher temperatures at the germination stage probably increased tendency of poor germination under the *co-situs* application conditions ; *Co-situs* spot application of LP70 further retarded seedling development, but such retardation was not obvious at the late growing period because of good water conditions, and in this treatment, the grain yield of both corns as well as the uptake amount of N, P, K decreased significantly, too, but there were no significant difference for harvest index and nitrogen harvest index as compared with control, suggesting that poor germination and less plant number is the main reason for significant decrease of yield and nutrients uptake. Based on the above results, it is therefore recommended that the *co-situs* application of CRF especially the *co-situs* spot application would not be applied in sweet corn production, and the *co-situs* band application of CRF is ideal fertilization method for dent corn production under upland conditions without irrigation in humid area.

Key words : Controlled release fertilizer, *Co-Situs* application, Dent Corn, Germination, Sweet Corn.

Introduction

About half of arable upland is covered by the volcanic ash soils in Japan, and the whole country is characterized by a humid climate ; it has an annual rainfall of 1,800 mm on the average (Hasegawa & Eguchi, 2002). In the moist hilly terrace areas upland crop production has great potential because of favorable soil water condition and high soil fertility. Although during the sowing season (in April and May) the weather is relatively dry and rainfall is variable in different years, usually soil water availability can guarantee upland crops to germinate under the conventional fertilization condition, and thus there is no need for irrigation. Once the seedlings are established, generally there is almost no soil water deficit for upland crop growth during the rest of growing season.

In upland areas dent corn as a major silage crop is widely cultivated for livestock production and sweet corn is produced only on a limited area of farmland as a kind of delectable food for people. However, in corn production, the N recovery rate of the applied readily available N fertilizer is always low because the usual occurrence of heavy continuous rain in June and July will disturb topdressing time and enhance leaching losses of N, especially when the root systems of the plants are not yet fully developed. Moreover, the N uptake amount by dent corn at the critical level (about 1 m of plant height) was only one-tenth of that at the maturity stage. Also mechanical topdressing is difficult in rainy seasons, and thus, it is not very easy to use readily available nitrogen fertilizer by top-dressing to maintain nitrogen nutrition during the late growth stage of corn as a tall crop (Saigusa et al, 1993, 1999 ; Tian & Saigusa, 2002). In addition, in order to prevent water and wind erosion of soil and to save energy and manpower, presently no-tillage or minimum cultivation is advocated for some upland crops including corn, and in this case, the controlled release fertilizer (CRF) and its *co-situs* application are thought to play very important roles (Inoue et al, 2000 ; Ito, 2002).

Due to the above reasons, the CRFs have been used in the corn cultivation. The dominant CRF types presently being available are polyolefin coated fertilizers (POCFs), which were first developed in Japan (Fujita, 1995), and its nutrient release is mainly dependent on the temperature and basically irrespective of other environmental factors. Thus POCFs have highly accurate release characteristics and can synchronize the nutrient demand of plants over the whole growing season (Shoji, 1999). When using the POCFs, the *co-situs* application method was recommended and advocated which means the whole fertilizer was dressed as a basal form and contacted with seeds (Shoji et al, 1991 ; Ito, 2002).

Because the nutrient is gradually released from POCFs, even though the fertilizer contacts the seeds, the harm to seed vigor is usually little. Furthermore, the nutrient recovery rate is rather high in comparison with other fertilization methods. The *co-situs* application method was demonstrated successfully in the cultivation of dent corn when POCFs were single basal dressed under the band application condition (Ito et al, 2000). In addition, it was reported that the polyolefin coated urea could sufficiently meet the N requirements of corn throughout the whole growing period in a volcanic ash soil under the field conditions (Shoji et al, 1991).

So far, both *co-situs* band application and *co-situs* spot application of CRF was reported to be practical in the pot experiment (Nihei et al, 1998). However, so far little information is available about the response of upland crops to *co-situs* spot application of CRF under field conditions. The seeds of different upland crops have different tolerance to high soil EC at the germination stage (Nihei et al, 1998), therefore, the adverse effect of *co-situs* application for some upland crops perhaps will be become obvious under field conditions if the weather is relatively dry at the germination stage.

The objective of this study is to evaluate response and adaptability of sweet corn and dent corn to the two forms of *co-situs* application of CRF under typical Japanese climate conditions and intend to present some valuable reference for extension and application of *co-situs* application of CRF.

Materials and Methods

The field experiment was conducted from late May to middle September in 2002 at the experimental farm of Tohoku University in Naruko, Miyagi prefecture, Japan (Latitude: 38°44′N, Longitude: 140°15′E). This area has an average elevation of 220 m, and annual average precipitation, sunshine and temperature recorded from 1979 to 2002 were 1,661 mm, 1,411 h, 10.2°C, respectively. The soil was a typical non-allophane volcanic ash soil (Alic Pachi Mellanudand) with loamy texture and the bulk density in the plough layer was 0.82 g/cm^3. Its total C and total N content were 105.2 and 6.4 mg/g, respectively; the nitrate-N and ammonium-N by Bremner extraction (2M KCl) were 15.4 mg/kg and 32.9 mg/kg, respectively, and the soil EC value was 0.178 mS/cm, pH (H_2O : soil = 1 : 2.5) was 6.68.

LP70 is a kind of polyolefin coated urea. Theoretically at 25°C it takes 70 days to release 80% of N from LP70 granules outwards when the moisture is over the wilting point. In this study, LP70 and common urea were chosen as two experimental fertilizers. Two forms of *co-situs* application methods were adopted, one was *co-situs* band application, with a band width for fertilization and sowing of 5 cm, and the other one was *co-situs* spot application, where fertilization

and seeding was restricted beyond the scope of the spot with 5 cm diameter.

Four treatments were designed as follows: A: *co-situs* band application of LP70; B: *co-situs* spot application of LP70; C: conventional side-band application of urea; D: *co-situs* band application of urea. Treatment C was regarded as the control, which has been practiced conventionally in the local area. The fertilization band is usually 5 cm away from the corn growing row, and with 5 cm in depth from the soil surface. The experimental design was a randomized complete block with three replications in the field.

The size of the experimental plot was 20 m^2 with 5 m long and 4 m wide. The amounts of N, P_2O_5 (fused phosphate) and K_2O (polyolefin coated K_2SO_4, 70-day-type) applied for each treatment were 150, 150, 150 kg ha^{-1}, respectively. In the case of N fertilizer, the N rate was equal to 2.14 g N/plant.

In treatment A, B and D, all of the N, P, K fertilizers were basally applied, but in treatment C, only two-thirds of the urea was basally dressed, and the left one-third urea (217.4 g/plot) was broadcasted at the heading stage (July 14, at 53 days after seeding).

Two weeks before planting, the experimental field was plowed and its surface was made flat mechanically. On 22 May 2002, seeding was conducted. Corn was planted with a seeding rate of 70,000 plants ha^{-1}, and each row was 0.7 m apart with an interval distance of 0.2 m between two plants. Each plot consisted of seven corn rows, among them four rows were planted by sweet corn (Cultivar was Pazuru corn 85) and the other three rows were dent corn (Cultivar was Paionia 3699 MR 107), and there were 20 sowing points for each corn row. Before seeding, the bands or spots in each plot were firstly made one by one. Secondly P and K fertilizers were applied into the bands or spots in the form of a mixture, and on the surface of them LP70 or urea was placed. Then at each sowing point three seeds were placed. Finally all bands and spots were covered by soil and every sowing row was pressed by tools in order to create favorable moisture conditions near the seeds which can be created through the force of capillary attraction at the germination stage.

The seed germination was investigated on June 10 (19 days after planting). After that, at every seeding point, only one corn seedling was maintained, and the surplus seedlings were thinned. The development status of corn plants was observed at the stem elongation stage (July 5, 44 days after seeding). In each plot, the sweet corn plants that grew in the intermediate two rows among four rows as well as the dent corn plants that were situated in the middle row among three rows were observed. The plant heights of corn seedlings were measured from the soil level to the tip of the uppermost fully expanded leaf. The plant age was obtained by counting the number of true leaves (the young leaf incompletely expanded was estimated by the decimal), and the tiller number for sweet corn was also counted in the field.

The experiment was carried out under upland conditions and the water requirement for seed germination and plant growth depended solely on the soil water conserved before seeding and natural rainfall during the whole growing period. Weeds were removed by hand every two or three weeks from every plot. Although in treatment D (*co-situs* band application of urea), nearly all the seeds of dent corn and sweet corn did not germinate. The practice of weed eradication for its three plots was done as same as other plots during the entire growing period.

Sweet corn was harvested as early as at the milk stage (August 18) in order to avoiding being eaten by wild animals. On the other hand, dent corn was harvested at the normal ripe stage (September 13). At harvesting, firstly corn spikes were stripped out and the outside shell leaves were still remained on the corn stems. The intact corn straw was taken as samples from each plot. The sweet corn spikes were dried in a big ventilation oven at 40°C for one week, whereas the spikes of dent corn were dried at 70°C for three days, and the corn grain was threshed by hand. Then the dry matter was weighed and the weight for every 1,000 corn grain was measured. After the digestion of grain, straw and cob samples using H_2SO_4-H_2O_2, N, P, K content was determined.

Four soil samples were collected from each plot after dent corn harvest (Sept. 14), and dent corn and sweet corn had two samples, respectively. One sample was taken just below the fertilization location (band or spot application, 5-10 cm deep), and the fertilizer granules were picked out; Another sample was taken from a place 5 cm away from the fertilization location (5-10 cm) and the soil EC was determined (H_2O : soil = 5 : 1).

The weather data including rainfall (mm), air temperature (°C), sunshine time (h) and wind speed (ms^{-1}) are presented in Table 1. During their respective growing periods of dent corn and sweet corn, the accumulated air temperature were 2,315.7°C and 1,755.9°C, respectively.

Table 1. Monthly total rainfall and daily mean of weather variables during the growing season[a]

Month	Total rainfall (mm)	Maximum daily rainfall (mm)	Maximum daily temperature (°C)	Minimum daily temperature (°C)	Mean daily temperature (°C)	Mean wind speed (m S^{-1})	Sunshine time (h)
May	141	44	19.4	8.3	13.0	1.3	165.8
June	137	49	22.1	11.2	16.5	1.2	135.8
July	268	79	26.4	17.5	22.3	1.0	89.5
August	137	38	27.7	16.8	22.3	0.9	94.9
September	85	39	25.2	13.1	18.4	0.8	131.9

[a] The weather data were recorded each day by an automatic weather station located at this farm.

Results

Effects of co-situs application on germination and growth of seedlings

At 19 days following the seeding (June 10), the germination number at each sowing point was investigated and the results are presented in Table 2. The theoretical germination percentages for the seeds of sweet corn and dent corn tested were 80% and 90%, respectively. In the conventional side-band application of urea (control), the mean germination number were 2.3 (76.7%) for sweet corn and 2.7 (90%) for dent corn, they were very close to respective theoretical value and were the largest compared to other treatments.

In the *co-situs* band application of urea, except that a few seeds, which located at the two edges of the sowing row, germinated, most of the seeds did not germinate, they in fact completely lost germinating power, and the average germination number for both sweet corn and dent corn were only 0.1 and 0.04, respectively (see Table 2). This fact indicates as long as the seeds directly contacted urea granules, very poor germination would happen.

In the *co-situs* band application of LP70, compared to the control, the mean germination percentage of sweet corn and dent corn at each sowing point decreased as 26.7% and 10.0%, respectively ; And in the *co-situs* spot application of LP70, the germination percentage of the two corns greatly decreased as 66.7% and 50%, respectively. It indicated that dent corn was more adaptable to *co-situs* application than sweet corn at germination stage.

On the other hand, among 80 (sweet corn) or 60 (dent corn) sowing points at each plot, in the conventional side-band application of urea, the sum of percentages of seeding points with two or three seeds of germination made up 86.3% and 93.4%, respectively (Figure 1). However, under the *co-situs* band application of urea condition, the corresponding percentages only accounted for 1.3% and 1.7%, respectively. Meanwhile, for sweet corn and dent corn, the seeding points at which no any seeds germinated occupied by 97.5% and 96.7%, respectively. Even if under *co-situs* spot application of LP, for sweet corn, the sowing points without any seed germination was as high as 68.8% and the sowing points in which only one seed germinated among the three seeds was relatively as high as 26.3%. For dent corn, the percentage of one seed germination was the largest (36.7%) (Figure 1).

Table 3 shows the growth situation of corn plants at the stem elongation stage. Because *co-situs* application especially *co-situs* spot application greatly influenced germination of sweet corn, the plant number also decreased. In the *co-situs* spot application of LP70, the average plant height and plant age of both corns were significantly lower than that of the other two treatments, and it indicated that this treatment further retarded development of seedlings for both corns until the stem-elongation stage ; In addition, the seedlings of sweet corn

Table 2. Average germination number and germination percentage at each sowing point[a]

Treatments	Sweet corn					Dent corn				
	Number				Percentage (%)	Number				Percentage (%)
	Rep.1	Rep.2	Rep.3	Mean		Rep.1	Rep.2	Rep.3	Mean	
LP70 (*Co-situs* band)	1.3	1.3	2.0	1.5	50.0	2.4	2.2	2.5	2.4	80.0
LP70 (*Co-situs* spot)	0.5	0.3	0.3	0.4	13.3	1.1	1.6	1.0	1.2	40.0
Urea (Conventional side-band)	2.2	2.2	2.5	2.3	76.7	2.5	2.8	2.7	2.7	90.0
Urea (*Co-situs* band)	0.03	0.03	0.1	0.1	3.3	0.03	0.0	0.1	0.04	1.3

[a] The values in the columns of Rep. 1, Rep. 2 and Rep. 3 were means of the total germination number divided by the sowing points in each plot (80, sweet corn) or (60, dent corn), and three seeds were placed at every sowing point.

Table 3. Plant number, plant height, plant age and tiller number at the stem-elongation stage (July 5, 44 days after seeding)[a]

Treatment	Sweet corn				Dent corn		
	Plant number	Plant height (cm)	Plant age	Tillers	Plant number	Plant height (cm)	Plant age
LP70 (*Co-situs* band)	27.0 (8.0)[b]	67.6 (1.5)[a]	9.5[a]	1.5	19.3 (0.6)[a]	93.3 (0.6)[a]	9.6[a]
LP70 (*Co-situs* spot)	13.7 (0.6)[c]	55.7 (3.8)[b]	8.4[b]	0.7	14.0 (2.6)[a]	75.7 (6.0)[b]	9.0[a]
Urea (Conventional side-band)[b]	39.0 (1.7)[a]	71.6 (0.9)[a]	9.4[a]	1.2	19.7 (0.6)[a]	94.1 (4.4)[a]	9.5[a]

[a] Observations were made in each plot, the middle two rows of sweet corn plants among four rows and the middle one row of dent corn plants among three rows were observed. Values are means of three plots for each treatment. Numbers in parenthesis are standard deviation. Means within a column were separated by Tukey's HSD test at the 0.05 level of probability.

[b] For the treatment of conventional side-band of urea, only two-thirds of N (100 kg N ha^{-1}) was applied before investigation.

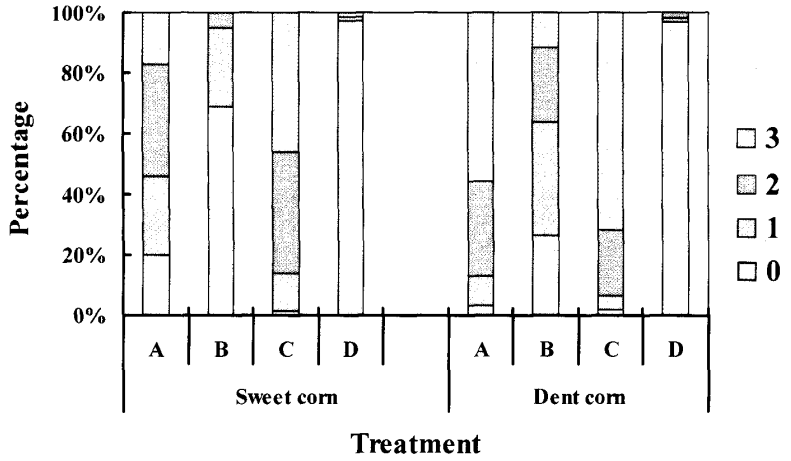

FIG. 1. Percentage of sowing points with different number of seeds germinated. A : *co-situs* band application of LP70 ; B : *co-situs* spot application of LP70 ; C : conventional side-band application of urea ; D : *co-situs* band application of urea. 3, 2, 1, 0 mean three, two, one, zero seeds germinated at one sowing point, respectively.

were more sensitive to the adverse effect of *co-situs* spot application than that of dent corn. Therefore, the largest influence of *co-situs* application of LP on sweet corn was inhibition of germination and reduction of plant number. This would affect the final grain yield.

Influence of co-situs application methods of controlled release fertilizer on corn yield as well as N, P and K nutrient uptake

Table 4 shows the weight of 1,000 corn grains, grain yield and dry weight of straw plus cob as well as harvest index for the three treatments. Among the three treatments, the *co-situs* spot application of LP significantly decreased yield of grain as well as yield of straw plus cob, and the grain yield of dent corn and sweet corn decreased by 26.0% and 75.6%, respectively, as compared with the conventional side-band application of urea ; For sweet corn, the grain yield under *co-situs* band application of LP also decreased by 25.0% as compared with the conventional side-band application of urea. However, between the three treatments, there were no significant differences for the weights of 1,000 corn grains for both dent corn and sweet corn, although the values of sweet corn were relatively low because harvest was conducted as early as at the milk stage ; In addition, there were also no significant differences for harvest index between the three treatments for two corns, although harvest index (HI) of dent corn (0.5-0.53) was three times higher than that of sweet corn (0.14-0.17). This fact indicated that *co-situs* application of CRF did not obviously affect growth of single plants of both corns at the late growing period.

The major reason which led to significant decrease of grain yield in the treatment of *co-situs* spot application of CRF lied in the plant number in the plots

Table 4. Weight for 1,000 corn grains, grain yield, straw and cob yield as influenced by co-situs application

Treatments	Weight of 1000 grains (g)	Grain yield (kg/ha)	Straw+cob yield (kg/ha)	HI (%)
	Dent corn			
LP70 (*Co-situs* band)	262.7±7.2[a]	7,595±286[a]	6,808±1,198[ab]	53[a]
LP70 (*Co-situs* spot)	267.2±6.1[a]	5,367±566[b]	5,338±368[b]	50[a]
Urea (Conventional side-band)	261.0±8.5[a]	7,257±657[a]	7,155±173[a]	50[a]
	Sweet corn			
LP70 (*Co-situs* band)	73.9±1.0[a]	1,127±527[ab]	5,441±290[b]	17[a]
LP70 (*Co-situs* spot)	65.2±10.7[a]	367±143[b]	2,261±544[c]	14[a]
Urea (Conventional side-band)	79.2±2.9[a]	1,502±400[a]	7,649±1,355[a]	17[a]

Values are means of three plots with standard deviation for each treatment. Means within the same column and same crop were compared by Tukey's HSD test at the 0.05 level of probability.

Table 5. N, P, K uptake amount in different parts of corn (kg/ha)[a]

Treatment	Dent Corn			Sweet corn		
	N	P	K	N	P	K
	Grain					
LP70 (*Co-situs* band)	123.8[a]	32.0[a]	37.2[a]	29.2[ab]	6.5[ab]	14.7[ab]
LP70 (*Co-situs* spot)	89.7[b]	18.7[b]	24.5[b]	9.9[b]	2.2[b]	4.9[b]
Urea (Conventional side-band)	116.3[ab]	28.6[a]	34.2[a]	39.0[a]	8.4[a]	18.5[a]
	Straw					
LP70 (*Co-situs* band)	57.3[ab]	8.7[a]	160.6[a]	64.0[a]	23.5[a]	123.2[b]
LP70 (*Co-situs* spot)	44.0[b]	6.2[a]	121.9[a]	29.6[b]	8.2[b]	51.5[c]
Urea (Conventional side-band)	62.8[a]	8.1[a]	170.6[a]	82.7[a]	30.3[a]	179.4[a]
	Cob					
LP70 (*Co-situs* band)	6.0[a]	0.6[a]	16.4[a]	7.9[ab]	3.1[ab]	13.5[a]
LP70 (*Co-situs* spot)	4.8[a]	0.5[a]	10.8[a]	4.5[b]	1.2[b]	7.1[b]
Urea (Conventional side-band)	5.3[a]	0.4[a]	14.3[a]	9.5[a]	4.8[a]	15.7[a]

[a] Each value is the mean of three plots. Means within the same column and the same part of corn were separated by Tukey's HSD test at the 0.05 level of probability.

decreased, because many seeds did not germinate, and the plant number in each plot in this treatment was only about one-third of the conventional side-band application of urea (see Table 2 and Table 3).

In comparison with the conventional side-band application of urea, in *co-situs* spot application of LP treatment, the N, P, K uptake amount in the grain of two

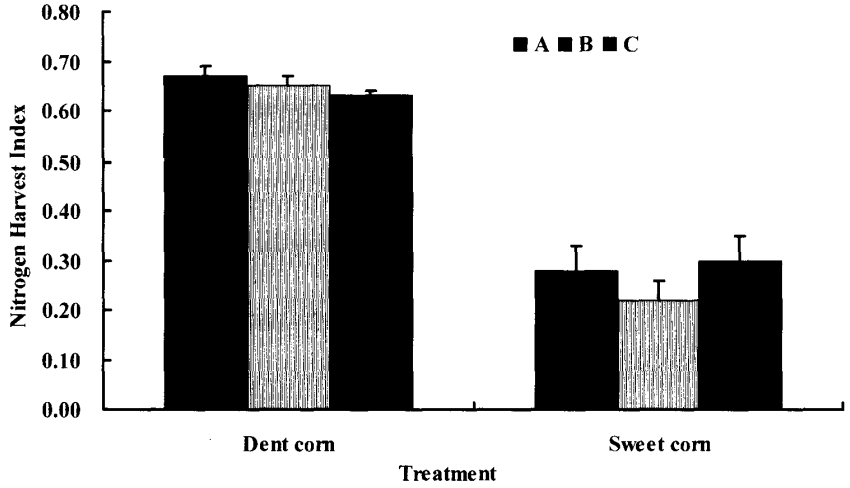

FIG. 2. Nitrogen harvest index of dent corn and sweet corn. A: *Co-situs* band application of LP70; B: *Co-situs* spot application of LP70; C: conventional side-band application of urea.

corns significantly decreased, and the N, P, K uptake amounts in straw and cob had the same tendency (Table 5). The reason should be the same as the above-mentioned.

For both corns, there was no significant difference for nitrogen harvest index between the three different treatments. And dent corn had over two times higher nitrogen harvest index (nitrogen HI) (0.63–0.67) than sweet corn (0.28–0.30) (Figure 2). In addition, nitrogen harvest index of two corns was larger than harvest index; this may indicate that nitrogen compounds were transferred into ear earlier than carbohydrates especially for sweet corn.

Soil EC after harvest

From fertilization (planting time) to soil sampling, the daily average temperature was 22.2°C when the harvest of dent corn was over, and the soil EC values below the fertilization locations were still obviously higher than those at 5 cm away, especially in the *co-situs* band application of LP and *co-situs* spot application of LP (Figure 3). The tendency in the growing zone of dent corn was the same as that in the growing zone of sweet corn. This showed that the nutrient in LP granules released gradually. Therefore, through an entire growing season the nutrient concentration near the fertilization location of LP was still high compared to that of urea and *co-situs* application of LP mainly affected soil EC near the fertilization location. In the case of treatment D (*co-situs* band application of urea), soil EC values were lowest at the fertilization location, and it probably implied the strong leaching occurred during the growing season.

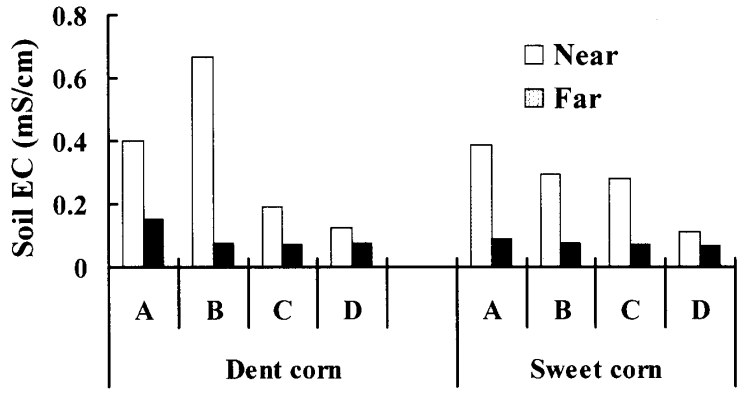

FIG. 3. Soil EC values after corn harvesting. 'Near' means soil samples were taken below fertilization; 'far' means sampling was done at 5 cm away from the fertilization location. A: *Co-situs* band application of LP70; B: *Co-situs* spot application of LP70; C: conventional side-band application of urea; D: *Co-situs* band application of urea.

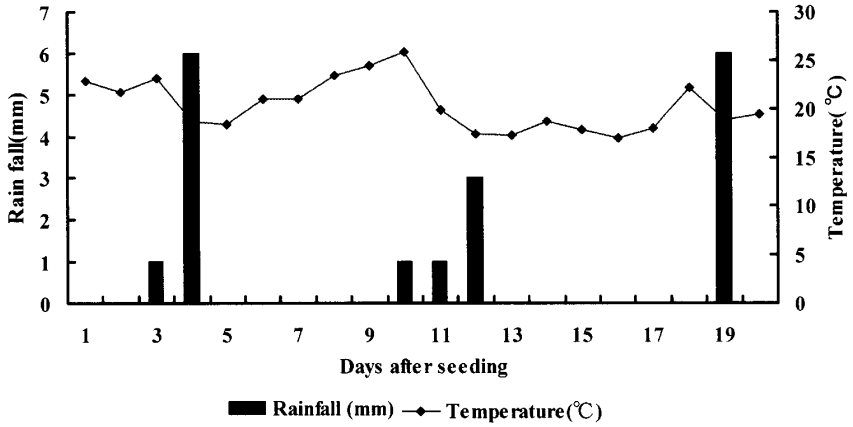

FIG. 4. Average daily temperature (°C) and rainfall (mm) at the germination stage (From May 23 to June 10, 19-day-long period).

Effects of rainfall and soil water conditions on germination and growth of corn plants

It was relatively dry at the germination stage in the year of 2002 (18 mm rainfall), and the average daily temperature reached 17.9°C (Figure 4). Under the *co-situs* application conditions particularly in the *co-situs* spot application, it seemed that high temperatures and little rainfall accelerated the consumption of stored soil water in the topsoil at the depth of 30 cm, and the nutrients at seeding location were highly concentrated, and thus this environmental condition maybe stimulate the adverse effects of *co-situs* application and further led to poor germination.

However, dent corn and sweet corn plants received 545 mm and 495 mm of rainfall, respectively, during their respective 95 and 69 days of growing days

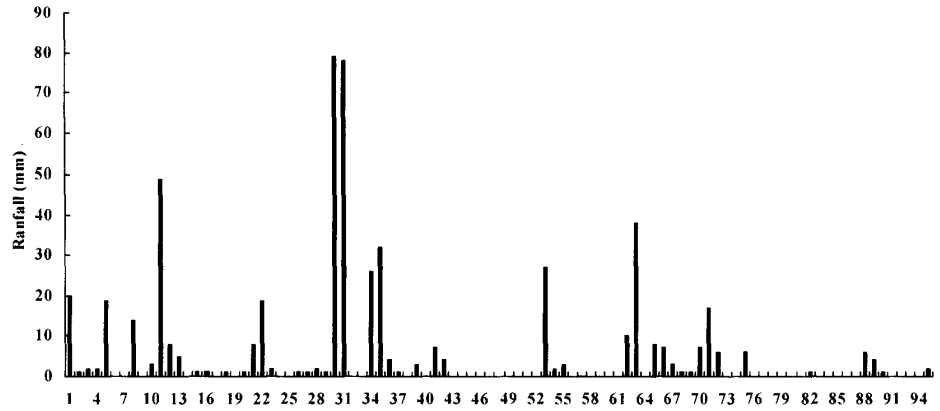

FIG. 5. Daily precipitation after germination during 95-day period (June 11 to September 13).

(after germination to harvest) (Figure 5). Especially there were frequent rainfall events at the seedling and stem elongation stage. The observation taken in the field showed that soil water stress for plants did not take place due to large rainfall since the establishment of seedlings. Therefore, it was concluded that water condition was not the constraint factor for corn growth and yield formation.

Discussion

This study investigated the feasibility of two different *co-situs* application methods of CRF on dent corn and sweet corn under upland field conditions in a humid area. It was found that in the treatment of *co-situs* spot application, poor germination occurred especially for sweet corn, although LP70 as one kind of polyolefin coated urea had good controlled release characteristics of nutrient (Shoji, 1999) ; and this treatment further retarded seedling development, but such retardation was not obvious at the late growing period because of favorable water conditions, and it was considered that significant decrease of yield was caused by lower germination percentage and less plant number compared to control. Such results suggest that *co-situs* spot application had more obvious adverse effects on seed germination as compared with *co-situs* band application, and the seeds of sweet corn were much more sensitively inhibited than dent corn under *co-situs* application conditions. It is suggested that *co-situs* application as one fertilization method of CRF being recommended in Japan, although which has many merits demonstrated (Inoue et al, 2000 ; Ito, 2002 ; Shoji, 1999), however, when applied in upland crops, the concrete practice (band or spot) and crop species should be taken into consideration.

A clear result is that under the conditions of *co-situs* application, CRF had much higher safety and adaptability for seed germination compared to the common readily available fertilizer under upland field conditions. For the urea,

co-situs application is scarcely practiced, because it make the seeds to lose germinating power (see Table 2 and Figure 1). In addition, CRF was applied as a single basal application, and topdressing can be omitted during the growing season.

In the *co-situs* band application of LP70, the fertilizer granules were dispersed in a much larger soil space compared to *co-situs* spot application of LP70. Therefore, the inhibition of the former to seed germination were relatively weak than the latter. The possible reasons for inhibition are as follows: ammonia produced from urea affected the seed vigor; LP fertilizer granules competed water with seeds, and the fused phosphorus and coated ammonium sulfate also jointly stimulated this competitiveness; relatively high temperatures and sporadic rainfall at the germination stage probably stimulated germination difficulty.

The response of sweet corn to *co-situs* application was much more sensitive than dent corn, probably because the seeds of sweet corn were wrinkly, needed much more water and were more sensitive to high nutrient concentration near the seeds at the germination stage.

Nitrogen, phosphorus and potassium fertilizers were applied in the same soil space, and these three elements commonly caused the increase of soil EC. However, it was obvious that after the end of the experiment, the LP (polyolefin coated urea) dominated the increase of soil EC (Figure 3). In addition, under *co-situs* band application of urea, although no corn plants grew in its three plots, but at the end of experiment, the soil EC value in this condition was very low, and therefore, it was postulated that N leaching or other N losses took place, because several heavy rainfalls (49 mm, 21 June, 157 mm, 10 and 11 July, 58 mm, 14 and 15 July) occurred during the experimental period.

It is worth mentioning that although the weather was relatively dry at the germination stage in our study, there was a rainfall event of 44 mm at 5 days before seeding, and particularly a large amount of soil water stored in volcanic ash soil profile below 30 cm depth is available to plants (Hasegawa and Eguchi, 2002). Therefore, in the treatment of conventional fertilization condition (control), it was found that the germination percentage of both corns were still very close to their respective theoretical value, and no water deficit occurred for corn germination (see Table 2). However, April and May belong to a windy season with low relative humidity and strong evaporation in this humid area. During the seeding period for corn crop, the variation range of rainfall is also large. For example, the total rainfall at the germination stage for corn production (usually two to three weeks long after planting) in 1996, 1997, 1998 were 6 mm, 108 mm, 64 mm, respectively (Ito et al, 2000). This suggests that when the *co-situs* application of CRF is practiced to upland crops, variable rainfall at the germination stage possibly can increase the risk of poor germination.

It may be concluded that although *co-situs* application of CRF had many

merits such as high nutrient recovery rate and low nutrient loss through leaching in humid areas, there are still some limitation to upland crop such as sweet corn to apply this technology, and the most serious influence is seed germination. The results indicated that it is true for crops such as dent corn that *co-situs* band application of CRF is of applied value, and *co-situs* spot application of CRF is not suitable for upland field conditions and two forms of *co-situs* application is not suitable for sweet corn production.

References

1) Fujita, T. Types of polyolefin resin coated fertilizers: LP coat and LONG. In: Shoji, S. (Ed.), *Challenges to New Farming Systems*. Hakuyusha Publishing House, Tokyo, pp. 93-104 (in Japanese) (1995).
2) Hasegawa, S. Evaluation of rainfall infiltration characteristics in a volcanic ash soil by time domain reflectometry method. *Hydrol. Earth Syst. Sci.*, **1**, 303-312 (1997).
3) Hasegawa, S. and Eguchi, S. Soil water conditions and flow characteristics in the subsoil of a volcanic ash soil: findings from field monitoring from 1997 to 1999. *Soil Sci. Plant Nutri.*, **48**(2), 227-236 (2002).
4) Inoue, H., Ito, T. and Saigusa, M. Weed growth and nutrient uptake in dent corn cultivation with single basal *co-situs* fertilization. *Jpn. J. Soil Sci. Plant Nutri.*, **71**, 345-349 (in Japanese with English summary) (2000).
5) Kaneno, R. *Agricultural Hydrology*. Kyoritsu-Shuppan Publishing House, Tokyo, pp. 148 (in Japanese) (1973).
6) Ito, T., Inoue, H. and Saigusa, M. Effects of tillage and nitrogen fertilizer type on emergence of dent corn in cultivation with single basal *co-situs* fertilization. *Jpn. J. Soil Sci. Plant Nutri.*, **71**, 187-193 (in Japanese with English summary) (2000).
7) Ito, T. Soil and plant nutrition science now developed from field study-acquisition and analysis of data from the new view point-6. Influence of no-tillage on soil properties and crop growth. *Jpn. J. Soil Sci. Plant Nutri.*, **73**, 193-201 (in Japanese) (2002).
8) Nihei, N., Ito, T. and Saigusa, M. Effects of *co-situs* application using controlled available fertilizer on root development of crops with different salt tolerance and root system, *Kawatabi Farm Report*, No. 14, 11-18 (in Japanese) (1998).
9) Saigusa, M., Kodama, H., Shibuya, K. and Abe, T. Single basal application of nitrogen fertilizer on dent corn cultivation using controlled release urea. *J. Jap. Soc. Grass. Sci.*, **39**, 44-50 (in Japanese with English summary) (1993).
10) Saigusa, M. Slow release nitrogen fertilizers and plant nutrition. In: Srivastava, H. R., Singh, R.P. (Ed.), *Nitrogen nutrition and plant growth*. Oxford & IBH Publishing Co. PVT. LTD., New Delhi, pp. 307-335 (1999).
11) Shoji, S., Gandeza, A.T. and Kimura, K. Simulation of crop response to polyolefin-coated urea: II. Nitrogen uptake by corn. *Soil Sci. Soc.*

Amer. J., **55**, 1468-1473 (1991).

12) Shoji, S. *MEISTER Controlled Release Fertilizer-Properties and Utilization.* Konno Printing Company Ltd. Seidai, Japan, 160 pp. (1999).

13) Tian, X.H. and Saigusa, M. Merits, utilization, and perspectives of controlled release nitrogen fertilizers. *Tohoku Journal of Agricultural Research.*, **52** (3-4), 39-55 (2002).