
USE OF CONTROLLED-RELEASE FERTILIZERS (CRF) FOR SUSTAINABLE CROP PRODUCTION IN ASIA

Hitoshi Kanno

Graduate School of Agricultural Science, Tohoku University
1-1, Tsutsumidori Amamiya-machi, Aoba-ku, Sendai 981-8555, Japan

Hitoshi Kanno holds a Doctorate degree in agricultural science from Tohoku University (in Japan) and is an assistant professor of Tohoku University. His expertise is in the area of soil science and plant nutrition.

ABSTRACT

Nitrogen (N) plays a central role in modern agriculture. It is an essential nutrient and it is also the major limiting nutrient in most agricultural soils growing non-leguminous crops. However, recovery of N in cereal crops is usually 30-50% worldwide (Ladha et al., 2005). The percentage is often lower for paddy rice (*Oryza sativa* L.) or for crops growing in high-rainfall or humid areas (Hauck, 1985). Low recovery of N in annual crop is associated with its loss by volatilization, leaching, surface runoff, and denitrification. Improving N use efficiency (NUE) is desirable to improve crop yields, reduce cost of production, and maintain environmental quality. One approach to increase NUE is to control the rate of N fertilizer dissolution. Synchrony of N supply with crop demand is essential in order to ensure adequate quantity of uptake and utilization and optimum yield. Controlled-release fertilizers (CRF) and nitrification inhibitors are potential sources for improving NUE in many crops (Shoji et al., 1991; Shaviv and Mikkelsen, 1993; Shaviv, 2001; Trenkel, 2010).

The slow-release characteristics of CRF permit N uptake by plants according to their demand, and reduce N leaching or denitrification losses. Polyolefin-coated fertilizer (POCF) is one of the CRFs developed in Japan that shows highly controlled nutrient-release characterized by temperature. This accurate nutrient control enables large amount of POCF to be placed with seeds or seedlings without salt damage (Kanno et al., 1993; Kaneta et al., 1994). In order to distinguish the placement of large amounts of POCF from seed-placement of small amount of soluble fertilizers, Shoji and Gandeza (1992) proposed to name this method “*co-situs*” application. The central concept of *co-situs* application is to apply the fertilizers at an intensive rooting zone with release patterns synchronized to the demand of the plant over the entire growing season (Shoji and Kanno, 1994). The *co-situs* application of POCF has been carried out for sustainable crop production in northeastern Japan.

It used to be common in Japan that a large amount of chemical fertilizer is applied to the paddy field by broadcasting as basal application and then rice seedlings grown in the nursery boxes are transplanted using mechanical transplanters. The recovery of the basal N applied by this conventional fertilization is low, mostly less than 25% in northeastern Japan (Shoji and Mae, 1984). The strategy of *co-situs* application was demonstrated in a paddy field at Akita Prefectural Agriculture Experiment Station, Ohgata, northeastern Japan (Kaneta et al., 1994). Polyolefin-coated urea (POCU) was used in a no-till paddy rice cultivation by transplanting the rice seedlings. All fertilizer N needed by rice for the entire growing season was applied to nursery boxes using sigmoidal POCF (POCU-S100 which had a lag period of 30 days and release duration of 70 days at 25°C). Rice seedlings were grown in 600g of POCU-S100 (240g N) applied nursery boxes (size: 30 x 60 x 3 cm) without salt damage. Rice seedlings in 260 nursery boxes were transplanted at a 30 x 15 cm spacing to a one-ha paddy field. This transplanting brought about 62 kg N ha⁻¹ to the paddy field because rice seedling roots held all fertilizer granules applied in the nursery boxes. Nursery box-applied POCU-S100 in a no-till transplanting paddy rice obtained a high correlation between the fertilizer-N dissolution and fertilizer-derived N uptake (FDNU), and the very high fertilizer-N recovery using the ¹⁵N tracer method, such as 87% of the dissolved N basis and 79% of the applied N basis in 1992. Compared to the recovery of basal N applied by broadcasting soluble fertilizers, that of POCU was doubled by broadcasting and almost tripled by *co-situs* placement in the paddy rice cultivation.

N release pattern, which includes soluble fertilizers with split-dressing and POCF with linear and sigmoidal release, might strongly affect crop growth, yield and FDNU in the upland field under humid condition. Several field experiments were conducted to determine (i) dent corn (*Zea mays* L.) N uptake from split-dressed urea, *co-situs* applied POCU with linear (POCU-70) and sigmoidal (POCU-30+S60) release using the ¹⁵N tracer method, (ii) N rate effect of single basal urea and two types of POCU (POCU-30 and POCU-70) using the ¹⁵N tracer method, and (iii) effects of N supply pattern on the movement of

inorganic N around the application site at the Kawatabi Experimental Station of Tohoku University, northeastern Japan. Fertilizer-N recoveries of POCU with a sigmoidal release in 1994 and 1995 ranged from 71 to 72% of the dissolved N basis, while those of POCU with a linear release and uncoated urea were 60-63% and 40-57%, respectively (Kanno et al., 1997; Kanno, 2008). Synchrony of N supply with crop demand using POCF improved NUE and reduced the N rate for target yield. Although N rate effect of basal urea and two types of POCU on FDNU in 1996 and 1997 depended on yearly variations in climate which related to the intensity of N leaching, the recovery of 150 kg N ha⁻¹ uncoated urea, POCU-30 and POCU-70 application were 49%, 61% and 63% in 1996 and 36%, 40% and 61% in 1997, respectively (Kanno et al., 2006). Mean recovery rate significantly decreased from 52-36% with increasing N rate to 50-250 kg N ha⁻¹ in 1997. Although the increase in N rate decreased the recovery rate, higher N recovery rate of POCU-70 was sustained compared to those of uncoated urea and POCU-30. Due to microbial transformations in most cultivated upland soils, mineral N source is likely to be oxidized to nitrate and relatively high fractions of the applied N may potentially be leached or removed from the rooting zone under humid condition. In this situation, N from POCF is expected to minimize or prevent nitrification or nitrate leaching. Greater amount of soil inorganic N, which remained around the application site in the middle to late growing season, increased fertilizer N uptake by dent corn in 1998 and 1999. The use of POCU minimized the downward movement of soil inorganic N from the application site (Kanno et al., 2000).

KEYWORDS

N use efficiency (NUE), controlled-release fertilizers (CRF), polyolefin-coated fertilizers (POCF), *co-situs* application, fertilizer-derived N uptake (FDNU)

REFERENCES

- Hauck, R.D., 1985: Fertilizers Technology and Use, Third Edition, Soil Sci. Soc. of America, Inc., Madison, Wisconsin, 293-322.
- Kaneta, Y., H. Awasaki and T. Murai, 1994: Jap. J. Soil Sci. Plant Nutr, 65, 385-391.
- Kanno, H., 2008: Tohoku J. Agri. Res., 58, 65-75.
- Kanno, H., K. Fukushima and S. Yamasaki, 2000: Bull. Exp. Farm, Tohoku Univ., 16, 53-59.
- Kanno, H., S. Obara, K. Fukushima and S. Yamasaki, 2006: (Unpublished).
- Kanno, H., S. Shoji and T. Ito, 1993: Bull. Exp. Farm, Tohoku Univ., 9, 23-29.
- Kanno, H., S. Shoji and S. Yamasaki, 1997: Plant nutrition - for sustainable food production and environment, 643-644.
- Ladha, J.K., H. Pathak, T.J. Krupnik, J. Six and C. Kessel, 2005: Adv. Agron., 71, 1-49.
- Shaviv, A. and R.L. Mikkelsen, 1993: Fert. Res., 35, 1-12.
- Shoji, S. and A.T. Gandeza, 1992: Controlled-release fertilizers with polyolefin resin coating, Konno Printing Co., Sendai, Japan.
- Shoji, S., A.T. Gandeza and K. Kimura, 1991: Soil Sci. Soc. Am. J., 55, 1468-1473.
- Shoji, S. and H. Kanno, 1994: Fert. Res., 39, 147-152.
- Shoji, S. and T. Mae, 1984: Ecophysiology of Crops, Bun-eido, Tokyo, 97-172.
- Trenkel, M.E., 2010: Slow and controlled-release and stabilized fertilizers, International Fertilizer Industry Association (IFA). Paris, France.

Use of Controlled-Release Fertilizers (CRF) for Sustainable Crop Production in Asia

Hitoshi Kanno
(Tohoku University, Japan)



1

Japanese potential for fertilizer technology demand in Asia

Keyword:

CRF (controlled-release fertilizers)

Two selected topics:

1. High performance CRF
2. CRF-specific application method

2

Introduction

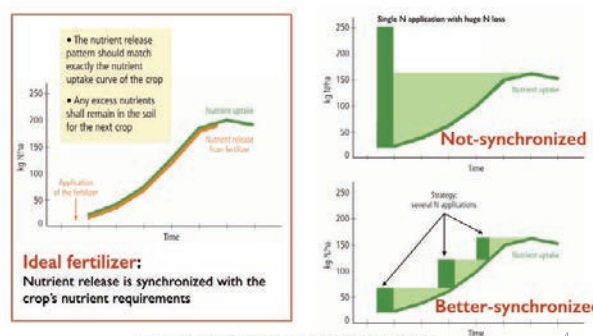
- Nitrogen (N) is the major limiting nutrient in most agricultural soils growing non-leguminous crops.
- Recovery of N in cereal crops is usually 30–50% worldwide, often lower for paddy rice or for crops growing in high-rainfall or humid areas.
- Low recovery of N is associated with its loss by volatilization, leaching, surface runoff and denitrification.
- Enhancing N use efficiency (NUE) is desirable to improve crop yields, reducing cost of production, and maintaining environmental quality.
- Essential approach to enhance NUE is to control the rate of N fertilizer dissolution.

3

3

Traditional enhanced-efficiency fertilization concept

Sigmoidal pattern of nutrient supply can be obtained by applying N fertilizer in several split applications (Lammel, 2005)



4

Special types of fertilizers: Alternative solution to enhance NUE

- Foliar fertilizers;
- Slow- and controlled-release fertilizers (SRF/CRF) with the release of nutrients over several months;
- Stabilized fertilizers (fertilizers associated with nitrification or urease inhibitors) delaying either the nitrification of ammonia or the ammonification of urea.

5

5

What is SRF/CRF?

A fertilizer containing a plant nutrient in a form which **delays** its availability for plant or which **extends** its availability to plant longer than a 'rapidly available fertilizer'

1. Organic-N low-solubility compounds

- Biologically decomposing compounds usually based on urea-aldehyde condensation products, such as urea-formaldehyde (UF)
- Chemically (mainly) decomposing compounds, such as isobutylidene-diurea (IBDU)

2. Fertilizers in which a physical barrier controls the release

- Inorganic materials such as sulphur or mineral-based coatings
- Organic polymer-coatings such as polyolefin's, rubber, etc.

3. Inorganic low-solubility compounds

(Trenkel, 2010)

6

CRF is a special one of SRF

Slow release fertilizers (SRF)

Delays its availability for plant or **extends** its availability to plant longer than a 'rapidly available fertilizer'

Controlled-release fertilizers (CRF)

Factors dominating the rate, pattern and duration of release are well known and controllable.

(Trenkel, 2010)

7

Why do you need CRF?

To synchronize N dissolution with crop demand.

- Accurate slow release (= controlled nutrient release) property of CRF permit N uptake by crops according to their demand, and reduce N leaching or denitrification losses.
- Polyolefin-coated fertilizer (POCF) is one of CRF developed in Japan, and shows highly controlled nutrient release characterized by a temperature.
- CRF is a potential source for a sustainable crop production in Asia.

8

8

Japanese potential for fertilizer technology demand in Asia

1. Manufacturing high performance CRF

- Nutrient release is accurately controlled.
- Many kinds of products are commercially available.

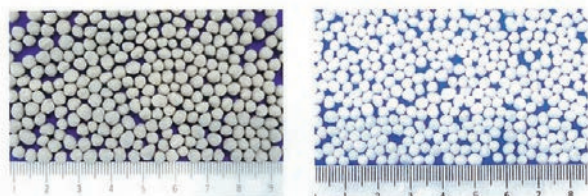
2. CRF-specific application method

- Optimum nutrient supply could be programmed with one time application.
- Placement could be optimized for crop use and/or farmer's operation.

9

1. High performance CRF

Appearance of polyolefin-coated fertilizers (POCF) developed in Japan



Nutricote®

Meister®

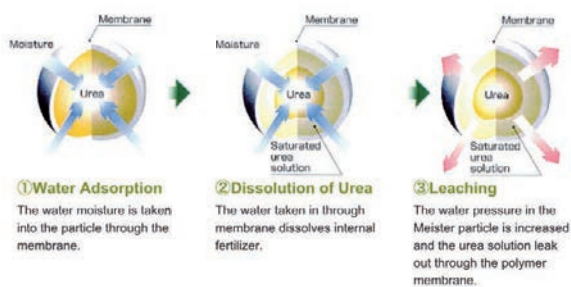
<http://www.jcam-agri.co.jp/en/product/meister.html>

10

10

1. High performance CRF

Release mechanism of POCF characterized by temperature



<http://www.jcam-agri.co.jp/en/product/meister.html>

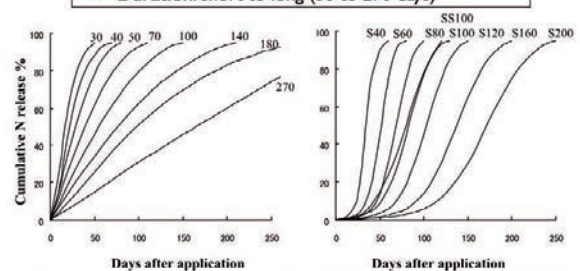
11

11

1. High performance CRF

N release of polyolefin-coated urea (POCU) in water at 25°C (Chissoasahi, 2005)

- Two groups: linear and sigmoid release formulation
- Duration: short to long (30 to 270 days)



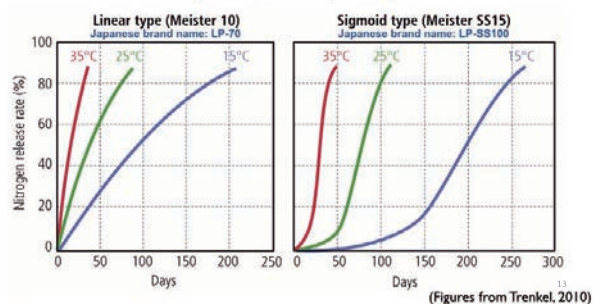
We can design any fertilization program by using both linear and sigmoid formulations

12

12

1. High performance CRF

Effect of temperature on N release of polyolefin-coated urea (POCU) (Chissoasahi, 2005)

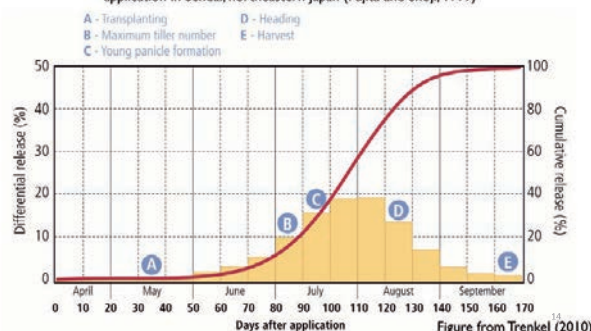


13

2. CRF-specific application

Sigmoidal pattern of nutrient supply can be obtained by one time application of POCF

Nitrogen release of Meister-S12 (Japanese brand name: LP-S80) for rice nursery application in Sendai, northeastern Japan (Fujita and Shoji, 1999)



14

2. CRF-specific application

Accurate nutrient control property enables POCF to place with maize seeds without damage



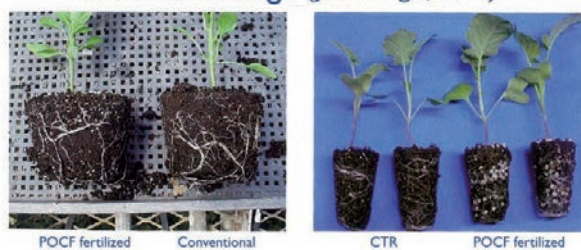
Conventional: soluble fertilizers should be kept off seeds

co-situs (contact) placement: POCF could be applied with seeds

15

2. CRF-specific application

Accurate nutrient control property enables POCF to place with seedlings without damage (JCAM Agri, 2011)



Bell pepper seedlings
(*Capsicum annuum* L. 'grossum')

Broccoli seedlings
(*Brassica oleracea* var. *italica*)

16

Case study

in northeastern Japan

Paddy rice:

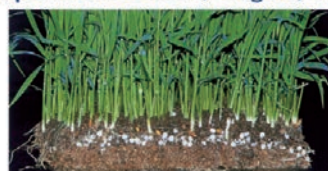
- Uptake process and recovery of POCU

Dent corn:

- Uptake process and recovery of POCU
- Recovery of POCU in a N rate study
- Soil inorganic N at POCU application site

17

No-till transplanting rice culture by one time nursery application in 1992 at Akita Prefectural Agriculture Experiment Station, Ohgata, northeastern Japan



No-till transplanter

(Photos by Prof. Kaneta)

18

No-till transplanting rice culture by one time nursery application (Kaneta et al., 1994)

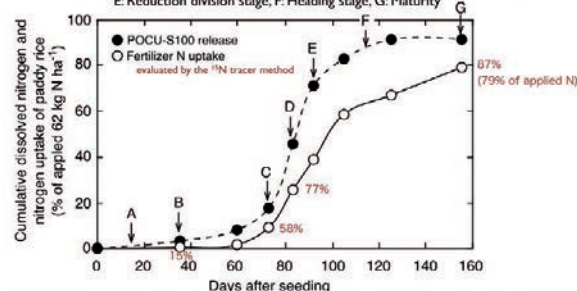
- All fertilizer N needed by paddy rice for the entire growing season applied to nursery boxes using sigmoidal POCF (POCU-S100)
- POCU-S100 had a lag period of 30 days and a release duration of 70 days at 25°C
- Rice seedlings were grown in the 600 g of POCU-S100 (240 g N) applied nursery boxes (size: 30 x 60 x 3 cm) by *co-situs* placement
- Rice seedlings of 260 nursery boxes were transplanted at a 30 cm x 15 cm spacing to a one-ha no-till paddy field
- This transplanting brought about 62 kg N ha⁻¹ to the paddy field because rice seedling roots held all fertilizer granules applied in the nursery boxes

19

19

Relationship between dissolved N and fertilizer-derived N uptake of paddy rice

A: Seedling stage, B: Transplanting, C: Most active tillering stage, D: Panicle initiation stage, E: Reduction division stage, F: Heading stage, G: Maturity



The N release from POCU-S100 was only a few percent during the seedling stage. The recovery of released N was 15% at the transplanting time. Gradual release of N from POCU was observed around 60 days. Thereafter, rapid N release of POCU and rapid N uptake by rice plants started. The recovery of released N was 58% at the active tillering stage and 77% at panicle initiation stage. It further increased and reached 87% of the released N and 79% of the applied N by harvest.

20

20

Comparative recovery of basal N by paddy rice in northeastern Japan

Placement	N source	Recovery (%)	Reference
Broadcast	Ammonium sulfate or urea	22–23	Shoji and Mae (1984)
Broadcast	POCU-100	48–62	Ueno (1994)
<i>co-situs</i>	POCU-S100	79	Kaneta et al. (1994)

- Recovery of basal N of POCU was doubled by broadcasting and almost tripled by *co-situs* placement with sigmoidal release.
- Increasing NUE and reducing N rate can notably decrease N fertilizer pollution.
- Capability of one time basal application, the labor-saving aspect of POCUs is the main reason for their use in Japan.

21

21

Case study in northeastern Japan

Paddy rice:

- Uptake process and recovery of POCU

Dent corn:

- Uptake process and recovery of POCU
- Recovery of POCU in a N rate study
- Soil inorganic N at POCU application site

Studies of dent corn were omitted today (see Abstract)

22

22

Summary of case studies: Precise nutrient management using POCF in northeastern Japan

- Fertilizer-N recoveries of *co-situs* applied POCU with a sigmoidal release were 87% in a no-till transplanting paddy rice and 71–72% in a dent corn cultivation.
- Rate effect of N source on fertilizer-N recovery of dent corn depended on yearly variations in climate.

Studies of dent corn were omitted today (see Abstract)

23

23

Optimum nutrient supply using high performance CRF and CRF-specific application method

Optimum nutrient supply controls nutrient losses and enhances NUE, and decreases rate of application maintaining target yield and minimize risk of environmental pollution.

- Nutrient supply should be timely and just enough.
- Selection of suitable CRF formulations for programmed N supply to meet the plant need by one time basal application.
- Fertilizer placement to supply N directly to the plant such as *co-situs* (contact) placement.
- One time basal application is necessary to a labor-saving nutrient management.
- Unfortunately, manufacturing cost of high performance CRF is still great.

24

24

**Conclusion: Japanese potential for
fertilizer technology to contribute to the sustainable
crop production in Asia**

1. Manufacturing high performance CRF: POCE

- Nutrient release is accurately controlled by temp.
- Many kinds of products are available: linear or sigmoid release and short to long duration (30 to 270 days)

2. CRF-specific application method

- Optimum nutrient supply could be programmed with one time application: Labor-saving
- Placement could be optimized for crop use and/or farmer's operation: co-situs placement

25

25

Chair Matsunaga: The second speaker is Dr. Hitoshi Kanno. He holds a doctorate degree in agriculture science from Tohoku University. His expertise is in the area of soil science and plant nutrition. He has made several research achievements on the work of Controlled-release Fertilizers. He is the proper scientist to talk about this fertilizer. Today's presentation is "Use of Controlled-release Fertilizers (CRF) for Sustainable Crop Production in Asia." Dr. Kanno, please.

Dr. Hitoshi Kanno: Thank you, Mr. Chairman. It's my pleasure to make a presentation in this symposium. In this session we are talking about Japanese potential for new technology demand in Asia so I'd like to focus on controlled-release fertilizers as a promising technology.

At first, I'll show you the keyword and topics of this presentation. The keyword is CRF, controlled-release fertilizer. Don't forget. Selected topics are high-performance CRF developed in Japan, and CRF-specific application method already practiced in Japan.

As you know, nitrogen is an essential element for plants. It's also the major limiting nutrient in most agricultural soils. However, recovery of nitrogen in cereal crops is usually 30 to 50 percent worldwide, often lower for paddy rice or for crops growing in high-rainfall or humid areas.

Low recovery of nitrogen is associated with its loss by volatilization, leaching, surface runoff, and denitrification.

Enhancing nitrogen use efficiency is desirable to improve crop yields, reduce cost of production, and maintain environmental quality. I think an essential approach to enhance nitrogen use efficiency is to control the rate of nitrogen fertilizer dissolution in order to match exactly the nutrient demand of target crop.

For optimum plant nutrition and reduction in the nutrient losses, the ideal fertilizer should release the nutrient in a sigmoidal pattern like this. By the traditional method, the sigmoidal pattern can be obtained by applying the nitrogen fertilizer in several split applications. If conventional nitrogen fertilizers are applied on only one occasion, it results in too-large amounts of nitrogen in the early growth stages and too little at the later stages, so-called not-synchronized nutrient supply.

Better synchronized nutrient supply will be possible by strategic several split dressings; however, it is clear this labor-consuming work will be unacceptable for farmers.

Fortunately, we can use special types of fertilizers. Foliar fertilizers, slow and controlled-release fertilizers with the release of nutrients over several months, and stabilized fertilizers delaying either the nitrification of ammonia or the ammonification of urea.

Slow and controlled release fertilizers contain nutrients in a form which delays its availability for crops or extends its availability to crops longer than the conventional soluble fertilizer.

There are three types of slow and controlled-release fertilizers.

First, organic nitrogen low solubility compounds such as ureaform and CDU and IBDU.

The second, fertilizers control the release by inorganic materials or organic polymer coatings. Organic polymer coatings, such as polyolefin, rubber, this is the main topic of this presentation.

Third, inorganic low-solubility compounds, such as magnesium ammonium phosphate.

In the group of slow- and controlled-release fertilizers, CRF, controlled-release fertilizer, is a special one. The

term “controlled-release” could be used for the fertilizer like this. The factors dominating the rate, pattern, and duration of release are well-known and controllable.

Controlled-release fertilizer shows accurate release control. We can use CRF in order to synchronize the nutrient supply with crop demand. This release property of CRF permits nitrogen uptake by crops according to their demand and reduces nitrogen leaching or denitrification losses.

Polyolefin-coated fertilizer, POCF, is one of the CRFs developed in Japan, and shows a highly-controlled release property, so we can call POCF a high-performance CRF in this presentation. I believe POCF is a potential source for sustainable crop production in Asia.

POCF is developed and manufactured in Japan, and its nutrient release is accurately controlled. Already many kinds of products are commercially available. POCF contributes to the development and extension of new application methods in Japan. Optimum nutrient supply could be programmed with one-time application. And placement could be optimized for crop use and/or farmer operation.

POCF is a capsule fertilizer like these, a granulated soluble fertilizer such as urea or compound fertilizer coated by a thermoplastic resin in the industrial plants. Nutricote is polyolefin-coated compound fertilizer. And Meister is a polyolefin-coated urea, called in Japan LONG and LP cote.

The release mechanism of polyolefin-coated fertilizer, POCF, has three steps, water absorption and dissolution of content and leaching from the capsule.

In these processes, water absorption is characterized by temperature, so the dissolution of urea and leaching process also show temperature dependency.

Nitrogen release of POCU. POCF has two groups of release patterns and various release durations. These figures show the linear and sigmoidal nitrogen release with various duration products in water at 25 degrees Celsius.

These figures show the effect of temperature on nitrogen release of POCF with a linear and sigmoidal type. For example, Meister 10 – this is called LP-70 in Japan – shows linear release and requires 70 days to release 80 percent of the nutrient in water at 25 degrees. Meister SS15 has a lag period of 45 days, and it needs 55 more days to release 80 percent of nutrient.

Nitrogen release is accelerated with higher temperature and slows down with lower temperature. These reactions are the same as the plant growth.

An accurate nutrient release rate, pattern and duration with a temperature of POCF enables one-time application for the whole growing season of crops. This one-time application is a CRF-specific application. This figure shows an example of nitrogen, the cumulative and differential release of Meister S12 for paddy rice cultivation. A period is transplanting, B period is maximum tiller number, and C period, young panicle formation, and D period, heading, E period, harvest. This is one-time application.

Another CRF-specific application is about fertilizer placement. An accurate nutrient control property enables POCF to be placed with seeds or seedlings without salt damage. We call this contact placement of large amounts of POCF with seeds or seedlings as *co-situs* application.

This is conventional soluble fertilizer. It should be kept off seeds. This is a corn seed. With *co-situs* placement, POCU could be applied with seeds without any damage. *Co-situs* placement is applicable to raise seedlings of horticulture crops. These are bell pepper and broccoli seedlings. These with POCF showed no salt damage.

Because these seedlings bring all fertilizer, all POCF, into the field by transplanting, farmers will not have to apply chemical fertilizers any more.

Next, I will show you the result of a case study of CRF-specific application in northeastern Japan.

From now, I'll show you the result of no-till transplanting rice culture by one-time nursery application in 1992 in Akita Prefecture, northeastern Japan. This picture shows a cross-section of rice seedlings in the nursery box. All fertilizer nitrogen for rice growth was applied to the nursery box by *co-situs* placement. They show no salt damage for growing.

These rice seedlings were transplanted by the machine mentioned before by a previous presenter. There are details of no-till transplanting rice culture by one-time nursery application. All fertilizer, nitrogen, needed by paddy rice for the entire growing season applied to nursery boxes using sigmoidal POCF. This type of POCF has a lag period of 30 days and a release duration of 70 days at 25 degrees Celsius.

Rice seedlings were grown in POCF applied nursery boxes. This is *co-situs* placement. Rice seedlings were transplanted and brought about 62 kilograms of nitrogen per hectare to paddy fields because rice roots held all fertilizer granules applied in the nursery boxes.

This figure shows the relationship between dissolved nitrogen and fertilizer-derived nitrogen uptake by paddy rice. The closed circles show polyolefin-coated fertilizer, POCF, dissolution. And open circles show fertilizer nitrogen uptake evaluated by the ^{15}N tracer method.

The nitrogen release from sigmoidal POCF was only a few percent during the seedling stage. The recovery of released nitrogen was 15 percent at the transplanting time. Gradual release of nitrogen from POCF was observed around 70 days. Thereafter, rapid N release of POCF and rapid N uptake by rice plants started.

The recovery of release of nitrogen was 58 percent at the active tillering stage and 77 percent at the panicle initiation stage. It further increased and reached 87 percent of the released nitrogen by harvest. This is 79 percent of applied nitrogen, a very high recovery rate.

This table shows the recovery of basal nitrogen by paddy rice in northeastern Japan. Broadcast of soluble fertilizer showed around a 20 percent recovery rate, a very low recovery rate. Recovery of basal nitrogen of POCF was doubled by broadcasting and almost tripled by *co-situs* placement with sigmoidal release. Increasing nitrogen use efficiency and reducing the nitrogen rate can notably decrease nitrogen fertilizer pollution. Capability of one-time basal application, the labor-saving aspect of POCF is the main reason for their use in Japan.

Another case study of CRF-specific application on corn production is omitted today. A short review of these topics are described in the abstract.

This is the summary of the case study of CRF-specific application in northeastern Japan. Fertilizer nitrogen recoveries of *co-situs* applied POCF with sigmoidal release were 87 percent in no-till transplanting paddy rice and 71 to 72 percent in dent corn cultivation.

Optimum nutrient supply controls nutrient loss and enhances nutrient use efficiency, and decreases the rate of application maintaining target yield and minimizes the risk of environmental pollution. For optimum nutrient supply, a selection of a CRF product to meet the plant needs by one-time application and the placement to supply nitrogen directly to plants are needed.

Of course, one-time application is necessary to labor-saving nutrient management. However, unfortunately, the

manufacturing cost of high-performance CRF is still great.

This is the conclusion. Manufacturing high performance CRF and CRF-specific application method, these two are very important. I believe high-performance CRF and a CRF-specific application method will contribute to sustainable crop production in Asia.

Thank you for your kind attention.

Chair Matsunaga: Thank you very much, Dr. Kanno, for your wonderful presentation. From the floor, you may have some questions for him, but already 20 minutes have passed. I'd like to move to the last presentation in this session. Thank you very much again.