POSSIBLE BREAKTHROUGHS SMART FERTILIZERS

Research and development in smart fertilizers focuses on improving nitrogen use efficiency (NUE). The NUE of urea, the major nitrogen fertilizer, currently only averages 30% to 40% due to its sensitivity to volatilization, denitrification and leaching.

Smart fertilizers that minimize these processes include: i) slow and controlled release fertilizers, ii) nitrification inhibitors, and iii) urease inhibitors. Technological advances in phosphorous fertilization include products that increase phosphorous availability in the soil for better uptake by plants.

ANNEX C

Description

A smart nitrogen fertilizer incorporates a mechanism controlling nitrogen release based on crop requirements. This function reduces unproductive losses, such as leaching and atmospheric emissions, while increasing nutrient use efficiency and yields. The major mechanisms used are:

(I) Slow and controlled mechanisms, achieved by:

- Controlled water solubility by semi-permeable coatings, occlusion, protein materials or other chemical forms;[1]
- Slow hydrolysis of water-soluble, low-molecular weight compounds.[2]

(II) Nitrification inhibitors, achieved by:

- Substances that inhibit the biological oxidation of ammonical nitrogen to nitrate nitrogen.[3]

(III) Urease inhibitors:

- Substances that inhibit hydrolytic action on urea by the enzyme urease.[4]

Based on these mechanisms, a wide variety of smart fertilizers has been developed and named after the developer or specific mechanism. Table 1 provides an overview of the variety of smart fertilizers available on the market.

Smart phosphorous fertilizers use specific fungi that stimulate the release of bound phosphorous from the soil for its improved uptake by plants or apply a phosphorous coating with polymers so as to reduce its precipitation or adsorption and improve plant recovery of phosphorous during the following months or years.

Table 1
Marketable smart nitrogen fertilizer products

Release mechanisms	Product
Slow and controlled release	SCU, POCU, PSCU, Meister, Nutricote
Nitrification inhibitor	Nitrapyrin, ATC, CI-1580, DCD, TU, MT, AM, DMPP, ASU, ATS, HPLC, Terrazole, 3-MP, CMP, Neem
Urease inhibitor	PPD/PPDA, hydroquinone (HQ), 2-NPT, ATS, NBPT (Agrotain)

Source: Trenkel, 2010

[1]Trenkel 2010, [2]Ibid. [3]Ibid. [4]Ibid

Geographical usages of smart fertilizer

The use of slow- and controlled-release fertilizers remains limited, amounting to 0.2% of global fertilizer consumption in 2004/05 (786,000 tonnes).[5] Usages of scale are only reported in North America (the United States and Canada), Europe and Asia (China and Japan).[6] The expansion of smart fertilizer usage is mainly constrained by low installed-production capacity of only 7.5 million tonnes. The main production facilities are in Canada (Agrium Inc.) and China (Hanfeng Evergreen Inc.). China is by far the largest producer and consumer of smart fertilizers, amounting to one-third of global smart fertilizer (CRF) production. Conducive policies in China and Japan are stimulating further expansion of smart fertilizer production capacity. China's guiding catalogue of *Industrial Infrastructure Adjustment* (2011 edition) classified CRF as one of the encouraged items, indicating that the development of CRF will speed up during China's 11th five-year plan, from 2011-2015.[7]

Hanfeng Evergreen Inc., China's second largest smart fertilizer producer, is working closely with China's Ministry of Agriculture on a large-scale, soil-based fertilization initiative to increase the use of smart fertilizers in the coming years.[8] Hanfeng is expanding activities to Indonesia, the Philippines and Malaysia to analyze the potential application of smart fertilizers in palm oil production, which in Indonesia alone is expected to increase from 4 million hectares in 2010 to 9 million hectares in 2015.[9]

[5]Trenkel, 2010, [6]Ibid, [7]CCM International, 2011, [8]Hanfeng, n.d., [9]Ibid

Table 2
Yield responses to different smart fertilizer mechanisms

Release rate regulator	Trial setup	Crop	Yield impact	Reference
Slow- and controlled-release fertilizer	CUF (common urea fertilizer) and CRF (controlled release fertilizer)	Rice	General 10-40% higher yield with CRF. 15% higher yield in CRF 2003, with only 1/3 of CUF	Min and Yingying 2005
	Coated urea (ESN) and CUF	Corn	10.9 (CUF) and 11.2 t/ha (ESN)	Killorn et al. 2004.
	CRF and soluble fertilizer	Citrus	Fertilizer application frequency reduced from 15 to 6, maintaining same yields	Zekri 1991 in Trenkel 2010
	CUF and CRF (Meister)	Japanese pear (Hosui)	CUF 230 kg N/ha and 60 kg/tree; CRF 161 kg N/ha en 70 kg/tree	Zekri 1991 in Trenkel 2010
	CUF and CRF	Apple	Increased yield with CRF	Shao et al. 2007 in Trenkel 2010
	Single CRF (Meister) application and split CUF application	Brown rice	CRF (Meister) yield 6.35 t/ha and CUF yield 4.45 t/ha	Ikeda et al. 1998 in Trenkel 2010
	Neem Cake Coated Urea (NCU) and prilled urea	Rice	Higher yields for NCU than CUF	Singh and Sing 1994 in Trenkel 2010
	Urea Supergranules and urea	Rice	Higher yields for NCU and CUF	Geethadevi et al. 1991

Table 2
Yield responses to different smart fertilizer mechanisms (continued)

Release rate regulator	Trial setup	Crop	Yield impact	Reference
Nitrification inhibitors	Urea (treated with DCD + Triazole) and urea alone	Multiple crops	Maize +12%, rice +9%, wheat +12%, potatoes +22% and beets +13%	Wozniak et al. 2010 in Trenkel 2010
	Urea (DCD treated) and urea alone	Multiple crops	Same yields for maize, potatoes, sugar beet and rapeseed with 20-30 kg N/ha less	Sturm et al. 1994 in Trenkel 2010
	Urea (DCD treated) and urea alone	Multiple crops	Wide row crops (maize) and crop preferring ammonium N (potatoes) benefit	Hege and Munzert 1991 in Trenkel 2010
	Urea (DCD treated) and urea alone	Multiple crops	Winter cereals, winter rapeseed and sugar beet no benefit	Hege and Munzert 1991 in Trenkel 2010
	Urea (DCD treated) and urea alone	Grazing systems	Improved pasture yield and quality	Moir et al. 2007 in Trenkel 2010
	ASN + DMPP and CUFRice	Winter wheat	0.6 t/ha yield increase	Pasda et al. 1999 and 2001, in Trenkel 2010
	Urea (DMPP treated) and CUF	Tomato	Increased yield and size of fruits	Banuls et al. 2000 in Trenkel 2010
	Urea (DMPP treated) and CUF	Vegetables	11% increase in yield	Hahndel 2005 in Trenkel 2010

Table 2
Yield responses to different smart fertilizer mechanisms (continued)

Release rate regulator	Trial setup	Crop	Yield impact	Reference
Nitrification inhibitors (continued)	Urease (DMPP treated) and CUF	Winter wheat	7% yield increase	Huther et al. 2000 in Trenkel 2010
	Urea (ASN+DMPP treated) and CUF	Cabbage	Increase of 2-5.5 t/ha and better quality	Xu et al. 2004 in Trenkel 2010
	Urea (DMPP) and CUF	Ryegrass	Higher above-ground dry matter content	Guillaues and Villar 2004 in Trenkel 2010
	Urea (Nitrapyrin; N-Serve) and CUF	Corn	10% yield increase	Iowa State University, in Trenkel 2010
Urease inhibitors	NBPT and urea	Multiple crops	Beneficial high crop yield potential, low soil N and high temperature	Grant et al. 1996, in Trenkel 2010
	NBPT and CUF	Corn	Increase of 0.6-0.8 t/ha	Lamond et al. 1993/1994, in Trenkel 2010
	NBPT and urea	Corn	7% yield increase	IMC-Agrici 1996, in Trenkel 2010

Energy

Smart nitrogen fertilizers reduce energy use by:

Reducing application volume

- Controlled release fertilizers (CRFs) increase NUE, reducing recommended application rates for conventional fertilizer 20-30% (or more) while maintaining the same yield.[10]
- Proportional savings in the consumption of naphtha or natural gas in nitrogen fertilizer production are possible as virtually all nitrogen fertilizers are derived from ammonia, and ammonia production accounts for 87% of the industry's total energy consumption.[11]

Application frequency

- Reduction of fertilizer application frequency, as smart nitrogen fertilizers need to only be applied once (sometimes twice) per cropping season. The reduction of application events reduces fuel use.[12]

Increasing nitrogen use efficiency

- NUE with controlled release urea on paddy fields has been found to be 50-100% higher than conventional urea, meaning fertilizer savings of 30%.[13]

Water

- Advances in biochemical research may produce a "smart fertilizer" that increases the soil's organic content and its ability to retain water.[14]
- The improved fertilizer use efficiency and uptake by plants shown by smart fertilizers means less leaching and water pollution.

[10]Trenkel, 2010, [11]Vyas n.d.; IFA n.d. [12]e.g. Linzmeier et al. 2001 [13]Mao et al. 2005, [14]Jacobs 1999

Productivity

- In-field experiments in China have shown 10-40% increases in rice yields with controlled-release fertilizers compared to those with urea.[15] Even when a third less nitrogen was used, controlled-release fertilizers increased rice yield by 15%.[16]
- Pre-plant inoculation of rice seedling-roots or wheat seeds with phosphorous solubilizing fungus *A. Awamori* led to a yield increase over non-inoculated treatments of 0.09-0.22 t/ha in rice and 0.15-0.45 t/ha in wheat in different years.[17]
- *P. pinophilum* fungi increased the yield of wheat grains by 28.9% and 32.8% in the soil treated with rock phosphate and superphosphate. It also increased the production of faba bean seeds by 14.7% and 29.4% with the same treatments, and the uptake of phosphorous by both plants significantly increased due to inoculation of the soil with the tested fungi.[18]

Climate change

Reducing CO_2 output during production

- Smart fertilizer use requires 20% to 30% less nitrogen fertilizer, reducing CO_2 emissions for production

Reducing nitrous oxide (N_2O) output after application

- Common nitrogen fertilizer loses 1-5% of application as N_2O, a greenhouse gas 300 times stronger than CO_2.[19]
- Over the last 150 years, atmospheric N_2O levels have risen 18%, largely due to nitrogen fertilizer use throughout the world.[20]
- Smart fertilizers have lower N_2O emissions during the growing season than common nitrogen fertilizers.[21]

Costs and benefits

- While the cost effectiveness of applying encapsulated controlled-release fertilizers in high-value crops is proven, there is also scope for their application to low-value crops.[22]
- Total production costs can be reduced by 30 to 50% using smart fertilizers.[23] Shoji and Kanno[24] reported a decrease in farming costs of 65%.[25]
- The controlled supply of nutrients by a single application of a CRF is expected to increase NUE, save labor and/or application costs and improve crop quality and yield.[26]
- Smart fertilizers are especially beneficial where nutrient losses from conventional fertilizers are high, such as on lightly textured soils with excess rainfall and/or irrigation.[27]

[15]Song et al. 2005, [16]Trenkel 2010, [17]Dwivedi et al. 2004, [18]Abdul Wahid and Mehana 2000, [19]Choudhury and Kennedy 2005, [20]Venterea et al. 2008, [21]Ibid, [22]Trenkel 2010, [23]Kitamura and Imai 1995 in Trenkel 2010, [24]Shoji and Kanno 1994, [25]Ibid, [26]Shaviv 2000, [27]Trenkel 2010

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