Update of Enhanced Efficiency Fertilizers (EEFs)

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New Technology for Commercial Crop Production (XII)
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What are Enhanced Efficiency Fertilizers (EEFs)?

- **American Association of Plant Food Control Officials (AAPFCO)**: Fertilizer products with characteristics that minimize the potential of nutrient losses to the environment, as compared to "reference soluble" products
- **The Fertilizer Institute (TFI):** Fertilizer products that can reduce nutrient losses to the environment while increasing nutrient availability for the plant or the crop.

Commercially Available EEFs:

1. **Slow release fertilizers (SRFs):** Synthetic organic compounds containing N, e.g., urea-aldehyde condensation products (urea-formaldehyde [UF])
2. **Controlled release fertilizers (CRFs):** Physical coating or barrier around soluble N fertilizer, such as SCU, PCU, and combination products
3. **Fertilizer stabilizers**, such as nitrification and urease inhibitors

Slow release (SRF) vs. controlled release (CRF)

- There is no official differentiation between SRF and CRF
- American Association of Plant Food Control Officials is currently working on updating the official definitions for SRF and CRF

The draft international standard (ISO/DIS 18644)

- SRFs by definition are fertilizers which, through a combination of hydrolysis, biodegradation, or limited solubility, release nutrients over an extended period of time.

- CRFs exhibit controlled nutrient release, typically through a fertilizer coating, in order to meet target release rate and time of a nutrient release at specific temperature.

Definition of SRFs and CRFs by our group

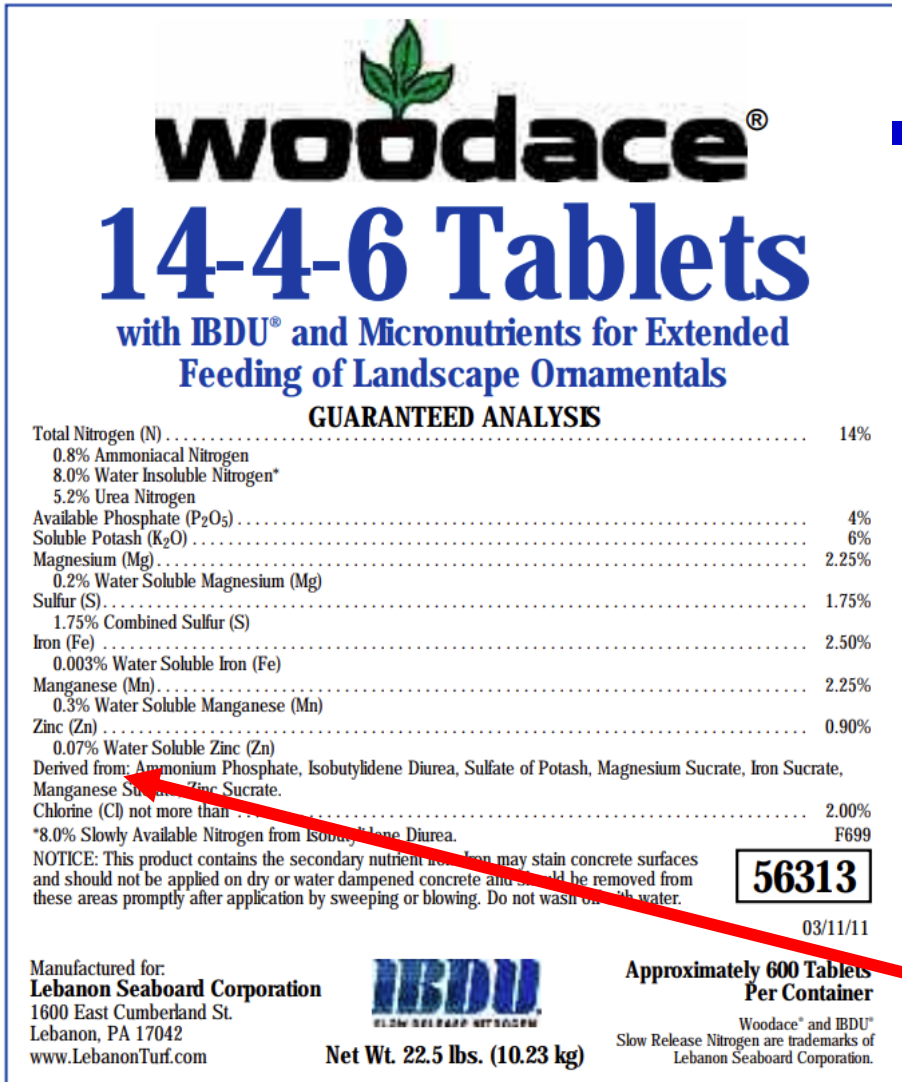
- **Slow Release Fertilizers (SRFs)** are fertilizer products characterized by complex chemical structures or high molecular weight, or both, leading to a gradual release of nutrients into the soil through microbial decomposition or low solubility.

- **Controlled Release Fertilizers (CRFs)** are coated or encapsulated fertilizer products. The nutrient release rates of CRFs are designed to align with crop nutrient requirements

Liu, et al. 2011 http://edis.ifas.ufl.edu/hs187

Slow Release Fertilizers (SRFs)

Slow-Release Fertilizers (SRFs)



woodace®

14-4-6 Tablets

with IBDU® and Micronutrients for Extended Feeding of Landscape Ornamentals

GUARANTEED ANALYSIS

Total Nitrogen (N)	14%
0.8% Ammoniacal Nitrogen	
8.0% Water Insoluble Nitrogen*	
5.2% Urea Nitrogen	
Available Phosphate (P_2O_5)	4%
Soluble Potash (K_2O)	6%
Magnesium (Mg)	2.25%
0.2% Water Soluble Magnesium (Mg)	
Sulfur (S)	1.75%
1.75% Combined Sulfur (S)	
Iron (Fe)	2.50%
0.003% Water Soluble Iron (Fe)	
Manganese (Mn)	2.25%
0.3% Water Soluble Manganese (Mn)	
Zinc (Zn)	0.90%
0.07% Water Soluble Zinc (Zn)	

Derived from: Ammonium Phosphate, Isobutylidene Diurea, Sulfate of Potash, Magnesium Sucrate, Iron Sucrate, Manganese Sucrate, Zinc Sucrate.

Chlorine (Cl) not more than	2.00%
*8.0% Slowly Available Nitrogen from Isobutylidene Diurea.	F699

NOTICE: This product contains the secondary nutrient iron. Iron may stain concrete surfaces and should not be applied on dry or water dampened concrete and should be removed from these areas promptly after application by sweeping or blowing. Do not wash off with water.

56313

03/11/11

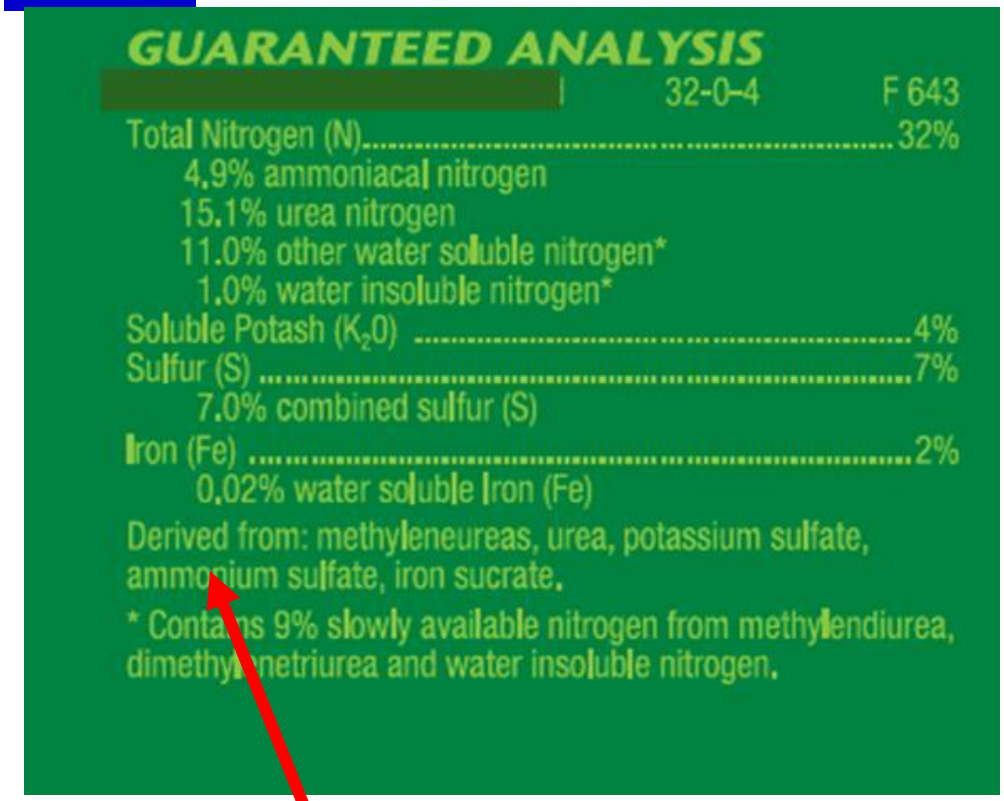
Manufactured for:
Lebanon Seaboard Corporation
1600 East Cumberland St.
Lebanon, PA 17042
www.LebanonTurf.com

IBDU

Net Wt. 22.5 lbs. (10.23 kg)

Approximately 600 Tablets Per Container

Woodace® and IBDU® Slow Release Nitrogen are trademarks of Lebanon Seaboard Corporation.



GUARANTEED ANALYSIS

32-0-4 F 643

Total Nitrogen (N) 32%
- 4.9% ammoniacal nitrogen
- 15.1% urea nitrogen
- 11.0% other water soluble nitrogen*
- 1.0% water insoluble nitrogen*

Soluble Potash (K_2O) 4%

Sulfur (S) 7%
- 7.0% combined sulfur (S)

Iron (Fe) 2%
- 0.02% water soluble Iron (Fe)

Derived from: methyleneureas, urea, potassium sulfate, ammonium sulfate, iron sucrate.

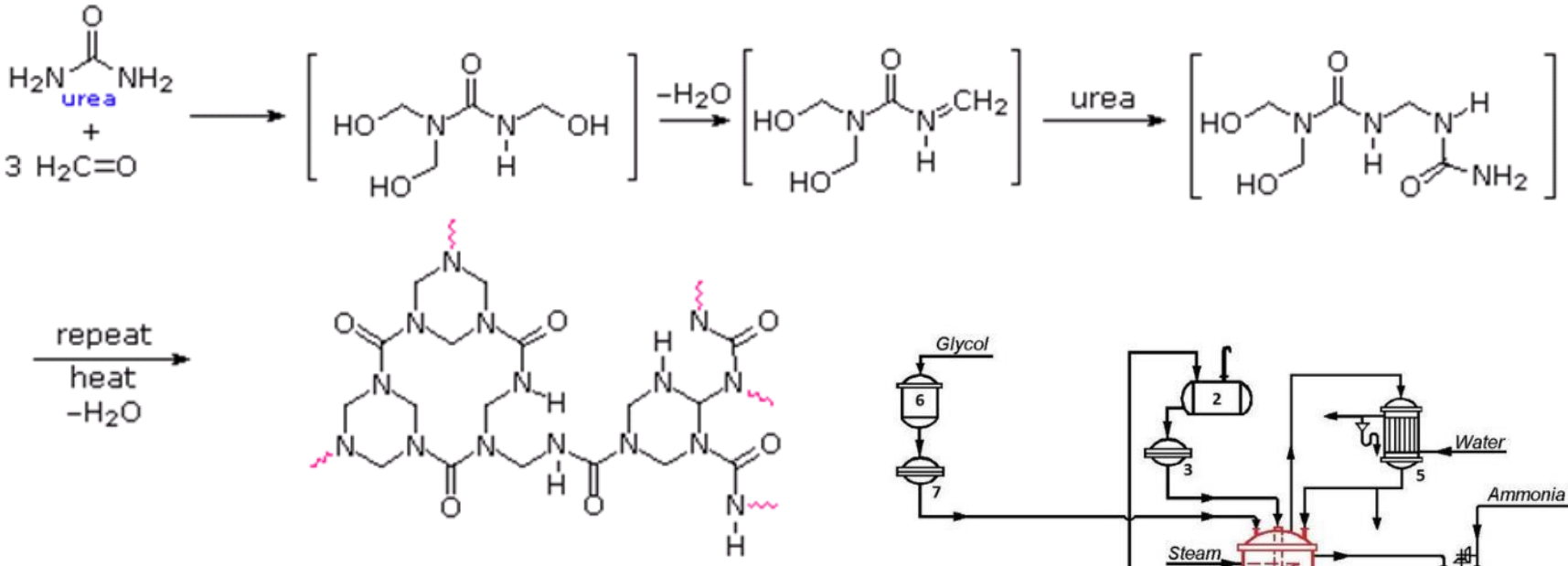
* Contains 9% slowly available nitrogen from methylendiurea, dimethylenetriurea and water insoluble nitrogen.

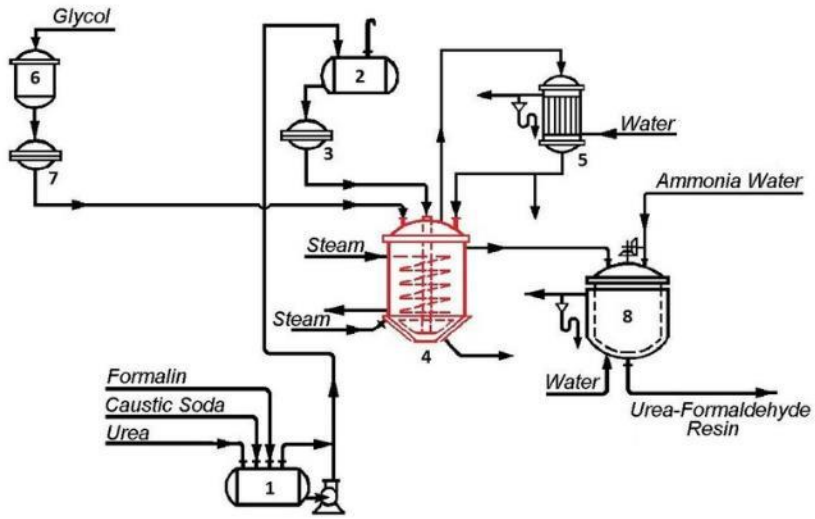
Derived from:

Slow-release fertilizers:

- Urea-formaldehyde (UF) –38% N
- Isobutylidene diurea (IBDU) –32% N
- Crotonylidene diurea (CDU) –32.5% N

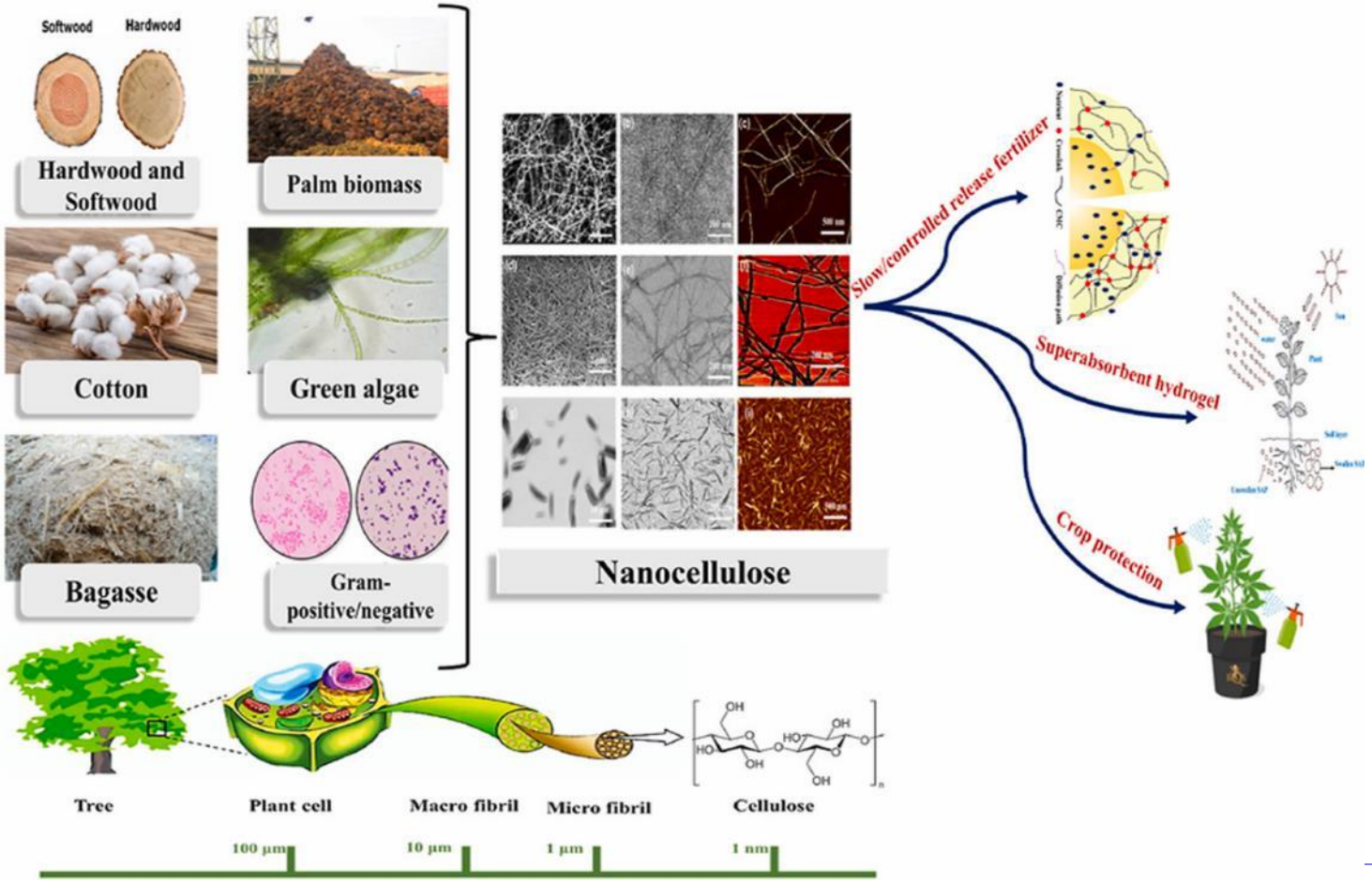
The formation of urea-formaldehyde resin (Patented in 1924)





https://petrochemicalprocesses.weebly.com/production-of-urea-formaldehyde.html

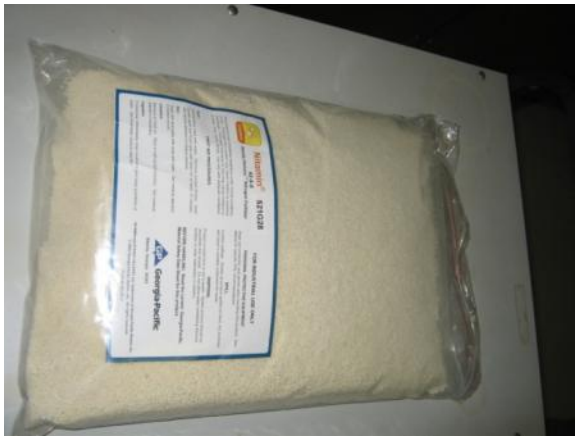
An example of new research on producing SRFs



Badr-Eddine Channab, et al. 2024, Journal of Environmental Management

Slow-release fertilizers
(produced by Georgia-Pacific)

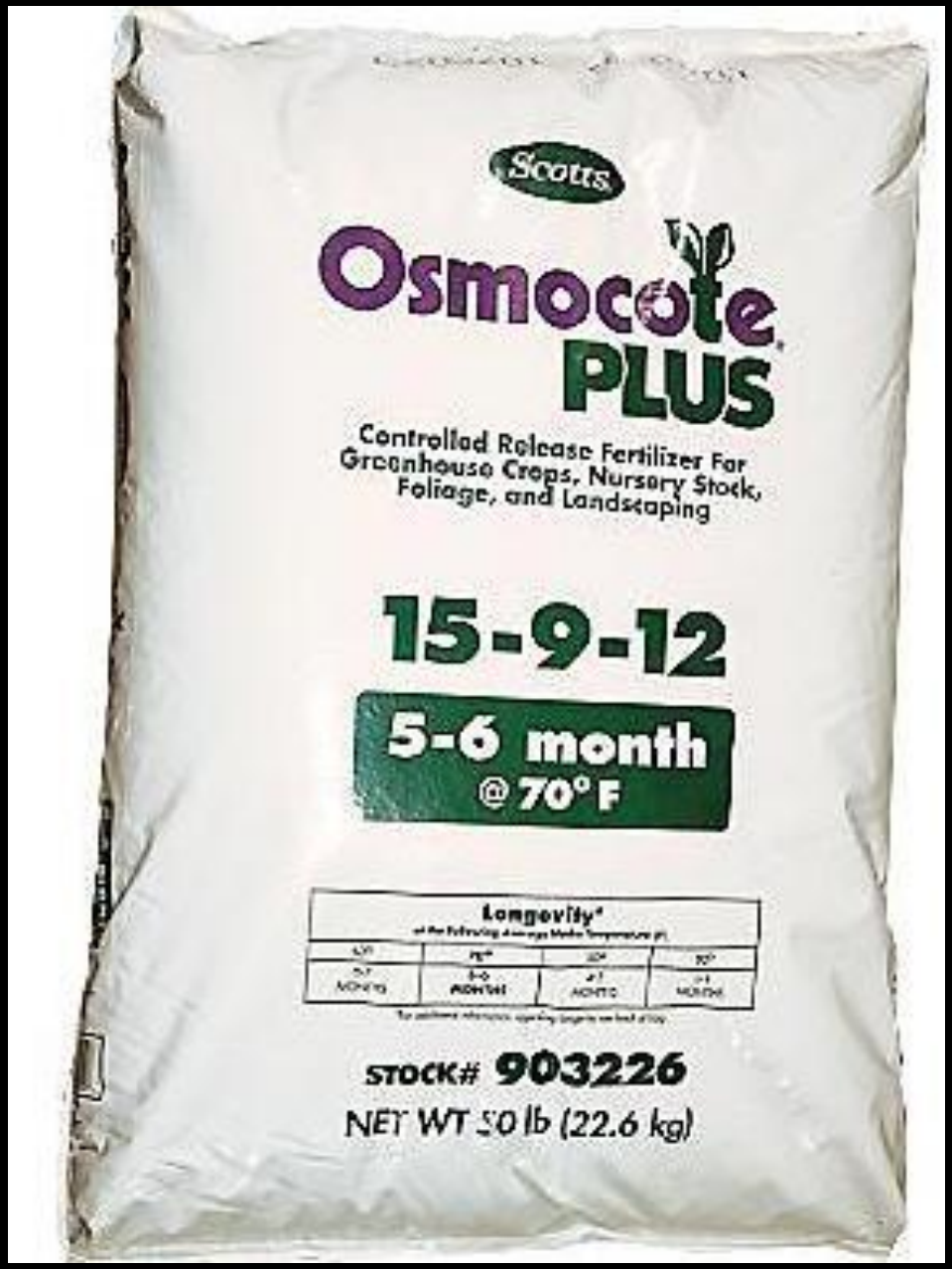
Nitamin 42G



RC 24-0-0

Nitamin 30L

Controlled Release Fertilizers (CRFs)


Scotts
Osmocote
PLUS
Controlled Release Fertilizer For
Greenhouse Crops, Nursery Stock,
Foliage, and Landscaping
15-9-12
5-6 month
@ 70° F
Longevity*
STOCK# 903226
NET WT 50 lb (22.6 kg)

39-0-0

LESCO® Poly Plus® Sulfur Coated Urea Controlled Release Fertilizer

LESCO PROFESSIONAL TURF FERTILIZER

For use in Rotary Spreaders Only

Contains LESCO® Poly Plus® Sulfur Coated Urea to provide uniform growth with extended nitrogen feeding.

50 lb COVERS 19,500 sq ft

DIRECTIONS FOR USE: This LESCO product is a professional quality turf fertilizer for use on all turf areas. The best results with this product are obtained when it is applied to actively growing grass, and watered into the turf soon after application. Avoid mowing immediately following application to prevent pick-up.

For best results, sweep or blow the fertilizer off walks and painted surfaces following application to avoid discoloration.

Recommended applications are at the rate of one pound of nitrogen per 1,000 sq ft. Actual rates and timing of applications will vary with weather, soil and turf conditions.

For additional product assistance, call LESCO, Inc. in Cleveland, Ohio at 1-800-321-5325.

COVERAGE: 50 pounds of LESCO 39-0-0 Fertilizer covers approximately 19,500 sq ft at the application rate of one pound of nitrogen (2.5 pounds of fertilizer) per 1,000 sq ft.

ROTARY SPREADER SETTINGS: Apply LESCO Fertilizers and Combination Products only with a rotary spreader. The following rotary spreader settings are approximate for the application rates of one pound of nitrogen per 1,000 square feet. You may need to adjust the setting depending on walking speed, spreader condition and product.

ROTARY SPREADER		SETTINGS
LESCO	Calibration Gauge	#13
SCOTTS® R8A		I ½
Cyclone® or Spyker®		3½
LESCO Pendulum		18
Lely®		3¼ II

GUARANTEED ANALYSIS

TOTAL NITROGEN (N) 39.00%
39.00% Urea Nitrogen*
SULFUR (S) Total 12.00%
12.00% Free Sulfur (S)
DERIVED FROM: Polymer Coated Sulfur Coated Urea.
CHLORINE (Cl) Max 2.00%
*35.10% Slowly Available Urea Nitrogen from Polymer Coated Sulfur Coated Urea.

\F1560

CONDITION OF SALE AND LIMITATION OF WARRANTY AND LIABILITY

NOTICE: Read the entire Directions for Use and Conditions of Sale and Limitation of Warranty and Liability before buying or using this product. If the terms are not acceptable, return the product at once, unopened, and the purchase price will be refunded.

The Directions for Use of this product must be followed carefully and completely. It is impossible to eliminate all risks inherently associated with the use of this product. To the extent consistent with applicable law, Buyer and/or User assume all risks of ineffectiveness or other unintended consequences or damages that may result from conditions outside or beyond the control of LESCO, Inc. including but not limited to, such factors as manner of use or application, weather or weather conditions outside the range considered normal at the application site or for the time period in which the product is applied, the presence of other materials, incompatible products, or other influencing factors which are beyond the control of LESCO, Inc.. To the extent consistent with applicable law, all such risks shall be assumed by Buyer and/or User, and Buyer and/or User agrees to hold LESCO, Inc. harmless for any claims relating to such factors.

LESCO, Inc. warrants that this product conforms to the chemical description on the label and is reasonably fit for the purposes stated in the Directions for Use, subject to the inherent risks referred to above, when used in accordance with the Directions for Use under normal use conditions. To the extent consistent with applicable law, this warranty does not extend to the use of this product contrary to label instructions, or under abnormal conditions or under conditions not reasonably foreseeable to or beyond the control of LESCO, Inc. and Buyer and/or User assume the risk of any such use. TO THE EXTENT CONSISTENT WITH APPLICABLE LAW, LESCO, INC. MAKES NO WARRANTIES OF MERCHANTABILITY OR OF FITNESS FOR A PARTICULAR PURPOSE NOR ANY OTHER EXPRESS OR IMPLIED WARRANTY EXCEPT AS STATED ABOVE.

TO THE EXTENT CONSISTENT WITH APPLICABLE LAW, THE EXCLUSIVE REMEDY OF THE BUYER AND/OR USER AND THE EXCLUSIVE LIABILITY OF LESCO, INC. FOR ANY AND ALL CLAIMS, LOSSES, INJURIES OR DAMAGES (INCLUDING CLAIMS BASED ON BREACH OF WARRANTY, CONTRACT, NEGLIGENCE, TORT, STRICT LIABILITY OR OTHERWISE) RESULTING FROM THE USE OR HANDLING OF THIS PRODUCT, SHALL BE THE RETURN OF THE PURCHASE PRICE OF THE PRODUCT OR, AT THE ELECTION OF LESCO, INC. REPLACEMENT OF THE PRODUCT, OR IF NOT ACQUIRED BY PURCHASE, REPLACEMENT OF SUCH QUANTITY. TO THE EXTENT CONSISTENT WITH APPLICABLE LAW, IN NO EVENT SHALL LESCO, Inc., BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL OR SPECIAL DAMAGES.

LESCO, Inc. offers this product, and Buyer and/or User accepts it, subject to the foregoing Conditions of Sale and Limitation of Warranty and Liability, which may not be modified except by written agreement signed by a duly authorized representative of LESCO, Inc.

Do not apply near water, storm drains or drainage ditches. Do not apply if heavy rain is expected. Apply this product only to your lawn and sweep any product that lands on the driveway, sidewalk or street, back onto your lawn.

Information concerning the raw materials composing this product can be obtained by writing to: LESCO, Inc., Attn: RA Dept, 1385 East 36th Street, Cleveland, Ohio 44114-4114, referring to the item number found on this bag.

Information regarding the contents and levels of metals in this product is available on the Internet at http://www.aapfco.org/metals.htm.

Poly Plus is comprised of Polymer Coated Sulfur Coated Urea.

LESCO and Poly Plus are registered trademarks and the sweeping design is a trademark of LESCO Technologies, LLC. SCOTTS is a registered trademark of The SCOTT Company. Cyclone and Spyker are registered trademarks of Spyker Spreaders, LLC. Lely is a registered trademark of C Van Der Lely N.V.

GUARANTEED ANALYSIS

TOTAL NITROGEN (N) 39.00%

39.00% Urea Nitrogen*

SULFUR (S) Total 12.00%

12.00% Free Sulfur (S)

DERIVED FROM: Polymer Coated Sulfur Coated Urea.

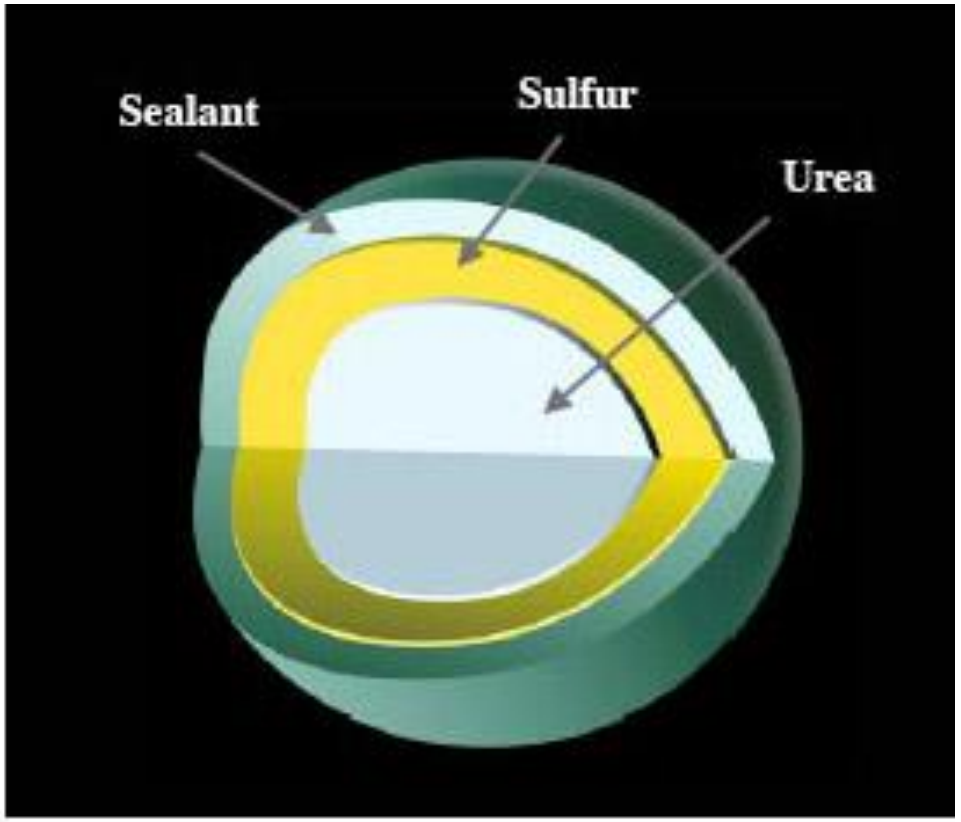
CHLORINE (Cl) Max 2.00%

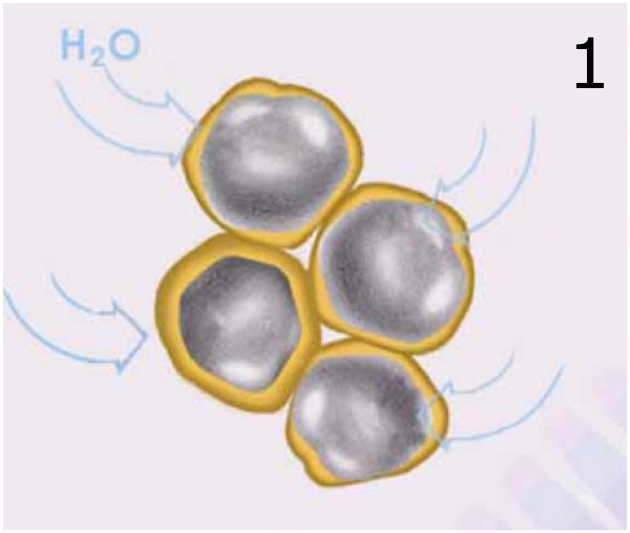
*35.10% Slowly Available Urea Nitrogen from Polymer Coated Sulfur Coated Urea.

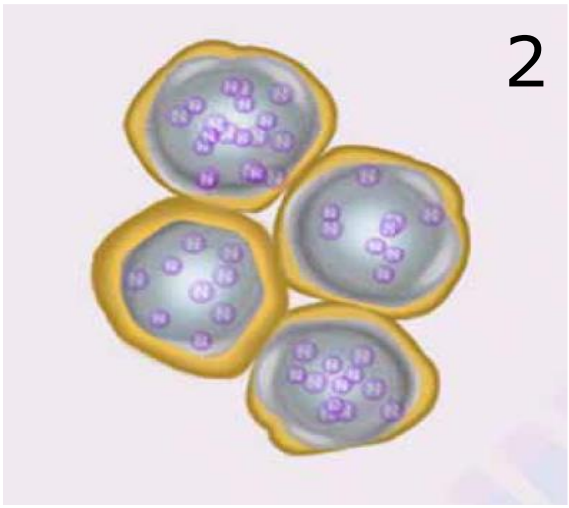
CRFs

- Sulfur
- Polymer (resin, plastic, etc.)
- Sulfur plus polymer

Sulfur Coated Fertilizers




H_2O
1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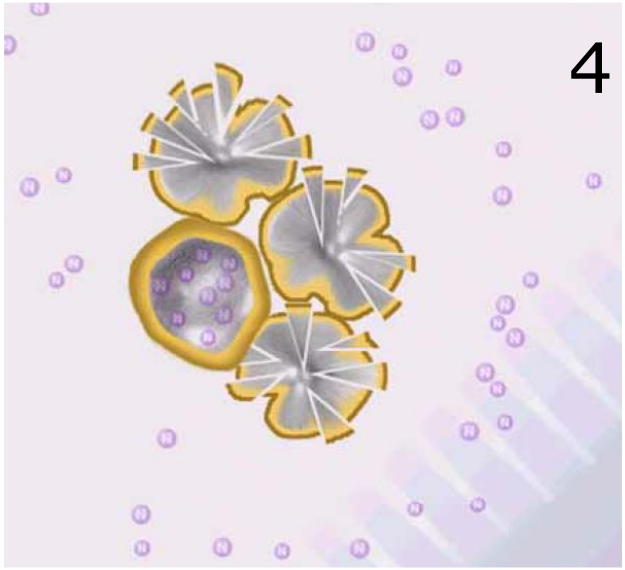
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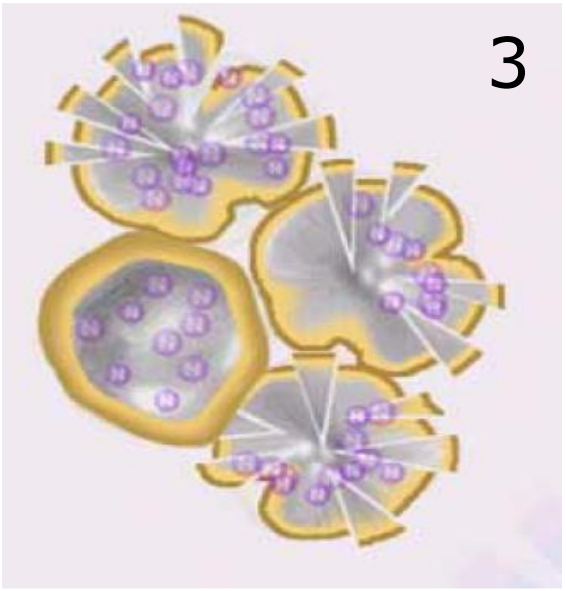
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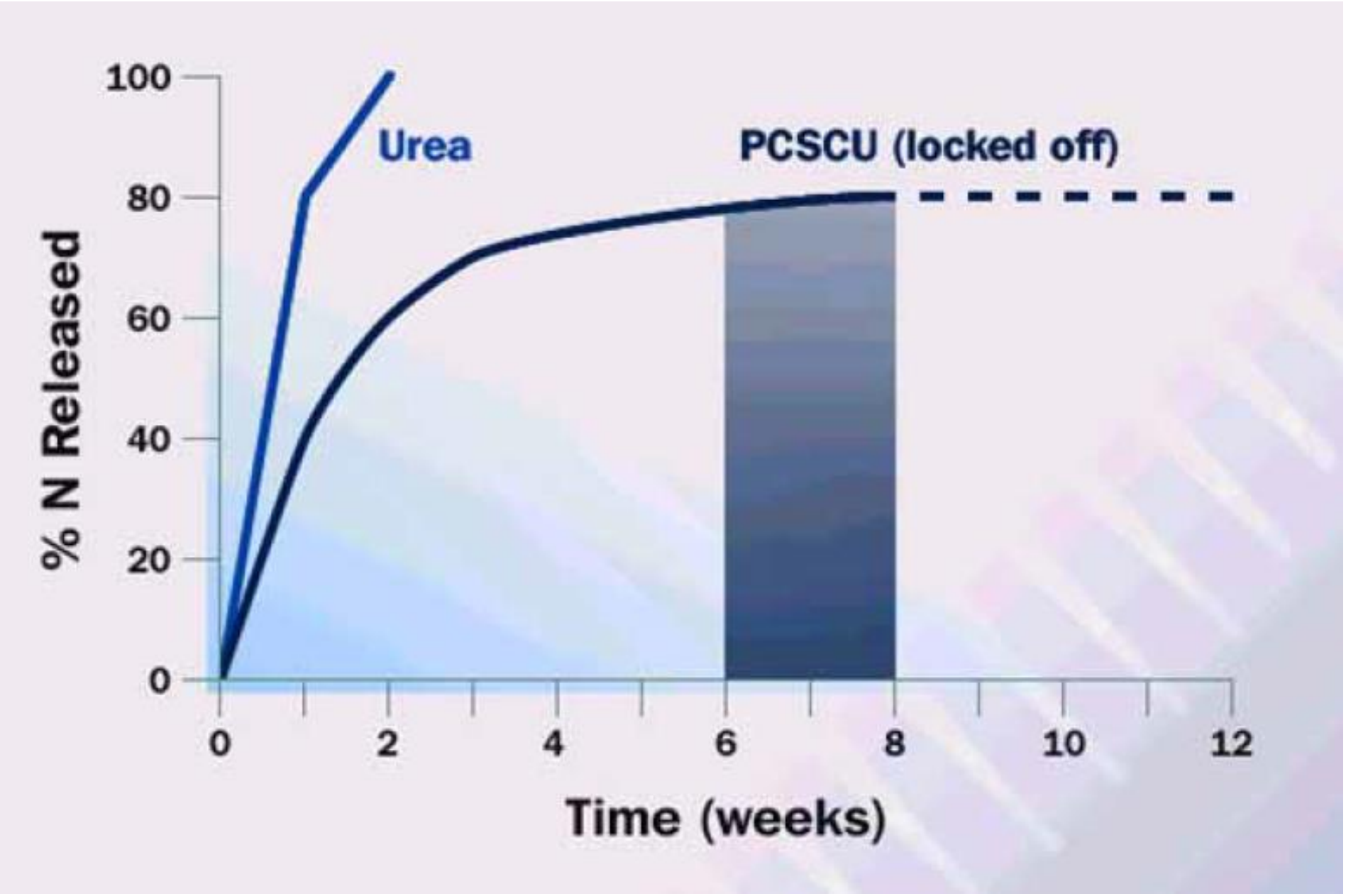
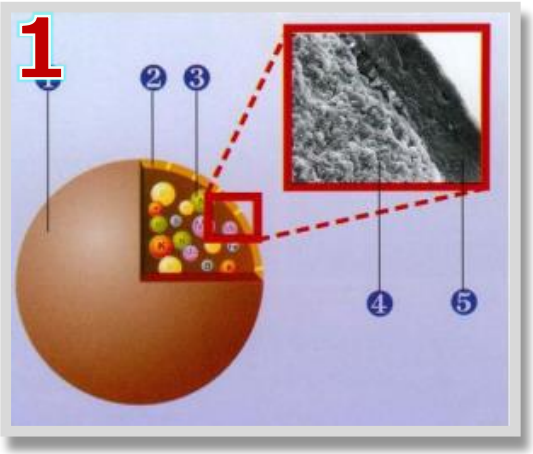

100
80
60
40
20
0
% N Released
Urea
PCSCU (locked off)
0
2
4
6
8
10
12
Time (weeks)

Polymer Coated Fertilizers

CRF-9 month

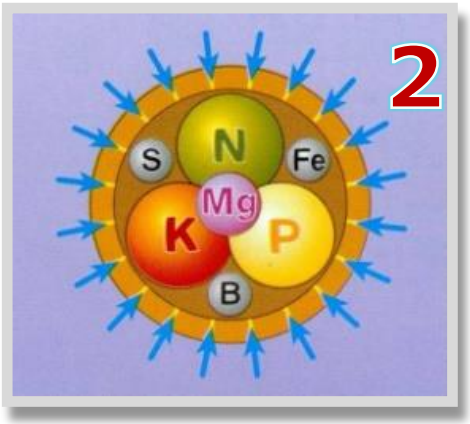
CRF-6 month

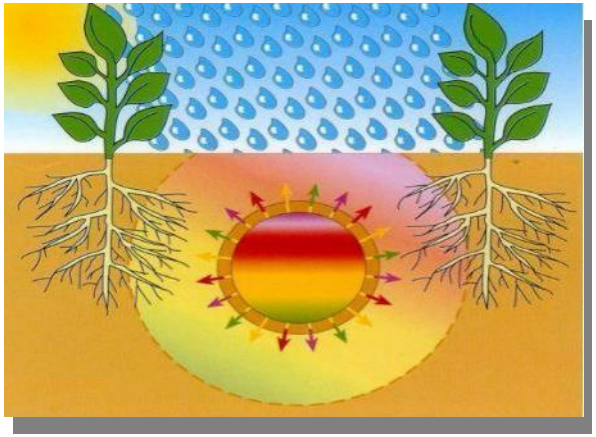
How does polymer coat fertilizer work?



Polymer Coated granule

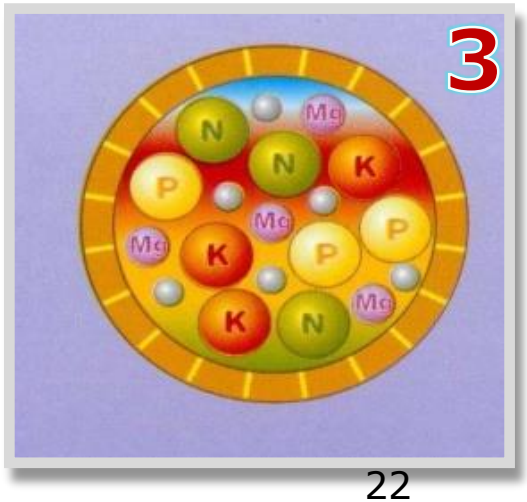
Water vapor penetrates the semi-impermeable membrane





Dissolved nutrients diffuse through the coat into the soil

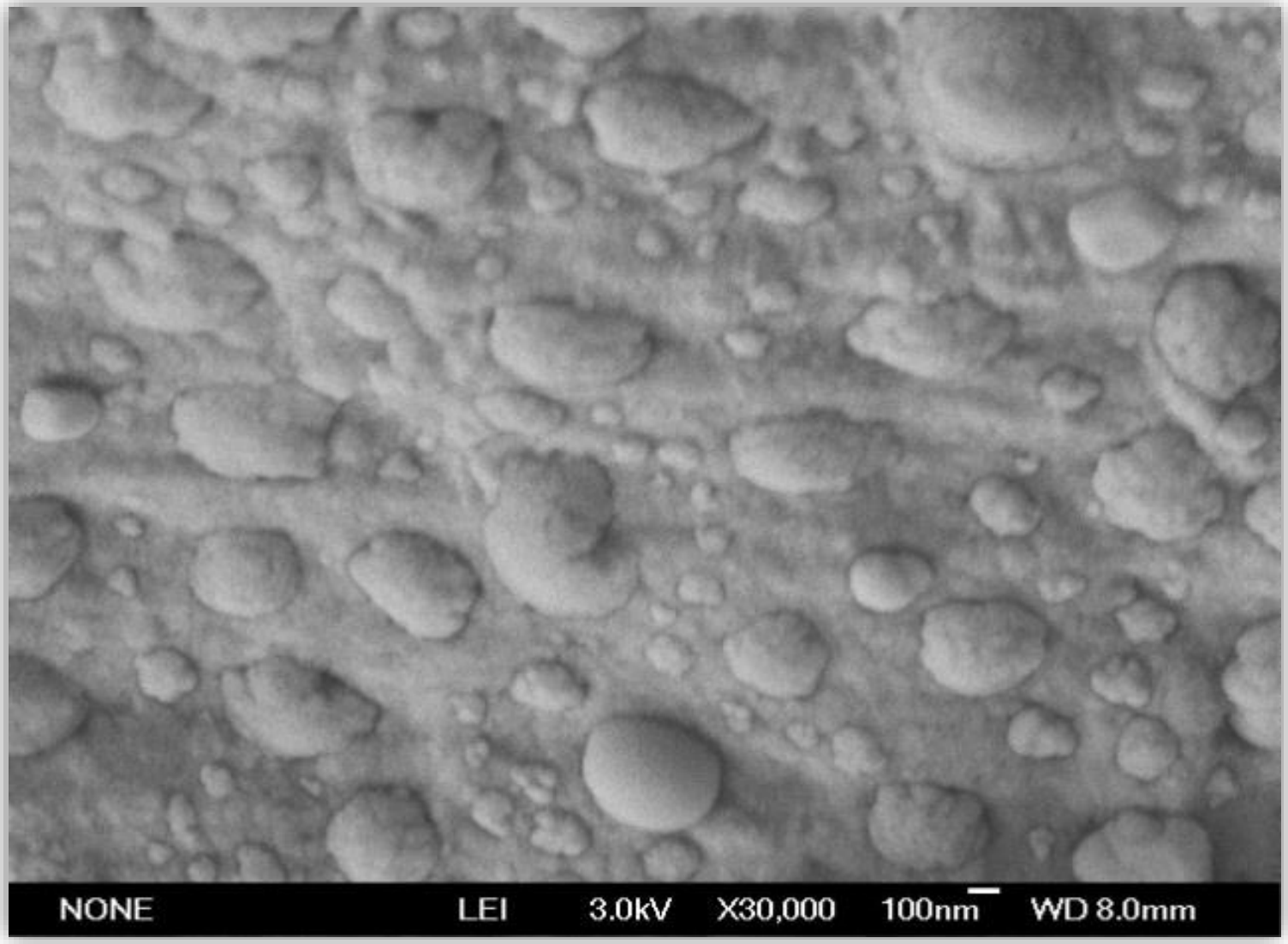
The moisture dissolves the water soluble fertilizer core



Main coating materials

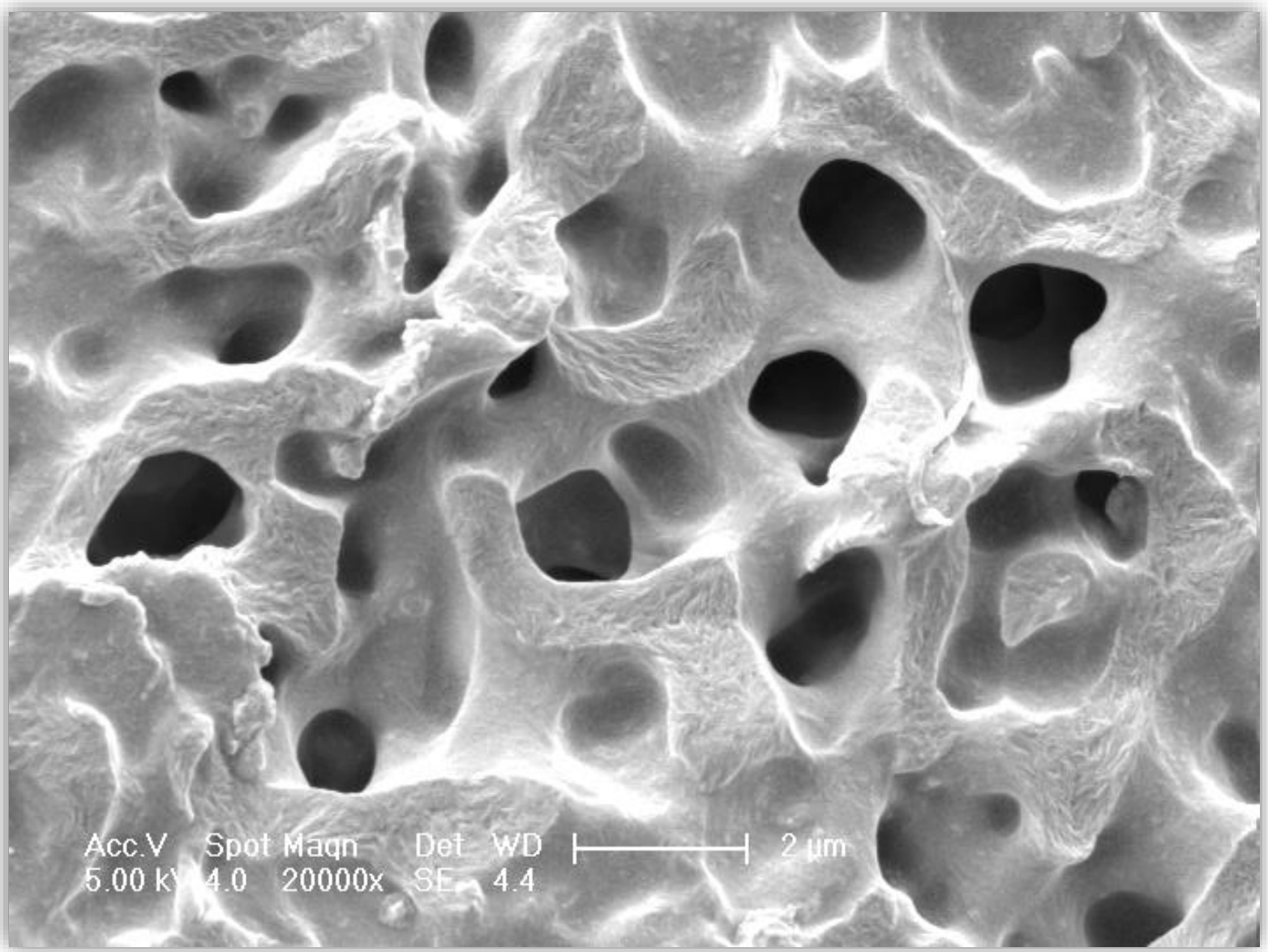
Chemicals	Commercial products
Polyurethane	Polyon, Multicote, Plantacote
Polyolefin	Nutricote, Meister
Alkyd resin	Osmocote

Coating surface (×30000)

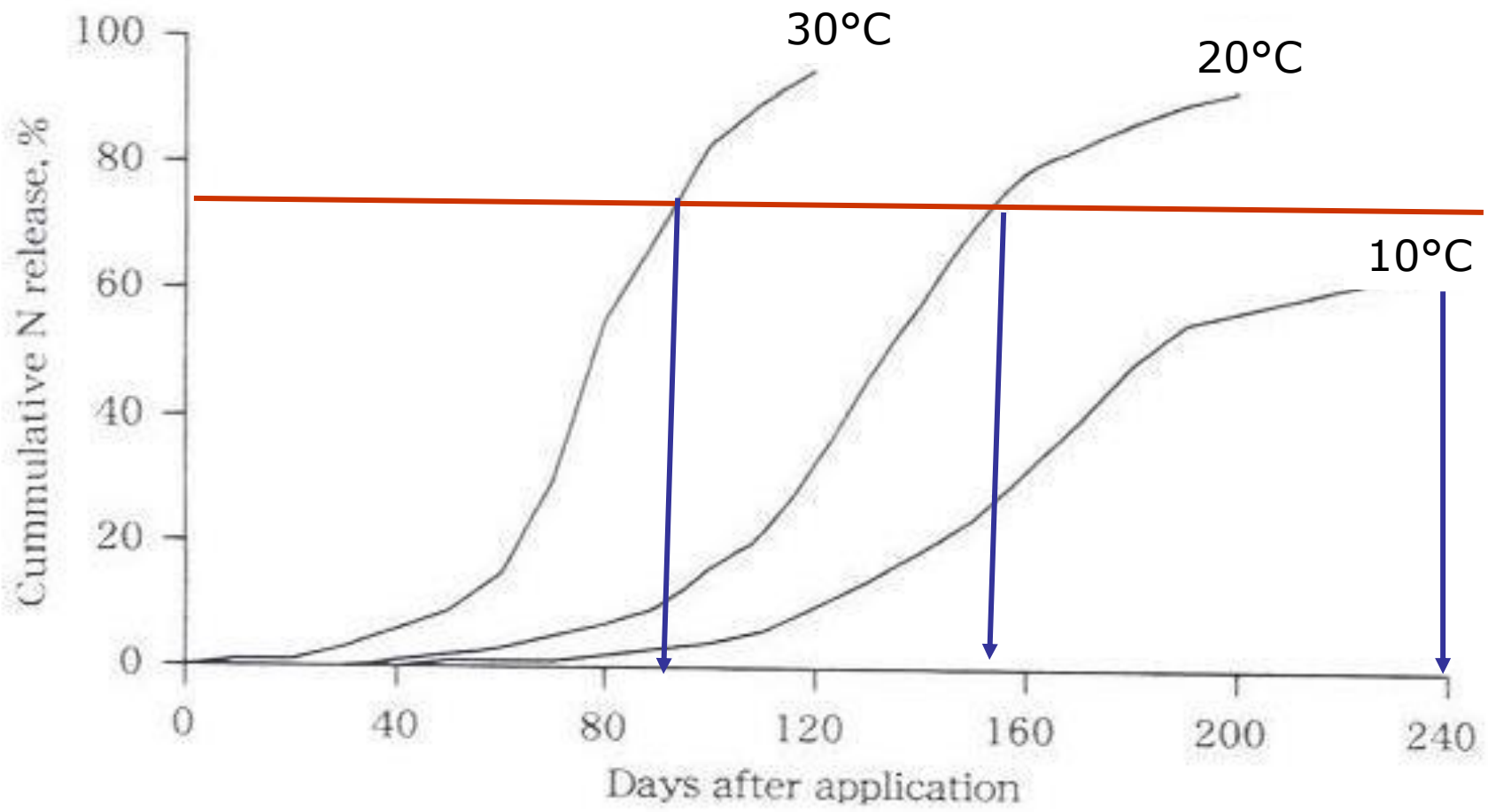


Adapted from Zhai 2013

Cross-sectioned surface (×30000)



Adapted from Zhai 2013


30°C
20°C
10°C
Cummulative N release, %
100
80
60
40
20
0
0
40
80
120
160
200
240
Days after application

Nutrient release rates of polymer coated fertilizers are controlled

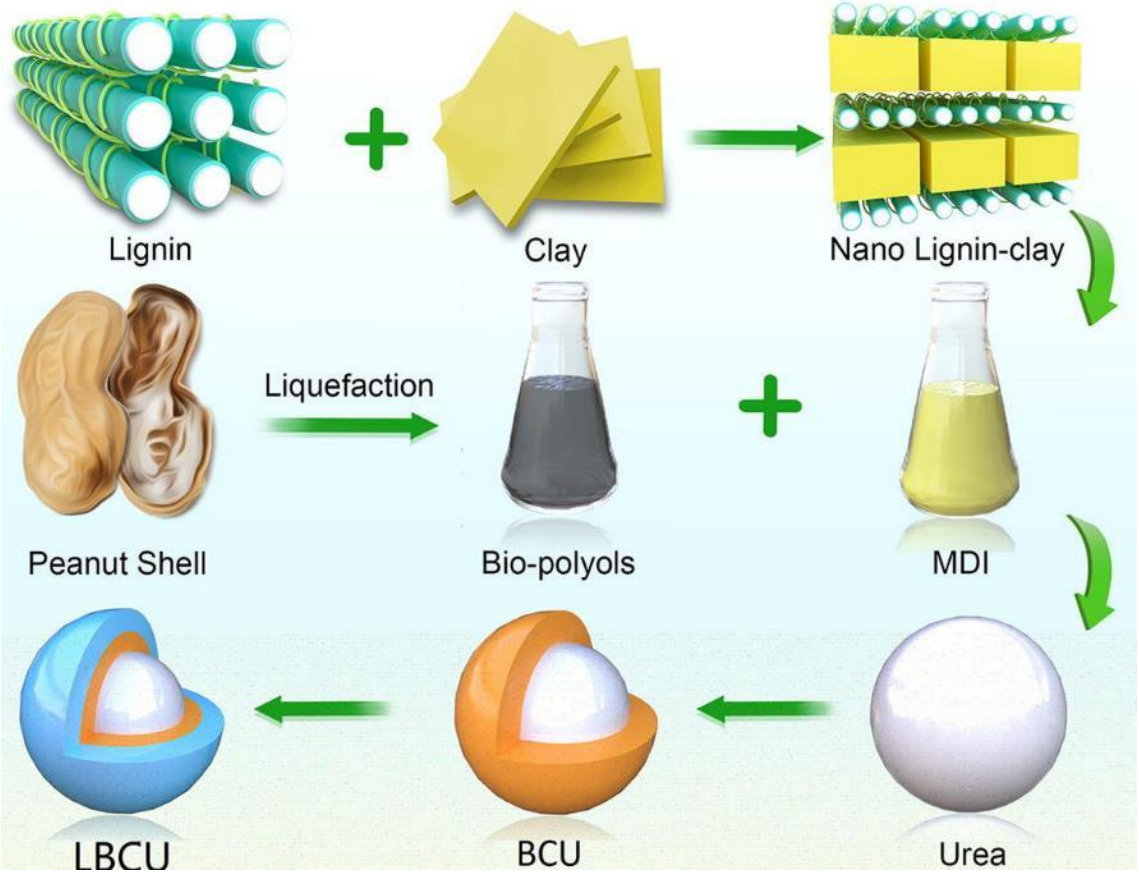
By

- Soil temperature
- Coating materials
- Coating thickness
- Core fertilizers

Not by

- Soil pH
- Soil salinity
- Soil texture
- Microbial activity
- Redox potential
- Ion strength

An example of current research on CRFs



Zhang, et al. 2022. Chemical Engineering Journal

Nano fertilizers

2012

- There is no refereed article on nano fertilizer (using Agricola database)
- Google Scholar:
  - 2,070 articles
  - 60 patents

2024

- Google Scholar:
  - 211,000 articles
  - 30,300 patents

Fertilizer stabilizers/Stabilizing materials: stabilized fertilizers

- Products claiming stabilization of nutrients must reduce the transformation rate of fertilizer compound(s), extending the time of nutrient availability to the plant by a variety of mechanisms relative to its unamended form.

Nitrogen fertilizer stabilizers

- Urease inhibitors
- Nitrification inhibitors

Urease Inhibitors

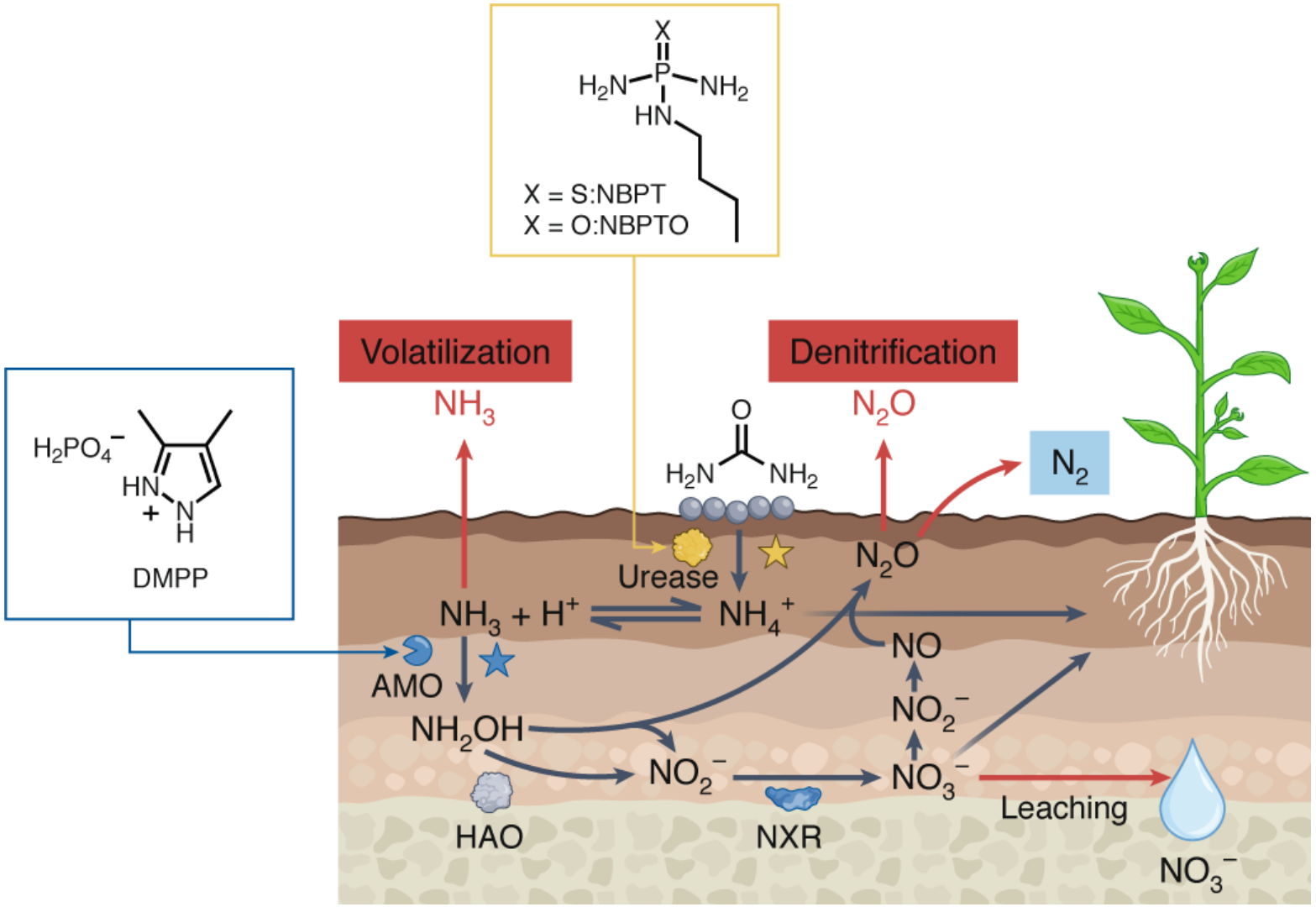
Name	Active Ingredients	Example products	Manufacturers
nBTPT	N-(n-butyl)-phosphoric triamide	Agrotain Sustain	Yara
2-NPT	N-(2-Nitrophenyl) phosphoric triamide	Piagran Pro	SKW Piesteritz
	nBTPT & 2-NPT	Limus	BASF

https://farmpep.net/topic/enhanced-efficiency-fertilisers

Nitrification Inhibitors

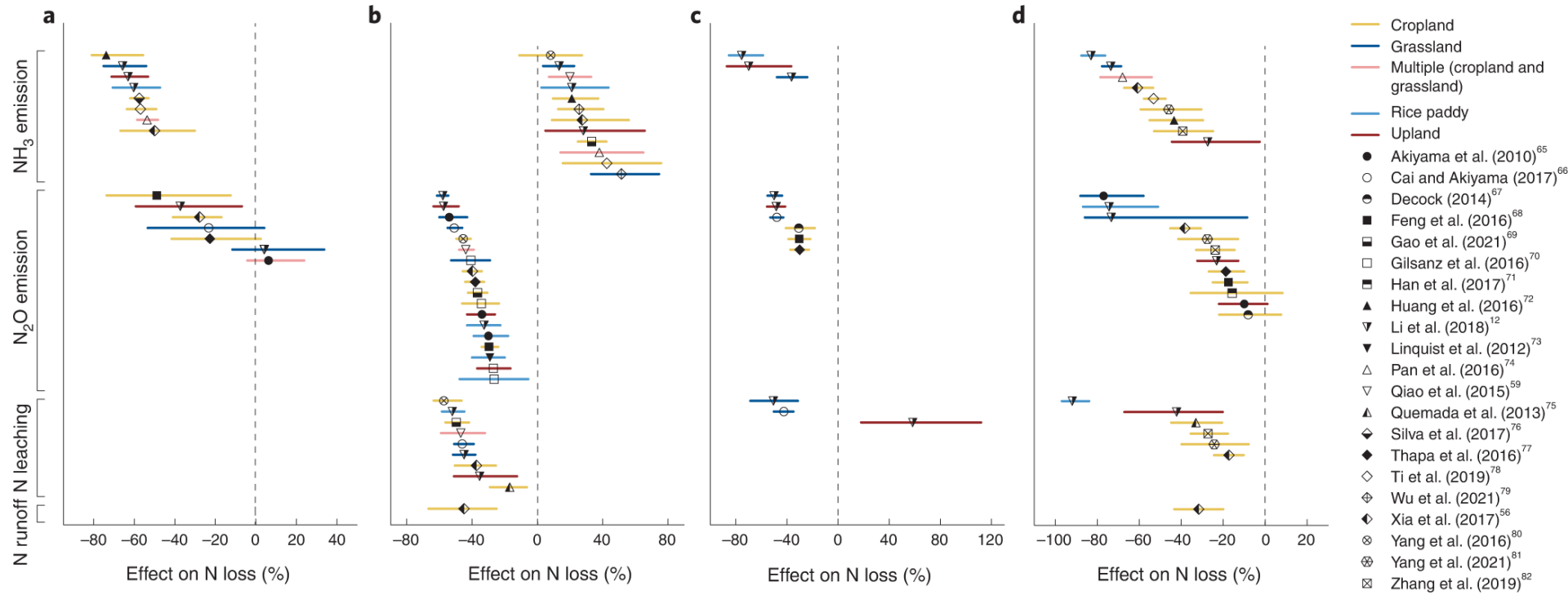
Name	Active Ingredients	Example products	Manufacturers
Nitrapyrin	2-chloro-6-(trichloromethyl)-pyridine	N-Lock	Corteva
DCD	Dicyandiamide	Didin	Omex
DMPP	3,4-dimethylpyrazole phosphate	ENTEC Vizura®/Vibelsol	BASF
MPA	N 3(5-methyl-1H-pyrazol-1-yl) methyl acetamide		SKW Piesteritz

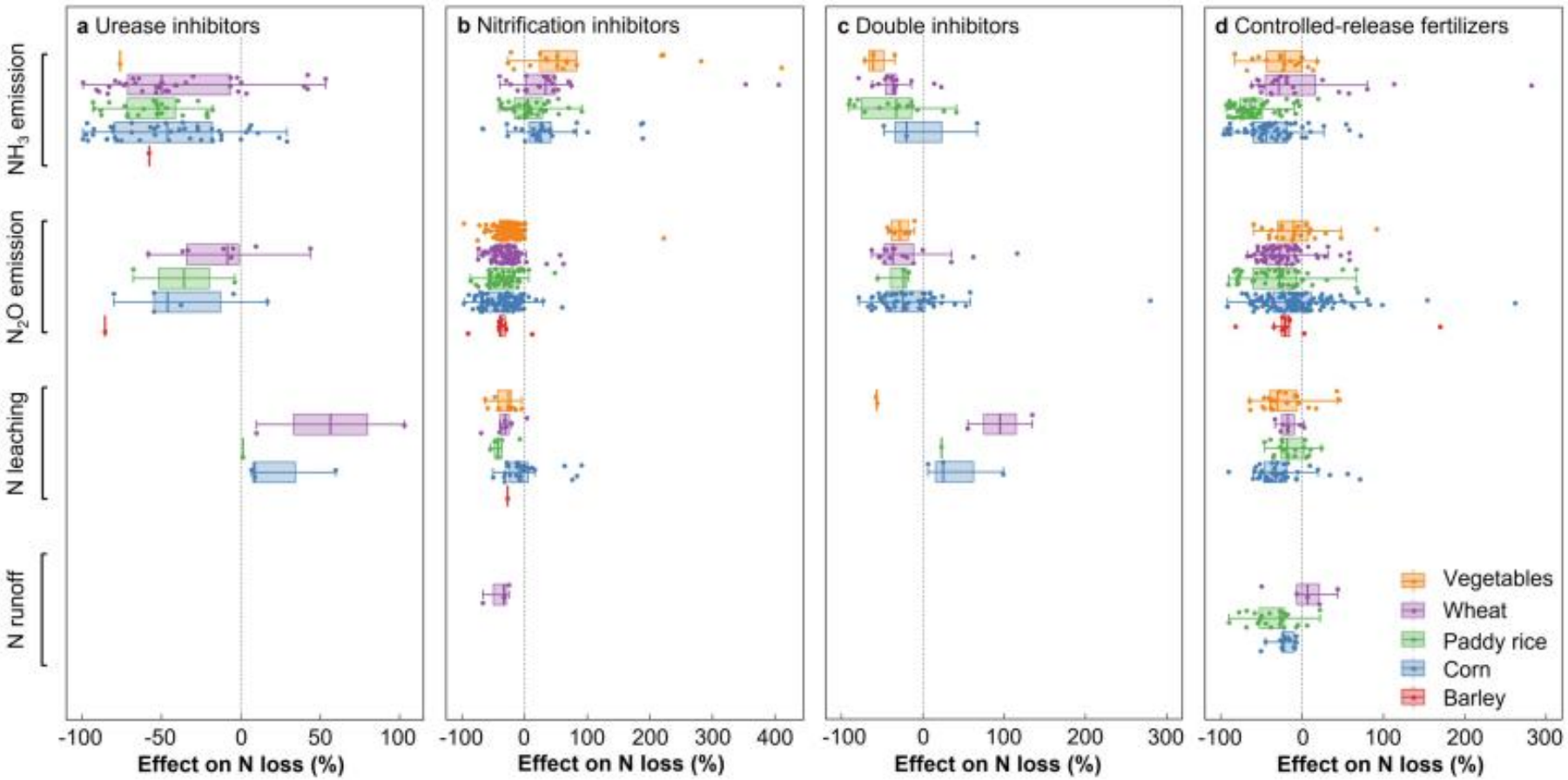
https://farmpep.net/topic/enhanced-efficiency-fertilisers



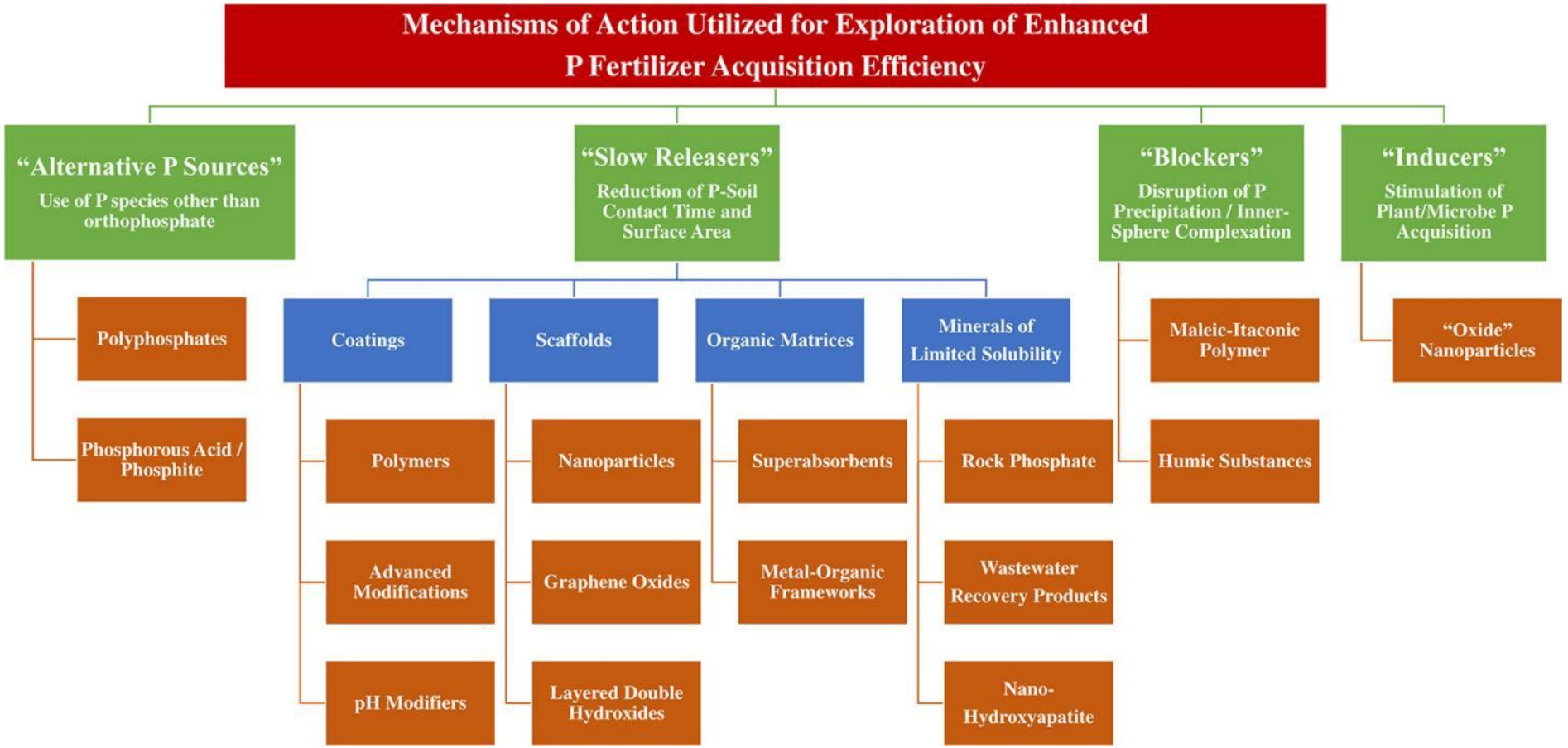
Lam et al. 2022, Nature Food

Meta-analyses of the effects of nitrogen inhibitors urease inhibitors (**a**), nitrification inhibitors (**b**), double inhibitors (using urease and nitrification inhibitors together) (**c**) and controlled-release fertilizers (**d**)

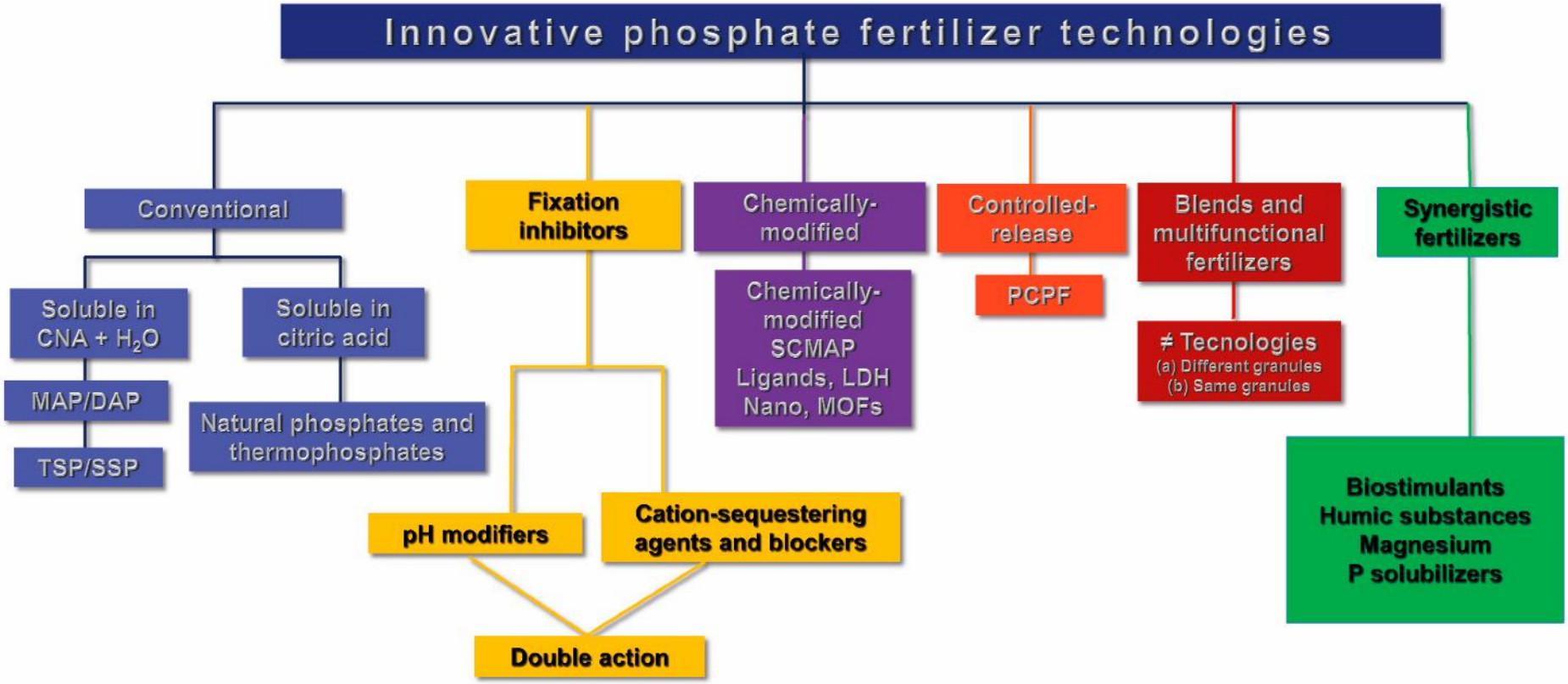



a Urease inhibitors
b Nitrification inhibitors
c Double inhibitors
d Controlled-release fertilizers
NH3 emission
N2O emission
N leaching
N runoff
-100 -50 0 50 100
-100 0 100 200 300 400
-100 0 100 200 300
-100 0 100 200 300
Effect on N loss (%)
Vegetables
Wheat
Paddy rice
Corn
Barley

Enhanced Efficiency Phosphorus Fertilizers (EEPF)



Weeks, et al. 2019. JEQ.
https://acsess.onlinelibrary.wiley.com/doi/full/10.2134/jeq2019.02.0067

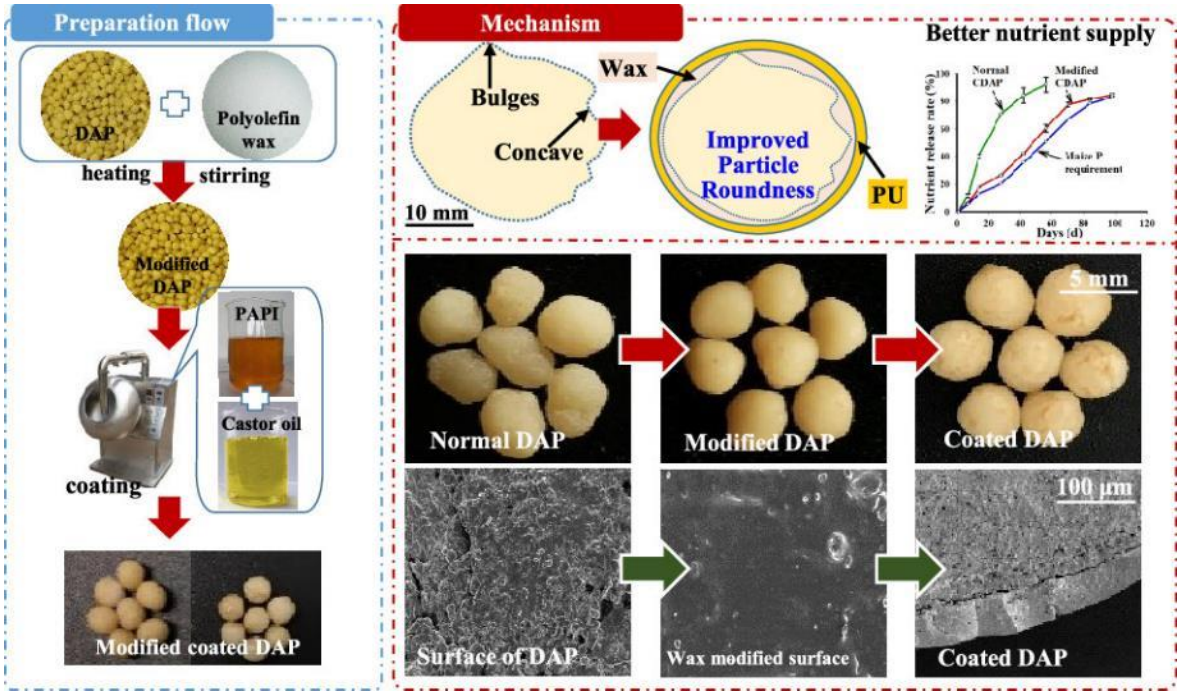


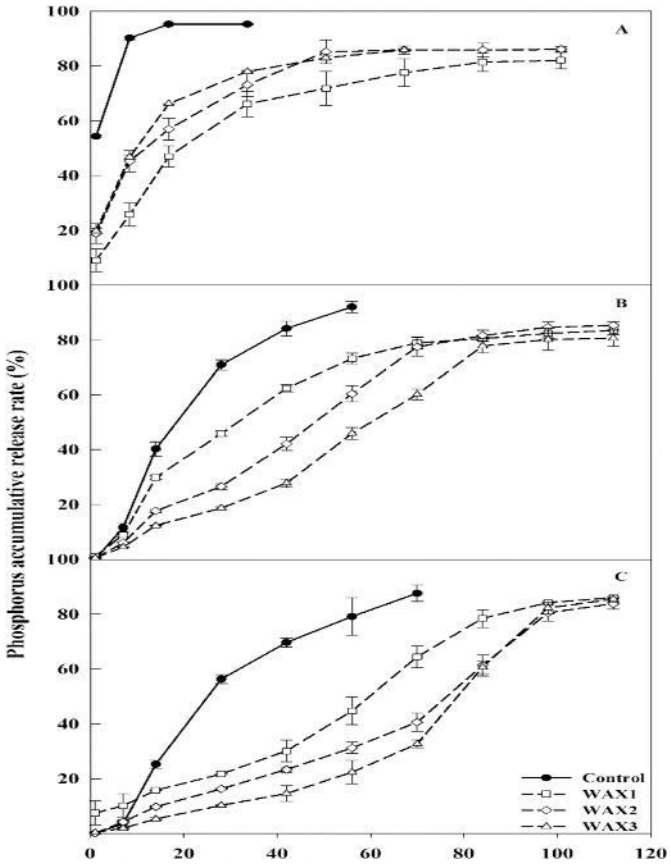
Guelfi et al. 2022. Innovative Phosphate Fertilizer Technologies to Improve Phosphorus Use Efficiency in Agriculture*Sustainability 14*(21), 14266 https://doi.org/10.3390/su142114266

ENHANCED EFFICIENCY P FERTILIZERS

- Controlled-release or coated P fertilizers
- Phosphate fertilizers with fixation inhibitors
- Chemically modified phosphate fertilizers
- Synergistic phosphate fertilizers

Controlled-release phosphorus fertilizers





Lu et al., 2019. Polyolefin Wax Modification Improved Characteristics of Nutrient Release from Biopolymer-Coated Phosphorus Fertilizers https://pubs.acs.org/doi/10.1021/acsomega.9b03348

Problems with controlled-release phosphate fertilizers

- Release too slow or too fast
- Carefully read labels: not all P coated

Home & Garden

Long-Lasting Controlled Release Fertilizer 18-6-12

Contains Osmocote®

Feeds plants at a constant rate for 8 to 9 months.
Can be used on most pot grown and bedding plants.

DIRECTIONS FOR USE

NEW PLANTINGS:

For potted plants, incorporate uniformly throughout the soil. Mix at the rate of 6 to 8 ounces (1/2 to 3/4 cupfuls) per cubic foot.
For plant beds, mix with soil to a depth of 4 to 6 inches at the rate of 1 to 2 pounds (1 1/2 to 3 cups) per 10 square feet.
If plants are being started from seed, propagated or are very young when planted, use 1/4 to 1/2 the rates given above.

ESTABLISHED PLANTINGS:

For potted plants, apply uniformly to the soil surface using the following amounts:

4 inch pot - 3/4 teaspoonful 5 inch pot- 1 1/2 teaspoonfuls 6 inch pot - 2 teaspoonfuls
1 gallon container - 4 teaspoonfuls 3 gallon container - 2 to 4 Tablespoonfuls

NOTE: For the above applications, use the lower rate for sensitive plants (rhododendron, azalea, heather, fern, orchid, etc.) and the high rate for rapidly growing, salt tolerant plants (rose, carnation, dracena, oleander, pyracantha, etc.)

FOR BEDDING PLANTS

Apply uniformly to the soil surface at the rate of 6 ounces (1/2 cup) per 10 square feet.
Till lightly into top 1/2" to 1" of treated area if tilling will not damage plant roots.

Caution:

May be harmful it swallowed. Do not ingest. Keep out of the reach of children and pets.
Store in a cool, dry area.

MINIMUM GUARANTEED ANALYSIS:

Total Nitrogen (N)*	18.00%
9.70% Nitrate Nitrogen	
8.30% Ammoniacal Nitrogen	
Available Phosphoric Acid (P_2O_5)	6.00%
Soluble Potash (K_2O)	12.00%
Chlorine, Not More Than	1.00%

Primary plant nutrients derived from: Ammonium Nitrate, Ammonium Phosphate, Calcium Phosphate, Potassium Sulfate.The Nitrogen, Phosphorus, and Potassium sources have been coated to provide 16% coated slow release Nitrogen (N), 5% coated slow release Phosphoric Acid (P_2O_5) and 11% coated slow release soluble Potash (K_2O).

Guaranteed by: Southern Agricultural Insecticides, Inc. P.O. Box 218 Palmetto, FL 34220

Osmocote® is a registered trademark of Scotts-Sierra Horticultural Products Co. for its brand of controlled release fertilizer.

NOTE: Sweep particles from driveways, curbs, etc. immediately following applications, to prevent staining of concrete, metal and wood surfaces. Keep away from and out of swimming pools. F672-1017

Southern Agricultural Insecticides, Inc.

Palmetto, FL 34220 Hendersonville, NC 28793 Boone, NC 28607

revised 1998

The nitrogen, phosphorus, and potassium sources have been coated to provide
16% coated slow release nitrogen (N),
5% coated slow release phosphoric acid (P2O5) and
11% coated slow release soluble potash (K2O).

GUARANTEED ANALYSIS F643

Total Nitrogen (N)† 14%

8.2% Ammoniacal Nitrogen

5.8% Nitrate Nitrogen

Available Phosphate (P_2O_5)† 14%

Soluble Potash (K_2O)†. 14%

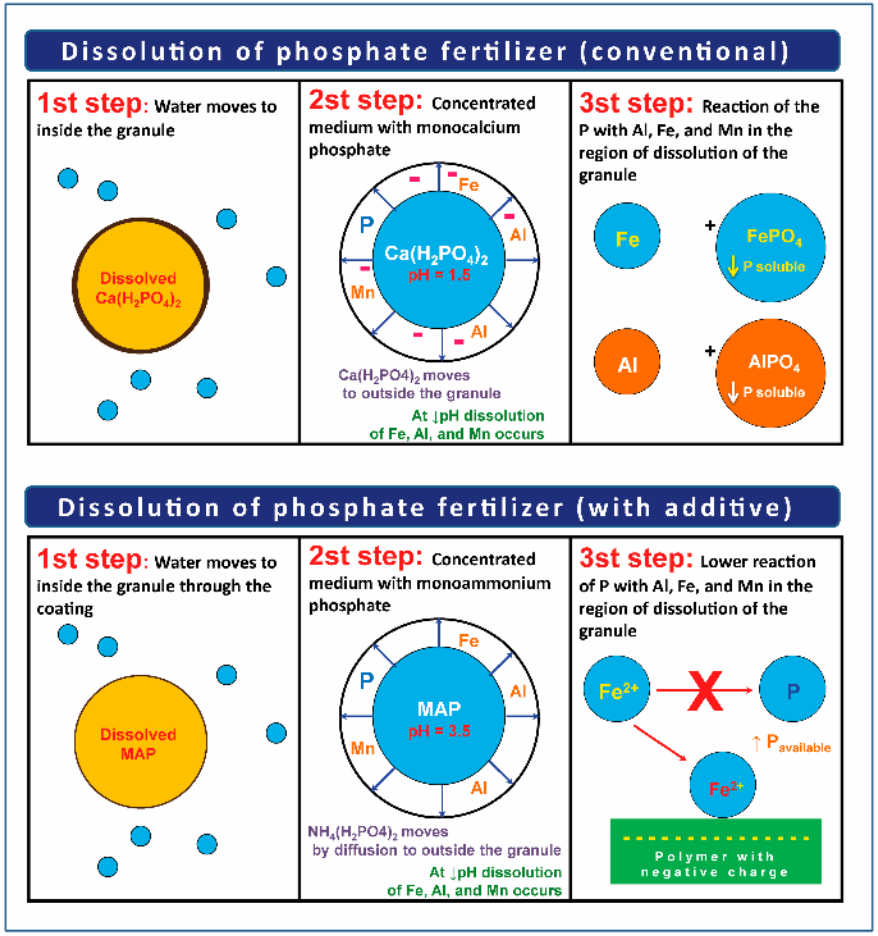
Derived from:

Polymer-coated: Ammonium Nitrate, Ammonium Phosphate, Calcium Phosphate and Potassium Sulfate.

Enhanced efficiency P fertilizers

1. Controlled-release or coated P fertilizers
2. Phosphate fertilizers with fixation inhibitors
3. Chemically modified phosphate fertilizers
4. Synergistic phosphate fertilizers

Phosphate fertilizers with fixation inhibitors



- pH Modifiers: the materials with acidity neutralizing power, such as oxysulfates, carbonates, oxides, and calcium and magnesium oxides, hydroxides, and elemental S.
- Cation-Sequestering Agents or Blockers: organic acids, such as fulvic and humic acids; anionic surfactants and/or cationic and chelating surfactants; and copolymers of the itaconic and maleic acids.

Guelfi et al. 2022. Innovative Phosphate Fertilizer Technologies to Improve Phosphorus Use Efficiency in Agriculture*Sustainability 14*(21), 14266 https://doi.org/10.3390/su142114266

Chemically Modified Phosphate Fertilizers using

- Metal-organic frameworks (MOFs)
- Layered double hydroxide (LDH)
- Graphene oxide (GO)
- Nanoparticles

Synergistic Phosphate Fertilizers with additives/biostimulants:

- Humic substances (humic acid and fulvic acid)
- Algae extracts
- P solubilizing bacteria

These potential enhanced efficiency P fertilizers

- They are theoretically sound and may perform well in laboratory or greenhouse conditions
- None of them are currently commercially available or used on a large scale

Next generation of EEFs

Next Gen Fertilizer Challenges

In 2022, Joint EPA-USDA Partnership and Competition on Next Gen Fertilizers to Advance Agricultural Sustainability in the United States

- To identify existing EEFs currently on or near-market that meet or exceed certain environmental and agro-economic criteria
- To identify concepts for novel technologies for fertilizers and other product technology innovations that can reduce the environmental effects from modern agriculture while maintaining or increasing crop yields.
- Submissions to the Next Gen Fertilizer Innovation Challenge may include technologies that are not currently on the market or technology concepts that are not traditional EEFs and not in commercial use as a fertilizer.

Tier 1 Winners ($17,500 prize):

#1: **"Urea 2.0"** which replaces the conventional urea core with a customizable mixture of inhibitors, micronutrients, and/or biological materials to provide fertilizers tailored to local needs (Pursell Agri-Tech).

Blended fertilizer?

Compound fertilizer?

Tier 1 Winners ($17,500 prize):

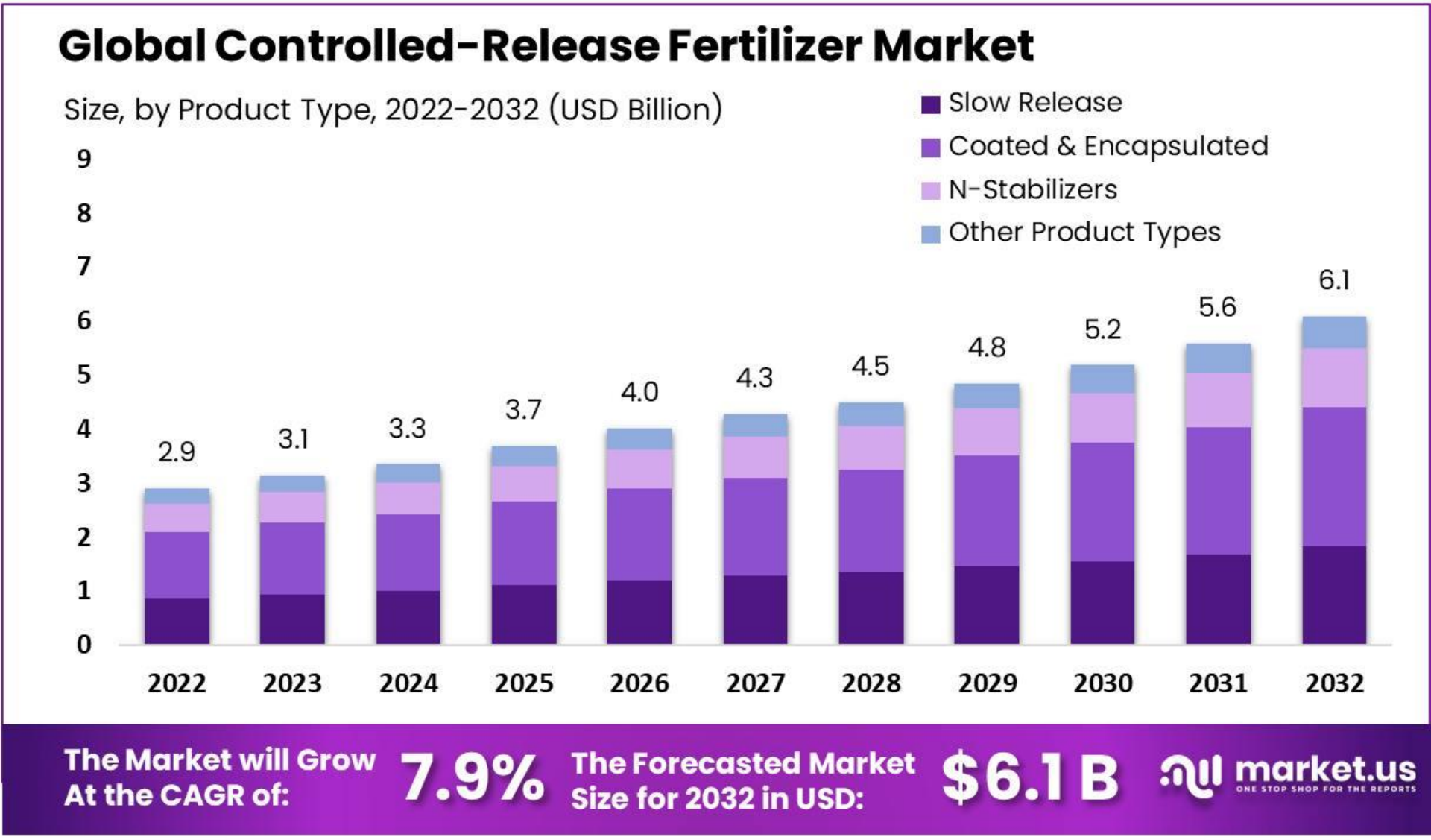
#2: Nano-smart-fertilizer based on silica nanoparticles that carry fertilizer cargo, dissolve into soil minerals, and release fertilizers upon contact with root exudates (Aqua-Yield).

Tier 2 Winners ($10,000 prize)

- Phosphate Liberation Booster technology which uses concentrated root exudates from P-starved plants to enable the application of less fertilizer P and more widely available P sources (Fertinagro Biotech International/ Agraux Solutions Internationa).

- Using innovative eutectic mixture technologies to dramatically improve the performance of an industry standard nitrapyrin for greater longevity, less nitrate leaching, and no evidence of corrosion of farm equipment (Verdesian Life Sciences).

- Smart-N which is a smart-fertilizer releases nutrient on-demand by the crop and is made up of short-chain polyphosphates linked with Ca to create a "cage" for urea which dissolves into plant nutrients (i.e., N, P, and Ca) when it comes into contact with root exudates (AgTec Innovations Inc.).



Market share for fruits & vegetables: 46.2%

Published in 2023

Summary

- Main drivers for use of EEFs are economic and environmental concerns
- Obstacles to wider use of EEFs are attributed to cost and quality
- New technologies will emerge to produce superior and more affordable EEFs
- Utilization of EEFs is anticipated to rise steadily both in the US and globally

Thank You!

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