Multicomponent hydrogel fertilizer technology for sustainable agriculture

Katarzyna Chojnacka*, Aleksandra Gersz, Anna Witek-Krowiak
Department of Advanced Material Technologies, Faculty of Chemistry, Wrocław University of Science and Technology

Wrocław University of Science and Technology

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Fertilizer crisis

Food security

Global food crisis looms as fertilizer supplies dwindle. A report from the United Nations' Food and Agriculture Organization (FAO) highlights the growing concern over the availability of key nutrients for crops, which could lead to reduced food production and increased prices. The report emphasizes the need for sustainable practices and the expansion of alternative sources of nitrogen to ensure food security for the world's growing population. The FAO suggests a focus on improving fertilizer efficiency, promoting soil health, and investing in research for new technologies that can enhance crop yields without overrelying on chemical fertilizers.
IFA:

- 46% ammonium nitrate,
- 23% ammonia,
- 14% of the urea volume,
- 11% ammonium phosphate,
- 21% of the global potassium trade, were retained as the consequence of Ukraine-Russia war.

Europe is more dependent on Russia in this regard. Russia and Belarus have been key EU partners in fertilizer trade.

It is estimated that it will take 10 years to rebuild the mineral fertilizer market.

According to the IFA, it is currently not possible to meet the global demand for fertilizers.
Russia and Belarus have supplied:
- natural gas
- 35% of phosphates
- 60% of potash and to the EU market.
Solution:

- Sustainable agriculture
- Locally available feedstock
- Circular economy – waste as a resource
- Integrated crop-livestock system
- Precision agriculture

https://www.researchgate.net/figure/Circular-agriculture-Source-ASG-Livestock-Manure-brochure-WUR_fig1_336085866
Challenges and problems in agriculture

- Population growth
- Climate change
- Overfertilization
- Nutrients leaching to groundwater
Nutrients for healthy plant growth

N, P, K, Cu, Fe, Zn, Mn

Water and sunlight are essential for plant growth.

ChemForAgro

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Hydrogel fertilizers - key to sustainable agriculture

- natural material
- high moisture storage capacity
- biocompatibility
- biodegradability
- controlled release of nutrients
Matrix based hydrogels

components

- ALG
- CMC
- ALG
- CMC
- ALG
- CMC
- PEAT
- PEAT
- STARCH

crosslinking in CaCl2

crosslinking in CaCl2 + NPK

coating that slows down the release

sorption of copper ions

N: ammonium nitrate NH4NO3
P: monoammonium phosphate (NH4)H2PO4
K: potassium chloride KCl
Matrix based hydrogels

<table>
<thead>
<tr>
<th>components</th>
<th>function</th>
</tr>
</thead>
<tbody>
<tr>
<td>sodium alginate</td>
<td>non-toxic, biocompatible, abundantly available and relatively cheap natural material</td>
</tr>
<tr>
<td>sodium carboxymethylcellulose</td>
<td>additional building component of hydrogel structures, increases strength, mechanical, stability, swelling properties</td>
</tr>
<tr>
<td>peat</td>
<td>rich in many functional groups, high affinity for ion sorption</td>
</tr>
<tr>
<td>starch</td>
<td>low-cost and biodegradable coating material, improves mechanical properties</td>
</tr>
</tbody>
</table>
Sorption kinetics of copper ions

\[ Q_t = Q_e - \left( Q_e^{1-n_1} + (1 + n_1)k_u t \right)^{1-n_1} \]

Sorption kinetics determined by generalized model for nutrients with:
- peat (A)
- and starch (B)
NPK release

NPK release in water after 24h

the release of nitrogen occurs during the degradation of alginate (about 2 weeks)

NPK release in sodium citrate after 24h

slow release of nitrogen through electrostatic interactions, nitrogen binds to the matrix
Release kinetics from coated composites

1 – ALG coated
2 – ALG + NPK coated
3 – CS coated
4 – hybrid coated
Germination tests

Legend:

K1 - Control test without fertilizer
K2 - Control test with liquid NPK fertilizer
% - the dose of applied fertilizer, where 100% = 140kg nitrogen/ha
I - ALG-based fertilizer
II - fertilizer based on ALG+CMC
Concentration optimization by RSM

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>MIN [%]</th>
<th>MAX [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALG</td>
<td>1,5</td>
<td>6</td>
</tr>
<tr>
<td>CMC</td>
<td>0,1</td>
<td>3</td>
</tr>
<tr>
<td>STARCH</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>PEAT</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

System response: content of adsorbed copper ions
### Raw material cost to produce 1 kg of fertilizer

<table>
<thead>
<tr>
<th>components</th>
<th>Cost [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>alginate sodium</td>
<td>5.88</td>
</tr>
<tr>
<td>carboxymethylcellulose sodium</td>
<td>2.47</td>
</tr>
<tr>
<td>peat</td>
<td>1.08</td>
</tr>
<tr>
<td>starch</td>
<td>1.10</td>
</tr>
<tr>
<td>ammonium nitrate</td>
<td>0.61</td>
</tr>
<tr>
<td>monoammonium phosphate</td>
<td>6.37</td>
</tr>
<tr>
<td>potassium chloride</td>
<td>6.66</td>
</tr>
<tr>
<td>calcium chloride</td>
<td>3.98</td>
</tr>
<tr>
<td><strong>summary</strong></td>
<td><strong>28.15</strong></td>
</tr>
</tbody>
</table>
To sum up

1) The designed matrices based on biopolymers, carboxymethylcellulose and alginate, demonstrated the ability to encapsulate fertilizer nutrients NPK.
2) The effectiveness of slow-release coatings has been demonstrated. They reduced the release of calcium and potassium by 35% and phosphorus by 45% per day.
3) Biosorbents such as peat enable the sorption of significant amounts of copper ions, making it possible to design fertilizers with extended micronutrient release times

WHAT’S NEXT?

Complete analysis of peat- and starch-supplemented hydrogels produced (e.g., release kinetics, bioavailability, germination and pot trials)

Use of other additives, e.g. bentonite, and coatings for more complex materials
prof. Katarzyna Chojnacka

Department of Advanced Material Technologies,

Faculty of Chemistry,

Wrocław University of Science and Technology, Poland

E-mail: katarzyna.chojnacka@pwr.edu.pl