Sustainability Innovation

Investigation Of The Elimination Of Nitrogen (as Ammonium) Of Planting Soy (Glycine Max Merr.) Near Field Waterways In Suburban Shanghai (Songjiang District)

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Summary

Farmland water pollution -- the result of the demand for productivity and, thus, excessive fertilizer application -- is a serious problem affecting the local water quality due to eutrophication, affecting the nearby neighborhood. In this project, we selected a patch of unwanted land near a waterway in suburban Shanghai to investigate the effect of planting legumes (i.e. soybean) near waterways on the regulation of water quality near agricultural lands. We devised a farmland architecture in which legumes (nitrogen-favoring plants producing beans) and applied it to a creek in Songjiang District. We found that this architecture can, to some extent, capture fertilizer leakages into waterways.

Choose the Topic

Identify the Challenges

Pollution of waterways near farmlands due to ammonium can cause serious deterioration in water quality in nearby water regions. Locally, it poses a stress on the purification of river water into drinking water (which will waste substantial labor force and nutrients). Furthermore, the impact on the local aquatic environment is much more significant: due to excessive nutrients, some organisms such as algae will boom in population (eutrophication, the process of containing excessive amounts of nutrients in water bodies). As a result, nearby facilities requiring water will lose access to clean water due to eutrophication and people will probably get diseases from these contaminated drinking water. Traditionally, to alleviate this problem, massive labor force and funds should be invested (which will add significant costs to the local economy); i.e. the local government will have less funds for investment on other services, in a way reducing the life quality of the local community.

As Thomas P. Tomich (2012) reported, over 80% of the total nitrogen leakages to the local groundwater in California is induced by cropping and livestock industries. (Tomich, T. (2012). Reducing nitrogen emissions. Issues in Science and Technology, 28(3), 19-19. Retrieved August 4, 2021, from http://www.jstor.org/stable/43315661) This means that controlling nitrogen leakage in agriculture is essential to the local environment. Also, K. FUJITA, K.G. OFOSU-BUDU and S. OGATA (1992) found out that a legume-cereal mixture of agricultural architecture can improve gross productions and regulate soil N absorption of other species when fertilizer is insufficient, (FUJITA, K., OFOSU-BUDU, K., & OGATA, S. (1992). Biological nitrogen fixation in mixed legume-cereal cropping systems. Plant and Soil, 141(1/2), 155-175. Retrieved August 4, 2021, from http://www.jstor.org/stable/42938001) which means that legumes (soy or related crops) can not only utilize nitrogen but also generate wealth for the farmers. As a result, not only the environment itself but also the farmers and any institute related to the local water quality will benefit from the regulation of agricultural N emission.

Identify a Root Cause

The root cause is the application of CHEMICAL FERTILIZERS related to ammonium, as farmers excessively pursue their fields' productivity.
Recent technological advancements has enabled humans to apply chemically-synthesized fertilizers to crops to increase production. However, problems are brought about upon fertilizer usage. Different countries' fertilizer usage is illustrated by G. Klaassen (1990); for example, UK uses 676,000 of 1,314,000 tons of specified ammonium fertilizers. (Klaassen, G. (1990). Emissions of Ammonia in Europe (p. 39, Rep.). International Institute for Applied Systems Analysis (IIASA). Retrieved August 4, 2021, from http://www.jstor.org/stable/resrep15831.14).
J. M. Bremner and A. M. Blackmer (1978) found out that nitrification of ammonium in fertilizers will produce the ozone-layer-harming nitrous oxides (and nitrate that will pollute the aquatic environment). (Bremner, J., & Blackmer, A. (1978). Nitrous Oxide: Emission from Soils During Nitrification of Fertilizer Nitrogen. Science, 199(4326), 295-296. Retrieved August 4, 2021, from http://www.jstor.org/stable/1745661). As a result, nearby residents will suffer from polluted water environments, and other stakeholders will suffer from related problems discussed earlier.

Generate Solutions

The key to deal with the challenge is to confine the spreading of fertilizer material, which will not harm the economic value ammonium fertilizers help create and partially preserve the local aquatic environment. All of us united, devised the following three approaches to solving the problem. Focuses are at: how they confine the pollutants, what can be gained from this method, and what the direct influence on the human community is.

1. Ion-exchange membranes. The pollutants in the waterways are generally ionic; these membranes can regulate the passage of certain ions, and there are types of ion-change membrane that limit the passage of ammonium ions. This model can separate the water body into two sections: the ammonium-rich close-to-field region and the ammonium-poor far-from-field region. Consequently, the N emissions will be retained in the fields in the horizontal plane, nourishing the crops to increase output. However, such membranes are currently limited to laboratory context.

2. Phytoremediation, in which plants are applied to the edges of fields. The leaking fertilizer materials can be captured by their root systems and can be utilized for their growth and reproduction. This methodology can be subdivided into another two subtypes.

(i) Tree phytoremediation. This classic solution is to plant trees near waterways. Their root system extends deep into the riverside soil and forms a complex network. Water containing N (ammonium) pollutants must be filtered by these roots, and the pollutants will eventually be taken in by the trees to support their growth and fruiting. This means can offer farmers an opportunity to benefit from the trees, such as fruits and lumber.

(ii) Legume/soy phytoremediation. We revised the tree-phytoremediation method and made some modifications: legumes (soy) is planted instead of trees near waterways. By similar logic, legumes' root system will filter the agricultural wastewater and take up any leftover N emission and transport it into its seeds (beans), which is an additional food (protein) source for the farmers (helping fight hunger or add food stock in case of a famine).

Table one lists the three methodologies described above and their costs, benefits and other aspects.

Table 1

Identify the Criteria

Five variables should be recorded at the beginning and end of the experiment (two of which should be constantly monitored). First of all, to monitor water quality, we are using the amount of nitrogen content as ammonium (i.e. ammonium nitrogen content) in the soil we apply and in the waterways nearby (To what extent can the planting mode regulate water quality and our regular fertilizing amount?). This set of data requires a reference set before fertilizer application. What is more, satisfaction, the impression of nearby residents on the water quality, can be assessed by questionnaires to qualitatively measure their opinions on the water quality (How satisfied are the nearby residents towards the local water quality?). Moreover, the cost of preparing the seeds will be measured in CNY when making purchases before the experiment (How much is applied to enact our plan?). At the end of the experiment, each plant's mass should be weighed to determine the absorption amount of nutrients in grams (How much excessive nutrients is recycled by these plants?). Finally, an additional constant variable is the dimensions of our land (measured in square meter) to fix our fertilizer application amount and planting density (By what means should we control our independent variable, nitrogen applied?).

Evaluate the Solutions

Several solutions can be applied to the regulation of agricultural ammonium N emission.
1. Semipermeable membranes (specifically, ion-exchange membranes): it will limit the passage of certain ions but not others. We are to set these membranes on the inner surfaces of local waterways, separating the fields and the river. Thus, leakages containing ammonium will not pass into the waterways. However, when we searched for the price, a sheet of 10cm*10cm will cost as much as approximately 200 CNY, which is too impossible to apply massively. As a result, though it can theoretically achieve desirable effects, it is not cheap enough to commercially implement. This solution's rank should be 3.

2. Planting trees near waterways (a type of phytoremediation): the root systems of the trees can extend to the deeper levels of soil to form a network of leaked-nutrition capture and transport into the trees to bear its growth and fruiting (and finally, lumber). On the other hand, the usage of lumber should not be available about 20 years since planting, which will be a delayed benefit for the local economy. Furthermore, this approach will also require farmers to develop multiple harvesting and planting methods, which is intellectually demanding; moreover, the utilization of lumber is related to the carpentry industry, which will require more human resource. This approach deserves a rank of 5.

3. Agricultural architectural redesign (in this case, plant nitrogen-demanding legumes / soy near waterways): the same logic of tree-phytoremediation applies to legumes (but the root systems of legumes will extend less deep). Also, as a commercial crop, the captured N leakage will be supporting the production of food (which can be immediately consumed when harvested, and its harvesting cycle is much shorter than that of lumber), and it is not quite intellectually demanding for farmers. Moreover, compared to the legume-other matrix, the central part of the filed can still adopt mechanical planting and harvesting (without requiring other industries than agriculture). This approach should deserve a rank of 6.

In comparing the method of tree-planting and legume-soy-planting, we thought that the relative production of edible parts of legumes is generally higher than that of trees, and more staple food production can partially alleviate the stress on fighting hunger or malnutrition. The legume/soy-planting method is a little better. Table 1 in the section of "generating solutions" is re-uploaded in this section for organized comparison.

Table 1

Make an Action Plan

Planting crops do not require so much labor force as constructing ion-exchange membranes or planting trees (which made the legume-phytoremediation method feasible). To implement our legume-phytoremediation plan, we need to select a cool (about 20 degrees Celsius) riverbank area for plantation of soy, (we no not to guarantee the prosperous growth of our crops) and fertilize the field on a regular basis at steady amounts of ammonium nitrogen once the plants successively germinate. Meanwhile, we need to monitor the nearby downstream water quality using related apparatus (in this case, a light spectrophotometer with quantitative display and its related chemicals). Interviews should be done to local residents to reflect on the qualitative impression on water quality at the beginning and end of the experiment. Plant height and any related physical quantities must be recorded to reflect the absorption of fertilizers. The test (experiment time) is designed as one week. Theoretically, emissions will be partially transferred to the plants but not directly into the local aquatic environment, solving all related problems arising from this (as discussed in previous parts).

A separate pdf is uploaded in this section as our steps specifically for the fertilization program.

experiment steps

Prototype and Test

Prototype Design

A patch of riverside free space is designated in Songjiang District, Shanghai. A space of about 1.5*5 meters (in order NOT to disturb local residents too greatly) is designed as the simulated "field" without weed being eliminated. Soy seeds (previously soaked in tap water for 3 hours) are distributed evenly at an average of 100 plants per square meter. The related fertilizer is ammonium chloride (NH_4Cl) to eliminate all other forms of nitrogen, and any phosphorus and potassium. Each day, 100 grams of NH_4Cl dissolved in 1 kilogram of tap water is applied to the field per square meter. Five minutes after the completion of fertilization, water sample from the waterway one meter downstream is taken for analysis to determine the concentration of N as ammonium. This experiment is done on six consecutive August days, with one sample taken from the same location prior to the experiment.

Figure one shows the surroundings of the simulated "field".

Figure One

Feedbacks learnt from users

After the process of experimenting, we have successfully collected valid data from filtrated water samples taken from the field's nearby waterways. We obtained these results from a handheld spectrophotometer. Subjectively, these water samples do not differ much in color, odor or visibility. However, quantitative measurements reflect that the ammonium concentration (calculated in the mass of nitrogen per liter of sample) is much higher in non-legume field than in the legume field. This implies that our prototype is somewhat effective in the process of fertilizer leakage capture.

Meanwhile, surveys with regards to local residents (because their drinking water comes from the local waterway network) were conducted. They did not report significant changes in water color, odor or visibility (primarily due to the limited time of experiment). However, when we explained what we are doing using simple sketches, they primarily feel persuaded by our prototypes. They realized the significance of capturing farming leakages and, thus, lessen the stress on their drinking water.

Improvement for next iteration

What our team should continue to do is to increase the leakage capture's efficiency and compatibility. For a field with a humid climate and a waterway network, leakages can enter the water bodies at different depths. As a result, increasing root depth of our architecture species is crucial. Our next itineration near waterways can still be planting legumes on the riverbank, but earthworms are introduced to the fields, for they can burrow down the soil layers, creating well-ventilated, soft soil with passageways for the plants' root systems to grow deeper. The plants can get not only softer soil but also access to the atmosphere, promoting their growth and, therefore, productivity and efficiency of fertilizer usage.

Apart from waterside conditions, fertilizer materials (for example, ammonium) can also seep down the soil layers into local groundwater system, which is directly related to local residents' drinking water. Hence, we devised a "dry itineration" in which the architecture species is no longer legumes, but crops with deep root systems (such as oat and barley). The extensive root systems of the crops can form a "nutrient sieve" on the vertical plane (instead of the horizontal plane in the waterside itineration) to capture any fertilizer material seeping downwards. This itineration is devised on account of the climatic differences between dry and wet geographic locations. Since deep-root species like oat and barley can grow well in dry conditions, they can be used as architecture species in dry environments (with the purpose of harvesting crops suitable for dry locations, creating extra revenues for local farmers).

Our action plans will be similar for these archetypes described above as the prototype (as in the "Prototype Design" section): we plant the architecture species, fertilize them on a regular basis and record the leakages. In the waterside itineration, the measuring method will still be monitoring the concentration of ammonium in samples taken from nearby waterways. However, in the dry itineration, we have to prepare soil solutions prepared by soils taken from different depths.

Team Credits

Junqi Fan is team leader, who is responsible for the coordination and supervision of the team members throughout the project time span.
Jingwei Xiang is responsible for the transportation of nstrument from the lab to the field and do the measurement for the water content for 3 days.
Qizhe Yang is responsible for the measurement for the water content.
Xijing Liao is responsible for all the collections of sample waters from the river and all the adding of chemicals into the field, also responsible for part of the cooperation and transportation of the samples.
Chengze Lyu is responsible for the investigation and monitor of the samples.
Xinyuan Chu is responsible for the data collection in tables and graphs.

Onsite Conference File

This section is currently unavailable for our team.

Judge Comments

" The team requires congratulations for being able to design and test out their project! I also applaud the team for diligent citation of scientific literature to support your project write-up.
I would have liked to see a more systematic approach in identifying the ranking for the solutions. While the logic and the overall ranking is sound, it would be helpful if the criteria identified in the previous section is applied to evaluate the costs and benefits of each of the solutions.
While I appreciate that the team took care to design and test out a complex experiment, it would be helpful to describe the results within the contours of the complex system that the experiment was done in. For instance, given the size of the water body in the picture and the relatively small sample size of water quality, how do you ascertain that the reduction in N can be attributed to the test planting and not some other external factor? Are there ways to structure the experiment to understand the size of the effect? i.e. do we get more reduction with 100 plants than with 50 plants? Intuitively, the answer is yes but how can one test that out? It would be helpful to open up these lines of enquiry within your work – including, at the very least, acknowledging that the test you conducted only starts the identification of some of these answers.
I highly recommend that the team continue their scientific enquiry on this challenging issue – over application of fertilizer and over use of water in agriculture are major issues that requires attention across the world. Congrats on a practical pilot test based approach to the problem! Good luck in the future.
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