agriculture

MDPI

Article

A New Approach for Agricultural Water Management Using Pillows Made from COVID-19 Waste Face Masks and Filled with a Hydrogel Polymer: Preliminary Studies

Haradhan Kolya and Chun-Won Kang *

Department of Housing Environmental Design, Research Institute of Human Ecology, College of Human Ecology, Jeonbuk National University, Jeonju 561-756, Republic of Korea
* Correspondence: kcwon@jbnu.ac.kr

Abstract: Face masks have become an essential commodity during the COVID-19 pandemic, and their use rises daily. Excessive face mask use will likely continue to combat the virus and bacterial impacts in the long term. Afterward, used face masks are hazardous to the environment since most are made of nonbiodegradable porous polymeric fibrous materials. Thus, finding new ways to recycle waste face masks is urgently needed. Similarly, managing agricultural water for irrigation is a crucial challenge in saving water. This study demonstrates an approach for recycling face masks as bag- or small-sized pillows filled with superabsorbent polymers (SAPs) for the slow release of water near plant roots. Previous studies have reported that SAPs or hydrogel could boost soil's water retention capacity, mixed with hydrogel/SAP. However, mixing SAPs into soil is improper because biodegradation generates low toxic organic molecules and contaminates soil and surface water. The objective of this research was to develop a face mask reuse approach, reduce irrigation water using polymers, and reduce toxic contamination in the soil. Here, swollen SAPs were taken inside the pillow and buried near plants, and the growth of the plants was studied. The moisture of the inner soil was constant for a long time, boosting plant growth. Afterward, the face mask pillows could be removed from the soil and maintained for further use. This new approach could be helpful in pot farming. This approach could contribute to the circular economy and the development of environmental sustainability.

Keywords: irrigation; COVID-19 waste; hydrogel/SAP; agricultural applications; face mask

check for updates

Citation: Kolya, H.; Kang, C.-W. A New Approach for Agricultural Water Management Using Pillows Made from COVID-19 Waste Face Masks and Filled with a Hydrogel Polymer: Preliminary Studies. *Agriculture* **2023**, *13*, 152. https://doi.org/10.3390/agriculture13010152

Academic Editors: Emanuele Radicetti, Roberto Mancinelli, Ghulam Haider and Na Duan

Received: 30 November 2022
Revised: 22 December 2022
Accepted: 4 January 2023
Published: 6 January 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The COVID-19 pandemic spread to more than 213 countries globally, and its impact on the environment was enormous [1]. In detail, the World Health Organization (WHO) recommends that health workers directly caring for COVID-19 patients should wear a surgical mask or respirator and personal protective equipment (PPE) to have protection from droplet contaminants [2]. The WHO also states that masks are part of a robust set of ways to prevent and control the spread of multiple infectious respiratory diseases, including COVID-19 [2]. Therefore, the public has started wearing face masks to save their lives from this crafty coronavirus. This generates a massive amount of 'COVID waste'—polyethylene, polypropylene, plastics, hand gloves, face masks, and sanitizer bottles—exhibiting a new kind of pollution in the total environment [3,4]. A recent study estimated that 129 billion face masks and 65 billion gloves are used monthly [5]. There is no basic waste disposal system to control the amount of COVID waste in many countries worldwide [6]. Sadly, we will likely see the waste finding its way downstream to beaches, contaminating water and the ocean [7,8]. Furthermore, face masks can generate massive amounts of microplastics that could significantly affect fauna and flora populations [9,10]. Thus, we need to be serious about reducing the quantity of COVID waste in our society where possible. At the same time, we must develop techniques to recycle or reuse COVID waste produced from lifesaving materials such as face masks [11]. Different face masks are available on the market [12]. Most are manufactured with polypropylene (PP) and polyurethane (PU) because of their hydrophobicity and nonallergic properties with respect to human skin [13]. Researchers have recently reported the best strategies to reuse face masks and minimize the creation of COVID waste [14–17]. However, the public is not aware of the reuse process of different kinds of face masks. The people who can handle the reuse process of disinfecting face masks are also not doing so because of the lack of mental satisfaction and the expensive apparatus for mask disinfectants. Therefore, an alternative process is required to minimize face mask waste in the environment. Recently, Joyce et al. reported an approach for upcycling face mask waste into membranes to separate various organic solvents using a nanofiltration technique [18]. In addition, Mohsin et al. reported a strategy to transform face masks into electrocatalysts for oxygen reduction reactions, hydrogen evolution reactions, and crude oil synthesis using the high-temperature pyrolysis technique [19]. In addition, a green approach has been reported in which fish-scale waste is used to make biodegradable face masks. It could contribute to the circular economy [20]. Here, we have reported a new approach to reuse waste face masks to make pillows to fill with superabsorbent hydrogel for agricultural applications.

Agriculture production depends heavily on water. However, the desertification and salinization of soil brought on by water scarcity and droughts threaten both agriculture's sustainability and food availability. The efficiency with which water is used in agriculture must thus be increased [21]. SAPs and HGs can improve water use in agriculture by keeping moisture in the soil and using less irrigation water because of their extremely high water absorption and retention capacities [22–26]. SAPs have demonstrated encouraging benefits in agriculture by lowering irrigation water usage, reducing plant mortality, enhancing nutrient retention in the soil, and raising plant growth rates [27–30]. SAPs are functional polymers that can absorb and hold huge amounts of water even at high pressures or temperatures [31,32]. The chain contains many hydrophilic groups that contribute to absorbing water hundreds to thousands of times their masses [33]. These polymers are quickly synthesized using natural polymers and crosslinker monomers. Regarding safety and environmental effects, using biopolymers for preparation provides benefits over synthetic polymers [34]. Numerous studies have shown the benefits of using biopolymer-based hydrogels in a wide range of applications [33,35]. Many studies focus on the evaluation of water absorbency, swelling behavior, and the water retention capability of hydrogels. Researchers are now focusing on the synthesis of starch-based graft copolymers using vinyl and acryl monomers, which could improve polymer biodegradability [34,36–38]. Hydrogels made of starch (grafting) are affordable and biodegradable, and their ability to retain water may be adjusted [39].

Furthermore, SAPs are utilized for controlled fertilizer delivery, enhancing soil's capacity to absorb water [40,41]. According to reports, traditional fertilizers typically include between 40 to 70% nitrogen (N) and 80 to 90% phosphorus (P), both of which cannot be absorbed by plants due to their high solubility in water and high diffusivity to the environment [42]. The efficiency of fertilizer usage is increased by loading SAPs, and needless environmental impacts are also reduced [43]. However, mixing SAPs or crosslinked polymers with fertilizers and spreading them on soils is not a good practice because SAPs can only be used once, and biodegradation takes a long time. It generates some low-toxic organic pollutants during biodegradation, which may pollute soil and surface water [44–46]. Therefore, recovering SAPs from soil and reusing them to reduce agricultural production costs is a significant issue [47].

This study used one of our synthesized hydrogels, made by grafting starch (St), acrylamide, and 2-acrylamido-2-methylpropane sulfonic acid [47]. Herein, we used this hydrogel in a face mask pillow and studied its slow-release water supply activity with respect to *Ophiopogon japonicus* grass growth. This hydrogel is an example of how to apply this method to several superabsorbent polymers used in agriculture. These starch-based hydrogels are not available on the market. However, superabsorbent polymers, such as sodium polyacrylate

(CAS No.: 9003-04-7) and potassium polyacrylate (CAS No.: 25608-12-2), are available on the market. Sodium polyacrylate is frequently used in agriculture [46,48]. Recently it was reported that potassium polyacrylate may be more beneficial than sodium polyacrylate because potassium ions promote plant growth effectively while sodium ions do not [49,50]. The grass was chosen for this experiment because of its beautiful evergreen leaves and because it is used as ground cover in Korea, Japan, and China. It grows well in average medium-moisture soil and is adaptive to various conditions. This new approach could entice pot farmers.

2. Materials and Methods

2.1. Materials

Waste face masks were collected from our buckets using hand gloves and face masks to avoid droplet infections, cleaned with liquid detergent, and used in this experiment. Pillows were made using needle and thread. Garden soil and *Ophiopogon japonicus* grasses were collected from the university campus. The hydrogel used in this experiment was prepared using rice-cooked starch wastewater. We have reported its synthetic process and characterizations in a previous article [47]. It has yet to become commercially available.

2.2. Water Absorbency, pH Effects, and Water Retention Capacity

Our previous article reported hydrogel's water absorbency, pH effects, and water retention (hydrogel mixed soil) characteristics [47]. It showed the water absorbency, urea water absorbency (0.1 M), and saline water (0.1 M) absorbency of NaCl, $CaCl_2$, and $FeCl_3$. The typical procedure involved about 1.0 g of hydrogel being taken into the face mask pillows and immersed in the water, saline solutions, and urea at room temperature. After 24 h, the face mask pillow was removed from the solutions and drained of excess water. Then, water absorbency was calculated using Equation (1). The face mask did not absorb water due to its hydrophobic nature. These experiments were performed three times (swelled hydrogel is shown in Figure 1).

$$WA = \frac{(MSP - MDP)}{MDP} \quad (1)$$

where *WA*: water absorbency, *MSP*: mass of swollen polymer, and *MDP*: mass of dry polymer.

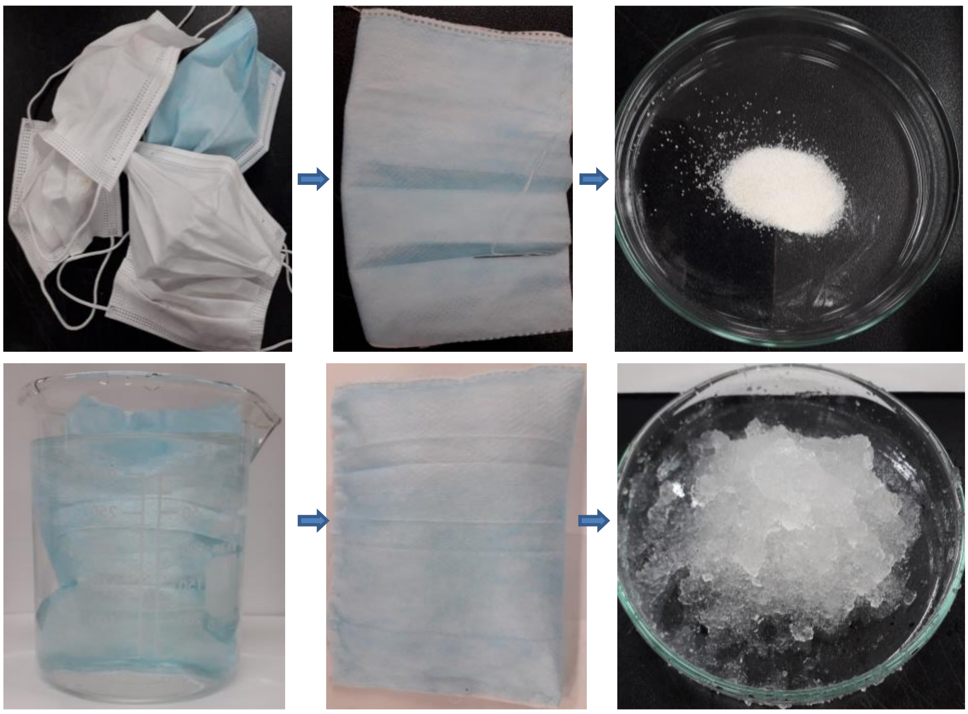

Figure 1. Schematic for making a face mask pillow and water absorbency test.

Herein, the water retention characteristics of the pillow with hydrogel inside the soil were analyzed. One thermocol box (size 300 × 200 × 60 mm) was filled with soil (moisture, 19%) of about 40 mm, and a face mask pillow with completely swollen HGs was kept in the middle position of the box and inside the soil (20 mm). Afterward, the box was kept in a hot chamber at 30 ± 1.0 °C for 20 days. After a one-day interval, the pillow was taken out to measure the weight.

Consequently, the soil moisture of the upper soil, below the pillow, the side of the pillow, and apart from the pillow was measured. A detailed schematic illustration is shown in Figure 2a–c. The above experiments were performed in an oven at 70 ± 5.0 °C for 24 h, and weight was taken every 2 h. The amount of water retained was calculated using Equation (2) [51]. This experiment was conducted two times. Slow evaporation or the slow release of water happened due to the small size of the pores (30.365 µm ± 0.939) present in the face mask [52]. The surface morphology of the face mask was examined using field emission scanning electron microscopy (FESEM-ZEISS SUPRA 40VP, Tokyo, Japan). A FESEM micrograph of a face mask is shown in Figure 2d.

$$Water\ retention\ (wt\%) = \frac{Mass\ of\ soil\ mixture\ dried\ after\ a\ day}{Initial\ mass\ of\ the\ soil\ mixtures} \times 100 \quad (2)$$

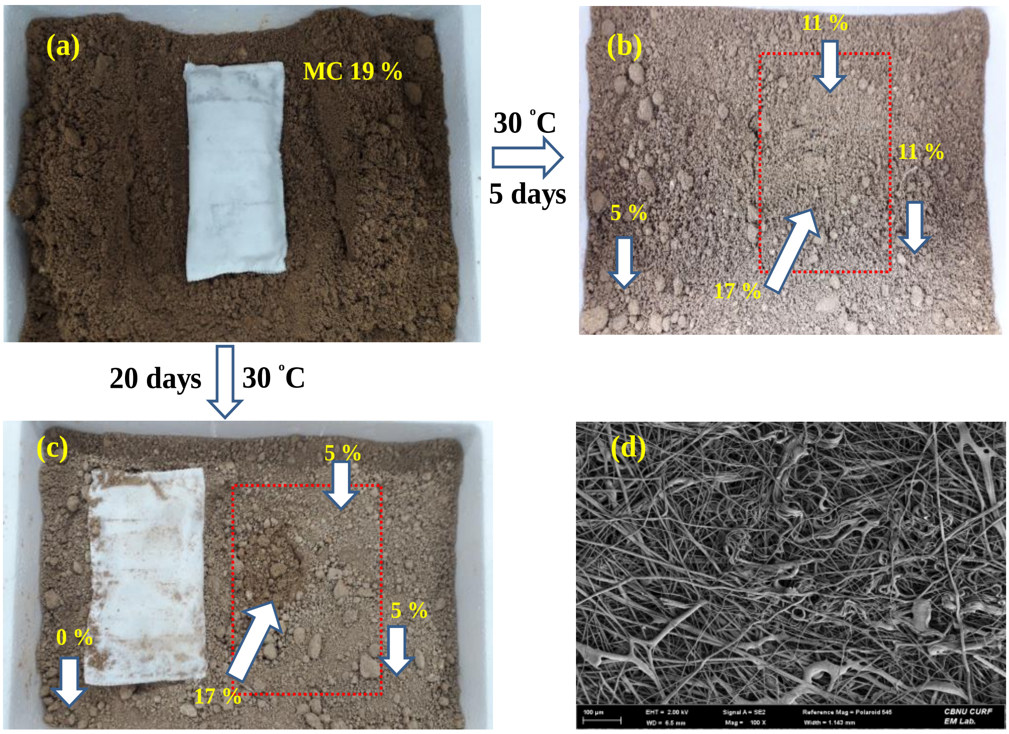

Figure 2. A schematic illustration of water retention in an oven at 30 °C: (**a**) initial soil moisture; (**b**) soil moisture after 5 days; (**c**) soil moisture after 20 days; and (**d**) FESEM micrograph of face mask.

2.3. Applications in Agriculture

First, the germination of ten peas (*Pisum sativum*) and ten mung bean (*Vigna radiata*) seeds was studied on a swelled hydrogel bed in a Petri dish. In addition, a control experiment was performed in a Petri dish containing only water and seeds. The germinated seeds are shown in Figure 3. The same test was performed and reported in our previous article [47].

Second, a plant growth study was conducted using *Ophiopogon japonicus grass*. For this investigation, we used two pots: one as a control with only 3 kg of garden soil (pot-a) and the other with a face mask pillow containing swollen HGs buried in the soil (pot-b). Then, healthy grasses were planted in the soil of both pots. About 100 mL of water was added to each pot. The pots were placed near the window in the laboratory for sunlight. The soil moisture was tested using a Test 606-1 moisture meter at room temperature (18 °C). After three days, the soil surface moisture in each pot was 52.4%. The growth of grasses was studied for 60 days. However, other than dryness, no pests or infections were found on the grasses. Grass growth experiments are shown schematically in Figure 4. This experiment was repeated twice.

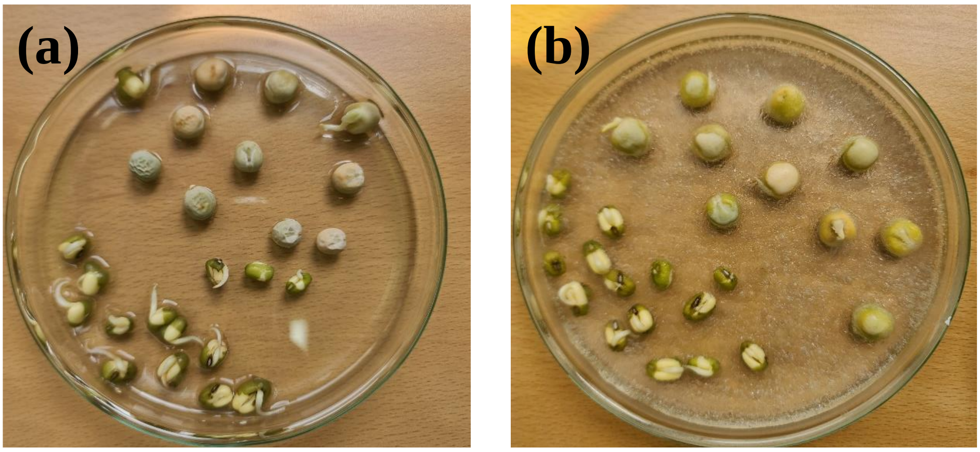

Figure 3. Digital photos of the germination of seeds: (**a**) water and (**b**) hydrogel.

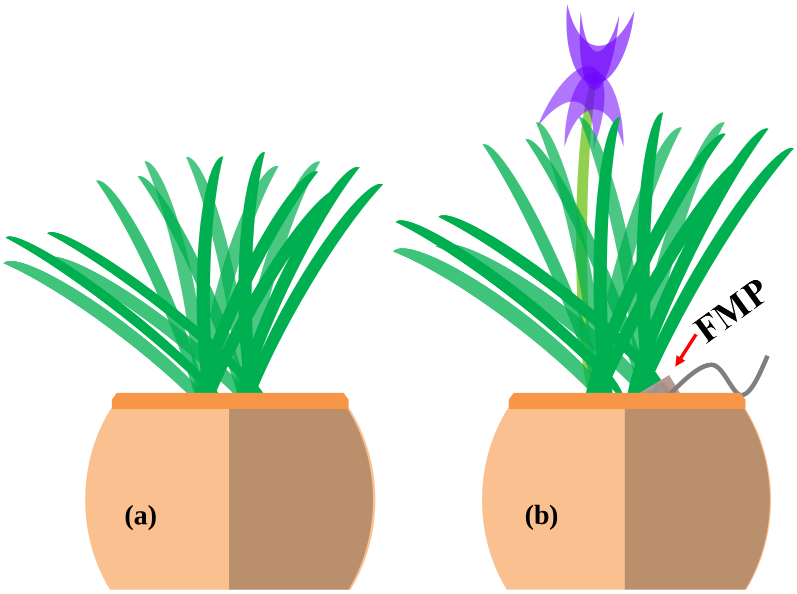

Figure 4. A schematic of the water supply using a face mask pillow: (**a**) control; (**b**) buried face mask pillow near the plant roots.

2.4. Reusability Test

The reusability of hydrogel was studied by measuring the loss of water absorbance over a five-cycle period. The agriculturally used hydrogel was collected from the face mask and dried in a hot air oven at 40 °C for 24 h. Afterward, the weighted hydrogel was again taken into the face mask and poured into the water for swelling for 24 h. Then, the face mask pillow was buried in the same soil from which it was collected 60 days later, and 100 mL of water was added to the soil. The process was repeated until the fifth cycle.

3. Results

3.1. Water Absorbency, pH Effects, and Retention

The results revealed a water absorbency order of water > urea > NaCl > $FeCl_3$ > $CaCl_2$. It is possible that multivalent cations interacted with the —OH- and —SO_3H-functional groups in the polymer to produce complex compounds that improve the crosslinking density of hydrogels. Therefore, the network of polymers shrinks, which might lower the water absorbency and the swelling of the polymer [47,53]. Furthermore, the highest water absorbance was observed at pH 7 (158.7 g/g 1.0) and the lowest (45.0) at pH 2.0. In acidic pH, many hydrogen bonds form, which may cause polymer networks to shrink and affect water absorbency. However, from pH 5 to 10, the number of hydrogen bonds formed may decrease, allowing the polymer network to swell and absorb more water. Furthermore, water absorbance was reduced at pH 10 due to the cationic effects of Na+ ions in the polymer networks. The effects of pH on hydrogel are described in detail in our previous article [47].

The HGs in the FMP and buried in the soil showed 89 wt.% water retention after 24 h at 30 °C (as shown in Figure 5). In addition, HGs in the FMP buried in the soil showed 5.2 wt.% water retention after 24 h at 70 °C. However, the soil moisture of the upper soil, below the pillow, the side of the pillow, and apart from the pillow (as shown in Figure 2c) showed 5%, 17%, 5%, and 0%, respectively.

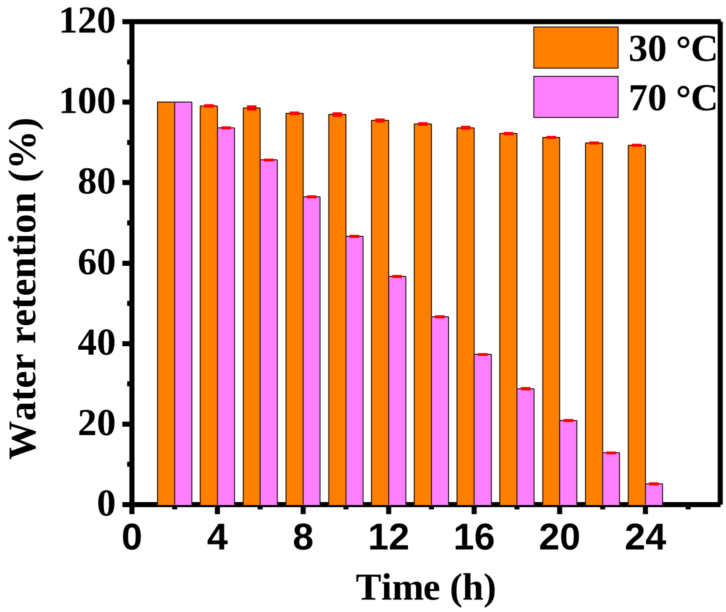

Figure 5. Water retention performance of the HGs–FMP in the soil at 30 °C and 70 °C.

3.2. Agricultural Use

The germination of seeds was good in both cases, including in the polymer bed and in the control after three days (as shown in Figure 3). This indicates that hydrogel does not release toxins during pea and mung bean seedling growth. In addition, this suggests that hydrogel may be used to promote seed germination and seedling growth, which offers a practical application for hydrogel use in agriculture [54].

On the other hand, grass growth was observed to be better in pot-b (containing the HGs–FMP) than in pot-a (the control), as shown in Figure 6. After 15–30 days, the grass leaves in pot-a were observed to dry and become yellowish. However, the grass in pot-b showed quite green and alive leaves. After 60 days, it was distinctly obvious that the grass from pot-b exhibited more freshness compared with the grass from pot-a. This is because of water retention in the polymers and the slow release of water to the soil in pot-b. The face mask pillow was removed from the soil, and the moisture levels were measured (5.2%). The HG polymers became yellowish; biodegradation and morphological changes were observed (Figure 6). The last image in Figure 6 was taken with a Dino-lite digital microscope (AM4132) at a magnification of 52×.

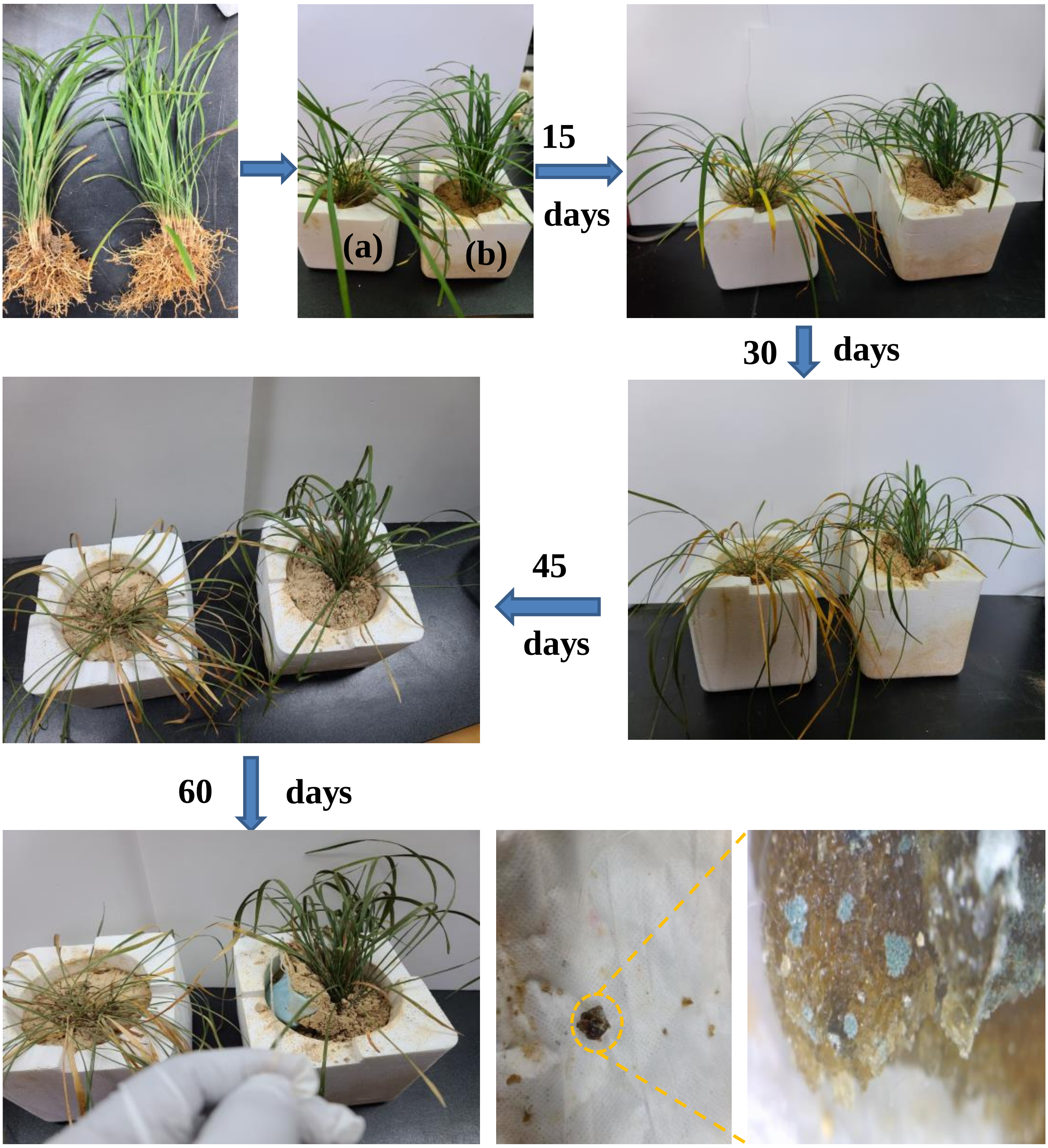

Figure 6. Growth studies of Ophiopogon japonicus grass over 60 days: (**a**) control and (**b**) FMP inside the soil.

3.3. Reusability

The results of the reusability test are shown in Figure 7. Figure 7a,b show the reswelling study of the used polymers, and Figure 7c shows that water absorbency decreased slightly after the first cycle (25.6%), after the second cycle (31.2%), after the third cycle (36.4%), after the fourth cycle (41.3%), and after the fifth cycle (43.4%) compared with the control. This may be due to the biodegradation of starch moieties in the hydrogel. The decreases in the rate of biodegradation from the third cycle may be due to the lower quantities of starch present in the hydrogel's backbone. The average loss of water absorbency was found to be 13.74 ± 15.13 g/g. Figure 7d presents an image of hydrogel loaded with water.

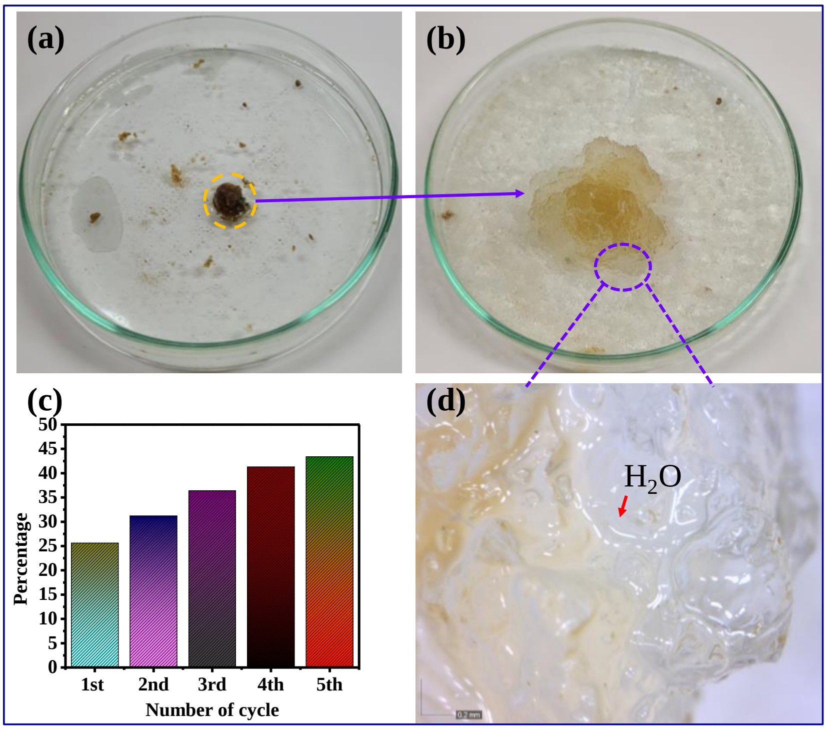

Figure 7. (**a**) Reswelling hydrogel after 2 min; (**b**) reswelling hydrogel after 24 h; (**c**) decreasing percentage of water swelling; and (**d**) image using Dino-lite digital microscope (AM4132) at a magnification of 54×.

3.4. Concept of Practical Utility

Pot farming is now an economical process for cultivating various vegetables and fruits. A pot can be placed indoors, outdoors, or in a greenhouse. It depends on what type of plants are to be grown. Pots can be made with clay, wood, plastic, or metal. Here, a schematic of pot farming is shown in Figure 8a. It shows a hydrogel- or SAP-containing face mask pillow in a pot. Water-loaded polymers inside the pillow slowly release water near the plant for a long period. However, this may vary with the plant's water requirements, soil texture, and environment. Therefore, water must be supplied to the polymer when it is almost out of water. Water may be injected into the SAPs directly, as shown in Figure 8c, to save irrigation water.

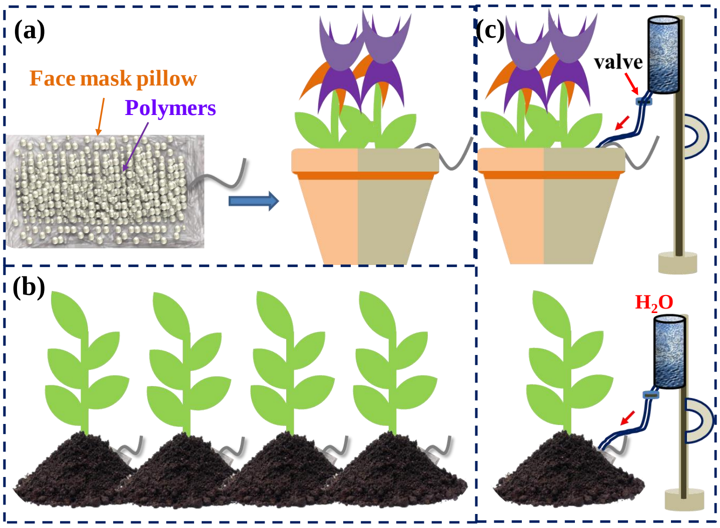

Figure 8. Schematic illustrations of (**a**) pot farming, (**b**) farming in an agricultural field, and (**c**) the water injecting process for the polymers–face mask pillow.

Furthermore, the face mask pillow with SAPs could also be helpful in the agricultural field, as shown in Figure 8b. Similarly, from time to time, water could be injected directly into the SAPs–face mask pillow, as shown in Figure 8c.

4. Discussion

A face mask pillow filled with swelling hydrogel retained around 5.2 wt.% water after 24 h at 70 °C and 89 wt.% water after 24 h at 30 °C inside the soil. However, the soil moisture values of the upper soil, below the pillow, the side of the pillow, and apart from the pillow were 5%, 17%, 5%, and 0%, respectively. The germination study suggested that hydrogel could be helpful for agricultural applications [54]. The plant growth study indicates that a face mask pillow filled with SAPs could help supply plentiful water to the plant roots for a long period. Therefore, the moisture in the inner soil was consistent for a long period and, thus, improved the effectiveness of irrigation [55]. In addition, enough urea water can be absorbed by polymers, which releases slowly into the roots of plants [56]. This could enhance plant growth and productivity. Hence, this hydrogel or commercially available SAPs with a face mask pillow might be helpful for pot framing. The polymers inside the pillow can absorb, retain, and slowly release water for a long period when soil moisture decreases. This entire process could decrease the utility of water and production costs and increase environmental sustainability. More research needs to be performed to check the toxicity parameters of soils and foods when using this starch-based hydrogel. However, according to the literature, it is anticipated that sodium polyacrylate use in agriculture is safe [57]. Afterward, the face mask pillow can be collected from the soil and immersed in water or urea water for subsequent use.

However, the research on the end use of face masks is quite challenging. Recently, some studies reported various approaches to the reuse and recycling of face masks [10,58–60], which could boost the circular economy [19]. Most of them established different strategies for converting hazardous face masks into other forms of use, but they are still hazardous to the environment. Therefore, face mask end use or biodegradation could be a significant research area.

5. Conclusions

A waste COVID face mask was used to make pillows to fill with superabsorbent polymers. Water-loaded polymer covered with a face mask was studied for its water retention capability inside soil at 30 °C and 70 °C. The crosslinked polymer (hydrogel) used in this study could be used as an example of this approach for several superabsorbent polymers in agricultural use. The water-loaded pillows near the plant's roots revealed acceptable evidence of plant growth. This could be due to the polymers in the face mask pillows slowly releasing plentiful water for plant growth. Furthermore, the reusability of hydrogel was investigated, and the results showed that hydrogel could be used repeatedly for up to five cycles with a loss of 43.4% water absorbance capacity. It was found that the average loss of water absorbency was about 13.74 ± 15.13 g/g. Superabsorbent polymers that are available in the market, such as sodium polyacrylate and potassium polyacrylate, could be more effective and helpful for repeated use in pillows for irrigation. This facile approach could help in the repeated use of polymers in agriculture. In addition, it could decrease agricultural irrigation water and enhance productivity and environmental sustainability.

Author Contributions: H.K.: conceptualization, formal analysis, investigation, writing—original draft, writing—review and editing. C.-W.K.: project administration, funding acquisition, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: The Basic Science Research Program supported this research through the National Research Foundation of Korea, funded by the Ministry of Education (NRF-2019R1I1A3A02059471), and it was also supported under the framework of an international cooperation program managed by the National Research Foundation of Korea (NRF-2020K2A9A2A08000181).

Institutional Review Board Statement: Not applicable for studies not involving humans or animals.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper. Moreover, there were no animal studies or human participants involved in this study.

References

1. Gautam, M.; Kumari, S.; Gautam, S.; Singh, R.K.; Kureel, R.S. The Novel Coronavirus Disease-COVID-19: Pandemic and Its Impact on Environment. *Curr. J. Appl. Sci. Technol.* **2020**, *39*, 13–21. [CrossRef]
2. World Health Organization. *Advice on the Use of Masks in the Context of COVID-19: Interim Guidance, 5 June 2020*; World Health Organization: Geneva, Switzerland, 2020.
3. Zambrano-Monserrate, M.A.; Ruano, M.A.; Sanchez-Alcalde, L. Indirect effects of COVID-19 on the environment. *Sci. Total Environ.* **2020**, *728*, 138813. [CrossRef]
4. Mejjad, N.; Cherif, E.K.; Rodero, A.; Krawczyk, D.A.; El Kharraz, J.; Moumen, A.; Laqbaqbi, M.; Fekri, A. Disposal Behavior of Used Masks during the COVID-19 Pandemic in the Moroccan Community: Potential Environmental Impact. *Int. J. Environ. Res. Public Health* **2021**, *18*, 4382. [CrossRef] [PubMed]
5. Prata, J.C.; Silva, A.L.P.; Walker, T.R.; Duarte, A.C.; Rocha-Santos, T. COVID-19 Pandemic Repercussions on the Use and Management of Plastics. *Environ. Sci. Technol.* **2020**, *54*, 7760–7765. [CrossRef] [PubMed]
6. Roberts, K.P.; Phang, S.C.; Williams, J.B.; Hutchinson, D.J.; Kolstoe, S.E.; de Bie, J.; Williams, I.D.; Stringfellow, A.M. Increased personal protective equipment litter as a result of COVID-19 measures. *Nat. Sustain.* **2022**, *5*, 272–279. [CrossRef]
7. Kampf, G.; Todt, D.; Pfaender, S.; Steinmann, E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *J. Hosp. Infect.* **2020**, *104*, 246–251. [CrossRef] [PubMed]
8. Nzediegwu, C.; Chang, S.X. Improper solid waste management increases potential for COVID-19 spread in developing countries. *Resour. Conserv. Recycl.* **2020**, *161*, 104947. [CrossRef]
9. Dharmaraj, S.; Ashokkumar, V.; Hariharan, S.; Manibharathi, A.; Show, P.L.; Chong, C.T.; Ngamcharussrivichai, C. The COVID-19 pandemic face mask waste: A blooming threat to the marine environment. *Chemosphere* **2021**, *272*, 129601. [CrossRef]
10. Ray, S.S.; Lee, H.K.; Huyen, D.T.T.; Chen, S.S.; Kwon, Y.N. Microplastics waste in environment: A perspective on recycling issues from PPE kits and face masks during the COVID-19 pandemic. *Environ. Technol. Innov.* **2022**, *26*, 102290. [CrossRef]
11. Tesfaldet, Y.T.; Ndeh, N.T. Assessing face masks in the environment by means of the DPSIR framework. *Sci. Total Environ.* **2022**, *814*, 152859. [CrossRef]
12. Xu, Y.; Zhang, X.; Hao, X.; Teng, D.; Zhao, T.; Zeng, Y. Micro/nanofibrous nonwovens with high filtration performance and radiative heat dissipation property for personal protective face mask. *Chem. Eng. J.* **2021**, *423*, 130175. [CrossRef] [PubMed]
13. Czigány, T.; Ronkay, F. The coronavirus and plastics. *Express Polym. Lett.* **2020**, *14*, 510–511. [CrossRef]
14. Rubio-Romero, J.C.; Pardo-Ferreira, M.D.C.; Torrecilla-García, J.A.; Calero-Castro, S. Disposable masks: Disinfection and sterilization for reuse, and non-certified manufacturing, in the face of shortages during the COVID-19 pandemic. *Saf. Sci.* **2020**, *129*, 104830. [CrossRef] [PubMed]
15. Hamzavi, I.H.; Lyons, A.B.; Kohli, I.; Narla, S.; Parks-Miller, A.; Gelfand, J.M.; Lim, H.W.; Ozog, D.M. Ultraviolet germicidal irradiation: Possible method for respirator disinfection to facilitate reuse during the COVID-19 pandemic. *J. Am. Acad. Dermatol.* **2020**, *82*, 1511–1512. [CrossRef] [PubMed]
16. El-Atab, N.; Qaiser, N.; Badghaish, H.; Shaikh, S.F.; Hussain, M.M. Flexible Nanoporous Template for the Design and Development of Reusable Anti-COVID-19 Hydrophobic Face Masks. *ACS Nano* **2020**, *14*, 7659–7665. [CrossRef] [PubMed]
17. Schwan, J.; Alva, T.R.; Nava, G.; Rodriguez, C.B.; Dunn, Z.S.; Chartron, J.W.; Morgan, J.; Wang, P.; Mangolini, L. Efficient facemask decontamination via forced ozone convection. *Sci. Rep.* **2021**, *11*, 12263. [CrossRef]
18. Cavalcante, J.; Hardian, R.; Szekely, G. Antipathogenic upcycling of face mask waste into separation materials using green solvents. *Sustain. Mater. Technol.* **2022**, *32*, e00448. [CrossRef]
19. Muhyuddin, M.; Filippi, J.; Zoia, L.; Bonizzoni, S.; Lorenzi, R.; Berretti, E.; Capozzoli, L.; Bellini, M.; Ferrara, C.; Lavacchi, A.; et al. Waste Face Surgical Mask Transformation into Crude Oil and Nanostructured Electrocatalysts for Fuel Cells and Electrolyzers. *ChemSusChem* **2022**, *15*, e202102351. [CrossRef]
20. Hou, E.J.; Hsieh, Y.Y.; Hsu, T.W.; Huang, C.S.; Lee, Y.C.; Han, Y.S.; Chu, H.T. Using the concept of circular economy to reduce the environmental impact of COVID-19 face mask waste. *Sustain. Mater. Technol.* **2022**, *33*, e00475. [CrossRef]
21. Wen, X.; Zhang, D.; Liao, Y.; Jia, Z.; Ji, S. Effects of Water-Collecting and -Retaining Techniques on Photosynthetic Rates, Yield, and Water Use Efficiency of Millet Grown in a Semiarid Region. *J. Integr. Agric.* **2012**, *11*, 1119–1128. [CrossRef]
22. Ullah, F.; Othman, M.B.H.; Javed, F.; Ahmad, Z.; Akil, H.M. Classification, processing and application of hydrogels: A review. *Mater. Sci. Eng. C* **2015**, *57*, 414–433. [CrossRef] [PubMed]
23. Ai, F.; Yin, X.; Hu, R.; Ma, H.; Liu, W. Research into the super-absorbent polymers on agricultural water. *Agric. Water Manag.* **2021**, *245*, 106513. [CrossRef]
24. Thombare, N.; Mishra, S.; Siddiqui, M.Z.; Jha, U.; Singh, D.; Mahajan, G.R. Design and development of guar gum based novel, superabsorbent and moisture retaining hydrogels for agricultural applications. *Carbohydr. Polym.* **2018**, *185*, 169–178. [CrossRef] [PubMed]

25. Guancha-Chalapud, M.A.; Serna-Cock, L.; Tirado, D.F. Hydrogels Are Reinforced with Colombian Fique Nanofibers to Improve Techno-Functional Properties for Agricultural Purposes. *Agriculture* **2022**, *12*, 117. [CrossRef]
26. Puoci, F.; Iemma, F.; Spizzirri, U.G.; Cirillo, G.; Curcio, M.; Picci, N. Polymer in agriculture: A review. *Am. J. Agric. Biol. Sci.* **2008**, *3*, 299–314. [CrossRef]
27. Klein, M.; Poverenov, E. Natural biopolymer-based hydrogels for use in food and agriculture. *J. Sci. Food Agric.* **2020**, *100*, 2337–2347. [CrossRef]
28. Chang, L.; Xu, L.; Liu, Y.; Qiu, D. Superabsorbent polymers used for agricultural water retention. *Polym. Test.* **2021**, *94*, 107021. [CrossRef]
29. Mohana Raju, K.; Padmanabha Raju, M. Synthesis of novel superabsorbing copolymers for agricultural and horticultural applications. *Polym. Int.* **2001**, *50*, 946–951. [CrossRef]
30. Yang, Q.; Zhu, Y.; Liu, L.; Wang, F. Land tenure stability and adoption intensity of sustainable agricultural practices in banana production in China. *J. Clean. Prod.* **2022**, *338*, 130553. [CrossRef]
31. Chang, C.; Duan, B.; Cai, J.; Zhang, L. Superabsorbent hydrogels based on cellulose for smart swelling and controllable delivery. *Eur. Polym. J.* **2010**, *46*, 92–100. [CrossRef]
32. Liu, X.; Liu, J.; Lin, S.; Zhao, X. Hydrogel machines. *Mater. Today* **2020**, *36*, 102–124. [CrossRef]
33. Guilherme, M.R.; Aouada, F.A.; Fajardo, A.R.; Martins, A.F.; Paulino, A.T.; Davi, M.F.T.; Rubira, A.F.; Muniz, E.C. Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. *Eur. Polym. J.* **2015**, *72*, 365–385. [CrossRef]
34. Zhang, M.; Biesold, G.M.; Choi, W.; Yu, J.; Deng, Y.; Silvestre, C.; Lin, Z. Recent advances in polymers and polymer composites for food packaging. *Mater. Today* **2022**, *53*, 134–161. [CrossRef]
35. Pasqui, D.; De Cagna, M.; Barbucci, R. Polysaccharide-Based Hydrogels: The Key Role of Water in Affecting Mechanical Properties. *Polymers* **2012**, *4*, 1517–1534. [CrossRef]
36. Supare, K.; Mahanwar, P.A. Starch-derived superabsorbent polymers in agriculture applications: An overview. *Polym. Bull.* **2021**, *79*, 5795–5824. [CrossRef]
37. Gilet, A.; Quettier, C.; Wiatz, V.; Bricout, H.; Ferreira, M.; Rousseau, C.; Monflier, E.; Tilloy, S. Unconventional media and technologies for starch etherification and esterification. *Green Chem.* **2018**, *20*, 1152–1168. [CrossRef]
38. Kalendova, P.; Svoboda, L.; Hroch, J.; Honcova, P.; Drobna, H.; Slang, S. Hydrogels Based on Starch from Various Natural Sources: Synthesis and Characterization. *Starch–Stärke* **2021**, *73*, 2100051. [CrossRef]
39. Jyothi, A.N. Starch Graft Copolymers: Novel Applications in Industry. *Compos. Interfaces* **2010**, *17*, 165–174. [CrossRef]
40. Joshi, P.P.; Van Cleave, A.; Held, D.W.; Howe, J.A.; Auad, M.L. Preparation of slow release encapsulated insecticide and fertilizer based on superabsorbent polysaccharide microbeads. *J. Appl. Polym. Sci.* **2020**, *137*, 49177. [CrossRef]
41. Dhanapal, V.; Subhapriya, P.; Sennappan, M.; Govindaraju, K.M. Controlled release characteristics of methylenebisacrylamide crosslinked superabsorbent polymer for water and fertilizer conservation in agriculture sector. *J. Polym. Res.* **2022**, *29*, 298. [CrossRef]
42. Corradini, E.; De Moura, M.R.; Mattoso, L.H.C. A preliminary study of the incorparation of NPK fertilizer into chitosan nanoparticles. *Express Polym. Lett.* **2010**, *4*, 509–515. [CrossRef]
43. Hou, X.; Li, R.; He, W.; Dai, X.; Ma, K.; Liang, Y. Superabsorbent polymers influence soil physical properties and increase potato tuber yield in a dry-farming region. *J. Soils Sediments* **2018**, *18*, 816–826. [CrossRef]
44. Cheng, P. Chemical and photolytic degradation of polyacrylamides used in potable water treatment. Ph.D. Thesis, University of South Florida, Tampa, FL, USA, 2004.
45. Zhuang, L.L.; Wu, Y.H.; Espinosa, V.M.D.; Zhang, T.Y.; Dao, G.H.; Hu, H.Y. Soluble Algal Products (SAPs) in large scale cultivation of microalgae for biomass/bioenergy production: A review. *Renew. Sustain. Energy Rev.* **2016**, *59*, 141–148. [CrossRef]
46. Liang, D.; Du, C.; Ma, F.; Shen, Y.; Wu, K.; Zhou, J. Degradation of Polyacrylate in the Outdoor Agricultural Soil Measured by FTIR-PAS and LIBS. *Polymers* **2018**, *10*, 1296. [CrossRef]
47. Kolya, H.; Kang, C.W. Synthesis of starch-based smart hydrogel derived from rice-cooked wastewater for agricultural use. *Int. J. Biol. Macromol.* **2022**, *226*, 1477–1489. [CrossRef]
48. Hong, S.H.; Ham, S.Y.; Kim, J.S.; Kim, I.S.; Lee, E.Y. Application of sodium polyacrylate and plant growth-promoting bacterium, Micrococcaceae HW-2, on the growth of plants cultivated in the rooftop. *Int. Biodeterior. Biodegrad.* **2016**, *113*, 297–303. [CrossRef]
49. Gómez, J.S. Characterization and effects of cross-linked potassium polyacrylate as soil amendment. Ph.D. Thesis, University of Seville, Seville, Spain, 2015.
50. De Oliveira, A.B.; Alencar, N.L.M.; Gomes-Filho, E. Comparison between the water and salt stress effects on plant growth and development. *Responses Org. Water Stress* **2013**, *4*, 67–94.
51. Chen, P.; Zhang, W.; Luo, W.; Fang, Y. Synthesis of superabsorbent polymers by irradiation and their applications in agriculture. *J. Appl. Polym. Sci.* **2004**, *93*, 1748–1755. [CrossRef]
52. Jang, E.S.; Kang, C.W. Do Face Masks become Worthless after Only One Use in the COVID-19 Pandemic? *Infect. Chemother.* **2020**, *52*, 583–591. [CrossRef]
53. Abdel Bary, E.M.; Fekri, A.; Soliman, Y.A.; Harmal, A.N. Novel superabsorbent membranes made of PVA and *Ziziphus spina-christi* cellulose for agricultural and horticultural applications. *New J. Chem.* **2017**, *41*, 9688–9700. [CrossRef]

54. Tao, J.; Zhang, W.; Liang, L.; Lei, Z. Effects of eco-friendly carbohydrate-based superabsorbent polymers on seed germination and seedling growth of maize. *R. Soc. Open Sci.* **2022**, *5*, 171184. [CrossRef] [PubMed]
55. Khodadadi Dehkordi, D.; Shamsnia, S.A. Application of Reclaimed Sodium Polyacrylate to Increase Soil Water Retention. *CLEAN–Soil Air Water* **2020**, *48*, 2000068. [CrossRef]
56. Zhang, Y.; Liang, X.; Yang, X.; Liu, H.; Yao, J. An Eco-Friendly Slow-Release Urea Fertilizer Based on Waste Mulberry Branches for Potential Agriculture and Horticulture Applications. *ACS Sustain. Chem. Eng.* **2014**, *2*, 1871–1878. [CrossRef]
57. Parmar, B.S. Superabsorbent Polymers: Material Safety of the Major Chemical Groups. *Pestic. Res. J.* **2014**, *26*, 119–127.
58. Maderuelo-Sanz, R.; Acedo-Fuentes, P.; García-Cobos, F.J.; Sánchez-Delgado, F.J.; Mota-López, M.I.; Meneses-Rodríguez, J.M. The recycling of surgical face masks as sound porous absorbers: Preliminary evaluation. *Sci. Total Environ.* **2021**, *786*, 147461. [CrossRef]
59. Emenike, E.C.; Iwuozor, K.O.; Agbana, S.A.; Otoikhian, K.S.; Adeniyi, A.G. Efficient recycling of disposable face masks via co-carbonization with waste biomass: A pathway to a cleaner environment. *Clean. Environ. Syst.* **2022**, *6*, 100094. [CrossRef]
60. Idrees, M.; Akbar, A.; Mohamed, A.M.; Fathi, D.; Saeed, F. Recycling of Waste Facial Masks as a Construction Material, a Step towards Sustainability. *Materials* **2022**, *15*, 18. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.