

A sustainable and slow-release organic silicon fertiliser derived from organic waste streams

Jac Dimond*, Gareth Griffiths, Michal M. Czachor, Christian J. Laycock, Alan J. Guwy

Sustainable Environment Research Centre, University of South Wales, Pontypridd, UK

* Presenting and corresponding author: jac.dimond@southwales.ac.uk



University of
South Wales
Prifysgol
De Cymru

1. Introduction

The development of sustainable fertilisers prepared from local and renewable resources is an increasingly urgent challenge faced by agricultural and food sectors globally. This challenge is complicated by the need to deliver nutrients directly to crops with minimal environmental impact. Here, we explore the characteristics of an organic silicon fertiliser (OSF) prepared by treatment of digestate using potassium silicate and calcium chloride (see Fig. 1).

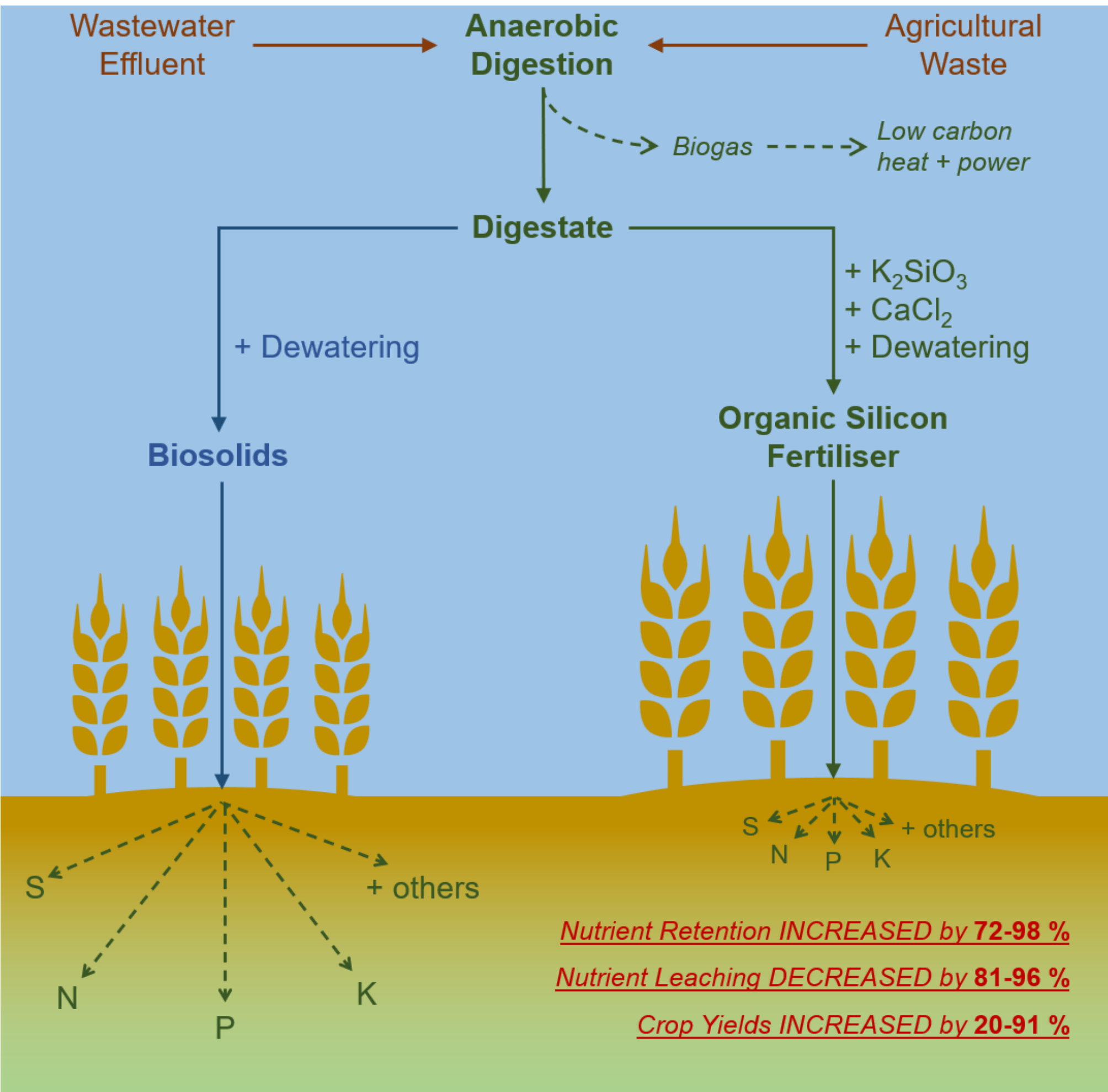


Figure 1. Graphical representation of OSF preparation and potential benefits for waste and nutrient management.

2. Experimental

OSFs were prepared using digestate, aqueous potassium silicate (Ciech Vitrosilicon, Vitrolig P-40), and calcium chloride dihydrate (Sigma-Aldrich, C8106). P-40 was added to the digestate under stirring to yield a mixture with a silica content of 1–5 wt %. Once mixed, calcium chloride was added at 4.0 wt % of the mixture under stirring. After 1 min, stirring was stopped and the mixture was allowed to gel for 10 min before centrifuging at $4,121 \times g$ for 10 min (see Fig. 2).

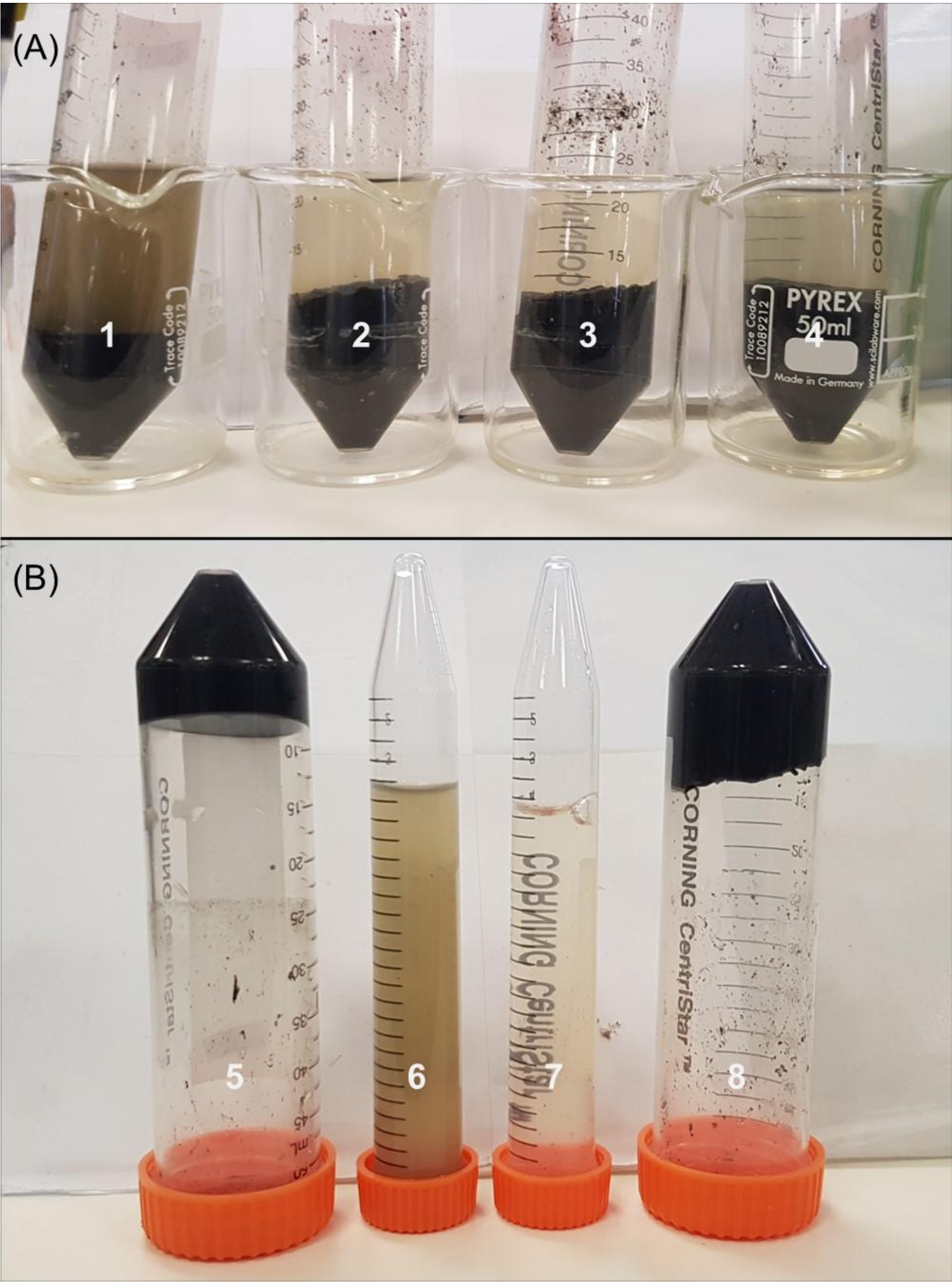


Figure 2. Photographs of centrifuged digestate and OSF.

(A) Digestate (1) and OSF samples (2-4) after centrifuging.

(B) Digestate solids (5) and supernatant liquid (6) after decanting are shown and compared with OSF solids (8) and supernatant liquid (7) after decanting.

Table 1. The effect of increasing the amount of potassium silicate added to digestate on the dewatering rate and nutrient retention of the OSF.

	Silica Content				
	1 wt%	2 wt%	3 wt%	4 wt%	5 wt%
pH after addition of potassium silicate	10.8	11.0	11.2	11.3	11.4
pH of OSF after addition of CaCl_2	9.1	9.4	9.8	10.0	10.3
Gel dewatering rate	57.9 %	46.0 %	35.4 %	28.0 %	25.0 %
Percentage nitrate retention	72.0 %	89.3 %	96.0 %	96.7 %	96.7 %
Percentage phosphate retention	83.4 %	87.6 %	94.3 %	97.8 %	95.8 %
Percentage K retention	4.7 %	34.6 %	33.1 %	38.5 %	49.3 %
Percentage Ca retention	46.2 %	52.3 %	56.3 %	64.8 %	88.4 %

3. Enhanced Dewatering, Nutrient Retention and Slow-release Properties of OSFs

The results show that OSFs have a porous structure (see Table 2) in which the organic matter and nutrients of digestate become embedded, thus facilitating the benefits of digestate as a fertiliser by increasing nutrient retention by 72%–98% (see Table 1 and Fig. 3) and decreasing the nutrient leaching rate by 81%–96% (see Fig. 4).

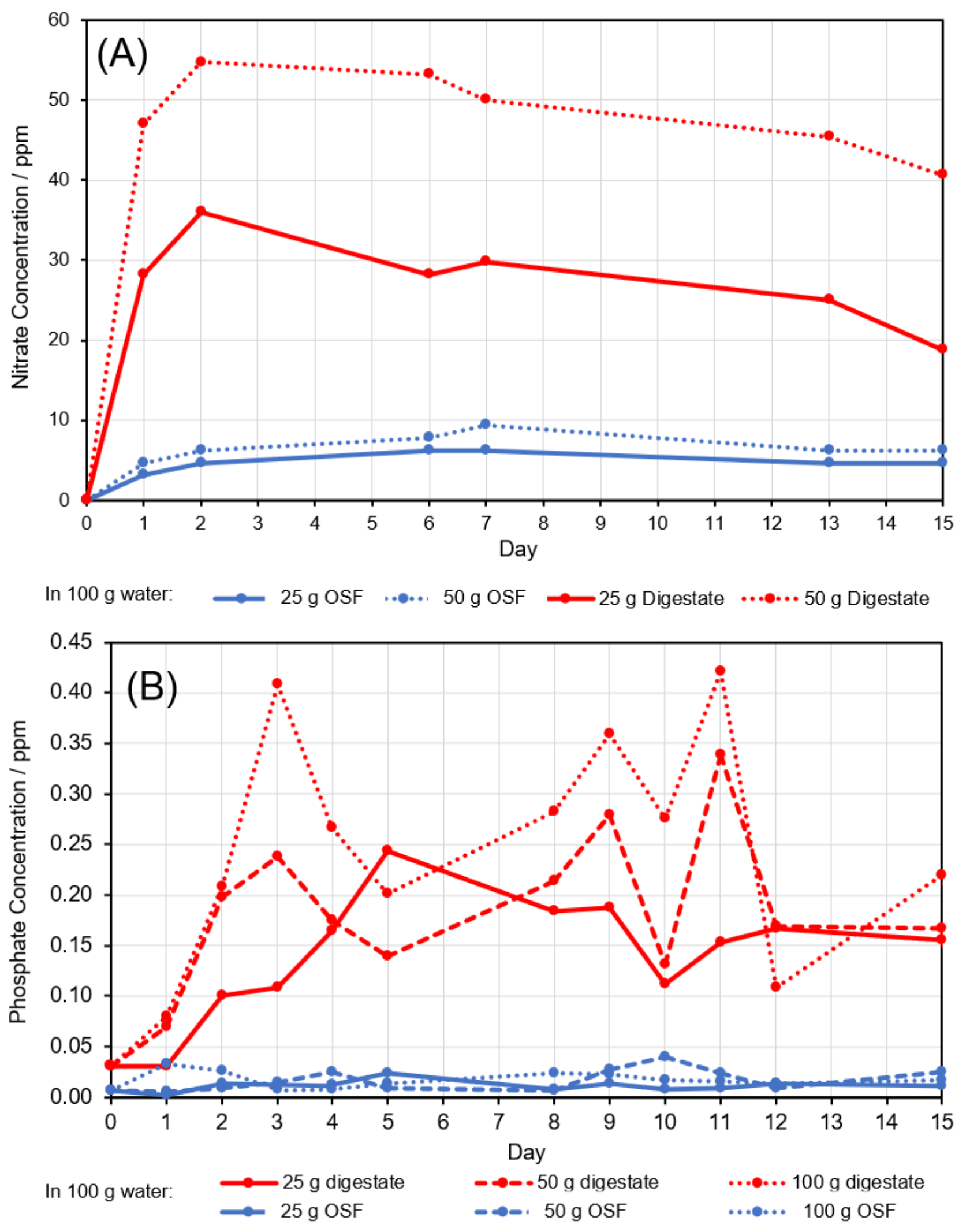


Figure 4. Slow release of nutrients from OSF when submerged in deionised water, compared with digestate.

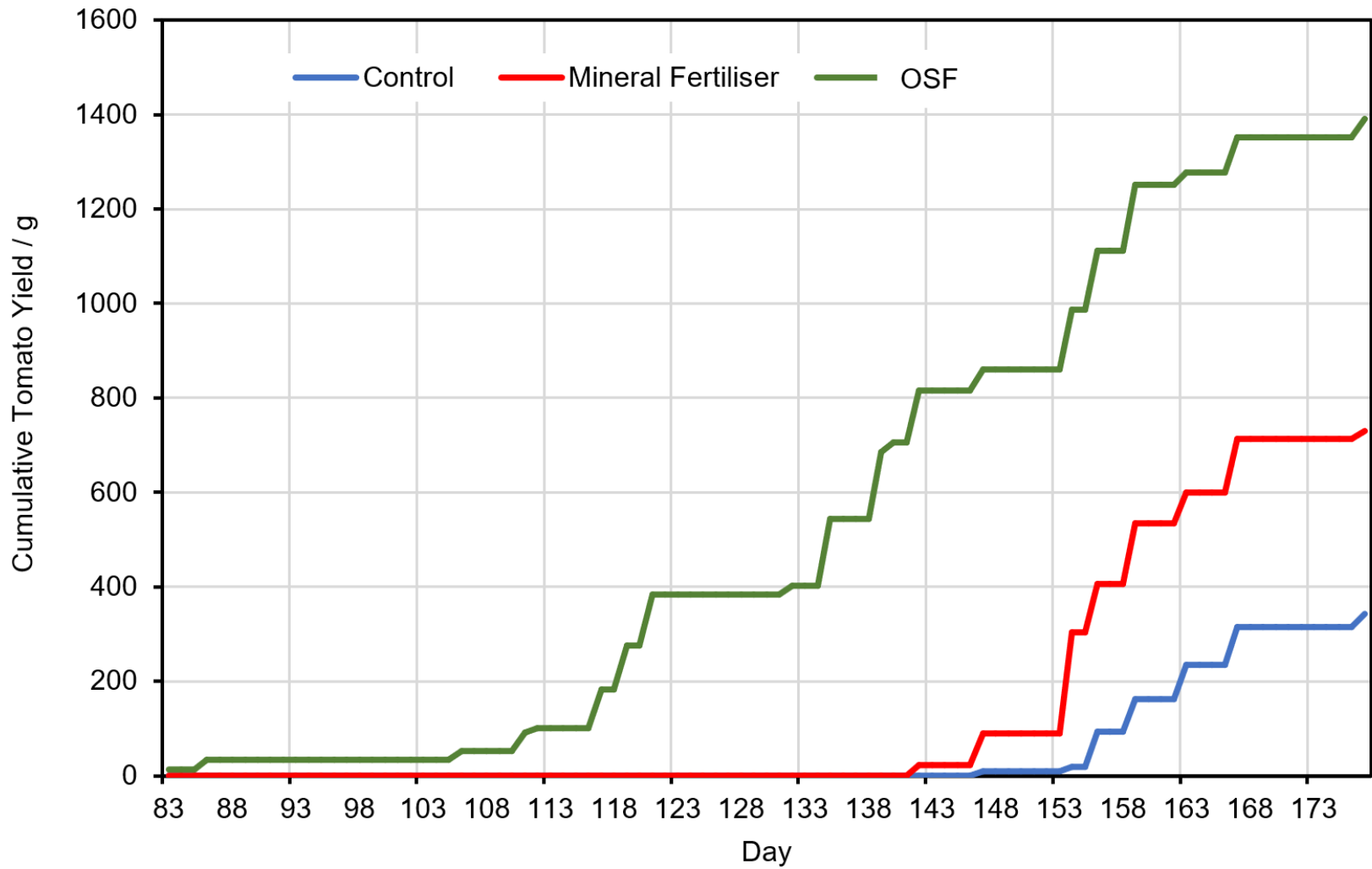


Figure 5. OSF provides increased yield of tomatoes after a 177-day growing period compared with mineral fertiliser.

	Control	Potassium Silicate	Digestate	Mineral Fertiliser	OSF
Spring Barley					
Average yield of green mass / g container ⁻¹	95.0	93.8	116.4	130.5	123.6
Percentage change with respect to control	0.0 %	-1.3 %	22.6 %	37.4 %	30.1 %
Standard deviation / g container ⁻¹	5.9	3.0	3.7	16.3	2.8
Relative standard deviation	6.2 %	3.2 %	3.2 %	12.5 %	2.2 %
Average yield of yellow mass / g container ⁻¹	4.7	5.2	5.1	4.6	4.9
Percentage of green mass	5.0 %	5.6 %	4.4 %	3.5 %	4.0 %
Romain Lettuce					
Average yield of green mass / g container ⁻¹	-	-	33.6	72.9	90.2
Standard deviation / g container ⁻¹	-	-	8.8	18.5	25.5
Relative standard deviation	-	-	26 %	25 %	28 %
Average yield of yellow mass / g container ⁻¹	-	-	1.5	3.9	1.9
Percentage of green mass	-	-	4.4 %	5.4 %	2.2 %

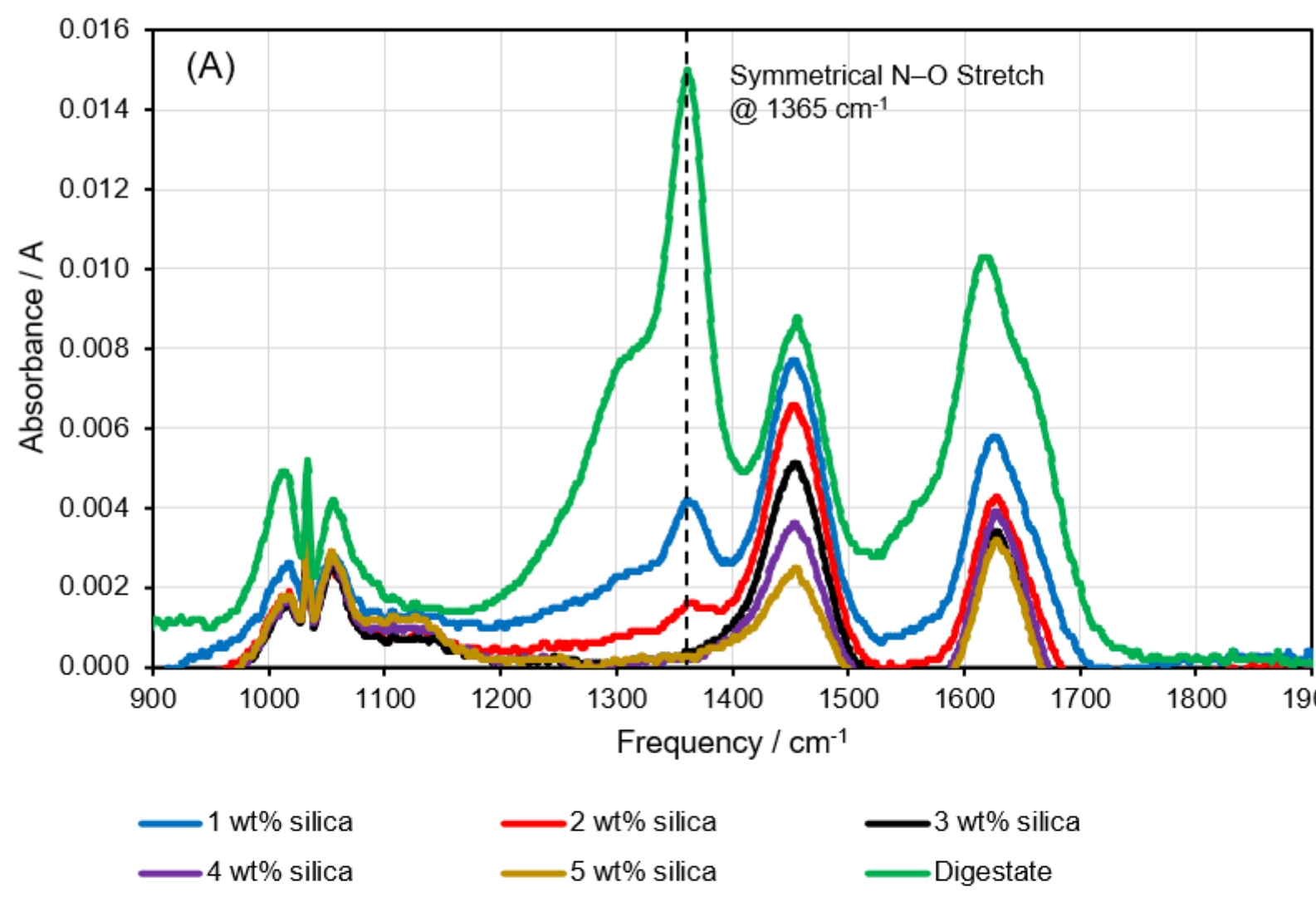


Figure 3. Enhanced nutrient retention of organic silicon fertilisers. (A) ATR-FTIR spectra of the liquid fraction obtained after centrifuging the OSF gel. (B) Bar chart comparing the nitrate concentration of the liquid fraction obtained after centrifuging.

Table 2. The effect of increasing the potassium silicate (silica wt %) on selected surface area and porosity characteristics of OSFs prepared with deionised water.

	Silica Content				
	1 wt%	2 wt%	3 wt%	4 wt%	5 wt%
BET Surface Area / $\text{m}^2 \text{g}^{-1}$	32.92	40.15	45.71	56.04	56.70
Microporous Area / $\text{m}^2 \text{g}^{-1}$	3.30	3.35	3.29	4.89	5.54
Micropore Percentage Area	10.0%	8.3%	7.2%	8.7%	9.8%
Average Pore Width / nm	11.94	13.01	13.77	13.47	13.14

4. Increased crop yields using OSFs

Crop trials demonstrated that crop yields were increased by 20%–91% compared with mineral and organic alternatives (see Fig. 5 and Table 3). In addition, observations indicate OSFs bring benefits to the quality of crops, soils and groundwater (see Fig. 6). Overall, the findings suggest that OSFs could enable a cost-effective end use for digestate and have profound implications for the achievement of net-zero policies.

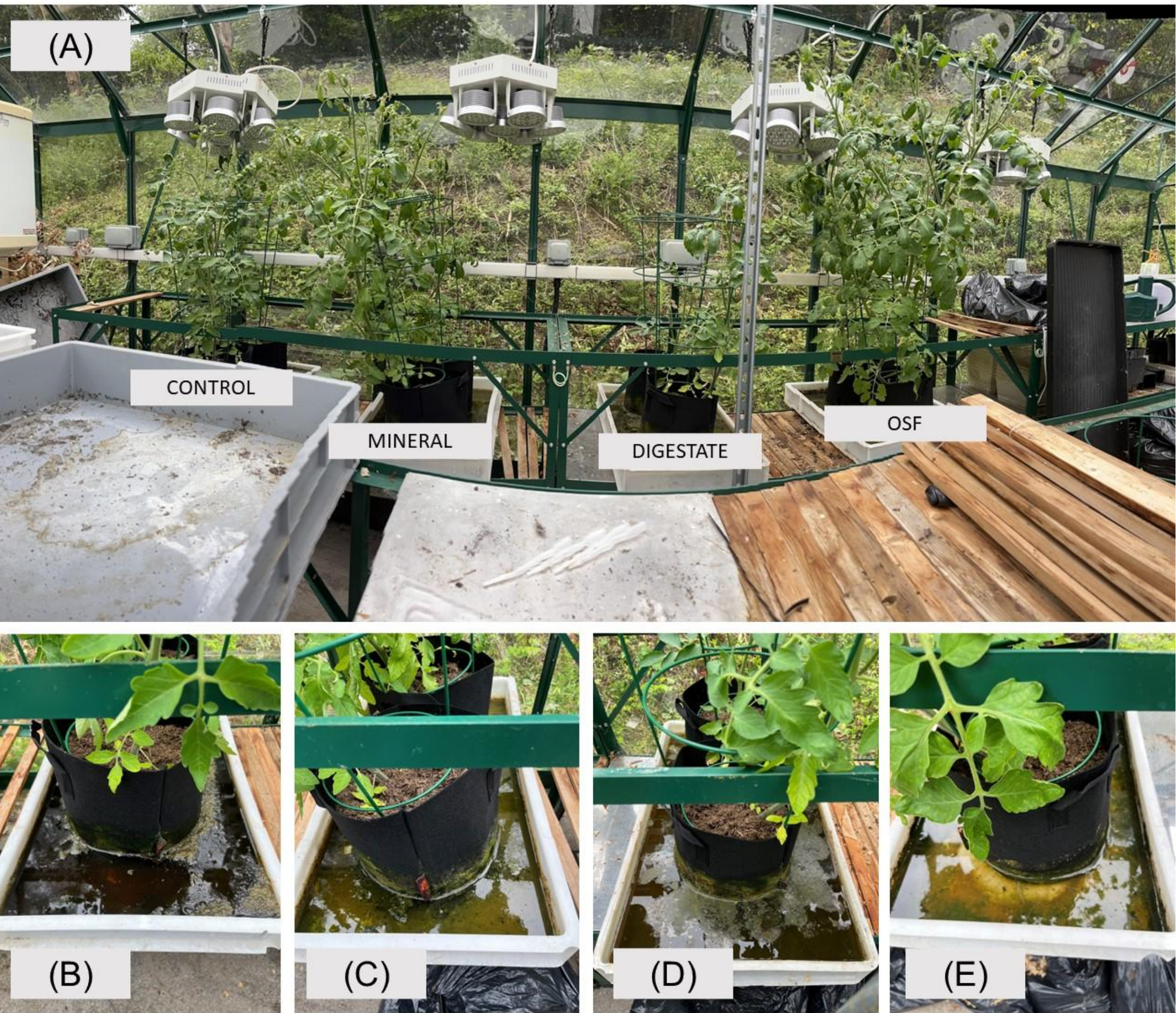


Figure 6. (A) Photograph comparing tomato plants grown during trials. Photographs of water accumulated during trials for (B) control, (C) mineral fertiliser, (D) digestate and (E) OSF.

Table 3. OSF provides increased yield of spring barley and romaine lettuce after a 10-week growing period compared with untreated digestate

Reference

Griffiths et al., Cell Reports Physical Science, VOLUME 5, ISSUE 2, 101823, FEBRUARY 21, 2024, <https://doi.org/10.1016/j.crp.2024.101823>



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Acknowledgements

The authors would like to acknowledge the funding provided for this work through the European Regional Development Fund FLEXISApp program and the KESSII scheme (MAXI 21482). Knowledge Economy Skills Scholarships (KESS) is a pan-Wales higher-level skills initiative led by Bangor University on behalf of the HE sector in Wales. It is partly funded by the Welsh Government's European Social Fund program for West Wales.