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Opportunities and challenges organo-mineral fertiliser can play in enabling food security

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Food security is a growing challenge related to an increasing global population. The agricultural sector is key for a secure supply of food but relies up to 50% on mineral fertilisers to meet crop nutrient demands. As mineral fertilisers production is energy intensive, causing close to 2% of global greenhouse gas (GHG) emissions, this poses greater challenge to meet net zero targets. Other challenges include extreme weather patterns, GHG during fertiliser applications and diffuse pollution, declining soil health, pest, disease, and loss of soil biodiversity. As mineral fertilisers' price increases and the state of soil health decreases, innovative solutions are needed to meet crop nutrient demands while ensuring that sufficient organic matter is conserved in the soil. One solution to achieve net zero in agriculture can be in the form of organo-mineral fertilisers (OMF). OMFs are a new concept that take organic feedstock (such as biosolids, livestock manure, crop residues, food waste) and combines them with reduced amounts of mineral fertilisers resulting in a balanced fertiliser product. This Perspective piece discusses a Strength-Weakness-Opportunities-Threats (SWOT) analysis on OMF and summarizes how OMF applications can play a role to improve food security. This is further linked with short, medium and long terms policy interventions that can be deployed to achieve a more sustainable approach by balancing between protecting the wider environment and meeting food security.

KEYWORDS

net zero, circular economy, fertiliser, organic amendments, food security, agriculture

Introduction

Continued transformation of the agricultural sector is essential to ensure that sufficient, safe and nutritious food is produced to meet the needs of a growing global population, which is expected to reach 10 billion by 2050 (United Nations, 2019). Agriculture is both a sink and a source of greenhouse gas (GHG) emissions. The OECD has estimated that the agricultural sector can make a net carbon (C) sequestration of 4% of global GHG emissions by the end of the century (Henderson et al., 2022). Coupled with socio-economic development and the need to meet the UN Sustainable Development Goals (SDGs), there is a societal urgency to transition toward a more sustainable food industry, with reduced GHG emissions and increased C-sequestration, while also protecting and enhancing biodiversity, soil health (Pawlett et al., 2021), water resources and air quality. Agricultural activities not only contribute to global GHG emissions but are also responsible for *ca.* 70% of freshwater consumption, loss of biodiversity and declining soil quality (Zhou et al., 2022).

However, the agricultural sector faces many challenges with changing weather patterns and increased climate uncertainty causing severe shocks including increased frequency of extreme rainfall and drought events, new pest and disease risks, and increased levels of soil degradation due to reducing levels of soil organic matter and soil biodiversity (Rickson et al., 2015). To exacerbate the situation, geopolitical instability has resulted in increased volatility and rising energy prices impacting on fertiliser supplies and production costs, and highlighted the risks associated with our dependence on importing key commodities.

While mineral fertilisers are essential to meet nearly 50% of global crop production, its production is energy intensive and causes close to 2% of global greenhouse gas emissions (Menegat et al., 2022). The rapidly increasing population and concurrent food demand escalation is putting increasing pressure on agricultural practices to continually maximize yield. Often, the method by which this is achieved is agricultural intensification. Current practices of intensification rely heavily on mechanization and supplementing the soil with macronutrient fertilisers (such as nitrogen, phosphorus, potassium, and sulfur). Inarguably this trend has led to the general decline of agricultural soil health worldwide, to the point at which the majority of the world's agricultural soils are classed as fair, poor, or very poor (FAO and ITPS, 2015).

With the price of mineral fertilisers increasing and the state of soil health decreasing, solutions are needed to meet crop nutrient demands while ensuring that sufficient organic matter is conserved in the soil. One option can be to use more organic feedstocks, but it needs to be topped up with mineral fertilisers to compensate for any deficiency from it. An innovative solution can be in the form of organo-mineral fertiliser (OMF). OMFs are a new concept that take organic feedstocks such as biosolids, livestock manure, crop residues, food waste and combines them with mineral fertilisers to produce a more desirable nutrient content. The mixture is then dried and pelleted to make it easily storable and transportable. The concept behind OMF is to couple the slow and fast release patterns of organic feedstock and mineral fertiliser, respectively, to minimize reliance on the latter. While this concept is still in its infancy, Deeks et al. (2013), Pawlett et al. (2015), and Antille et al. (2017) have pioneered on OMF using biosolids as feedstock. Burak and Sakrabani (2023) reported novel approaches in formulating OMF using carbon capture technology resulting in fertilisers which resulted in crop yield comparable to mineral fertilisers. This recycling of organic waste promotes a circular economy and provides a sustainable source of nutrients that will both feed the crops and act as a tool for the re-introduction of organic matter into agricultural soils (Sakrabani et al., 2023).

The current challenges faced globally due to extreme weather conditions, increasing cost of energy and soil degradation, all directly affects food security. Tackling food security is vital to address the increasing global population. Circularity in use of resources is key in sustainability and this article adopts this approach and will set the way to a new approach that adopts technology to turn underutilized resources (such as manure, crop residue, digestate) into valuable products such as organo-mineral fertilisers (Sakrabani et al., 2023). This Perspective article covers agriculture, crop and soils, natural environment, food security and the wider landscape. It also touches on aspects related to the SDGs to improve land quality, minimize hunger by providing food security, climate action, industry and innovation. This Perspective article presents a forward-looking net zero vision and approach on how to valorize organic resources using nature-based solutions while using technology and minimize reliance on processes that pose greater harm to the environment. The aim is to present an outlook on how OMFs can be considered as part of the toolbox to tackling some of the challenges and what will the opportunities and challenges pose in implementing sustainable agriculture.

Approach

The approach of this Perspective article is in the form of a framework for a Strength Weakness Opportunities and Threat (SWOT) analysis as shown by Figure 1. The SWOT analysis will be used as means to link each section to debate how OMFs can play a role in implementing sustainable agriculture while tackling food security. The challenges highlighted in earlier section will be categorized into short, medium and long term and the SWOT will be used to match where possible to assess how feasible will be the various options to tackle the challenges.

The *strengths* of using OMF shows potential to increase soil organic matter and water holding capacity (Oliveira et al., 2017; Moreira et al., 2021; Kumar et al., 2022). There has been evidence to reduce soil compaction through decreasing bulk density, allowing good transport of water and nutrients. The carbon content of the feedstocks used to formulate OMFs can be important for improving soil health, allowing soil microbial proliferation which facilitates residual nutrient mineralization for subsequent seasons (Semida et al., 2014; Mumbach et al., 2020). Due to the on-going challenges in increasing fertiliser prices, there is a growing need to ensure sustainable sources of fertilisers are available in order not to compromise on food security (Mazeika et al., 2021). Nevertheless, currently as OMF is a new approach in agriculture allowing circular economy approach, it may not necessarily fetch a lower price as it will need new technologies to process the feedstock, dry and pelletize it. However, with more development in such technologies and better logistics of getting the feedstock, there is a possibility that prices can become more competitive. There is a real need for innovative techniques and optimizing existing ones to valorize organic feedstock to make OMF more mainstream products in agriculture.

The nutrient composition of organic feedstock is usually imbalanced, i.e., N:P ratio, where application based on one nutrient will cause under application of the other. This is where in OMF, the mineral part tackles nutrient imbalance, making it a balanced fertiliser product. The carbon sources of OMF feedstock can also potentially contribute to carbon sequestration, albeit being slow depending on soil type, crop, land management and climate. Activities that can sequester carbon have been claimed to enhance soil fertility, increase soil biodiversity, improve water retention and reduce runoff and erosion (Smith, 2012). There are claims that soil carbon sequestration would be able to support five, seven and up to 12 SDGs (Smith et al., 2019). However, Moinet et al. (2023) argue that soil carbon sequestration is context specific and there is a saturation point (after 20 years as standard or ranging from 5 to 50 and up to 85 years) and non-permanence which needs to be seriously considered. In this context, any potential carbon build-up related to applications of OMF needs to be accurately quantified for its permanence. This is an important consideration, due to potential remuneration options for farmers in terms of carbon credit. While there is limited information assessing the carbon credit potential of OMFs, Paul et al. (2023) highlight the following as principles that must be considered to close

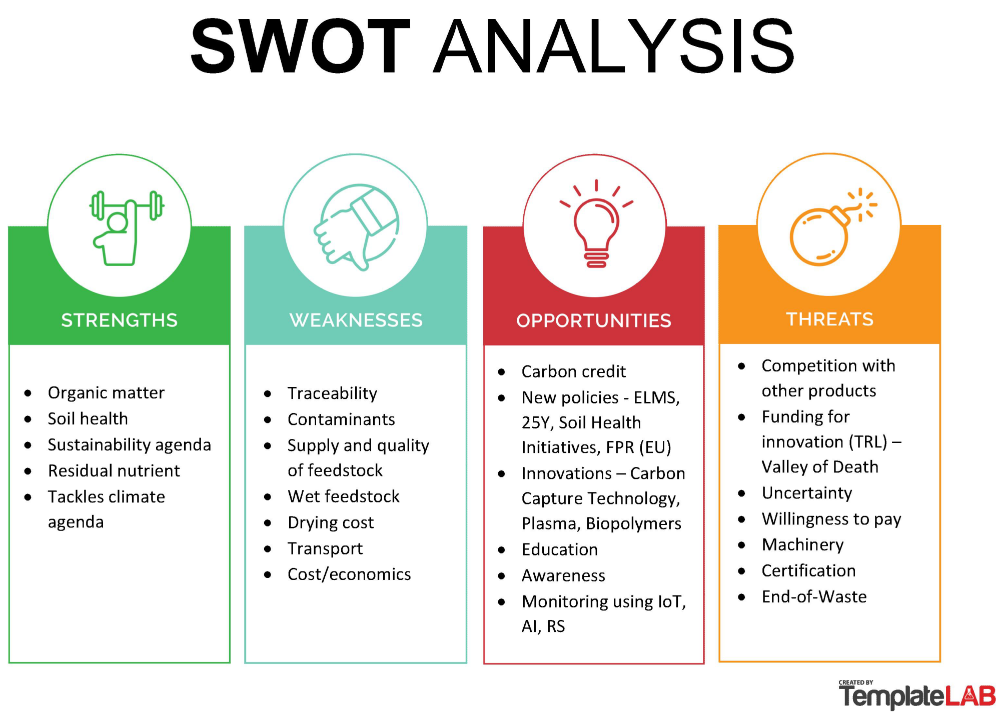

FIGURE 1
SWOT analysis of utilizing OMF in agriculture. EMLS, Environmental Land Management Systems; FPR, Fertiliser Products Regulation; IoT, Internet of Things; AI, artificial intelligence; RS, remote sensing.

this knowledge gap: additionality, emission reductions, permanence, quantification of soil organic carbon changes, leakage effects, synergies and trade-offs, and transparency, legitimacy, and accountability. Strict regulatory procedures need to be implemented to ensure farmers are protected and properly remunerated for actions related to making soil carbon sequestration more permanent.

The *weaknesses* of using OMF can be related to traceability due to variability of feedstocks used to formulate it. Gathering evidence on how to quantify the variability of nutrient content will provide confidence on OMF applications. There is on-going work on in-field technology using near and mid-infrared sensors that can be developed to determine nutrient content of organic feedstocks (Barra et al., 2021). There is also a need to ensure that contaminants of feedstocks are controlled so that the final product can be suitably applied in agriculture. A control of contaminants at source is the best way to manage this challenge. Depending on the organic feedstocks, control of these contaminants can be managed differently. Levels of contaminants in biosolids such as organic compounds (flame retardants) or microplastics are more challenging to control compared to heavy metals where there is the Sewage Sludge Directive (Egle et al., 2023) that provides limits that cannot be exceeded. Feed additives containing trace elements such as Cu and Zn can be cause for concern when present in animal manure (Bünemann et al., 2024). This is essential to not only minimize accumulation of these heavy metals but also its potential impact to form stable complexes with soil organic matter which can promote antimicrobial resistance (Bengtsson-Palme et al., 2023). However, on-going regulatory framework by governments will lead to lower inputs of these elements in the future.

In terms of nutrient content, some organic feedstocks are not in readily available forms but instead in more slow-release forms. This slow-release nutrient supply coupled with a mineral fertiliser will be a win-win solution if it is matches with crop demands at its key crop growth stages. This slow-release feature ensures a more gradual and sustained nutrient release, reducing the risk of nutrient leaching and runoff. It helps plants receive a continuous supply of nutrients over longer period, leading to better nutrient use efficiency and minimizing the potential for nutrient imbalances or wastage (Semida et al., 2014). However, what makes it challenging is we need to source a large amount of organic feedstock to meet crop requirements in a timely manner. These feedstocks also tend to have a high moisture content (10–20% for crop residue, 80–90% for biosolids and manure) (AHDB, 2023) which requires drying to reduce its bulk. This naturally increases cost due to energy needed for partly drying the feedstock. If the energy for drying can be from renewable sources (i.e., solar, biomass), then this makes it more sustainable as otherwise it increases the cost. Reducing the bulk of the feedstock also allows for ease of transportation from source to locations where it will be needed. The cost benefit must be considered to ensure what type and how much energy is needed to dry the feedstock to formulate OMFs. Techno-economic analysis will need to be carried out to have a holistic view on cost implications resulting from drying feedstock and its impact on the final price of OMFs to farmers.

The *opportunities* for using OMF can be capitalized by increasing innovations such as carbon capture (Burak and Sakrabani, 2023), plasma, super critical oxidation technologies among some of them to valorize organic amendments. Each of these technologies has its advantages and disadvantages and needs to be used where suitable to optimize use of organic amendments. Technologies such as artificial intelligence, remote sensing and Internet of Things (IoT) can be very valuable in collating data on soil health and crop productivity associated with application of OMFs. The impact of OMF application on soil and crops requires long-term trials and use of such technologies is particularly important to enable more regular monitoring compared to conventional approaches. To enable any new technologies and interventions it must be accompanied with an awareness or educational campaign. There will be some skepticism and reluctance to use any new product or technology until there is confidence in its use. This can create opportunities for gathering scientific evidence and communicating about it to relevant stakeholders.

On aspects related to traceability highlighted earlier, there is on-going work using novel technologies such as neutron tomography and muonic X-rays to assess heterogeneity within OMF pellets. As OMFs involve organic feedstock of varying quality, how these are packed within a pellet is important to assess how it can be evenly spread and breakdown to release nutrients. As an example, neutron tomography can determine extent of moisture levels of the constituents within each pellet which will inform how it will disperse when subjected to a force such as that from a fertiliser spreader spinning disc. Muonic x-rays involves a non-destructive technique capable of determining key elemental composition at various depths within a pellet. These information on particle arrangements within a pellet is also important to inform on response to moisture absorption (determined by neutron tomography) and how it will influence it to disintegrate and release nutrients and elements (determined by muonic X-rays) when in contact with soil.

Current policy drivers such as the Environmental Land Management Systems (ELMS), Soil Health Action Plan for England (SHAPE), Defra 25 Year Environmental Plan and new UK Fertiliser Products Regulations (derived from the EU), promote proper use of organic resources to improve soil health and minimize reliance on mined sources of material to ensure sustainability is firmly embedded in practice. In Europe similar policies such as the Fit for 55 package, the Zero Pollution Action Plan and the EU Soil Strategy for 2030 all aim to protect soil as part the EU Green Deal (Panagos et al., 2022).

The *threats* related to use of OMF can be associated to competition from other amendments such as compost, digestate, animal manure, crop residues and biosolids which are widely used and have more credibility in the agricultural sector. When using new products such as OMF, there is also a need to assess the willingness to pay for it, due to uncertainty on its efficacy. There is also a need to ensure the OMFs do not require new machinery as farmers will be reluctant to invest in new equipments for products which are not well understood. Using new products such as OMF will also be subject to regulatory restrictions to ensure that it is not classed as a waste and requires End-of-Waste status. To achieve this, there needs to be evidence that is a product and is comparable to existing options that are being used in the sector.

Forward outlook considering policy aspirations

National and international policies are key to implement application of OMF in agriculture but require robust scientific evidence to ensure that it is a product and not classed as waste. This will not be easily achieved if there is no clear drive and vision and short-, medium- and long-term policy interventions are briefly discussed here.

In the short term there needs to be a clear definition and guidelines on what is a suitable comparator to existing OMFs to gather the evidence needed for it to reach End-of-Waste status. The evidence gathered will be on OMF characteristics and should be within the allowed legal guidelines for target parameters. There needs to be energy incentives for drying feedstocks so that a sustainable business case is feasible for processing of feedstock. The approach for drying will be targeted on feedstock which are semi-solid such as composted material or manure mixed in with straw. These will still contain lower amount of available N, so there needs to be some caution for losses as ammonia. Policy incentives for provision of renewable sources of energy will be well suited to incentivize processing of feedstock to produce OMFs. These incentives will also influence the final price of OMFs making it more affordable and available to farmers. There should also be strict policy interventions (e.g., Sewage Sludge Directive as discussed by Egle et al., 2023) to ensure contaminant levels of organic feedstock such as biosolids adhere the safe threshold levels as this will influence the quality of OMFs and finally impact on soil health.

In the medium term there needs to be collation of evidence from longer term field trials. This is necessary to ensure impact of OMFs on soil and crops can be monitored as nutrient release patterns are much slower compared to mineral fertilisers. The available technologies need to be cost effective so that feedstock can be valorized and be suitable to formulate OMFs. Innovations associated with technologies suffer from funding challenges especially in mid-range Technology Readiness Level (TRL) (Figure 1) which needs funding boost to make it viable in the market. The lack of funding at these TRLs sometime can be seen as missed opportunities and policy interventions are necessary to mitigate this (Sakrabani, 2023). Policies also tend to be regional and there needs to be harmonization especially when there can be potential transportation of OMFs from one part of the country to another. If an organic feedstock component of the OMF is not classed as waste, then it will cease to be a product and when it will be transported to another country or region which operates using different legislation, this can cause problems for applications in agriculture. This lack of harmonization can limit the full use of OMFs, and rigorous paperwork is needed to enable easier transportation of OMFs. The paperwork can have information on location of feedstock origin, composition of feedstock and its characteristics (physical, chemical and biological) and volume. These will provide traceability and lead toward greater confidence when OMFs will be transported between regions.

In the longer term there needs to be certification so that feedstock can be fully valorized and validated to become products marketed as OMFs. The initial steps required for the certification will be liaison with institutions such as the British Standards Institution (UK), European Committee for Standardization (Europe) or International Organization for Standardization (International). There are dossiers which needs to be developed for OMFs on its nutrient and contaminants (chemical and biological) contents and its variability. In these dossiers the ranges of nutrients and contaminants including corresponding analytical methods will be highlighted. Limits for the ranges of parameters will be corroborated with conventional fertilisers currently used in agriculture, considering feedstocks that constitute the OMFs. There will be an expert Panel committee which will validate the data and information presented in the dossier leading toward obtaining the certificate. This requires some joint up approach between waste and fertiliser regulations and harmonizing to ensure successful implementation of OMF applications in agriculture to meet food security and maintain soil health.

Conclusion

There is clearly a need to consider OMF as part the solution to reduce reliance on mineral fertiliser requirements to meet crop demands. OMF is not a panacea and has its own challenges in terms of traceability, its nutrient content to meet crop demands, moisture content of feedstock and the need to dry as pellets or granules it to make easier to handle. Innovation is key in acting as a conduit to mitigate some of the challenges to valorize organic feedstock. However, policy interventions are key to address any potential barriers. Consequently, this Perspective piece sets an outlook on how based on the SWOT analysis, short, medium- and long-term policy aspirations can be achieved by implementing use of OMFs in agriculture to attain a net zero and sustainable approach while balancing between protecting the wider environment and meeting food security.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

RS: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing, Resources, Visualization.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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