Mini-paper – End-user requirements for recycled and bio-based fertiliser products

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1. Introduction

Recent EU circular economy policies promote recovery and recycling of excess nutrients from agricultural, industrial and urban waste streams into products that can be used as agricultural fertilisers. Farmers are the primary end-users of these recycled and bio-based fertiliser products, and it is important to understand their requirements and decision-making processes underlying the use of such processed and unprocessed organic waste-based fertilisers. However, it is also relevant to consider which other stakeholders may have an interest in the increased use of recycled and bio-based fertilisers, and what perceptions and requirements they may have.

This is the topic of the current mini-paper, as we hope that a better understanding of the perceptions, requirements and choices of all these primary and secondary end-users or stakeholders may help to guide future policies on waste management and the development of industries related to organic waste processing and recycling from agriculture, industry and households.

By increasing organic waste processing, there is scope to increase the amount of agricultural fertilisation in the EU provided by recycled nutrients (Buckwell and Nadeu, 2016[1]). Organic wastes intended for agricultural application as fertilisers can be broadly classified into three categories: i) animal-based organic wastes such as manure and urine, ii) green manures based on plant sources, and iii) urban wastes such as sewage sludge and organic household waste (Oelofse et al., 2013[2]). Organic waste-based fertilisers can be processed in a number of ways to increase the retention of nutrients and ensure they are suitable for agricultural application while minimising environmental impact (Rigby et al., 2016[3]; Sommer et al., 2013[4]), but technical and economic issues need to be considered before undertaking organic waste processing. Processing can be performed to separate components (e.g. manure separation technology to improve handling and optimise nutrient content), recover energy (e.g. anaerobic digestion, AD), remove unwanted substances (such as pathogens), or retain nutrients (Sommer et al., 2013). Depending on the technology used, processing may improve the product in terms of manageability, fertiliser value and nutrient use efficiency, or soil quality improvements, and hence enhance their economic value.

However, to increase the adoption of organic waste processing technologies and production of new types of organic fertiliser on a large scale, a good understanding of the fertiliser market and the end-users requirement is needed. In the following sections we therefore aim to analyse, discuss and develop an understanding of technology adoption by farmers and other stakeholders in relation to innovations of recycled and bio-based fertiliser products.

[1] Buckwell, A., Nadeu, E., 2016. Nutrient Recovery and Reuse (NRR) in European agriculture. A review of the issues, opportunities, and actions. RISE foundation, Brussels.
[2] Oelofse, M., Jensen, L.S., Magid, J., 2013. The implications of phasing out conventional nutrient supply in organic agriculture: Denmark as a case. Org. Agric. 3, 41–55.
[3] Rigby, H., Clarke, B.O., Pritchard, D.L., Meehan, B., Beshah, F., Smith, S.R., Porter, N.A., 2016. A critical review of nitrogen mineralization in biosolids-amended soil, the associated fertilizer value for crop production and potential for emissions to the environment. Sci. Total Environ. 541, 1310–1338.
[4] Sommer, S.G., Christensen, M.L., Schmidt, T., Jensen, L.S., 2013. Animal manure recycling: Treatment and management. John Wiley & Sons Ltd., Chichester, UK.

2. Stakeholders and definitions

A range of stakeholders are relevant for the issue of enhanced use of recycled and bio-based fertiliser products. Figure 1 presents an interest-power matrix with primary and secondary stakeholders.

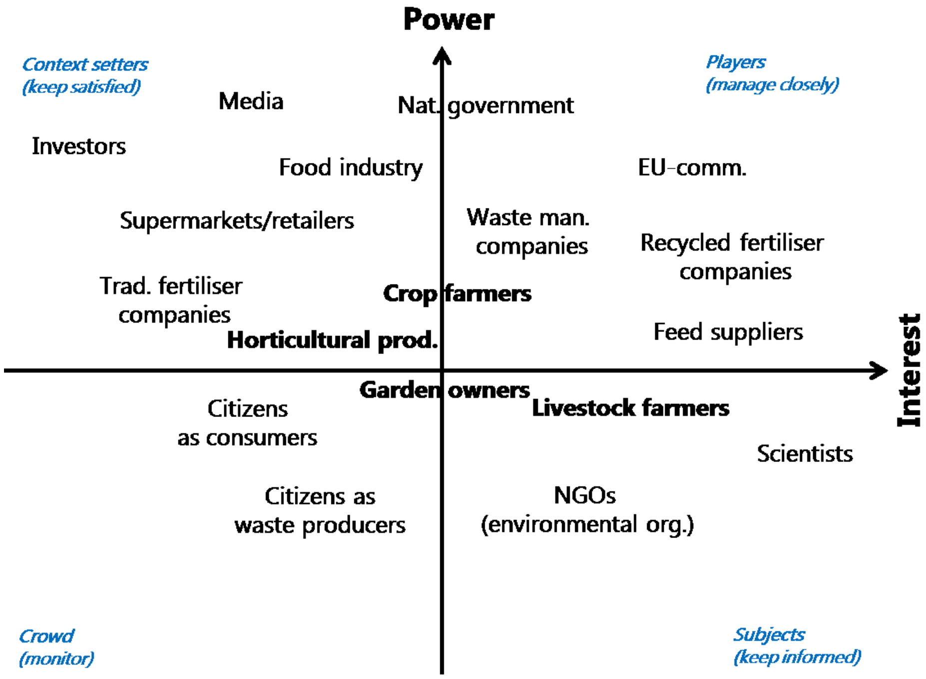

Figure 1 Stakeholder interest-power matrix, with ***primary stakeholders*** *indicated in* ***bold****. Italicised blue text indicates the four types of stakeholders (according to Ackermann & Eden, 2011[5]), depending on their power and interest and in brackets actions to manage such stakeholders.*

Farmers, both pure livestock farmers (typically having a surplus of manure needing export/processing) and pure crop farmers (potential end-users of bio-based fertiliser products) are considered primary stakeholders, but also other end-users like the horticultural producers (vegetables, ornamentals) and private garden owners are primary stakeholders. The secondary stakeholders comprise e.g. food industry, food retailers and citizens /consumers of agricultural products, as well as agricultural suppliers (e.g. fertiliser and feed industry) and waste management companies. Other stakeholders include governing bodies (local/national/EU), NGOs, investors, media, as well as scientists working/interested in the topic.

As primary stakeholders the farmers are of course of major importance for increasing the use of bio-based fertiliser products (both supply and demand), but in reality, their power is not large, and their interest may also differ, since livestock farmers with a large manure/nutrient surplus may have a larger interest in solving this problem, but in reality high dependence on potential end-users (whether recycling/processing companies or crop farmers for direct export), while crop farmers may have a somewhat lesser interest but higher power, as they have alternative sources of nutrients (chem. fertilisers) and power to decline the recycled products, based on their preferences and the fulfilment of their requirements by the bio-based fertiliser products.

It is also necessary in this context to define what we mean by 'requirements' and 'preferences'. A requirement is a singular documented physical and/or functional need that a particular design, product or process must be able to perform. A preference also reflects a need, but is less absolute, e.g. if two different products both fulfil a specific requirement, then the end-user may have a preference for one, based on other characteristics or needs that the product fulfils.

[5] Ackermann, F. & Eden, C., 2011. Strategic Management of Stakeholders: Theory and Practice. *Long Range Planning*, 44(3), pp.179–196.

3. Farmer and other primary end-user requirements

Farmers from traditional mixed-farms have for generations been well acquainted with the use of manures in their crop production; however, with the specialisation and intensification into larger and larger farm units over the past few decades in many parts of Europe, this is no longer true. Arable crop farmers, the primary end-users of bio-based fertiliser products, are most familiar with the application of commercial mineral fertiliser formulations, which are typically concentrated in nutrients, highly uniform in chemical and physical properties, have high storage-stability and relatively predictable fertiliser value, provided they are applied in the right way, rate and time. These farmers will therefore often have mineral fertilisers as their reference, against which they evaluate advantages and disadvantages of bio-based fertiliser products. Since the above parameters are typically rated lower than for mineral fertilisers, sufficiently low cost of the bio-based fertiliser products (purchase+application) could be expected to be the primary requirement for arable crop farmers receiving bio-based fertiliser products, whether raw or processed manures, digestates, compost, concentrates etc. – but if crop farmers perceive other benefits of bio-based fertiliser products than those directly comparable with their mineral counter-parts, this may affect their requirements and preferences for the former.

Manure exchange

However, relatively few studies have specifically considered manure and organic fertiliser adoption or acceptance by farmers. An early study from the US (Núñez and McCann, 2004[6]) surveyed 138 crop farmers' willingness to use manure and found that transportation costs, odour, awareness of others using manure, and low off-farm income were major factors affecting the willingness of arable farmers to accept manure. Similarly Battel (2006[7]) surveyed 161 farmers from Michigan, USA, and found that younger farmers (< 50 years old) and those with larger land areas (> 161 ha) were more concerned with negative effects of manure use such as the spreading of weed seeds and increased soil compaction. Farmers with larger land areas were also more likely to be concerned with manure use interfering with aspects of cropping operations. Younger farmers were more likely to say they would consider accepting manure only if it was provided to them without cost.

In the EU, where the EU Nitrates Directive limits the rate of manure total N that can be applied to 170 kg N ha^{-1}, this implies manure exchange between livestock intensive farms exceeding this threshold and arable crop farms with no or less manure, necessitating either farmer-to-farmer exchange agreements or a local or regional trading/exchange marketplace. Asai et al. (2014a[8], b[9]) examined a large number of collaborative arrangements between intensive livestock farms in Denmark with surplus manure and farms requiring crop nutrients, and found that 50% of all farms, managing 70% of the Danish agricultural area, were involved in manure exchange, indicating that collaborative arrangements are widespread. Most of these knew their partner before they established the arrangement, either through family, neighbors or their local or professional network. Asai and Langer (2014[10]) further surveyed partnerships between dairy farms and arable farms and compared partnerships between organic farms (95) with partnerships between conventional farms farms (144). They found that the character and functioning of the organic partnerships were influenced by the high demand for organic-certified manure on organic arable farms (who cannot purchase mineral fertilisers), and many of the organic dairy-arable partners also had strong social connections, irrespective of the distances involved, and trust and reciprocal relationships through high-quality communication and well-functioning agreements play pivotal roles for maintaining partnerships.

Case et al. (2016[11]) surveyed a representative sample of Danish farms (452 respondents) for their current and future use of raw and processed manure and other bio-based fertiliser products, and found that while only 35% were livestock farmers, 72% indicated using at least one form of organic fertiliser, mostly manures received from neighbouring farms, but also processed manure (19%) and urban waste-derived products (9%). The vast majority, 79%, indicated that three years from now they expect to use the same amount of

[6] Núñez J., McCann L., 2004. Crop farmers' willingness to use manure, in: Proceedings of the American Agricultural Economics Association 2004 Annual Meeting. Presented at the American Agricultural Economics Association 2004 Annual meeting, American Agricultural Economics Association, Denver, CO, p. 25.

[7] Battel R.D., 2006. Farmer willingness to enter into manure exchange agreements: differences based on age and farm size. J. Ext. 44, 3RIB4.

[8] Asai M, Langer V, Frederiksen P, 2014a. Responding to environmental regulations through collaborative arrangements: Social aspects of manure partnerships in Denmark. Livest. Sci. 167, 370–380.

[9] Asai M, Langer V, Frederiksen P, Jacobsen BH, 2014b. Livestock farmer perceptions of successful collaborative arrangements for manure exchange: A study in Denmark. Agric. Syst. 128, 55–65.

[10] Asai M, Langer V, 2014. Collaborative partnerships between organic farmers in livestock-intensive areas of Denmark. Org. Agric. 4, 63–77.

[11] Case SDC, Oelofse M, Hou Y, Oenema O, Jensen LS, 2017 Farmer perceptions and use of organic waste products as fertilisers – a survey study of potential benefits and barriers. Manuscript submitted to Resources, Conservation and Recycling.

organic fertiliser as today, but 15% expected to be using more. Nearly half (47%) indicated that they would be interested to use a form of organic fertiliser not currently available to them (most interest for processed manure (42%), then unprocessed manure, and lastly sewage sludge or municipal bio-wastes). This indicates potential for increasing availability of bio-based fertiliser products for farmers; however, properties of these must match farmer's requirements and preferences.

The farmers were also asked to prioritise their motivations or perceived barriers to organic fertiliser use indicated by the farmers overall were (1st) odour nuisance, (2nd) uncertainty of nutrient content, (3rd) difficulty in planning for application (supply and nutrient availability), and (4th) cost of specific equipment needed for handling. However, there were significant difference in 1st and 2nd priorities amongst the farmer and farm types; livestock farmers considering high costs, organic farmers considering restrictions on application. The three most important advantages for using organic fertilisers were (1st) improvement of soil structure by organic fertiliser (2nd) low cost (particularly manure) and (3rd) easily available nearby (Table 1); these priority rankings were much more consistent across all categories of farms and farmers.

Table 1. Ranked barriers to (A) and advantages from (B) the use of organic fertiliser as perceived by respondents. Responses are shown for ALL and split into different categories according to farm or farmer characteristics. Rank 1 = most important barrier/advantage, rank 15 = least important barrier/advantage. Dark cell background and white text: barrier in the same row ranked 1-3; grey cells with black text: rank 4-8; white background rank 9-15. (Case et al., 2017)

A. Barriers to use of organic fertilisers **Farm / farmer characteristic**		Number of respondents	**Odour nuisance**	**Unreliable nutrient content**	**Difficult to plan**	**Expensive machinery**	**No quality certification**	**Other**	**Difficult to handle**	**High costs**	**Restrictions on application**	**Unsuitable nutrient content**	**Difficult to get permit**	**Lack of subsidies**	**More pollution risk**	**Not easily available**	**Lack of expert advice**
ALL		**107**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**10**	**12**	**13**	**14**	**15**
Farm activity	**Arable/horticulture**	**57**	1	2	3	4	5	8	6	7	11	8	11	10	13	13	15
	Mixed	**36**	1	3	5	8	4	1	7	14	6	12	8	10	10	13	15
	Livestock	**8**	7	1	7	1	11	4	5	1	5	11	7	11	10	11	11
Farming system	**Conventional**	**95**	2	1	3	4	4	7	6	8	11	9	10	12	13	14	15
	Organic	**11**	2	7	5	2	6	2	11	14	1	14	8	8	8	11	13
Farm size (Ha)	**10-19.9**	**20**	4	1	8	5	5	9	3	7	2	10	10	10	14	13	15
	20-29.9	**13**	5	6	3	2	1	14	3	8	8	7	10	10	12	12	14
	30-49.9	**16**	2	2	2	6	1	7	5	10	13	10	12	7	9	13	13
	50-99.9	**23**	3	5	1	1	6	4	9	7	7	11	10	11	11	14	15
	> 100	**30**	1	3	4	7	5	2	9	9	14	7	5	9	13	9	15
Age	**18 - 49**	**31**	1	5	6	3	2	4	10	14	8	7	11	8	11	11	15
	50 - 64	**55**	4	1	2	3	8	7	6	5	10	12	9	11	12	14	15
	65 +	**18**	1	3	5	6	2	10	4	9	6	6	10	14	10	10	15

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B. Advantages from use of organic fertilisers — Farm / farmer characteristic		Number of respondents	Improves soil structure	Low cost	Easily available	Low pollution	Other*	Reliable nutrient content	Suitable nutrient content	Little odour	Government subsidy available	Easy to handle	No application restrictions	Easy to get permits	Expert advice available	Machinery inexpensive	Official quality certifications
ALL		**100**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**8**	**10**	**10**	**12**	**13**	**13**	**15**
Farm activity	**Arable/horticulture**	**55**	1	2	3	6	8	4	6	11	5	14	9	9	11	15	11
	Mixed	**27**	1	2	3	4	6	10	4	8	12	9	10	12	15	6	14
	Livestock	**11**	1	2	4	6	3	7	9	5	7	9	9	9	9	9	9
Farming system	**Conventional**	**88**	1	2	3	4	9	4	4	7	7	10	10	15	12	12	14
	Organic	**12**	1	3	3	6	2	7	12	7	9	9	9	5	12	12	12
Farm size (Ha)	**10-19.9**	**18**	1	2	3	4	8	6	8	4	7	10	12	12	12	12	11
	20-29.9	**12**	1	2	3	5	11	4	9	8	6	11	11	6	9	11	11
	30-49.9	**16**	1	2	4	7	5	3	13	10	10	8	10	13	5	13	8
	50-99.9	**22**	1	2	3	7	4	10	7	14	5	9	5	14	10	13	10
	> 100	**28**	1	2	5	8	4	13	3	8	10	10	10	5	15	5	13
Age	**18 - 49**	**29**	1	2	5	4	10	7	3	7	12	12	10	7	15	14	6
	50 - 64	**51**	1	2	3	6	4	5	10	8	7	10	12	14	9	13	14
	65 +	**16**	1	2	4	11	6	5	14	10	6	6	11	6	14	3	11

A similar study by Tur Cardona et al. (2015[12]) surveyed farmers (705) in 8 EU countries for their preferences in accepting bio-based fertiliser products to replace their current mineral fertiliser counterparts. Using a choice-experiment survey design, based on 7 fertiliser attributes (price, form, volume, certainty of N content, rate of nutrient release, organic carbon content, hygiene) they were able to identify that across all countries low price, high certainty of N content and low volume/high concentration was highly significant criteria; however, also hygienisation and high organic Carbon (soil improvement) was found of significant importance in more than half of the countries.

The results of Case et al. (2017) and Tur Cardona et al. (2015) are in correspondence regarding the advantages and disadvantages/barriers perceived by farmers; low cost/price, high nutrient concentration and certainty of fertiliser value is not surprisingly essential; however, farmers in both studies also clearly indicated that one of the major advantages of bio-based fertiliser products is the content of organic matter/Carbon and hence opportunity to improve soil quality and fertility. These results indicates some significant opportunities for manure processing (AD, separation, composting/drying), but also points at the most important characteristics which such bio-based fertiliser products should possess.

As indicated in the previous sections, there may be considerable potential among end-users for more processing of manure and other organic waste products, to produce better bio-based fertiliser products. However, if this is to happen at the livestock farms with a manure surplus, this requires significant technology implementation and adoption, which depends on a range of factors. In a survey amongst 111 Dutch dairy farmers the role of farm and farmer characteristics influencing the adoption of mechanical manure separation technology, Gebrezgabher et al. (2015[13]) found that lower age, lower education level, larger farm size, and a positive attitude towards the future of the farm increased interest in adoption of manure separation technologies.

[12] Tur Cardona J., Speelman S., Verpecht A., Buysse J., 2015. Farmers' reasons to accept bio-based fertilizers – A choice experiment in 8 European countries. Presentation at FIRe conference, Germany, 26 May 2015.
[13] Gebrezgabher SA, Meuwissen MPM, Kruseman G, Lakner D, Oude Lansink AGJM, 2015. Factors influencing adoption of manure separation technology in the Netherlands. J. Env. Man. 150, 1–8.

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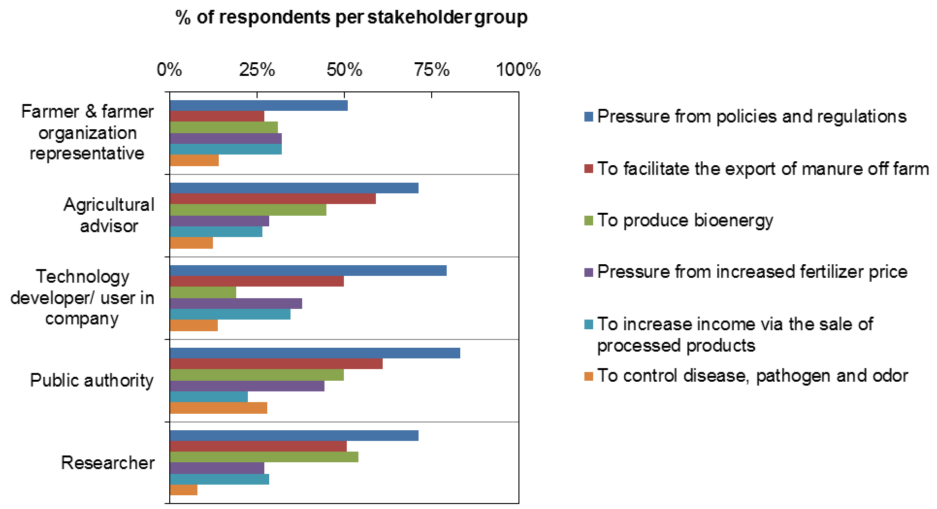

Fig. 2 Responses to the question: "please indicate the top three reasons that can stimulate farmers to apply manure treatment technologies." (multiple responses permitted) for different stakeholder groups, across all four surveyed countries (DK, I, NL, E) (Hou et al., 2017)

Hou et al. (2017[14]) analysed differences in stakeholder staff perceptions of manure treatment technologies in four European countries with regions of intensive livestock production (Denmark, Italy, the Netherlands and Spain); stakeholders included farmers, farmer organisation representatives, agri-advisors, agri-industries, environmental authorities and researchers. They found that in practice across all countries, adoption of manure treatment technology depends on policy pressure (it doesn't happen by itself), see Fig. 2, and is limited by financial cost (or rather cost-benefit under the given regulation). Other major drivers identified were need to export manure off farm and recovery of bio-energy. Slurry separation and anaerobic digestion were perceived to have the greatest potential for a common adoption but technology preferences also differed among farm types (simple, low-tech in smaller farms, high-tech advanced in larger farms or industrial/communal scale) and countries; bioenergy recovery was prioritised in Denmark and Italy, but less important in Spain and the Netherlands, whereas acidification dominate in Denmark, composting in Spain, and drying and reverse osmosis in Netherlands. The authors conclude that their results imply that manure treatment will remain a regional activity.

Widespread farm-adoption of manure processing technology is therefore unlikely, and considerations for more centralised, communal manure and biowaste processing, e.g. anaerobic digestion, composting or further refinement into bio-based fertiliser products must be considered.

Anaerobic digestion

Anaerobic digestion (AD) processing and technologies are described in detailed in other mini-papers; here we focus on distribution, marketing and end-user requirements for digestates, the residual (typically liquid) product from anaerobic digestion of manures, biowaste and energy crops. There are relatively few publications which address recycled nutrient use from a market approach, rather than from the position of the producer of the products. Two recent reports assess the challenges to marketing of digestates.

Based on a literature review and a stakeholder survey, King et al (2013[15]) analysed potentials for applications of digestate from AD of biowaste (urban and industrial) concluded that a number of potential uses can be identified. Those that show greatest potential for use, as they are more suited to the application and have fewer technical problems to overcome, are i) Field grown horticulture, ii) Organic component for soil manufacture, iii) Production of pelleted organic fertiliser and iv) Land restoration, i.e soil forming or soil improvement for degraded or marginal land. Options that show some potential for use, but only after specific technical barriers have been overcome/solutions tested comprised i) Liquid fertiliser for turfgrass, ii) Component of growing media and iii) Thermal conversion (for energy recovery). However, they also identified that the main potential problems would relate to odour, high salt content and public concern (contaminants, pathogens). See also Appendix 1 for further details from King et al (2013).

[14] Hou Y., Velthof G.L:, Case S., Oelofse M., Grignani C., Balsari P., Zavattaro L., Gioelli F., Bernal M.P., Fangueiro D., Trinidade H., Jensen L.S., Oenema O. (2017) Stakeholders' perceptions of manure treatment technologies in Denmark, Italy, the Netherlands and Spain. *J Clean Prod*, in press, http://dx.doi.org/10.1016/j.jclepro.2016.10.162.
[15] King C., Bardos P., Nortcliff S., Chapman A., Collett S. and Kepp U., 2013. Market expectations and requirements for digestate – what are the options? Report published by The Waste and Resources Action Programme (WRAP), Oxon, UK www.wrap.org.uk

Dahlin et al. (2015[16]) assessed biogas digestate marketing, based on a survey of digestate marketing information online and on in-depth interviews with companies marketing digestate, based in Germany, Switzerland, Austria, Netherlands and France. Interviews included biogas plant operators, agricultural contractors, soil and organic fertiliser manufacturers, brokers and technology suppliers. Based on the literature search, they concluded that marketing issues have largely been ignored in publications on digestate management to date (see e.g. Schüsseler 2009[17]). Digestate marketing is complicated because digestates are very variable, depending on the input materials and treatment processes. Dry matter content, nitrogen, phosphorus and potassium content can vary widely. Digestate treatment can reduce volume and facilitate transport to areas with nutrient demand, and digestate upgrading processes may include solid-liquid separation, evaporation – drying and membrane separation. In some cases, regulation or subsidies can drive processing, e.g. the German renewable energy heat incentive bonus includes digestate drying and the German bio-waste ordinance obliges treatment of digestate used on grassland if feedstock includes household wastes. Nonetheless, the authors estimate that only c. 3% of digestate produced in Europe is currently being upgraded. They also note that although upgrading increases the potential sale price of digestate, this may not be sufficient to cover the processing costs if digestate is sold to mainstream agriculture. Markets such as horticulture, private gardeners and soil manufacturing (incl. substitution of peat) can however offer higher prices. Today c. 17% of digestate processed to solid forms is sold to such markets. They outline a number of key issues for digestate marketing:

- digestate marketing is often driven by difficulties to dispose locally of digestate, because of local / regional nutrient surpluses or because the digestate plant operator itself does not control farmland
- new business niches: e.g. agricultural contractors or organic fertiliser manufacturers can act as value-chain intermediates finding customers and suitable applications for digestates
- certain digestates can be used in specific markets: organic farming, chicken litter (dried fibre fraction), horticulture, home gardening
- marketing mix: digestate production and processing can be adapted to produce digestates corresponding to different market demands, including with different nutrient balances, or with different physical properties for spreading or transport (e.g. pelletising increases bulk density, so reducing transport costs). Some digestate producers offer a catalogue of different digestates (up to 24 for one producer) and organic fertiliser manufacturers even more (up to 200)
- digestate quality is key to marketing, including hygienisation (pathogen limits), nutrient content, contaminants and foreign materials (glass, stones). Quality control systems, for both feedstock and output digestate, are important
- quantities produced will define possible markets and require appropriate product packaging and distribution channels

The authors note that farmers often understand their interest of digestate in bringing organic carbon to the soil and also calculate the economy in substitution of mineral fertiliser costs related to digestate nutrient content. However, local excesses of digestate availability enable farmers to negotiate down prices, and the digestate price also depends strongly on whether it is sold in bulk or in small-scale retail-type "on the shelf", as well as on the degree of processing. Farmers are noted to be sceptical concerning digestate containing household wastes as input materials, although this can also be a price bargaining strategy.

The authors conclude that there is a need for better understanding of users' concerns and preferences by companies marketing digestates, and a better education of potential users concerning both the safety and the benefits of digestate. The authors advise that specific digestate marketing competence is developed and used, rather than marketing being attempted by actors whose core competence is digester plant operation. This can be facilitated by cooperation of producers to develop brands or labels, share marketing costs, and provide a range of specialist digestate products for different target markets. The authors also note that new players, such as agricultural contractors, digestate upgrading/processing technology providers or franchise marketers, are entering the market and can provide such marketing competence. Marketing can also use the positive arguments that digestate enables renewable energy production and nutrient stewardship.

[16] Dahlin J, Herbes C, Nelles M, 2015. Biogas digestate marketing: Qualitative insights into the supply side. *Res, Cons Recycl* 104, 152–161.
[17] Schüsseler, P., 2009. Gärrest für eine Pflanzenbauliche Nutzung – Stand und F+E Bedarf; Gülzower Fachgespräche. Aktueller Stand bei der Gärrestaufbereitung Band 30, 160–165 http://refhub.elsevier.com/S0921-3449(15)30073-2/sbref0175

Improved end-user trust in digestate product quality as a fertiliser can also be promoted by certification schemes, such as the voluntary certification system for digestate from biogas plants in Sweden (SPCR 120[18]) or the Biofertiliser Certification Scheme (BCS[19]) for recently introduced in the UK to enhance the quality and end-user trust in digestate from anaerobic digesters. The certification builds on the PAS 110 (publically available specification) standard and covers anaerobic digestion of source-segregated biowastes, specifying i) controls on input materials and the management system for the process of anaerobic digestion and associated technologies, ii) minimum quality of whole digestate, separated fibre and separated liquor, and iii) information that is required to be supplied to the digestate recipient.

Compost

Similar to manure or digestate adoption or acceptance by farmers, relatively few studies have specifically considered compost adoption by farmers, horticultural producers and private garden owners. As noted in the previous section, agricultural customers may not be willing to pay a price profitable for processing by composting, but markets such as horticulture, private gardeners and soil manufacturing (incl. substitution of peat) may be willing to pay higher prices – however, acceptability of the compost product is still key.

Biosolid based compost acceptance by citizens was investigated by Borden et al (2004[20]) who surveyed Nevada residents to determine their perceptions and attitudes towards composted biosolids (sewage sludge) for residential use. Three quarters of the respondents rated recycling as important or very important and indicated that it is important or very important to find uses specifically for sewage sludge. However, high level of support was mainly for the use of composted sludge on golf courses and public landscapes but much smaller for its use on vegetable gardens and houseplants, respondents were concerned about safety and health. It was found that differences in the level of education, income, sex and ethnicity influenced responses , suggesting that educational and marketing approaches may need to be considered.

Rahmani et al. (2004[21]) conducted a surves of citrus growers, golf courses, landscaping service businesses, and ornamental plant growers in Florida. They suggest that in order to promote more widespread compost use, information and product quality are the key. All the other issues are part of or closely related to information and quality. Cost of compost application, availability and quality consistency, and the benefits of compost application are the crucial information that potential compost users want to have. To make compost a more widely used input in agriculture, more information needs to be disseminated and the quality of compost needs to be improved and kept consistent. To promote using compost, a market and demand need to be established, and compost should be considered as a commodity that has some net benefit for the users rather than a waste material for disposal. Similarly, Walker et al. (2006[22]) analysed the horticultural industry in the US as a potential value-added market for manure-based composts, and found the operational classification showing the most interest in composting were commercial tree growers, commercial nurseries and greenhouses, landscape contractors and lawn care operations. Their primary reasons for using compost were related to soil tilth, building humus content of the soil and increased plant growth. Replacement of chemical fertilizer use was surprisingly not cited as primary reasons for using compost, but this is most likely because mineral fertiliser cost is a quite minor fraction of total production costs.

Barriers to on-farm composting and to agricultural use of composts in Flanders, Belgium, was investigated by Viaene et al. (2015[23]) based on interviews of 86 stakeholders (including 21 farmers) and questionnaire returns from 83 farms (all in conservation areas or organic). Nearly all the farmers use inorganic fertilisers and slurry/manure, and most also plough in straw. The authors also note that some 40 companies produce compost at a commercial scale in Flanders (c. 360 000 t/y, containing c. 3 000 tN) but that only around 5% of this is used in agriculture, most goes to parks and gardens. They identified that the barriers to on-farm composting of manures are

- shortage of woody biomass for use as bulking agent, resulting from subsidies to green energy (combustion, AD)

[18] See http://avfallsverige.se/in-english/swedish-certification-rules-for-digestate/
[19] See **http://www.biofertiliser.org.uk/**
[20] Borden GW, Devitt DA, Morris RL, Robinson ML Lopez J 2004. Residential Assessment and Perception Toward Biosolids Compost Use in an Urban Setting. *Compost Science & Utilization,* 12, 48-54.
[21] Rahmani M, Hodges AW, Kiker CF, 2004. Compost Users' Attitudes Toward Compost Application In Florida. *Compost Science & Utilization*, 12, 55-60.
[22] Walker P, Williams SD, Waliczek TM, 2006. An Analysis of the Horticulture Industry as a Potential Value-Added Market for Compost. *Compost Science & Utilization*, 14, 23-31
[23] Viaene J, Van Lancker J, Vandecasteele B, Willekens K, Bijttebier J, Ruysschaert G, De Neve S, Reubens B 2016. Opportunities and barriers to on-farm composting and compost application: A case study from Northwestern Europe, *Waste Management* 48, 181–192

- licencing obligations if farmers wish to use off-farm materials in composting, whereas this is necessary to achieve viable scale and appropriate input material mixtures
- investment costs for equipment for aeration of compost and for monitoring
- lack of knowledge
- costs or perceived (anticipated) costs and so profitability

Barriers to use of composts by the farmers were identified to be:
- regulatory complexity and overlap, e.g. Manure Decree (Nitrates Directive and phosphorus limitations), soil organic matter (CAP Mid Term Review, greenhouse emissions mitigation)
- competition with regional manure supply surplus
- transport regulations
- real or perceived issues with compost quality: respondent farmers believe that compost composition is variable (e.g. unpredictable availability of nitrogen to crops) and that all compost poses risks of weed seeds and diseases (lack of confidence in compost sanitisation)
- lack of experience and knowledge concerning compost use

The barriers identified here regarding compost quality, availability and price were similar to the barriers identified by Rahmani et al (2004) and Walker et al. (2006) as discussed above.

Organic farming sector – a special market opportunity

The organic farming sector represents a special market opportunity across Europe, since the organic farms are not allowed to use synthetic fertilisers or pesticides. Therefore their willingness to pay for bio-based fertiliser products will typically be much greater than their conventional colleagues; furthermore, organic products typically receive a price premium, enabling accommodation of somewhat higher production cost than conventional. Recycling of resources (e.g. phosphorus, P) as bio-based fertilisers are also in line with the philosophy and foundation of organic farming, however, at the same time, the organic sector is greatly concerned about the integrity of their produce, and therefore may organic farmers, food processors and retailers may have some reservations against recycled products, due to concern for contaminant, and other concerns related to consumer perceptions of the organic brand. The principal nutrient sources currently authorised under the EU Organic Farming Regulation: animal manure, including after processing (if not from factory farming), digested or composted source-separated household organic wastes (green waste, food waste), certain animal by-products (meat and bone meal, fish meal). Rock phosphate (soft, ground) is also authorised, but is not readily plant available in most soils. Some other materials are authorised under certain conditions but are generally available only in certain local situations, such as seaweeds, stillage extracts, freshwater dredge sediments.

Løes et al. (2016[24]) collected 213 questionnaires at stakeholder workshops held in seven countries to discuss the use of secondary P sources in organic farming. The respondent stakeholders were generally reserved about acceptability of conventional manure in organic farming, with comments showing concerns about residues of pesticides, hormones and pharmaceuticals. Results varied in different countries, but often <50% of respondents considered conventional manure acceptable. Ruminant and horse manure was generally preferred to manure from poultry or pigs (both c. 55% acceptability) or fur animals. Appropriately treated park and recreation green waste achieved the highest acceptance (>90%) along with source-separated municipal food waste (85%) and (non-animal) food industry residues (77%) and catering food waste (71%). More than 60% of respondents also considered acceptable the use of human urine and human sewage in organic farming, with a general order of preference precipitates (69%) > urine > sewage sludge > sewage sludge incineration ash (56%). Meat and bone meal ash was also acceptable to over 70% of respondents, but with comments that this often comes from non-organic / intensive production or should be applied under specific safety conditions (e.g. injected into the soil). Phosphate rock was considered acceptable to only 50% of respondents, with concerns expressed concerning the country of origin. The authors note that farmers were generally more sceptical than farm advisors and scientists or other stakeholders, concerning use of secondary phosphorus sources in organic farming.

[24] Løes,A.K. 2016. Phosphorus supply to organic agriculture. What does the organic sector think about different phosphorus fertilisers? NORSØK report vol. 1 / nr. 3 / 2016. http://orgprints.org/30368/1/NORS%C3%98K%20RAPPORT%20nr%203%202016%20P%20FERTILIZERS.pdf

4. Requirements from other stakeholders – Food and feed industry, supermarkets etc.

While there is a reasonable body of literature on farmers and other primary end-user requirements and preference for manures and bio-based fertiliser products as reviewed in the previous section, there is virtually no literature related to many of the secondary or tertiary stakeholders outlined in Fig. 1.

However, it is clear that especially the food and feed industry, as well as the retailers (supermarket chains), have a significant interest in the potential impacts from increased used of bio-based fertilisers at their primary producers, the farmers. Of particular interest will be any undesirable or unwanted substances/ pollutants – heavy metals, medicinal residues, pathogens – which enter the food chain via these.

It is therefore clear that development of traceability and quality assurance schemes, such as Global-GAP[25] or ISO 13065:2015 "Sustainability Criteria for Bioenergy"[26], will be key to achieving acceptability of bio-based fertilisers by these very important stakeholders.

At the same time, increased use of recycled and bio-based fertiliser products are completely in line with the cradle-to-cradle philosophy and circular economy principles, so this also offers great branding opportunity (e.g. sustainability, CSR) for companies, especially in the fertiliser sector (whether traditional or recycling based). However, against this may be brand protection concerns (over negative associations if ever a problematic case hits the media) and here especially large multinational food corporations may apply the precautionary principle and prioritise brand protection over sustainability for their food and feed products.

An example of precautionary policies applied by multinational food companies with regards to waste-based fertilisers is the Scandinavian dairy company Arla, which in their "Arlagården Quality Assurance Programme" [27], having been in force for more or less the last decade, state clearly that it is not permitted for their dairy farm milk suppliers to feed their cows any feed crops grown on soils fertilised with sewage sludge or waste products. However, at the same time Arla has recently decided a Corporate Responsibility Strategy, which includes a statement on high priority for increasing "resource use efficiency"; this dilemma has caused a lot of discussions with stakeholders along the milk chain, and considerations for modifying the quality assurance programme to allow certified digestates and other well-controlled bio-based fertilisers is underway.

Food companies and supermarkets have a marketing strategy where they interpret what they think the public will pay for, and they base this on the solid evidence they have continuously as feedback in their sales-figures – price and market availability of food products is very dynamic – but in reality, the consumers "social perception" of what is sustainable may be influenced by many other factors and actors than just the supermarkets and other retailers. Referring again to Fig. 1 NGOs (environmental, consumer associations) and media may also influence consumers opinion, perceptions and market choices greatly, which again will eventually feed back to food, feed and fertiliser industry and supermarkets criteria for sustainability.

5. Conclusions: key challenges for meeting end user requirements

This studies reviewed here confirms that for conventional arable farmers as end-user of manure and bio-based fertiliser products, the primary criteria or requirement is low cost. This means that the price must be sufficiently low to compete with traditional mineral fertilisers, when considering higher logistics cost (transport and application), less predictable nutrient content and availability, physical parameters (compatibility with handling and spreading equipment) and potential nuisance (odour, dust) for neighbours. The only exemption is the organic farming sector, where the fact that there is no synthetic fertiliser alternative enhances the willingness to pay, but where also at the same time the concern for integrity of the production chain sets extra requirements for absence of contaminant and for traceability.

However, it is also clear that bio-based fertilisers are valued highly by all farmers for their content of organic matter and contribution to soil quality, yielding a certain soil amelioration value, which it is difficult to

[25] G.A.P. stands for Good Agricultural Practice – and GLOBALG.A.P. is the worldwide standard that assures it, see http://www.globalgap.org
[26] See http://www.iso.org/iso/catalogue_detail?csnumber=52528 and http://www.iso.org/iso/home/news_index/news_archive/news.htm?Refid=Ref2009
[27] Arla, "Arlagården Quality Assurance Programme" Version 5.2, with effect in Denmark from January 2017, http://www.arla.com/company/responsibility/farm-quality/arlagaarden/

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associate a sepcific monetary value to in the same manner as for mineral fertiliser nutrient substitution; however, that it is something valued highly by farmers is consistent across several studies.

Regarding other end-users, such as horticultural producers, soil manufacturers, landscapers, turfgrass managers, who all operate in markets with much higher profit margins and hence larger willingness to pay for the right product. However, producing the right bio-based fertiliser product may not be so easy, as processing and marketing is often driven by the need to dispose of waste/residue surplus, than by producing a valuable refined product, and often other barriers like availability of co-substrate (for AD), bulking agents (for composting) or regulations – much is still to be learned and innovated before this sector becomes profitable, and new business niches develop, though some producers are already quite far with extensive ranges of digestate, compost and organic fertiliser products.

6. Proposals for R&D needs from practice and operational groups

As discussed by Riding et al. (2015[28]), whilst the ability of agricultural, urban and bioenergy residuals to substitute synthetic fertilisers and provide a number of ecosystems service, a major step-change is required by both politicians, industry and end-users to alter perceptions of 'waste', from an expensive problem, to a product with environmental and economic value. This can only be achieved by well-informed interactions between scientists, regulators and end end-users, to improve the spread and speed of innovation with this sector.

Case et al. (2017) also discussed this challenge and identified the need to increase both supply and demand of bio-based fertiliser products. They proposed a list actions that could be taken (Table 2) by various actors, including government, academia and industry. Actions to increase demand mostly related to making bio-based fertiliser products more attractive to end-users (less odor, more concentrated and reliable nutrient value, certification of quality) as well as cheaper and easier to handle and apply, whilst those related to increased supply mostly address increased processing and production capacity (on-farm manure, AD, solid waste sorting, composting, WWTP), removing irrational and inappropriate barriers for market access (regulations) and creating a better and more level market place.

[28] Riding MJ, Herbert BMJ, Ricketts L, Dodd I, Ostle N, Semple KT, 2015. Review - Harmonising conflicts between science, regulation, perception and environmental impact: The case of soil conditioners from bioenergy. *Environment International* 75, 52–67.

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Table 2. Actions suggested by Case et al (2017) to address issues related to both supply and demand of bio-based fertilisers.

Aim	Action	Mechanism	Actors
Increase demand: Improve attractiveness of organic fertiliser products for farmers	Increase R&D on technological issues of organic fertilisers e.g. to reduce odour, uncertainty in nutrient contents, and volume	Increase funding for further R&D, particularly combining academia / industry	Industry / Academia / Government
	Reduce costs for handling and improved spreading of organic fertiliser products	Subsidies to farmers to reduce costs of new management and spreading equipment	Government
	Introduce certification schemes and regulations to ensure quality and fertiliser value of organic fertilisers	Fertiliser value testing and validation procedures established. Certification guidelines created and implemented with respect to desired nutrient contents and availability, and undesirable components (pollutants, pathogens, etc.) A unified regulatory system for both synthetic and waste or bio-based fertilisers (i.e., along the lines of the ongoing revision of the EC Fertiliser Regulations, (European Commission, 2016)	Academia / Government
Increase supply: Develop organic waste treatment capacity and distribution systems	Increase 'on-farm' processing of animal manures, e.g. acidification or separation technology	Subsidies or removal of credit constraints for purchase of farm-scale treatment equipment.	Government and industry
	Expand the number and capacity of anaerobic digestion plants utilising organic wastes from area	Subsidies or removal of credit constraints for establishment of farm/area-scale/communal AD infrastructure. Streamlined regulation and approval process to remove constraints on construction of new plants.	Government and industry
	Create regional / district virtual 'market places' or trading platforms for surplus raw or processed manures	Funding for creation and maintenance of web platform market places	Industry / Government
	Strengthen distribution systems to deliver treated organic fertiliser products directly to farmers (particularly for areas of primarily arable/horticulture farming)	Streamlined regulations for trading and transport of organic fertilisers, particularly across borders, i.e. the proposed new EU Fertiliser Regulation Creation of well-functioning market channels	Government / Industry
	Upgrade waste water treatment plants to recover nutrients and produce processed urban waste fertilisers of interest to farmers	Installing nutrient recovery technology on WWTP plants Provide high-quality organic fertiliser products to the market	Industry and Government
	Increase collection and sorting of food / green wastes by municipal authorities, aiming at utilisation for combined nutrient and energy recovery	Government targets for organic waste recycling Banning landfilling and increased taxes for organic wastes to incineration	Government

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APPENDIX 1

From
King et al (2013)

Different end-user responses to digestates

Table 10 Review of respondents to digestates (whole, solid and liquor) for crop end-uses: awareness, attractiveness, ease of use and barriers

Group- taken from Table 7	Sub-group	Awareness of digestates in sector	Attractiveness of digestates to sector	Ease of use	Existing applications	Possible applications	Barriers
Field grown horticulture (group 1)	Vegetables	✓✓	✓✓	✓✓✓	Possibly on some vegetables	Soil improver (whole or solid)	××
	Trees (top fruit nursery stock)	✓	✓	✓✓✓		Soil improver (whole or solid)	×
	Soft fruit	✓	✓	✓		Liquor	×××
Land restoration (group 2)	Biomass	✓✓	✓✓✓	✓✓✓	Trial	Soil improver (whole or solid)	×
	Forestry	✓✓	✓✓	✓✓✓	Trial	Soil improver (whole or solid)	×
	Industrial spoil reclamation	✓✓✓	✓✓✓	✓✓✓	Trial	Soil improver (whole or solid)	×
	Urban green space	✓✓	✓	✓✓✓		Soil improver (whole or solid)	×
Forestry (group 3)	Conventional forests	✓	✓	✓		Soil improver (whole or solid)	×
Amenity (group 4)	Landscape	✓✓	✓	✓✓		Soil improver (whole or solid)	××
	Grass parks/(roadsides)	✓	✓	✓✓		Liquor	××
Liquid feed for Sports Turf (group5)	Pitches	✓	✓✓	✓✓	Trial	Liquor	×
	Fine turf -golf	✓	✓	✓✓	Trial	Liquor	××
Soil manufacture (group 6)	Amenity Land restoration	✓✓✓	✓✓	✓✓	Trial	Solid	×
Container production horticulture (group 7)	Professional & Amateur	✓✓✓	✓	✓		Constituent of peat free growing media	××
Dried fertiliser pellets (group 8)	Various Horticulture	✓	✓✓✓	✓		Dried product	×

Key ***Awareness** (excluding trial managers)* ✓ some respondents were not aware of AD outputs. ✓✓ respondents foresaw possible digestate applications in their sector with prompting. ✓✓✓ respondents were aware of products or trials in their sector using digestates.
Attractiveness ✓ some major barriers to or concerns over digestate use foreseen by some respondents. ✓✓ potential applications (after discussion). ✓✓✓ products could readily be used.
Ease of use ✓ niche opportunities, specialist users, pre-treatment of digestate needed. ✓✓ wider opportunities but needing pre-treatment of digestate. ✓✓✓ potential or actual applications no pre-treatment needed
Barriers × some barriers mentioned. ×× many barriers mentioned. ××× "show-stoppers", i.e. no use possible.

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Based on the survey (King et al 2013), potential applications for digestate-use were identified, grouped into two blocks of either high potential (land restoration, soil manufacture, field horticulture, pelleted organic fertiliser) or some potential (liquid fertiliser for turf, component of growing media, thermal conversion):

End-use and sectors that show the greatest potential for digestate use

Land restoration i.e. soil forming or soil improvement for degraded or marginal land (see glossary) Key benefits: ■ Acknowledged benefits of organic matter and nutrients. ■ Need for physical soil improvement. ■ High nitrogen can boost early growth. ■ Supplies other major and minor nutrients. ■ It can be used in its current form as a whole digestate or solid fibre. ■ Tolerate variability in amount and balance of nutrients. ■ Often economically attractive to users under current pricing. Problems to be overcome: ■ Odour. ■ Some sites require PAS110 compliance. Further possible enhancements: ■ Further aerobic stabilisation to reduce odour. ■ Reduced water content to improve material handling characteristics.	**UK use or trials underway**
Organic component for soil manufacture Key benefits: ■ Provide organic component for soil manufacture. ■ Provide nutrients which may be beneficial when mixed and with other constituents. ■ PAS110 compliance ensures PTEs, pathogens and organic contaminants are monitored and kept within safe levels. Problems to be overcome: ■ Digestate's physical characteristics can make it difficult to mix with mineral soil components. ■ Odour. ■ Soluble salts would need to be appraised. Further possible enhancements: ■ Reduced water content e.g. more efficient method of dewatering and/or further drying. ■ Further aerobic stabilisation to reduce odour. ■ Co-composting with green waste would improve physical consistency and make a friable product.	**Potential and emerging applications**
Field grown horticulture Key benefits: ■ Supply readily available nitrogen fertiliser (whole digestate). ■ Supply organic matter as soil improver beneficial on light/medium horticultural soils (fibre digestate). ■ It can be used in its current form as a whole or fibre digestate. ■ PAS110 compliance ensures PTEs, pathogens and organic contaminants are monitored and kept within safe levels. Problems to be overcome: ■ Concern over pathogens on edible crops. Confidence in pathogen control essential.	**UK use or trials underway**
Production of pelleted organic fertiliser Key benefits: ■ Nutrient content to produce a fertiliser product. ■ Slow release form of nitrogen suitable for some uses e.g. amenity sector ■ Organic fertiliser. ■ Green credentials: produced from recycled product. ■ PAS110 compliance ensures PTEs, pathogens and organic contaminants are monitored and kept within safe levels. Problems to be overcome: ■ Energy cost of thermal drying. ■ Odour. ■ Soluble salts would need to be appraised. Further enhancements: ■ Thermal drying.	**Potential and emerging applications**

Other end-uses that show some potential for digestate use

Liquid fertiliser for turf Key benefits: ■ Good balance of nitrogen relative to phosphate and potash. ■ High readily available nitrogen content to boost growth. ■ PAS110 ensures pathogens, PTEs and organic contaminants are monitored and kept within safe levels. ■ Environmentally friendly product. Problems to be overcome: ■ Odour. ■ Solid fraction may cause blockage of spray equipment especially where dilution is required. ■ High soluble salts need to be appraised. ■ The need for a consistent product. Further possible enhancements: ■ Further aerobic stabilisation to reduce odour. ■ Further nutrient stripping may be needed to separate unwanted salts such as sodium or chloride.	**UK use or trials underway**

Component of growing media Key benefits: ■ Provide peat alternative as growing media constituent. ■ PAS110 ensures pathogens, PTEs and organic contaminants are monitored and kept within safe levels. Problems to be overcome: ■ Odour. ■ Digestate's physical characteristics can make it difficult to mix with other growing media constituents. ■ Nutrient levels too high – particularly ammonium. ■ Soluble salts would need to be appraised. ■ Possible herbicide contamination. Further possible enhancements: ■ Further aerobic stabilisation to reduce odour. ■ Co-composting with green waste probably essential to improve physical, chemical and biological characteristics.	**Potential and emerging applications**

Thermal conversion This market provides an opportunity for digestates that are unsuitable for application to land. Key benefits: ■ Potential good calorific value. Problems to be overcome: ■ Too wet - uncertainity over calorific value and materials' classification. ■ Unknown compositional value of materials: cadmium, mercury and chlorine. Further enhancements: ■ Reduced water content e.g. more efficient method of dewatering and/or further drying. ■ Heavy metal stripping.	**UK use or trials underway**

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