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Adoption of solid organic waste composting products: A critical review

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A B S T R A C T

Rapid increase of solid wastes is a global challenge and organic waste takes the majority part. Composting is an efficient and effective way of converting solid organic wastes to fertilizers, which could be returned to agricultural lands and at the same time, mitigating pollutions. But by far, composting of solid organic wastes has not been widely used. It is determined by complicated factors and one of them is the low adoption level of composting products, which would hinder the upstream composting practices, but has not been sufficiently studied yet. This review paper tried to identify the main factors that may affect people's adoption of composting products from solid organic wastes, by carefully reviewing 10 related papers. It is found that efforts could be made in three aspects to encourage people's adoption of food waste derived fertilizers. The first one is to supply sufficient information about the fertilizers, including nutrient content, trace metal concentration, salinity and pathogen condition to reassure the users about the fertilizers' quality. The second one is the effective pricing system, which could fully reflect the value of re-using food waste and at the same time make the price of food waste composting products competitive compared to the price of chemical fertilizer. The third one is related regulation, which should encourage and facilitate the market of organic waste-based fertilizers. Those findings point to the directions of empirical studies in future.

1. Introduction

Rapid increase of global population together with urbanization and industrialization has lead to fast generation of complex solid wastes (Singh et al., 2014). Among them, solid organic wastes have gotten particular attention, which usually comprise of organic biodegradable fraction with a moisture content below 85–90%. Sewage sludge, municipal solid waste (MSW), food waste, kitchen waste, garden waste, agricultural wastes, animal wastes, etc. could be classified as solid organic wastes (Mata-Alvarez et al., 2000). Inappropriate dealing with this sector would lead to subsequent negative social, economic and environmental impacts, so it deserves more attention from scholars as well as policy-makers (Diener et al., 2011). Currently, the world population is around 7.6 billion and it will probably reach 8.6 billion in 2030 and 9.8 billion in 2050, and in addition, majority of population increase will take place in developing countries, like India, Pakistan and Indonesia (Singh and Kumari, 2019), with demands for better living standards. Then population growth together with higher personal demands would consequently contribute to rapid increase of solid waste generation. That is, fast economic growth, rapid urban sprawl, low efficiency of waste collection and treatment systems are the main factors that lead to the generation of huge amount of wastes with high complexity. Globally, the wastes would increase from 2 billion tons in 2016 to 3.4 billion tons in 2050 and the countries in Asia and Africa would be the major contributors (Karim et al., 2019). The amounts of municipal wastes that are generated by Asian urban cities per day are expected from 760,000 tons in 2016 to 1.8 million tons by 2025 (van Huis and Oonincx, 2017).

Confronting this trend, current waste management systems need to admit new ideas, methods and technologies, particularly those dealing with solid organic wastes, which contain valuable organic matters and are worth reusing, recycling and recovery. Currently, most solid organic waste (SOW), such as biodegradable Municipal Solid Waste (MSW), animal manure, agricultural residues and so on, are disposed in conventional ways, like landfilling

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and incineration, which are not sustainable, due to limited space (Slater and Frederickson, 2001; Soobhany, 2018), and environmental impacts (Ilgen et al., 2008; Lou and Nair, 2009; Suthar, 2008). Particularly, landfilling usually causes greenhouse emissions, such as CH_4, CO_2 and N_2O, and leaching of heavy metals and other contaminants. In addition, leaching, runoff and erosion from the dumping sites will further pollute ground water (Mor et al., 2006). Incineration of solid wastes usually releases some noxious and toxic gases, such as chlorinated dibenzo-p-dioxins, dibenzofurans and so on, and greenhouse gases as well (Sharma et al., 2018). In addition, the valuable nutrients embedded in SOW get lost (Ghosh et al., 2004; Meng et al., 2017; Zhang and Sun, 2016). Some countries have started to seek more sustainable ways of disposing SOW, which could valorize materials from them (Khan et al., 2020; Rehman et al., 2020).

Commonly, material valorization is carried out through biological processes, which mainly include composting and anaerobic digestion. Both of them go through biological degradation of organic matters in FW, but occur under aerobic and anaerobic conditions, respectively. Compost is the final product of the composting process and is usually used as organic fertilizer. While, biogas and a non-stabilized digestate are the final products of the anaerobic digestion process. And biogas mainly contains methane (CH_4) and carbon dioxide (CO_2). Diverting SOW from landfills to composting or anaerobic digestion could gain great environmental benefits (Cerda et al., 2018). Among the benefits, reduction of greenhouse gases compared to landfill emissions and improvement of soil properties by applying composting products have been highlighted (Bernstad et al., 2017). The latter benefit is quite outstanding, because those nutrient-rich fertilizers could not only restore land, but also maintain soil quality (Garg et al., 2006) and it turns out to fit circular economy concept better. In addition, the principle of compost is easy to understand, which is a biological process, during which microbes change the organic matters into stabilized and sanitized products and nutrients are biologically stabilized. And the techniques and facilities required by compost are not complex.

Composting is a biochemical process, during which diverse groups of microorganisms and nematodes play critical roles. Specifically, it is a solid-state fermentation process and is mainly carried out by aerobic thermophiles (Pietronave et al., 2004; Thambirajah et al., 1995). The physiological activities of various microbial groups, to some extent, contribute to the nutrient potential of compost and its effect on agricultural productivity (Pepe et al., 2013). Besides, microbial communities in compost could control the soil-borne pathogens in the plants (Mehta et al., 2014). Specifically, these microbe in compost could produce some antimicrobial compounds, release heat, compete with pathogens and influence the viability of soil-borne pathogens and then inhibit the development of plant diseases. It is generally agreed that composting process has three stages and at each stage, participating microbe vary because of different physicochemical conditions (Bhatia et al., 2013; Mehta et al., 2014). At the beginning stage, the temperature is moderate and the degradable soluble compounds are ready to be decomposed mainly by mesophiles. The metabolic activities and growth of mesophiles lead to heat release and rapid temperature increase. Higher and higher temperature replaces mesophiles by thermophilic microorganisms, which could decompose polysaccharides, proteins and fats. The other critical role that higher temperature plays is that it could also kill weed seeds and soil-borne pathogens. At the final stage of composting, mesophiles come back to the dominant position, which helps cool down and get compost matured. This stage makes sure that the compost is stabilized and could be directly applied for plants (Bhatia et al., 2013; Pepe et al., 2013).

There are a number of factors that could affect composting effectiveness, which include temperature, aeration, moisture content, C/N ratio, particle size, PH and degree of compaction (Juarez et al., 2015; Li et al., 2013) and so on.

Temperature is a significant factor that determines the effectiveness of composting. It evolves through the whole composting process and according to different temperatures, composting process could be divided into four phases, namely mesophilic, thermophilic, cooling and maturation stages (Chen et al., 2015). On one hand, the temperature determines the relative advantage of some microorganism over another, which make composting happen; on the other hand, the temperature plays an important role in making sure no harmful, but valuable microbe in the composting products for the plants. Temperature above 55° C could eliminate parasites and pathogens to ensure the maximal sanitary conditions (Ravindran and Sekaran, 2010). And if the compost could stay in the thermophilic phase longer than three days, the compost would get rid of weed seeds and pathogens and the sanitation requirement for the compost could be achieved (Zhang and Sun, 2014). But the temperature is not the higher the better and if it is greater than 65° C, almost all the microorganisms would die and the composting process ceases (Imbeah, 1998). So the suitable temperature range for composting is 40–65° C (Rigby et al., 2016). Based upon this, the temperatures of the composting materials could indicate the composting phase as well as show the real-time condition of the microbial degradation (Awasthi et al., 2014).

Fundamentally, composting is an aerobic process, through which O_2 is consumed and CO_2 and H_2O are released (Awasthi et al., 2014) and aeration is another important factor that influences composting (Chen et al., 2015). Aeration provides O_2 required by the oxidation of organic materials, helps evaporate surplus moisture from the substrate (Petric and Selimbasic, 2008) and distribute the temperature across composting mass. Aeration rate affects the microbial activities in the composting process and further the quality of the compost (Gao et al., 2010). Increased aeration could also lead to higher evaporation rate and quicker cooling of the compost (Sundberg and Jonsson, 2008), and if the excessive cooling happens at the thermophilic stage, it probably prevents the decomposing process (Gao et al., 2010). So it is critical to keep aeration within a suitable range.

Moisture content is critical in the composting process, by mainly influencing the oxygen uptake rate, the temperature, free-air space and the activity of microbial (Petric et al., 2012). There have been some discussion about the optimal moisture content for effective composting (Bernal et al., 2009; Onwosi et al., 2017), but no uniform conclusions have been reached yet. During the composting process, the increase of moisture content would lead to the decline of gas diffusion rate, and then the oxygen uptake rate might not be able to meet the metabolic demands of the microorganisms. Then the process could finally turn to be anaerobic because of restricted microbial activity (Mohammad et al., 2012). However, moisture content could not be very low, because on one hand, it is key to distributing soluble nutrients required by the microbial metabolic activity (Guo et al., 2012) and on the other hand, very low moisture content would cause dehydration at the early stages of composting process and that could hinder biological process (Makan et al., 2013). So a suitable initial moisture content is important to composting and it has been found that different composting materials may have different optimal moisture content. For example, 70% initial moisture content is suitable for composting poultry and wheat straw (Petric and Selimbasic, 2008) and 60–70% is good for composting pig slurry (Ros et al., 2006). Food waste has a high-moisture content, which needs to be adjusted to a suitable one at the initial stage to ensure microbial activity and biological process.

During composting, C, N and K are the major nutrients that the microorganisms need (Darby et al., 2016). And they acquire those nutrients by breaking down the organic compounds and at the same time obtain energy for metabolism (Chen et al., 2015). Among the three nutrients, C and N are particularly crucial, because C is used as energy source and N is for building cell structure (Chen et al., 2015; Iqbal et al., 2015). So when the N is in shortage, microbial growth will be constrained and the decomposition of the C will be slowed down (Igoni et al., 2008). However, if the N is much more than the required amount by the microbial population, some other problems will occur. Microorganisms use C 30–35 times faster than the rate, at which they convert N (Igoni et al., 2008), so the C/N ratio should be controlled within suitable range. If the C/N ratio is low, then the extra N will be released as ammonia gas, which has very unpleasant odor. In addition, lower C/N ratio will liberate huge amounts of soluble basic salts, which would turn the soil unfavorable for plant growth (Awasthi et al., 2014). If the C/N ratio is high, it means N is not sufficient for microorganism growth and it will slow down the composting process (Chen et al., 2015). Since the initial C/N ratio is crucial, a number of materials, called bulking agents, have been proposed to be added to adjust the ratio, which include rice husk, wood chip, peanut shells, urea and so on (Wang et al., 2015; Zhang et al., 2016; Zhang et al., 2016). In a word, the initial C/N ratio will affect both the mineralization of organic matter and nitrification processes (Ros et al., 2006).

Above all, composting mechanism is not hard to follow and be utilized. Then with all these advantages, why is compost not as popular as expected?

So this review would like to identify the possible reasons, from demand side, for its unpopularity. By far, there have been quite a few of studies about compost. For example, some valuable reviews have been done on its fundamental natural science (Alavi et al., 2017), its technologies (Li et al., 2013), and some specific aspects, like the feed material type (Wang et al., 2013). And it has been agreed that compost products from solid organic waste, including food wastes, can support plant growth as well as improve soil fertility (Mohee and Soobhany, 2014; Soobhany et al., 2015). However, few of the researches have paid attention to the demand side as to the composting products. According to the classic principle of supply and demand, low demand for composting products from SOW will restrain the application of the process, but high demand would stimulate it. People may be not sure about the fertility (Lupton, 2017), and/or toxicity (Lekfeldt et al., 2017) of the fertilizers recovered from SOW and refuse to apply them in their fields. And competitive price could also be another important concerns when people make choice between chemical and organic fertilizers (Case et al., 2017; Dannehl et al., 2016). In a word, the popularity of SOW composting products among the end users will encourage the SOW compost, and vice versa.

Fortunately, more and more efforts have been put to promote the application of composting products, particularly fertilizer. In 2015, European Commission (EC) action plan for the 'Circular Economy' proposed some changes to the EC fertilizer regulations, which are mainly to include EU-wide recognition of organic and waste-based fertilizers in order to stimulate an EU-wide market for those fertilizers (European Commission, 2015). And in 2018, the agreement was achieved for those changes to further foster cooperation among sectors and territories across the world to encourage the conversion of unused or under-utilized biowaste, residues and discards into valuable resources, particularly organic fertilizers and their application (European Commission, 2018). So it is necessary to find out the current attitudes of people towards the fertilizers and other products made from solid organic wastes and figure out the main factors that may affect people's acceptability, which may be knowledge gaps, technical defects, price advantages, cultural barriers and so on. As long as the main factors are identified, the further efforts could be more focused. So this paper would like to seek the answer to the question that what are the main factors that may influence people's adoption of organic fertilizers derived from SOW.

This review is structured as follows: firstly, the background is introduced including the mechanism of composting; secondly, the methodology is briefly presented; thirdly, the main factors that may affect people's adoption of composting products are brought forward; and lastly some suggestions on how to improve people's adoption of the composting products are supplied.

2. Methodology

This review paper is based on secondary data and information available in scientific domain. This paper chose Web of Science Core Collection as the database and the search rule is that both "waste" and "fertilizer" show in the title and the years are limited to last decade, 2010 to 2020, because the application of fertilizers made from organic wastes was not gained much attention until recently. We broadly use "waste" instead of "organic waste" or "solid organic waste" in order to cover as many as related articles as possible. And only the category "Environmental Science"is selected. The first search resulted in 536 articles. And then all these articles were screened one by one to eliminate those did not touch upon people's adoption of composting products as well as their attitudes towards the fertilizers' application. So in the end, 10 papers were carefully reviewed to identify the potential factors that may affect people's decision on adoption of composting products and the other articles supply the background information and knowledge. The Fig. 1 is the flowchart of the methodology.

3. Factors that may affect people's adoption of composting products

3.1. Content analysis

Based on the 11 articles reviewed, the main factors that may affect people's adoption of compost-based organic fertilizers are listed in Table 1.

In Denmark case, the uncertainty of organic fertiliser use is an important concern to the farmers, which refers to the "uncertainty in N, P and K content" and "increased difficulty in planning for organic fertiliser use compared with mineral fertilisers" (Case et al., 2017). The uncertainty caused by the lack of the nutrient content information was the main barrier for the farmers to adopt the organic fertilizers and it would bring them difficulty in planning for fertilizer use.

In Lupton's article, it brought forward a question about the data availability for the production of waste, which is not sufficient at all, even for European countries (Lupton, 2017). Without knowing the rough number of local solid organic waste produced yearly or quarterly, it is hard to predict the amount that is available for organic fertilizer, so it is difficult for the farmers to plan the agriculture. Besides, Perceived superior profit of applying composting fertilizers compared to chemical fertilizers is also an important factor that influence farmers' decisions. It could include the price, transport cost, spreading costs and so on (Lupton, 2017). Last but not least, various actors could also play a role in determining the organic fertilizers' adoption. Lupton (2017) pointed out that agricultural organizations, retail industry and food industry requirements on the quality of food products, national policies encouraging the use of organic fertilizers or not, could both empower significantly the consumers and citizens to make a decision on the adoption of organic fertilizers.

In Caribbean islands case, low education level and lack of

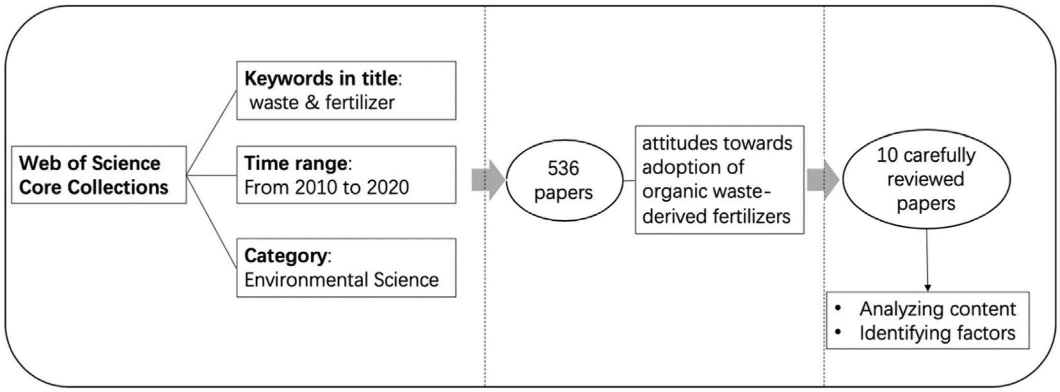

Fig. 1. Flowchart of methodology.

Table 1
The main factors that affect people's adoption of compost-based organic fertilizers.

Applications	Region	Study method	Factors	Reference
Farms	Denmark	survey	Uncertainty in nutrient content; Difficulty in planning and use; Potential of improving soil structure; Low cost; Ease of availability	Case et al. (2017)
Farms	France, Switzerland	Second-hand materials	Any toxic materials contained in the fertilizers; Environmental impacts; Knowledge on the quantities of waste materials; Relative price to chemical fertilizers	Lupton (2017)
Farms	Caribbean islands	Survey, logit model	The labor intensity of manual application; The cost of the practice; The lack of information about compost quality	Paul (2017)
Rice and banana farms	Guangxi, China	Survey, tobit and double-hurdle models	Whether to increase yield and soil quality; Whether to increase the cost or not	Chen et al. (2018)
Farms	Seven different European countries	Questionnaires and discrete choice experiment	Certainty in the nitrogen content;(common) Lower price than chemical fertilizer; (common) Presence of organic carbon; Hygienization of the product; Fast release of nutrients	Tur-Cardonna (2018)
Farms	South American countries	Questionnaire	Sufficient information and knowledge; Specific laws	Herrero et al. (2018)
Farms	Northwestern Italy	Questionnaire & hands-on experiment	Total nitrogen content; Organic matter; Carbon to nitrogen ratio; More information and knowledge	Pampuro et al. (2018)
Orchard	China	Survey & tobit model	nutrient content; Membership in agriculture cooperatives; Subsidies on organic fertilizers;	Wang et al. (2018)
Garden	Germany	discrete choice experiment	price; nutrient content; ease of access	Dahlin *et al.*, (2019)
Agricultural lands	Northern China	chemical testing and simulation prediction	trace metal content; nutrient content	Gong, *et el.*, (2019)

professional organizations, which guide and facilitate farmers to apply organic fertilizers, inhibit the adoption of the compost products (Paul et al., 2017). Besides, to switch to a new fertilizer needs some new instruments, like new spreaders, and new knowledge. Both of them mean additional costs to farmers. Without new instrument, the application of the new fertilizer would be labor intensive and without the new knowledge, especially the fertilizer quality, the uncertainty might lead to yield loss. The cost of transporting raw materials to the farm is also taken into consideration, especially to smallholder farmers.

In Guangxi, China case, the perception of yield-increase and soil quality-improvement is the main determinant for farmers' adoption of organic fertilizers. And cost increase would discourage the adoption. The concerns about the environment do not make an obvious difference (Chen et al., 2018).

In the case of farmers across Europe, if the organic fertilizer has certainty in nitrogen content and could release nutrient fast and in other words, is similar with the chemical fertilizer used currently and the cost is lower, then the farmers would adopt the organic fertilizers. Without obvious advantages, the farmers are hard to switch from chemical fertilizers to organic ones, since they have used the chemical fertilizers for a long time, which are reliable nutrient source to them. In addition, the composting products have various origins and nutrient concentrations, which make farmers reluctant to adopt them. Without related knowledge, farmers can hardly trust the efficiency of those composting products' nutrients by their crops. Besides, the composting products may confront logistical problems, because they do not have mature distribution channels as the chemical fertilizers do, unless there are localized composting facilities (Tur-Cardona et al., 2018).

In South America case, there are important needs to promote farmers to adopt the organic fertilizers, pressure from governmental legislations and "manual or guide for manure application" (Herrero et al., 2018). In those countries, manure is the main origin of organic fertilizers. To appropriately utilize great amount of manure has both environmental and resource benefits, but the processing technologies and manure-based products are relatively new to the farmers there, so both regulations and knowledge popularization and application training are in need.

In Italy case, though people expressed interests in applying composted animal manures, few of them put into practice. The main barrier is the lack of knowledge about the chemical properties of organic fertilizers, especially their total nitrogen content, which, in their mind, directly connecting with crop production (Pampuro et al., 2017).

In China's orchard case, farmers do not trust organic fertilizer which could bring the same yield as the chemical fertilizer does. In addition, the fruits cultivated by organic fertilizers cannot get higher prices than those by chemical ones, because of the lack of the traceable system. But the subsidies on organic fertilizers could encourage farmers to use more organic ones. Besides, if the farmers belong to the group, whose orchard got certifications, they tend to apply more organic fertilizers (Wang et al., 2018).

In Germany's garden case, price and the origin resource of the fertilizers are the top two concerns (Dahlin et al., 2019). In other words, people still care about the nutrient content of the organic fertilizers, which should have competitive prices. In addition, the ease of access to those organic fertilizers could also influence people's decisions.

In Northern China, farmers concern most about the nutrient and trace metals of organic fertilizers. Particularly reducing the content of Cr, Cu, Zn, As, and Cd could minimize the damages cased by trace metals (Gong et al., 2019).

3.2. Factors analysis

All the potential influencing factors presented in the content analysis could be categorized into three main ones: 1) compost quality, which include heavy metals and other organic matters content and maturity and stability; 2) the competitive economic benefits of organic fertilizer compared to the chemical fertilizers, including the fertilizer price, logistical costs and the recognized values of the organic agricultural products in the market; 3) government support, including subsides and related regulations and policies to encourage the adoption of compost products.

The quality of composting products is an important aspect as to the confidence of compost users (Cerda et al., 2018). One main concern is the possibility of loading the soil with metals that can lead to the increase of mental in the crops (Hargreaves et al., 2008). There is increasing evidence that the fertilizers from the organic wastes may have high concentrations of trace metals such as Cr, Ni, Cu, Zn, As, Cd, and Pb. If those fertilizers are applied to the agricultural lands, some of those trace metals will be accumulated in the soils and some of them would be further transferred to human bodies through plants (Franco et al., 2006; Lopes et al., 2011) and livestock (Kumpiene et al., 2008; Kupper et al., 2014). So the potential presence of the trace metals in the fertilizers from organic wastes is one reason for limiting its application (Gong et al., 2019). In Europe, there has been a directive (the European Directive 86/278/CEE) limiting the total concentrations of those metals in agricultural soils (Margui et al., 2016). Another concern is the high salt concentrations of initial materials, for example, food wastes. The high salt concentration would be inherited by the composting products, and they will inhibit plant growth and negatively affect soil structure (Hargreaves et al., 2008). Besides that, some other impurities, particularly plastic, glass and metal objects, would also negatively affect the land. So to sort the solid organic wastes well at the source could make the organic mass more suitable for composting and avoid much of impurities (Huerta-Pujol et al., 2011) and collection systems play a fundamental role in removing some pollutants from wastes, especially organic fraction of municipal solid wastes, and improving compost quality (Cesaro et al., 2015).

Besides the potentially toxic elements and risky matters that may exist in the composting products, maturity and stability are another two important parameters that most fertilizer users concern about the quality of composting products. Maturity generally describes the suitability of the compost for plant growth and commonly associates with phytotoxicity. Stability describes the degree of decomposition of biodegradable organic matters and indirectly relates to the biological activities of the composts (Barrena et al., 2009). Somehow, these two parameters correlate with each other, because phytotoxic compounds are usually the products of the microbial activity of unstable organic matters (Komilis and Tziouvaras, 2009; Oviedo-Ocana et al., 2015). But maturity is not described by a single property, and it is better to use at least another parameter to assess the quality, so stability is not unneeded (Cerda et al., 2018). If some composts are immature, they usually contain large amounts of free NH_3, certain soluble compounds and organic acids which would limit seed germination and root development; and those characteristics are the sources for many maturity indices and some commonly used are summarized in Table 1. Fertilizer users usually require mature compost products, which are free of those potentially phytotoxic components. So it is better to monitor and supply maturity information to fertilizer users, otherwise, they are not confident in using the composts, especially when they could relatively clear know the composition of chemical fertilizers (Tur-Cardona et al., 2018). By far, there have been no consistent parameters and values to evaluate compost maturity across the world. Table 2 presents some maturity parameters, which evaluate the maturity from different aspects. It would be better to have a series of global standard parameters to do the evaluation, however, each region could have its own threshold values for different organic sources and treatment measures. Common parameters would help people make comparison among organic fertilizers from various origins.

Among numerous factors that determine people's demand for waste composting products, an important one is the possible profitability of replacing chemical fertilizers by those new ones (Nunez and McCann, 2008), which are determined by a number of factors, including the price, transport (Lupton, 2017), spreading costs, quality (Bernal et al., 2009; Costa et al., 2017), geographic location, reputation (Lupton, 2005), availability of waste composting products (Odhiambo and Magandini, 2008), farm size, ownership of farms or lands and so on.

As to the price, there are no available statistics on the evolution of prices for different waste composting products (Lupton, 2017), except in France, where some related prices could be found as Table 3 shows.

The great variability of prices in Table 3 could somehow show the various agronomic values of different waste composting products. However, this table cannot reveal more information about a specific fertilizer, like its local demand or its local competition. One

Table 2
Maturity index for compost maturity from solid organic wastes.

Parameters	Brief description	References
Germination index	Relating to phytotoxicity.	Guo et al. (2012)
Dissolved organic matter electron transfer capacity	Showing the decomposition degree; Correlating with phytotoxicity	Yuan et al. (2012)
Polymerization degree	Formation of simple sugars; Reduction of non-humic substances	Zhang and Sun (2016)
Fluorescein diacetate enzymatic assay	Correlating with phytotoxicity	Komilis et al. (2011)
Phytotoxicity index	Indicating any toxicity degree	Young et al. (2016)

Table 3
Indicative sale prices of some waste-derived composting products.

Type of waste-derived composting products	Price (€/t)	Source
Urban sewage sludge compost	3.3	AMORCE (2012)
Mushroom compost	10	ATV 49 (2013)
Green waste compost	26	
Grape marc compost (pulp, skin and grape-seed)	32	
Cattle manure compost	40–90	
Composted wood chips	306	
Organic fertilizer composed of fish meal	426	

of the main reasons for the price information gap is that these transactions are informal; even there are spreading contracts, but there are no centralized data available on prices agreed upon (Lupton, 2017).

However, processing and re-using nutrients from some organic wastes on site, especially the ones from farm lands and livestock, could avoid the long-distance transport of these nutrients. This positive effect is usually ignored (Lory et al., 1995). A survey based on thorough communication with farmers showed that if farmers knew the valuable nutrients of those organic wastes and the embedded benefits of utilizing organic wastes on site, they were willing to apply the waste composting products for the agriculture (Schroder, 2005), particularly when the prices of chemical fertilizers were high.

The widespread use of fertilizer around the world indeed improved food production, but at the same time, the problems of excessive using fertilizers are being recognized, including greenhouse gas emission, groundwater pollution, eutrophication of water bodies, acidification of soils and so on (Liu et al., 2011; Tilman et al., 2001; Wang et al., 2018). So more and more countries are encouraging people to replace chemical fertilizers by organic fertilizers by issuing a series of regulations and action plans.

European Union is a forerunner. In 2016, European Union Commission proposed a regulation “Circular economy: new regulation to boost the use of organic and waste-based fertilisers”, which was agreed upon in 2018. Like Jyrki Katainen, Vice-president for Jobs, Growth, Investment and Competitiveness, said: “Unlike traditional fertilisers which are highly energy intensive and rely on scarce natural resources, bio-waste fertilisers have the potential to make farming more sustainable. These new rules will also help to create a new market for reused raw materials in line with our efforts to build a circular economy in Europe.” This regulation would promote the application of solid organic waste composting products.

Besides European Union, China, one of largest fertilizer consumers in the world, also took some actions. The Ministry of Agriculture and Rural Affairs of the People’s Republic issued the “Action Plan for Zero Growth of Fertilizer Consumption until 2020″in 2015 and the “Replacing Chemical Fertilizer with Organic Fertilizer Action Plan “in 2017 (Gong et al., 2019).

Though there have been few empirical studies on the effectiveness of those regulations, based on experiences from some studies on environmental regulations, people/organizations would actively respond to those regulations to maximize their utilities (Ambec et al., 2013; van Grinsven et al., 2012).

3.3. Strategies to encourage people’s adoption of compost products

Based on the analysis of the influencing factors, some strategies are brought forward to encourage people’s adoption of compost products.

As to the uncertainty about nutrient and trace metal content of organic fertilizers, using standard technologies and machinery could increase the homogeneity of the nutrient content, at least within a region. In addition, to make the measurement of the organic fertilizers’ nutrient content easy and convenient to access, then it would help the farmers plan accurate dose of the products. Reducing trace metal inputs is critical to protect agricultural land and ensure food safety. So it requires information about the trace metal content in the organic fertilizers and estimation of the impact of applying organic fertilizers on soil and human health, those could help develop appropriate management strategies and policies.

The void of knowledge on the evolution of quantities of waste materials produced and used in agriculture makes it difficult for economists to understand how demand would evolve in long term, and what factors affect or even determine the demand. This void could be filled if the governments impose statistics to all the actors, including the ones that produce waste and use compost-based fertilizers in agriculture. This knowledge could help governments better inform farmers and to some extent, regulate the externalities. Knowledge popularization and demonstration about organic fertilizer use through directly evolving farmers in the field could be an effective way in increasing farmers’ awareness of the benefits from organic fertilizers (Huang et al., 2015). To bridge the knowledge and information gap, countries could prepare some technical manuals, taking into account of both international standards and local conditions. These manuals are not only meant for the farmers, but also for other stakeholders, such as organic fertilizer producers, agricultural consultants and so on, or it will be still hard to improve the whole application system.

Government subsidies could neutralize the high cost that may be caused by switching from chemical fertilizers to organic ones. Those subsidies could be used for more suitable equipment to handle and spread new organic fertilizers, or to credit the farmers who are willing to produce and apply organic fertilizers. So the cost factor could be eased by subsidy for applying organic fertilizer processing technologies, promoting and training the farmers to adopt organic fertilizers (Xu et al., 2014).

To reduce the transportation cost of the composting products and increase their the availability of access, it is better to localize the composting facilities or gradually establish efficient distribution channels. However, localization is more sustainable to the local development and has more potential to keep the costs low.

If the vegetables and fruits cultivated by organic fertilizers could be recognized by the market for their outstanding value in terms of safety and nutrient, then the farmers would have more incentives to adopt organic fertilizers.

Above all, to encourage people's adoption of composting products, efforts could be made in three aspects: sufficient information, comprehensive and transparent price system, and supportive regulation system as Fig. 2 shows. First of all, it is fundamental to inform potential users the nutrient content, the trace mental concentration, the pathogen conditions of the waste composting products. It gives people confidence in using those products. However, to gain the fundamental information requires some uniform parameters and standards as well as appropriate and convenient test measures. Secondly, a comprehensive and effective pricing system is required, which should not only reflect the full value of re-using the organic wastes, but also make the waste composting products competitive compared to chemical fertilizers. Thirdly, supportive regulations could encourage and facilitate the application of waste composting products.

4. Conclusion

Solid organic waste contains a high organic as well as moisture content, which makes it a quite suitable raw material for biological treatment (Guo et al., 2018). Composting has proved to be an enchanting way of dealing with solid organic waste, because of less environmental pollution (Wei et al., 2017) and valuable final products (Benito et al., 2006). Actually, composting is a mature measure to return valuable nutrients to the soil, which could date back to the ancient agricultural society, and technological advancement shortens the process and improves its effectiveness (Lim et al., 2016). Solid organic waste composting has both environmental and resource benefits and is not difficult to be implemented. But the reality is that solid organic waste compost and its composting products have not been applied well as expected. By far, majority researches have tried to seek the reasons for its unpopularity from composting technologies, process control and some other aspects of compost *per se*. Few efforts have been made to increase the adoption of organic waste composting products. With the ignorance of the demand side, it is impossible to promote the supply, according to the classic principle of supply and control. In this case, if the composting products are not utilized, then the compost is meaningless and impossible to be commonly applied. Therefore, this article reviewed people's attitudes towards the adoption of solid organic waste composting products and tried to identify the main factors that affected their adoption. This review paper finds that currently people's acceptance level of solid organic waste composting products is low and it has considerably held back the adoption of solid organic waste compost. The main factors are as follows: 1) insufficient information about the solid organic waste composting products, including their nutrient content, pathogen, trace metals, supply volume and son on; 2) weak incentives to use solid organic waste composting products, due to the unrecognized economic benefits embedded; 3) deficient policies or regulations to encourage the adoption of solid organic waste composting products. Therefor, this paper claim that efforts could be put into three aspects to improve the adoption level: sufficient information, effective pricing system and related regulations. The confidence of people in the nutrient content and safety of the fertilizers is fundamental for their acceptance. Then if the price could comprehensively reflect the environmental as well as nutrient values of the waste-based fertilizers and it is also competitive compared to the price of chemical fertilizers, people will have higher willingness to accept the waste-based fertilizers. All the related regulations could facilitate the waste-derived fertilizer market. The main limit of this paper is that it did not discuss the solid organic wastes by their

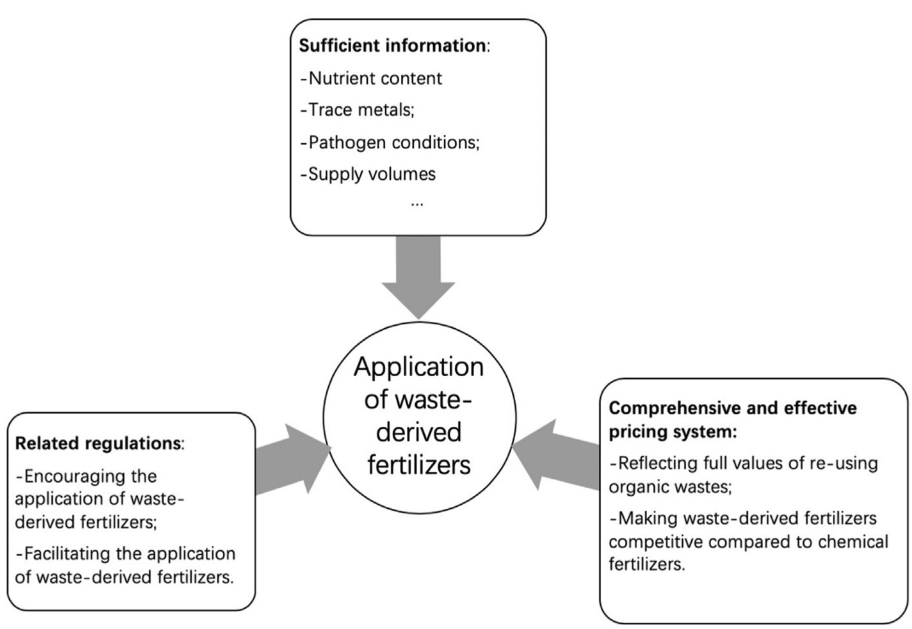

Fig. 2. Categorized factors that may influence people's utilization of waste composting products.

different origins and applications of their final products respectively. However, this review paper points out the main directions for the future empirical studies on how to improve people's adoption of solid organic waste composting products.

CRediT authorship contribution statement

Tianming Chen: Conceptualization, Methodology, Writing - original draft. **Shiwen Zhang:** Writing - review & editing. **Zengwei Yuan:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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