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Growing media for food and quality of life in the period 2020-2050

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Abstract

Growing media in soilless cultivation allow growers to apply water and nutrients more accurate (+15% growth) and to avoid soil diseases (+5/50% growth). Growing media, in combination with recirculation of drainage solution, reduce water use by about 50% and nutrient use by about 60%. For that and other reasons it is expected global growing media use will increase. A more precise estimation of the increase in demand is made, based on the expected growth of the world population, the expected increase in living standards for most people and the influence of several trends. Trends for vegetables include the need to address obesities, chronic micronutrient deficiencies and product safety. Trends for ornamentals include appreciation of natural aesthetics and ameliorating indoor climate and city climate. General trends include dealing with water scarcity, urbanisation, and more. The consequences of the possible higher demand are discussed in view of the availability of common growing media constituents like peat, coir, wood fibre, bark, compost, perlite, stone wool and tuffs as well as for less common but potentially available growing media (constituents) like *Sphagnum*, water and biochar. The influence of irrigation, drainage and support systems on growing media preference are discussed, as affected by trends, including recirculation of drainage solution, the use of organic fertilisers and developments in remote growing. In conclusion, the global growing media market is highly dynamic with the potential to increase four-fold between 2017 and 2050 with the highest per continent use shifting to Asia. The population increase is expected to contribute about 40%, income increase about 80% and trends about 40% for vegetables and 270% for ornamentals, totalling a market increase of 260% for vegetables and 490% for ornamentals. Growing media can contribute to a more sustainable production of vegetables and ornamentals as well as to public health and quality of life.

Keywords: Substrates, rockwool, statistics, vision, resource use efficiency

INTRODUCTION

The use of growing media in soilless cultivation allows for frequent per plant supply of small quantities of water and dissolved nutrients. The frequent and accurate supply of water and nutrients allows for a +15% increase in growth (Silber et al., 2003; Xu et al., 2004). The use of growing media in many cases also helps to avoid soil diseases, which results in +5/50% increases in growth (Minuto and Garibaldi, 2005; Van Os and Bruins, 2003). Growing media in combination with the collection and recirculation of drainage solution reduce water use by about 50% and nutrient use by about 60% (Stanghellini, 2014). These advantages make soilless cultivation with recirculation of drainage solution potentially the agricultural cultivation system with the highest possible resource use efficiencies and lowest emissions of water, nutrients and crop protection agents (Grewal et al., 2011). This allows concentration of the production of food and ornamentals close to consumers and frees a part of the area for restoration into nature (Jonathan et al., 2005).

The global volumes produced in greenhouse horticulture, tree crops and consumer gardening have been increasing in the past decades (ISHS, 2012). This also increased the use of growing media and growing media constituents, such as peat products, coir products, wood products, composts, perlite and stone wool (Raviv and Lieth, 2008).

Given the advantages of soilless growing and the increasing world population up to 2050 (FAO, 2017b), growing media producers and researchers expected the growing media market to expand along with this population increase. The present authors were challenged by the International Peatland Society (IPS), to move this market expectation from an estimate based on population increase only, into a more nuanced prediction. The goal was set to deliver a prediction

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of the growing media volumes needed in 2050. Aspects to take into account were a) combining existing data into a more global estimate of volumes traded; b) taking into account restrictions in available volumes of single materials based on environmental concerns (e.g. peat), availability (e.g. coir) and user quality (e.g. compost); c) weighing of seemingly contradicting trends of population increase, stricter environmental demands, a healthier life style, increasing meat consumption, and an increase in numbers of people living in cities.

METHODS AND MATERIALS

Present volumes traded

An overview of existing estimates of the current market was tabulated as a basis to get to a global estimate of the current market for growing media and growing media constituents. We choose to describe the volume-wise important growing media constituents peat, coir, wood fibre, bark, compost, perlite, stone wool and the container term "tuff", but many more materials might have been mentioned (Barret et al., 2016). The heading "tuff" is used to describe a much wider class of mineral materials found in natural bodies and fit for use as a growing medium with minimal breaking and sieving. The reason to include "tuff" is to be aware of this form of growing media cultivation which is often poorly visible in statistics.

Potential market in 2050

A separate estimate was made of the increase in demand for a) the production of greenhouse vegetables, and b) the demand for potting soils for ornamentals. The term ornamentals is used in a broad sense, combining the consumption of cut flowers, container plants, garden plants and public green. The magnitude of increases in demand up to 2050 were founded on market surveys for vegetables (ManifestMind, 2014) and ornamentals (Simpkins et al., 2015).

The expected increase in demand was divided over a division of the world population in four distinct income classes in time, as advocated by Hans Rösling (Rösling et al., 2018). For each income class the amount of people involved and their income level in 2015 and 2050 were available. Furthermore, it was possible to find data on the present day use of vegetables and ornamentals (ISHS, 2012; OECD-FAO, 2014; Simpkins et al., 2015; Worldwide_Market_Reports, 2017). This allowed the calculation of an expected quantity needed in 2050, based on population increase, income increase and the remainder an expected trend increase.

The trends identified as driving the expected increase in vegetable demand are health awareness and product safety concern (FAO, 2014; FAO, 2017b). Health awareness is fed by a desire to fight obesities and chronic micronutrient deficiencies. At present 2.1 billion people are obese, 0.8 billion people do not have enough to eat and 2.0 billion suffer from some form of chronic micronutrient deficiency (FAO, 2017b; Voogt et al., 2010; White and Broadley, 2009). Concerns for product safety include public risk perception of chemical or microbial contaminants. A counter trend is a decrease in growing media use per unit vegetables produced.

The trends driving an increase in ornamental demand are the appreciation for the aesthetics of flowers and plants, of street views and parks (Trépanier et al., 2009) and the improvement of the home and city climate by any combination of temperature buffer, humidity buffer, rain water buffer / flooding control and air filtering (Poppe et al., 2009; UrbanAg, 2013). These trends result in both, more ornamentals in private homes and gardens (Klein Hesselink et al., 2009) and more ornamentals in the public space in cities (Xplorelab, 2010).

General trends considered were global fresh water scarcity, the increasing urbanisation, environmental awareness and the counter trend of meat consumption. The trend to reduce water consumption by agriculture from 70% now to 55% in 2050 is driven by the rapidly increasing scarcity of fresh water sources (Assouline et al., 2015). The urbanisation trend is reflected in the increase from 50% in 2009 to 70% living in cities in 2050 (FAO, 2009; Rösling et al., 2018). The increasing environmental awareness is focused on emission reduction of nitrate and phosphate. The trend to reduce the emission of nitrate and phosphate is driven by the wishes to reduce eutrophication which reduces biodiversity, to avoid the energy use for nitrate production, to avoid depletion of phosphate resources and to realise a more circular fertilisation. Increasing meat consumption was regarded as a counter trend as it significantly increases emissions and use of water and land surface and is driven by the increasing incomes.

The trend increases mentioned above are visible in Western societies and Asian mega cities but still are quite different per region (FAO, 2017b).

Market development per continent

The estimates for the market development per continent are based on figures for the greenhouse area at present (ISHS, 2012; Stanghellini et al., 2019) and on our assumptions about the part of the area actually using growing media. It was decided to go specifically into the developments in China, as China is thought to have tremendous horticultural potential as well as compelling reasons to increase the use of growing media, possibly followed by the use of recirculation of drainage solution. One major reason is the concentrations of plastic covered horticulture around some tens of China's mayor cities offering both the opportunity to build a knowledge intensive production industry as well as reason to check the emissions of water, nutrients and crop protection agents (Figures 1 and 2). The estimates for China were based on a recent report on the market situation in China (Derks and Yang, 2018), notably on the growth data reported for a large propagator over the last years. The presented annual market increase of 23% in 2015 was used to assume a linear decrease to 4.7% growth in 2050.

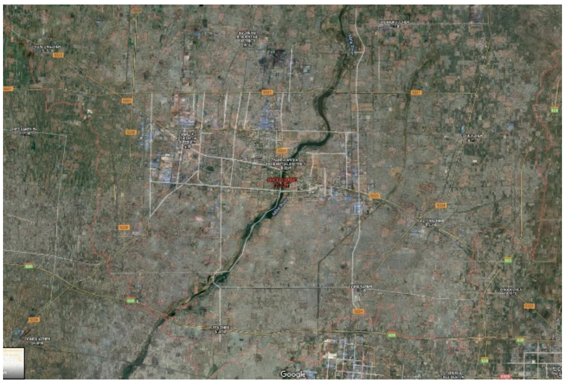

Figure 1. City of Shouguang in the north-east of China showing a small urban area surrounded by a much larger area of plastic greenhouses.

Figure 2. A detail from the centre of Figure 1 showing the change from urban housing into the plastic greenhouse production area, with individual greenhouses just recognizable.

Potential volumes available per material

Per material estimates were made of the annually available quantities. These potential quantities were based on publicly available statistics. As the potential quantities were usually not reported in Mm^3y^{-1}, most data had to be converted via several steps which included assumptions on conversion factors. Sources for both statistics and conversion factors, are mentioned in the result section. Furthermore, to allow checking the data, the conversions are detailed in tabular form. To convert the potential volumes to more realistic volumes in 2050, for each material an estimate was given of the percentage of growth these materials were expected to sustain. The total of tabulated outcomes was compared with the estimate for the potential volume needed in 2050 and the difference was interpreted as room in the market for potential alternative growing media.

Chances for alternative growing media

The market prospects of water, *Sphagnum* and biochar were evaluated as an example of possible alternative growing media or growing media constituents. The criteria to assess water, *Sphagnum* and biochar were present day interest, available volume, sustainability and end of life solution, inertness, stability and water/air supply.

Trends in technology

For growers the choice for a certain growing medium is often dictated by the technical cultivation system (Savvas and Gruda, 2018). Orchids as container plants are grown on mixtures with very high air contents such as bark/coir chips (Kerloch and Michel, 2015). The development of the ebb and flood system on floors and tables gave rise to new airy but quickly rewetting potting soil mixtures like peat/perlite and peat/coir pith mixtures (Zaccheo and Cattivello, 2009). Some trends in horticulture thus affect the use of growing media. Trends which potentially also might change the formulation of growing media include the recirculation of drainage solution, the use of organic fertilisers and the chances offered by remote growing. Recirculation requires growing media to be low in accumulating ions such as sodium, boron and fluor. Organic fertilisers increase oxygen use and therefore require better air transport properties. Remote growing might require media which can more easily be monitored by optical or other sensors.

RESULTS

Present volumes traded

Information on areas and volumes traded is shown with the sources (Table 1). These per region data were combined to arrive at an estimate of the global volume traded.

Table 1. Estimates for growing media volumes traded.

Source	EU countries	Mm^3 Peat	Period	%Peat	Mm^3 GM
Schmilewski, (2017)	16	26	2013	75	34
Schmilewski, (2009)	13	27	2005	77	35
Verhagen et al.,(2009)	EU	29	2005	75	39
Altmann, (2008)	EU	28.6	2005	77	37
Bohlin, (2002)* in Waller (2006)	8	16	2000/2001	-	-
DEFRA, (2010)	UK		2007		3.9
Waller, (2006)	UK		2005		3.6
Blok and Verhagen, (2009)	Netherlands		2005		4.4

GM = Growing Media and growing media constituents. *Original not readily electronically available: Bohlin, C. (2002).

Potential market in 2050

Table 2 shows the number of people expected in 2050 divided over four income classes. The expected increase in population number is 43%. The expected rise in world income is 74% and the trend increase, 38% for vegetable consumption and 274% for ornamentals.

Table 2. Three estimated increases in demand for vegetables and ornamentals for 2017 to 2050.

	People (Billion)	Class (c)	Income ($ d^{-1} p^{-1})	Income (B$ d^{-1})	F&V (g d^{-1} p^{-1})	F&V (kt d^{-1})	Plants (L y^{-1} p^{-1})	Plants (Mm^3 y^{-1})
2017	1	Poor	1	1	0		0	0
2017	3	Low	4	12	25	75	0	0
2017	2	Middle	16	32	100	200	5	10
2017	1	Top	64	64	100	100	12	12
Total	7			109		375		22
2050	0.5	Poor	1	0.5	0	0	0	0
2050	3	Low	4	12	25	75	0	0
2050	4	Middle	16	64	120	480	12	48
2050	2.5	Top	64	160	160	400	24	60
Total	10			237		955		108
Per capita				152%		178%		344%
World	143%			217%		255%		491%
F&V	+43%			+74%		+38%		
Ornamentals	+43%			+74%				274%

Income — Income in US dollar per day per person. Income in billion US dollar per day.
F&V — Fruit and vegetables consumed in gram per day per person. Fruit and vegetables consumed in kilo ton per day. Plants — Amount of rooting medium used in litre per year per person (L y^{-1} p^{-1}). Amount of rooting medium used in million cubic metres per year (Mm^3 y^{-1}).

Market development per continent

The expected market increase divided over the continents showed Asia is rapidly becoming the main consumer of growing media constituents with 93 Mm^3 y^{-1} of which China will eventually use much more than a third i.e. 41 Mm^3 y^{-1}. For the other continents figures are Europe 34/70; North America 17/70; South America 4/20; Australia 2/8; Africa 3/23 (Mm^3 y^{-1} for 2017 respectively 2050).

Potential volumes available per material

The quantity of peat annually available is both, the most important volume wise and the most difficult to assess. As peat is not harvested and regrown, no annual volume produced can be calculated as for the other growing media constituents. The total available volume is taken as a substitute of kinds. The world's peatland area (Maltby and Immirzi, 1993; Verhagen et al., 2009) is combined with our estimate for the average depth of this area and the dry bulk density of this mass (Table 3). The result is the staggering amount of 1130 Gt of peat ($7.5x10^6$ Mm^3). This dry weight estimate is, using a conversion factor of dry peat to carbon of 50% w w^{-1}, 565 Gt carbon. This estimate is close to the 600 Gt reported elsewhere (Yu et al., 2011; Yu et al., 2010).

The quantity of coir annually available is based on the well documented mass of coconuts harvested annually (www.fao.org.faostat; www.statista.com; www.worldatlas.com). By conversions of coconuts into coir and coir mass into volume an estimate of an annual volume of 60 Mm^3 is found. This amount is close to the estimate delivered by van Doorn in 2017 (oral in ISHS symposium on Rooting Media and Compost) and published by Bragg (Appleby, 2018).

The quantity of wood fibre theoretically available is based on the fairly well documented mass of wood harvested annually (Arets et al., 2011; FAO, 2017a). As present day production of wood fibre for growing media is mainly restricted to softwood pine, the mass is reduced in proportion to the share of soft wood pine (Arets et al., 2011). Even so the eventual annual volume of softwood pine, assuming a conversion into wood fibre, is a staggering 1200 Mm^3.

The quantity of bark annually available is derived from the mass of softwood pine harvested annually by assuming a set relation between wood harvested and bark produced (Antony et al., 2015; Miles and Smith, 2009). This delivers an annual volume of bark of 140 Mm^3.

For the quantity of compost annually available statistics per country were too diverse in describing amounts and qualities. As in many countries compost is not even separated from household waste, we decided to apply a quick and dirty approach taking the properly documented Dutch ratio between population and compost produced (Milieu, 2013), and apply that ratio globally, albeit with an estimated lower percentage for waste production per capita for most regions (Table 3, including footnotes). Thus we arrived at a global annual volume of 371 Mm^3.

The quantity of perlite annually available was based on fairly well documented global production figures (Bolen, 2011) of 1.7 Mio t.y^{-1} and 14% used in horticulture. After conversions to the density for horticultural applications this amounted to a potential annual volume of 16 Mm^3.

For stone wool no estimate of annually produced mass or volume was found, other than a potentially unreviewed marketing report (Global Mineral Wool Market Report, 2017). The turnover mentioned in the report was converted into a potential annual volume of 120 Mm^3 assuming an average price of 0.10 € per litre and the density for horticultural product (Table 3).

The heading "tuff" actually stands for a much wider class of mineral materials found in geological formations and - after processing - fit for use as a growing medium. Such materials include sand, pumice, gravels and volcanic porous gravels known as pouzzolane/picòn/lapilli. The materials are available in very large amounts in many countries and are used in building and road construction with horticultural tuff as a poorly registered by-product. Tuff-like growing media remain in place for often over 10 years. As an example we mention the practice of enarenado in Almeria (40 Mm^3 based on 20000 ha using a 20 cm layer of coarse gravel like sand). Or the cultivation of bananas on the Canary islands (9000 ha with 50 cm crushed volcanic rock of cut-out terraces; Freshplaza, 2012). Similar systems exist in the Middle East and the North West of South America, lending some credibility to our 8 Mm^3 y^{-1} estimate.

Table 3. Calculation of annual volumes possible for various of growing media (constituents), aimed at reporting in Mm^3 of ready-to-use growing media per year (Mm^3 y^{-1}).

	Area (M km^2)	**Depth** (m)	**Volume** (Mm^3)	**Density** (kg m^{-3})	**Mass** (Gt)		
Peat	5	1.5	$7.5x10^6$	150	1130		
	Nut (t y^{-1})	**Husk** (%)	**Husk** (t y^{-1})	**Density** (kg m^{-3})	**Volume** (Mm^3 y^{-1})		
Coir	$60x10^6$	12.5	$7.5x10^{-6}$	125	60		
	Trade Mm^3 y^{-1}	**S. Pine** %v v^{-1}	**S. Pine** (Mm^3 y^{-1})	**Density** kg m^{-3}	**Mass** (kg y^{-1})	**Density** (kg m^{-3})	**Volume** (Mm^3 y^{-1})
Wood fibre	1708	25%	427	400	$1.7x10^{11}$	150	1138
	Volume (Mm^3 y^{-1})	**S. Pine** (% v v^{-1})	**Volume** (Mm^3 y^{-1})	**Density** (kg m^{-3})	**Mass** (kg y^{-1})	**Density** (kg m^{-3})	**Volume** (Mm^3 y^{-1})
Bark	1138	14%	59	350	$21x10^9$	150	139
	Holland (Mm^3 y^{-1})	**Europe**[a] (Mm^3 y^{-1})	**Africa**[a] (Mm^3 y^{-1})	**Asia**[a] (Mm^3 y^{-1})	**N.America**[a] (Mm^3 y^{-1})	**S.America**[a] (Mm^3 y^{-1})	**Total**[a] (Mm^3 y^{-1})
Compost	2.0	58	12	217	57	25	371
	Mass	**Density**	**Volume**[b]				

	(t y^{-1})	(kg m^{-3})	(Mm^3 y^{-1})		
Perlite	$2x10^6$	125	16		
	Trade	**Price**	**Volume**[b]		
	(€ y^{-1})	(€ L^{-1})	(Mm^3 y^{-1})		
Stone wool	$12x10^9$	0.10	120		
	Region	**Area**	**Depth**	**Period**	**Volume**
		(m^2)	(m)	(y)	(Mm^3 y^{-1})
Tuff[c]	Almeria	$2x10^8$	0.2	20	2
Tuff[c]	Canaries	$0.9x10^8$	0.5	20	1

a The calculation involves the number of inhabitants and a reduction factor; for Holland 17 M and 100%; Europe 738 M and 80%; Africa 1216 M and 10%; Asia 4436 M and 50%; N. America 579 M and 100%; S. America 422 M and 60%.

b Assuming all volume produced would have been a horticultural grade. Actual production volumes for horticulture are about 1.5 $Mm^3.y^{-1}$ for perlite and 1.0 $Mm^3.y^{-1}$ for stone wool.

c Not a global total but two examples showing Almeria, Spain and the Canary Island, Spain.

Once the potential possible volumes were known (Table 3), a next step was to estimate to what extent each material might contribute to the envisioned potential market in 2050 (Table 4).

It is assumed that the main constituent so far, peat, can increase the annual volume with 200% by 2050 but this is less than half as fast as the market expands. The debate is still raging but it might be that European production will halt at the present level with Canada still expanding and possible new production from e.g. Siberia or Mongolia. Coir is a proven high quality peat alternative, resulting in an already a fierce competition over the available sources. Some part of the coir produced will be bought for non-horticultural uses i.e. the quantity available for growing media production is maximised below the potential 60 Mm^3 available. The growth rate of the market is expected to be met by coir (418%) but most growth will be in the next decade and less so in the years closer to 2050. Wood fibre is in a position to grow faster than the market and to deliver the required volumes. Even so wood fibre producers will have to work on the desired quality properties to benefit of the market demand peat and coir cannot fill. Bark can follow the market increase, but only if bark producers overcome some recent and persistent quality issues with plant diseases, pests and fungi. Compost use is increasing but predominantly as a low cost peat alternative in relatively small percentages and never as a sole growing medium. Perlite may be able to surpass the market growth, despite being a niche product for relatively high tech ebb and flow systems. Stone wool is mainly used in vegetable production and therefore cannot grow as fast as the total market but still faster than the vegetable market. The use of "tuff" will also expand due to its availability at low prices but the increase is slower than the market growth as tuff is often used for 10-30 years before the cultivated material is replaced with new material. All in all this leaves a gap of 65 $Mm^3.y^{-1}$ which may or may not be filled by other materials.

Table 4. Total estimated market in 2050 based on the expected market increase (Table 2) and a more realistic estimate of the potentially available materials (Table 3).

	2017	**2050**	**Increase**
	(Mm^3 y^{-1})	(Mm^3 y^{-1})	%
Peat	40	80	200%
Coir	11	46	418%
Wood fibre	3	30	1000%
Bark	2	10	500%
Compost	1	5	500%
Perlite	1.5	10	667%
Stone wool	0.9	4	433%
Soils / tuffs	8	33	413%
New		65	
Total	67	283	

Chances for alternative growing media

Water culture is an accepted growing medium with a track record for the production of lettuce and herbs (Barbosa, 2015). The availability for growing media applications is limitless and water can easily be reused. Drawbacks at present are severity of infections and the need to control oxygen supply and distribution (Blok et al., 2017a; Meador et al., 2012). The term water culture is synonymous to hydroculture and used here to avoid confusion with hydroponics (hydroponics meaning water culture in e.g. Europe but including growing media cultivation in e.g. the USA).

Sphagnum is a genus of plants which, when dead, makes up most of the peat material found in raised bogs. Living *Sphagnum* (peat moss) can be harvested from the top of pristine mires or from re-growing peat extraction areas in paludiculture. *Sphagnum* is already in the market as potting soil constituent and as slab for fruit vegetables (e.g. Novarbo, Eura, Finland). It is regarded as part of a sustainable greenhouse system (Verhagen et al., 2009). The volumes are however still very small. Every 20 years 0.2 kg m^{-2} y^{-1} *Sphagnum* is harvested (dry bulk density is 20 kg m^{-3}).

The suitability of biochar as a horticultural growing medium (constituent) is still debated. The quality is incidentally sufficient for use in mixes up to 50% v v^{-1} (Di Lonardo et al., 2017). The quality however requires most factories producing biochar to redesign their process to meet the demands of biochar use in horticulture (Blok et al., 2017b).

Trends in technology

Recirculation of drainage solution is an opportunity for authorities to substantially decrease water use and nutrient use per unit crop as well as to prevent the emission of nutrients and crop protection agents into the environment. The monetary advantages for individual growers are relatively small compared to the required knowledge and the risks of mistakes. The ban on methyl bromide in the Netherlands, Europe and many other countries illustrates how government intervention can speed up acceptance (Minuto and Garibaldi, 2005; UNEP, 1999).

The conversion from chemical / non-renewable fertilisers to organic or rather more renewable fertilisers is a large future challenge of mankind (Hajdu et al., 2015; Motesharezadeh et al., 2017). Greenhouse horticulture may be in a position to pioneer novel circular but highly technical fertilisers (Blok et al., 2017c) in combination with full recirculation of drainage solution.

Increasingly it turns out that the very high level of skills required to independently operate a greenhouse by automated climate and irrigation settings cannot be met; there are simply not enough growers with the required skills in the world. On the one hand this leads to increased training (Brunsting, 2019), on the other hand growing systems are increasingly combined with electronic cultivation monitoring and remote advice (Hemming et al., 2019).

DISCUSSION

Present volumes traded

The present data are to a large extent provided by the industry. The sentiment of individual growing media producers is, these figures are rather low. Data for Europe and North America are available but in other continents relatively large volumes already used may have been overlooked. Furthermore it is difficult to get proper estimations of the various sub markets (e.g. consumer growing media, mushroom casings, propagation, tree crops, nurseries) without getting some overlap in data. Even so the general figures in Table 1 are deemed reliable for our purpose.

Potential market in 2050

The estimates for the potential market in 2050 were based on market prognoses for vegetables (ManifestMind, 2014) and ornamentals (Simpkins et al., 2015). These market prognoses are offered as commercial products and can thus only be checked after paying a substantial fee. The prognoses were rudimentary cross checked against the increases in greenhouse area available. As far as these prognoses were not running up to 2050, we took the annual growth figures for the present day market and assumed these would linearly decrease in time, reaching 0 in 2050 for vegetables but 5% for ornamentals. It stands to reason the vegetable market will top off as the per capita consumption is physically limited which is not the case for ornamentals. The developments in the vegetable market may be underestimated as the figures include outdoor vegetables and the use of growing media in greenhouse growing is increasing faster than the outdoors application. The large increase of the ornamental markets is favoured by the relatively low per capita use of growing media at present and the lack of an immediate physical reason to limit the per capita use of growing media for ornamentals.

The most solid contribution to the market increase prognosis is the 43% population increase, as many of those economically active in 2030-2050 are already born (FAO, 2014).

The contribution of the income increase is 52% per capita (117% for the total world income). The 117% increase includes the effect of a 43% population increase, divided unevenly over the income classes. The expectation of income increase we adopted is based on FAO and WHO findings (Rösling et al., 2018). Obviously disruptions like global war, climate change and epidemics could all negatively influence the expected income development whereas developments more positive than expected are much less likely. Nevertheless the income increase predicted for the world as a whole already happened in north-west Europe (1900-1950), Sao Paulo province in Brazil (1950-1990) and coastal China (1970-2000).

The expected 38% extra trend influence for fruit and vegetables seems plausible based on an expected lasting demand and attention for healthy and safe food. The expected 274% extra trend influence for ornamentals is much harder to support from the now visible trends in the appreciation of green environment with regard to quality of life. Nevertheless we believe the 70% of the population living in the cities in 2050 (FAO, 2009), combined with a clear increase in living standards, will translate itself in more parks, green buildings, improved indoor and city climate and more rain water buffer). Trends which for vegetables decrease the volume of growing media are the yield increase per unit growing medium (Higashide and Heuvelink, 2009) and the decrease in volume of growing medium used per unit area. For ornamentals growing media remain part of the product delivered to the customer and thus production increase just increases the demand.

Of trends not included we mention the increasing use of rooting media for new crops as berries and marihuana and government intervention such as bans on chemical crop protection.

Population, income and trends were split in 43% by population increase, 74% by income increase and 38% and 274% by trends for vegetable consumption and ornamental consumption. In reality the contributions are interdependent and the split is to be considered an illustration.

Market development per continent

The developments per continent show the European and American markets increasing but slowing down in Europe and North America, the Asian market expanding the fastest and widest and the African market expanding but not yet reaching its full potential. The African developments are at the moment discussed: present day growth is indeed encouraging (East Africa, West Africa) driven by foreign capital, but structural growth is expected to still meet considerable problems (Frankema and van Waijenburg, 2018). The estimated annual market for China is 41 Mm^3, which is considerably lower than the 150 Mm^3 estimated by the Chinese sources mentioned (Derks and Yang, 2018). Reasons for the difference include our exclusion of the huge markets anticipated for rice propagation and soil amelioration and fertilisation.

Potential volumes available per material

The area figures for peat are based on well validated remote sensing techniques. The most uncertain parameter in our approach is the estimate for depth of the layers. The second uncertain parameter is the implicit assumption of proper horticultural quality of the peat in the layer. Deep mires may be almost 100% w w^{-1} of growing media grade organic material but many shallow layers are intimately mixed with minerals or non-*Sphagnum* plants. Apart from that some peats are too acid, too saline, too degraded or too degradable. Even so the main question is if peat use for horticulture will be condoned by the authorities for much longer (Verhagen et al., 2009). In most of Europe authorities are already restricting the use of peat (Appleby, 2018; Barrett et al., 2016; Carlile and Waller, 2013). The debate in Canada, Scandinavia and Russia (including Siberian stores) seems more inclined to allow some harvesting under strict conditions. This results in the questionable assumption that the global use could double to an annual volume of 80 Mm^3 up to the year 2050. This volume will rapidly decrease if the public debate dictates restrictions.

The amount of coir available is thought to be a credible figure which will not react to changes in demand for this growing medium constituent as coir is not produced for the sake of growing media but for the production of oil or copra. Furthermore some competition for the fibres exists with other uses for coir fibres. This means the bulk of coir will be used as a growing medium but the quantity will not be enough to meet the global demand.

The amount of wood fibre is a reasonable estimate and clearly enough to meet the increased market demand. Obviously some competition will occur between other uses such as the furniture boards market but the production volume required should not disrupt the wood market. It might even give rise to the development of other wood sources besides the softwood pine this survey was restricted to. The volume of bark available is 50% of the expected market but given the dry nature of bark in potting soils it is not expected to be more than one of the possible constituents so no volume problems with regard to bark are expected.

Of the calculated amount of compost we estimate less than 5% can be used in horticulture as the other 95% is too saline, too dense, too wet, contains human pathogens, plant pathogens, heavy metals, toxic compounds, impurities etc. Even the remaining 15 Mm^3 is not yet on the market. We believe compost will play a marginal role as a cheap component of potting soils though it can be an important additive to carry or boost microbiological activity (Antoniou et al., 2017).

The amounts of perlite and stone wool available are of little consequence as both materials are man produced in factories and the production capacity can rapidly follow the demands.

The use of "tuff" like materials will remain an alternative for quite some years to come as in many places the material is easy to obtain and the price is low. Higher value crops, including the propagation stage of less expensive crops, will move on to a higher quality of materials.

Chances for alternative growing media

Of the three materials discussed, peat moss harvested in paludiculture is the least likely to rapidly become a volume wise important growing medium. This assumption is based on the large area needed to produce a significant quantity. Based on the previously mentioned dry weight production of 0.2 kg m^{-2} y^{-1} and a dry bulk density as growing medium of 100 kg m^{-3}, an area of 500 km^2 would be needed to produce 1 Mm^3 y^{-1}. Water culture is however a real opportunity and is already steadily increasing in area. Plant factories and highly automated greenhouse production systems for lettuce and herbs attract the capital needed to further develop the systems. Biochar at present is still a dark horse for only when the bio-based economy takes off and the production of bio oil and bio gas via pyrolysis remains the backbone of the bio-based industry will the expected massive quantities of biochar reach the market (Nowicki et al., 2008).

Apart from the examples mentioned, the rapid increasing market and the fast development of increasingly robust growing systems means there is still ample opportunity for alternative growing media and growing media constituents. In Table 4 the class "New" indicates the room the market offers for not yet identified alternatives.

Trends in technology

A first and important potential trend is the recirculation of drainage solution. Once growing media systems are installed, it is very easy and cost effective at low investments to collect and reuse drainage solution. Nevertheless recirculation of drainage solution is only routinely done in the Netherlands albeit by force of law. At present virtually all growers worldwide decide that the risks involved such as invisible accumulation and or depletion of elements and spreading of diseases, far outweigh any reduced costs and increases in yield. Growing media producers may, using their advisory experience, play a role in such a knowledge intensive transition.

A second potential trend is the desire to abandon chemical / non-renewable fertilizer sources and convert to using fertilisers of a more circular nature. This transition, again, would require a massive amount of knowledge and new technology. Growing media producers are in a position to use this development to their advantage.

The interest in autonomous growing in controlled environment agriculture the last five years is clear and attracted the attention of global companies and capital investors (Jackson, 2015). Even though such systems often claim to be water cultures, the amount of growing media used (for propagation) is surprisingly large because of the fast growing cycles and the multiple layers in cultivation. Again growing media producers are in a position to use this development.

CONCLUSIONS

The global growing media market nowadays delivers about 67 Mm^3 of growing media annually and is expanding (Table 4). The increase could potentially be four-fold between 2017 and 2050. Reasons include population growth, global per capita income growth, health arguments in favour of vegetables and quality of life arguments in favour of public and private ornamentals. The highest per continent use is expected to shift from Europe and North America to Asia. Growing media systems can contribute positively to society for they potentially serve to make production of vegetables and ornamentals more sustainable, less area demanding and the products contribute to health and quality of life. The developments can be faster than expected when trends and technological packages match and when the societal advantages of recirculation gain wider support. The developments can be slowed by any disaster with economic consequences or by any disqualification of growing media and growing media systems in the public eye.

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