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Exploring the contribution of vertical farming to sustainable intensification from the point of view of the innovator and the farmer

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Contents

Abstract

The innovation that is vertical farming has attracted significant attention in the popular media, yet there is lack of understanding of farmers' perception of its potential to contribute to sustainable intensification. Using the case-study method combined with information from conferences, technical journals, radio interviews, and triangulated with information from specialists, this working paper attempts to discover links between potentially higher yields (intensification) and minimised environmental impacts and, with a focus on indoor horticulture in a UK context, how commercial growers translate sustainable intensification into practice. Critical assessments reveal the importance of a holistic view of the farm when considering environmental sustainability, plus an important role for plant health in minimising environmental. Moreover, etymological differences between academia and practitioners with reference to total yield and saleable yield have been observed, once understood, these can help us better understand how sustainable intensification can work in practice, from the point of view of practitioners of vertical farming.

Key words: sustainable; intensification; vertical; farming;

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1. Introduction

The objective of this working paper is to explore the practices of vertical farming, and consider the potential of this method for farm-scale contributions to sustainable intensification, thus increasing production without further damaging the environment Pretty (2008, 2016, 2014b, 2010, 1997). Sustainable intensification relates to the relationship between farming and eco system services and is part of the land sparing paradigm debate, where there can be a trade-off between agricultural production and an ecological benefit such as species conservation (Gunton et al., 2016) or biodiversity.

Using the case study method to follow a company that has developed a vertical farming system suitable for commercial growers and the early adopters of the system, this working paper attempts to find links between potentially higher yields (intensification) and minimised environmental impacts. Differences between how sustainable intensification is seen by practitioners of vertical farming and how it relates to the academic literature on sustainable intensification in agriculture are critically assessed within the context of indoor horticulture in the UK with the aim of better understanding of how the concept works in practice at farm level. Intensification in agriculture is traditionally defined as increasing yields per unit of land, increasing cropping intensity (such as growing more crops per unit of land or other input, e.g. water) or growing higher value crops (Pretty and Bharucha, 2014a), with which may be achieved principally by technological change to improve efficiency of resource use. Previous periods of intensification (such as the Green Revolution) are generally considered to have compromised the environment (Pretty and Bharucha, 2014b), and there has been a search for alternative ways which reduce this damage and are more sustainable (Pingali, 1995).

Sustainable intensification, as a concept and a guiding principle, has been widely adopted by international research and policy organisations such as the Consultative Group on International Agricultural Research (CGIAR), the Food and Agriculture Organisation of the United Nations (FAO), the World Economic Forum (Davos, 2012), the Montpellier Panel (2013) or the Sustainable Development Solutions Network (SDSN, 2013), and by national policies such as the ‘Feed the Future’ program of the US Government. The term is now also widely employed in the agribusiness world or by large international donor organisations, although there are variations in interpretation (Pretty and Bharucha, 2018). Another term that is closely associated with these ideas is eco-efficiency, or producing more value with less impact, which was first coined around the time of the Earth Summit of Rio in 1992 by the World Business Council for Sustainable Development (WBCSD) (Tittonell, 2014). Critics of sustainable intensification see it as a Trojan Horse (Garnett and Godfray, 2012), a way of bringing in technological changes in agriculture which have been developed by large commercial ventures to continue ‘business as usual’, and are not compatible with environmental needs (Collins and Chandrasekaran, 2012). This view may partly be a result of the Foresight Panel (Godfray et al., 2011) not excluding technology as a means of achieving it, thus there could also be claims SI has been adopted by commercial organisations marketing biotechnologies, pesticides and fertilisers. The concept of sustainable intensification is itself open to debate, as there are no set goals to measure economic efficiency nor environmental sustainability (Godfray, 2015, Godfray and Garnett, 2014).

While ‘intensification’ is generally accepted to be connected to productivity (including yield and/or food nutrient levels) per unit of land area, the definition of the term ‘sustainable’ has been the subject of much debate from a broad spectrum of perspectives. It is generally agreed that it is making the most of environmental goods and services while not degrading them so future generations are unable to benefit from them and is "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (Brundtland, 1987pp 8-9). In the agricultural context, sustainability is made up of three dimensions: environmental, social and economic (Struik and Kuyper, 2017); while this study is mainly focused on the former, the others are also taken into consideration. In the context of environmental sustainability, there is also a broad spectrum of attitudes regarding ‘weak’ and ‘strong’ sustainability. In the former, natural and man-made capital are combined, with importance being given to the total availability, whereas natural capital is non-negotiable for strong sustainability (Neumayer, 2007). This is particularly relevant to this study because vertical farming uses man-made capital to provide food, and therefore arguably well-being to the population, through the use of man-made capital as well as natural capital. Combining sustainability and intensification together as one umbrella concept has further challenges and there are concerns that productivity has been ranked above sustainability in the context of biodiversity and social benefits (Whitfield et al., 2015, Godfray, 2015). On the other hand, any trade-offs which result in lower productivity per unit of land could lead to more land being used for agriculture and are also subject to debate (Godfray, 2015). However, Franks (2014) argues that the Foresight Report (Godfray et al., 2011) does not mention bringing more land into production.

Moreover, in addition to debate centred around these concepts, measuring the extent of intensification of food production can also be difficult. Debate centres around yield gap analysis or land-use analysis (Dietrich et al., 2012). Nevertheless, the most common metric for measuring intensification remains relatively simple: yield per unit of land (Smith et al., 2017). Commercial yield (which is the produce which is of sufficient quality to be deemed acceptable by the customer) also needs to be considered as it is deemed crucial for professional growers. Sustainability is more problematic because it can include elements which are measurable (such as pesticide usage) but also those with social elements. To measure improvements in sustainability there are a number of assessment tools which work at different hierarchical levels (de Olde et al., 2017), going from the abstract, to specific themes, and indicators. These include Sustainable Assessment of Food and Agriculture Systems Response Inducing Sustainability Evaluation (Häni et al., 2003) Public Goods Tool (Gerrard et al., 2012), and Indicateurs de Durabilité des Exploitations Agricoles (Zahm et al., 2004). Complexity brings further challenges; there are concerns about the validity of conclusions that can be obtained from such a wealth of variables. To address this Firbank (2013) suggests using a simple way of assessing sustainable intensification that encompasses a small number of variables placed under group headings rather than trying to asses them individually. These comprise measures taken from five ecosystem services: biodiversity, air quality, climate regulation, water quality and agricultural production. This broadly is in agreement with the views of Pretty, who goes further by noting that measuring everything quantitatively is not always possible as factors connected with social capital such as trust, social connections, human capital and innovation are not measurable in this way (2008). Notwithstanding, a later study considers that any reduction in environmental damage could be considered a move in the right direction for sustainability (Pretty and Bharucha, 2014b), thus reducing the need to measure all the variables precisely.

Identifying resources which can be used to intensify production is crucial to success (Pretty and Bharucha, 2018). To achieve substantial improvements in productivity, agricultural systems have to be devised to enhance growing conditions and make the most efficient use of resources such as water. In this context innovation emerges as critical to developing new combinations of technology and resources, such as those for vertical farming sector. The concept of vertical farming, which extends plant cultivation into the vertical dimension (Touliatos et al., 2016), has the potential for higher yields, and therefore may provide a means for achieving a higher degree of intensification. This type of farming is usually undertaken indoors in glasshouses (greenhouses) or polytunnels or it can be on buildings (retro-fitted or specially constructed) and therefore the crops grown are less dependent on the weather. Plants can be grown in modules which have a growing medium inserted rather than soil (hydroponic), which allows for greater precision when applying nutrients and plant protection products than when done outside. Thus, innovation may be assumed to be implicit in the hardware used for growing the product, such as the ways of delivering plant nutrition to the crops grown vertically or by diffusing the light in such a way that the plants at the bottom of the stack receive sufficient light for photosynthesis to grow at a similar rate and to a similar quality to those at the top. Any of these could be considered to be the value offering. For example, Despommier (2010, 2009, 2012, 2008) proposes a concept of vertical farming which is stacking high-tech greenhouses on top of each other and claims a number of benefits, including higher productivity as crops can be grown throughout the year, reduction in water use, reduced use of pesticides and herbicides. Nevertheless, a weakness in Despommier's promotion of vertical framing is the lack of information on methods to achieve these benefits or evidence to show the farming technique fulfils the advantages so there are challenges about the validity of some of these claims (Specht et al., 2013, Specht et al., 2015, Thomaier et al., 2014). Nevertheless, vertical farming, through the use of the vertical plane for cultivating plants and crops, could have the potential to contribute to sustainable intensification, but part of the challenge of studying this concept of sustainable intensification is lack of guidance on how it can be achieved, or even an indication of which technologies or organising principles should be used (Tilman et al., 2011). Therefore, there is a need for empirical exploration of how this system operates in real-life farming operations to better understand how sustainable intensification may function in practice.

This working paper explores how vertical farming may provide one of the potential pathways towards sustainable intensification of fruit and vegetable production at a commercial scale. To explore behind the rhetoric of vertical farming, the case study method of a practical application of vertical farming technology in a commercial context has been used; this is important because in many cases research has resulted in systems only suitable for research stations (Pretty, 1997, Carter, 1995). Sustainable intensification can only be achieved by numerous farms contributing towards higher production without compromising the environment. Contributions towards this can entail greater efficiency within different aspects of agronomy and growing systems, in addition to reducing waste not only of inputs but also product rejections due to mechanical damage, pest and disease, and failure to meet customer specification. Nonetheless, despite these differences and challenges, a study of 286 farm-level projects undertaken by Pretty and Barucha (2018), it was found that that there has been progress towards sustainable intensification across farms in both developed and developing countries.

Decisions guiding which sustainability indicators to use depend on their relevance to what is being assessed; those aimed at arable and livestock farming differ quite widely, and as yet there is no guidance for vertical farming in a protected crop (grown in a greenhouse or polytunnel). Nevertheless, as this working paper is focused on sustainability at farm (micro) level, it will be important to use a tool that is focused at this level. Gunton and Firbank (2016) have categorised four alternative versions of sustainable intensification: agronomic efficiency, agronomic sustainability, global efficiency and global sustainability. As the former two are key to farm level, they provide a guide for our framework. Pretty (2018) emphasises the importance of best use of resources to achieve better efficiency at farm level, advocating the adoption of new technologies such as hydroponics, to intensify their use. This includes avoidance of unnecessary inputs, minimising greenhouse gases, effective use of clean water, but there is no single composition, and these can be considered indicators of the farming enterprise moving towards sustainability.

Farmer values and attitude towards sustainability may also play a role; their understanding of what sustainability means may vary including what they consider the problem to be and the challenges in overcoming them (Garnett and Godfray, 2012). As a result, prioritisation of the objectives they are trying to achieve may vary from farmer to farmer according to their perception of viability of the practices necessary for conservation agriculture. In many cases, they may underestimate or even deny the environmental risks (Silvasti, 2003), following the ‘productionism paradigm’, although it may be necessary to exercise caution by taking context into consideration (Coteur et al., 2016, Silvasti, 2003).

The successful trial of a vertical hydroponic growth system for Pak Choi at a polytunnel operated by Valefresco is mentioned on p26 in the UK Government’s 25-year Environment Plan (2018) as an example of sustainable intensification. The report highlights that this method of growing “*has demonstrated between a three- and four-fold increase in crop yield on the same land area, with reduced input requirements (water, fertiliser and pesticides) and improved crop quality”.*

2. Materials and Methods

To explore the potential of vertical farming to contribute to sustainable intensification, a case study approach has been used for this research with the aim of using a case study to gain insights into commercial firm perspectives on sustainable intensification and to learn about implementation of vertical farming in practice. It has the aim of better understanding of commercial firm perspectives on SI and to learn about implementation of vertical farming in practice as their business develops. The case study consists of an innovative company, Saturn Bioponics, which has developed a tower method for growing fresh fruit and vegetables (called the Saturn Grower). Two farms which are early adopters of this system, Manor Farm Fruits and Valefresco, are being used as key informants. Key reasons for choosing this enterprise include the company’s active status, accessibility and amenability to participating in the study.

The innovation (the Saturn Grower) comprises modular towers with spaces to plug the plants in, and uses a hydroponic (soilless) growing system. Fertigation (delivery of nutrients and water to the plant) is done by pumping the water and nutrients to the top of each tower, which is then allowed to drip through each module so all plants receive the correct amount of water and nutrition for maximum yield. There are both ‘hardware’ and ‘software’ aspects to the innovation, and it could be described as a dynamic phenomenon as Saturn Bioponics has continued developing not only the modules, but also has created a management system which is run remotely from the company’s headquarters in Birmingham, and is capable of turning irrigation on or off, the need to turn heating on etc. (for more details see Appendix 1).

Due to its complexity and challenges, a precise definition of sustainability, and hence sustainable intensification, results in it being notoriously difficult to measure (Pretty, 1995). This is because systemic, transferable indicators which characterise the ecosystem and its relationship with agriculture are difficult to find. As the physical measurements were taken by the case study companies themselves, for this assessment it was decided to use the simple change in yield per unit of land as one unit of measurement, as described by Smith (2017) (see Table 1).This is because it is arguably the main driver of intensification from the grower’s point of view, but also take into account reasons behind the increase. It is important to emphasise here that farmers are focused on increasing the saleable yields they produce so they can earn sustainable profit margins and this is reflected in the data as each interviewee refers to this. The yield data collected by Saturn Bioponics, which has been triangulated with that from an independent paper produced by Touliatos (2016) about similar methods of growing, and coded to look for alignment with sustainability criteria. The results are combined with data on sustainability provided trade certification bodies such as Linking Environment and Food (LEAF). However, previous data about farm efficiency prior to trialling vertical farming with the Saturn Grower is not available and Valefresco and Manor Farm may have been already be working close to their production frontier with only a small margin for increasing yield in the way they were previously working (Neumann et al., 2010), so opening up to work in three dimensions may have made a significant difference to their yields.

Given the complexity of sustainable intensification discussed above, the evaluation framework for assessing alignment between sustainable intensification and vertical farming has looked to advice and elements from academia and the agricultural industry. This framework for this work is based around the overarching theme of agronomic efficiency and sustainability coined by Gunton (2016) and discussed above. Moreover, it attempts to remain simple by keeping to just a small number of variables which group related factors together, as advocated by Firbank (2013). These have been complemented by practices to take into consideration when looking at sustainable agriculture defined by Pretty (2008) and include integrated pest management, integrated nutrient management, conservation tillage practices, agroforestry, aquaculture, water harvesting, and integration of livestock with arable farming. However, while integrated pest management, nutrient use, and water harvesting are relevant to the hydroponic growing methods used with the vertical farming equipment in this study, the others are not. As a result, in addition to the case study companies' data, this study has also included some of the sustainable practice criteria used in the Linking Environment and Food (LEAF) certification scheme, as explained below. This has broadened the information base as the yield measurements were done by Saturn Bioponics so this source has been supplemented by information on vertical farming in technical trade press in addition to interviews with others in the sector. Together they form a basis for reviewing the environmental criteria relevant to a system such as the Saturn Grower because the LEAF certification criteria take account of the whole farm and not just the proportion under cultivation, thus including hedges, grass margins which are not used for farming but which have potential for providing habitats for vertebrates and invertebrates. The study looks for potential improvement of sustainability, following Pretty and Bharucha (2014b) who assert that it is not important to have accurate measurements, as any improvement is a step in the right direction.

Table 1 below shows brings together the criteria for sustainable intensification from Pretty and the LEAF certification scheme, with a simple increase in yield considered to be a contribution to intensification (Smith et al., 2017). However, while some of the criteria are relevant to vertical farming, others such as soil health, are not because the crops are not planted in soil but grown hydroponically on a medium such as clay balls.

Table 1: Building blocks for potential alignment between vertical farming and sustainability

Criteria	Alignment potential
Increase in yield	✓
Decrease in crop waste	✓
Decrease in pesticide use	✓
Nutrients/Water efficiency	✓
Land suitability	✓
Soil health	x
Biodiversity	x
Lighting/UV for photosynthesis	✓
Carbon footprint	Variable

Agro-ecological system	x
Relationship with the whole landscape	When whole farm-scale is taken into consideration
Livestock Integration	x
Aquaculture	There is potential integration for this to work with vertical farming

Source: compiled by authors, based on Pretty (2008) and LEAF (2018)

LEAF inspections evaluate the sustainability of its members' production methods. Its criteria are useful for this study because they are more stringent than government regulations on environmental management in areas such as buffer zones, integrated pest management, nutrient management, pollution control and energy efficiency. This makes a useful proxy for measuring the extent of the environmental impact of the vertical farming system. This certification is voluntary and, at this stage, although Valefresco, as a supplier to fresh produce and packers, is LEAF Marque certified, the other companies in the study are not. Nevertheless proof of concept can be determined by assessing whether the method of using the Saturn Grower is acceptable for certification by examining their criteria against those used for standard LEAF certification (LEAF, 2018). It should be noted that although there are a number of organisations providing certification, including the British Retail Consortium (BRC), Sedex and supermarket schemes (e.g. Tesco Nurture), which audit food producers and the supply chain for compliance in areas such as health and safety, labour rights and traceability, LEAF was chosen because it is more centred on environmental sustainability than the others and takes a whole-farm focus in addition to providing a platform for knowledge exchange between innovative farmers. The criteria from the published standard of its published standard audit papers make a useful base for helping to understand on-farm sustainability (LEAF, 2018). Table 2 (below) details the certification criteria applied by LEAF for exploring the links between vertical farming methods applied by Saturn Bioponics.

Table 2: LEAF marque certification criteria for Integrated Farm Management

Criteria	Benefits	Applicable to vertical farming
Organisation and Planning	Identification of what needs improvement, drive forward improvement and chart progress	Yes
Soil management and fertility	Optimise soil health for yield and maintain/improve biodiversity	No
Crop Health and Protection (Pesticides)	Clear documented policy showing strategies to IPM and conventional, cultural and biological means of controlling pests and disease	Yes
Pollution Control and By-Product Management	Reduce, reuse and recycle; use of carbon footprint tool to understand environmental impacts	Yes
Animal Husbandry	Animal Welfare and Health, protection of resources and optimisation of grass production	No
Energy Efficiency	Optimisation of yields rather than maximisation	Yes

Water Management	Optimisation of water use for crop while reducing leakage and environmental impact from Its discharge.	Yes
Landscape and Nature	Aims to enhance the farm and encourage greater biodiversity and enhance landscapes on the farm, and the protection and maintenance of archaeological or historical sites.	Yes
Community Engagement	Regular communication and participation with local community initiatives to communicate a balanced and positive approach to farming.	Yes

Source: LEAF Marque Standard Audit (LEAF, 2018)

To complete the assessment and include the intensification, the above factors have been added to those assessing commercial yield (including crop quality aspects) by looking at agronomic efficiency (Gunton et al., 2016). Resilience, input efficiency and yield variability also form a framework for assessing intensification.

The material under analysis here has been collected from a series of interviews, emails and telephone calls, observations from visits to the site owned by the innovator, including an experimental station and also the farms of the two early adopters (see Appendix 1). Where possible, direct observation and exploratory face-to-face interviews took place with stakeholders, with field notes being taken. When this was not possible, interviews were held by Skype or over the telephone. The aims of these interviews were:

- To obtain an expert/practitioner view of sustainable intensification and its importance to the business;
- To observe and discuss the agronomic methods used for putting sustainable intensification into practice;
- To explore how these sustainable intensification practices are communicated to

others, for example through marketing literature and activity or conferences.

This has been complemented with information from company literature and websites, articles in the technical press, conference speeches and award nomination forms (see Appendix 2). The advantages of this method have been to obtain the views and reflections of the actors but the disadvantage is that the information was not independently collected. To overcome this, other players outside the case study parameters have been interviewed, such as the growers using the Saturn Grower system, and this has also been triangulated by drawing on independently collected data on yields using a similar system to the Saturn Grower which had been published in a peer-reviewed journal by the Association of Applied Biologists (Touliatos et al., 2016).

The information gathered from direct sources has been complemented by analysis of presentations at conferences by Saturn Bioponics and other technical specialists in horticulture/vertical farming, technical magazine articles, press releases and marketing materials to help reveal further information on the practicalities of environmental sustainability in an agricultural context, plus printed information from LEAF on requirements for certification to triangulate the data concerning this early adopter. Agronomic data gathered from early trials on Saturn Bioponics' hydroponic system published by the Association of Applied Biologists (Touliatos et al., 2016), was also assessed to triangulate information given in interviews. All the data was digitised and imported into the qualitative analysis software package NVivo, key words determined and coded thematically for both intensification and sustainability. For the environmental theme, words included 'water use', pesticides, recycling and their synonyms, while for intensification 'yield', 'saleable crop' and 'productivity' were sought. The collected information was then scrutinised for patterns (Miles and Huberman, 1994) to identify potential areas where the Saturn Grower could contribute to sustainable intensification at farm scale and thereby be aligned with this concept at farm level.

3. Findings

This section presents the elements of vertical farming in which there is the potential for alignment with sustainable intensification.

a. Attitude towards sustainable intensification

Discussions with Saturn Bioponics and Valefresco to explore their attitudes towards what they consider to be sustainable intensification has identified key responses to show sustainability to be of high priority by providing a "*safe food supply with lower chemical inputs*" (See Appendix 1 Table 6, 12 April 2016 Ref: SB05). When taking both sustainability and intensification together, Saturn Bioponics CEO highlights the concept to be about "*producing more with less"* and thus draws attention to the importance of using "*more space which becomes available in the three dimensions*" of vertical farming

(Ref: SB05). To achieve sustainable intensification factors to consider include financial sustainability, as the grower needs to make a profit to remain in business. If this comes under threat, *"ethics do not enter into it commercial pressures are enormous*" (Ref: SB05), when considering the environment. Therefore, there is a clear view that "for sustainability there needs to be profit through productivity" (CEO Saturn Bioponics 24th June 2014, Ref: SB01), and this has been corroborated in more recent interviews with the company (13 December 2018 Ref: SB19).

Secondly, elements of the diverse nature of sustainable intensification and the different needs became apparent in the time Saturn Bioponics took to develop the Saturn Grower*: "work has been slow at the beginning to get things right for the farmer and the environment*" (Ref: SB05). This led the company to take its time in creating a system which can provide a return on investment for the grower as well as minimising impacts on the environment. To achieve this the company emphasises the importance of its work "c*ollecting data on resource use and associated costs*", which included chemical inputs for nutrients and plant protection. The latter proved challenging because "*intensification can mean higher rates of pest and disease, so good solutions are needed to control diseases*" (Ref: SB05) This concurs with the view of horticultural agronomist Chris Wallwork, as pests and diseases can move quickly through mono-cropped areas (BCPC Pest and Diseases conference 12 October 2018, Ref: M19) Nevertheless, the confidence held by Saturn Bioponics' CEO in the ability to provide a product which facilitates sustainable growing practices evident: *"All waste needs to be properly recycled, and if the Saturn Grower were not a clean and recyclable system I would not promote it*." (Interviews April 2016, December 2018 Ref: SB05, SB19).

b. Exploring the potential for sustainable yield increases

Detailed information from trials undertaken by Saturn Bioponics and presented at the GrowQuip Conference 2017 (Table 7, Ref: SBC01) showed single-cut yields doubled in size, (reaching 3.25 kg/sq. m compared with 1.6 kg/sq. m using a gutter system), thus showing an increase in production per unit of land. Data from early adopter Valefresco, who installed a system for pak choi production, also shows an increase in yields from 3kg per square metre to 11.5kg per square metre per crop cycle (see Appendix 2 for more details). These results are similar to those revealed by a similar company, Aponic, whose trials (held at both commercial scale and smaller scales), have shown an increase in vigour in a number of crops such as spinach, lettuce and pak choi, again impacting on yields (Ref: AP01). An extra crop of late strawberries harvested in October was achieved by Manor Farm Fruits, who were using Saturn Grower system for their strawberry plants for the first time (Vegetable Farmer article October 2016 p19, Table 7,Ref: SBP10). Yield data from the Elsanta Light Weighting Bed plants showed an increase of nearly four-and-a-half times, equivalent to 5kg more fruit per square metre of land. This increase is due to optimisation of crop growing times, faster turn-round between crops and increased yield from using the vertical plane as well as the horizontal one.

According to Saturn Bioponics, this has not all been due to using the vertical plane; attention to detail in a number of areas has played a key role (See Table 3). These include:

- knowledge of which varieties are more suited to the growing medium,
- a tailored nutrient strategy which provides the right nutrient at the right time to maximise growth and crop quality;
- reduction in time between crops as improved plant health means less time is needed for sterilisation, but also growing an extra crop per year.

By shortening the growing cycle from 45 days to 35 days (See Appendix 2), there is a gain of ten days. Over the length of the year, this builds up to three more crop cycles, which can make a significant difference to the total annual crop yield. There is no downtime necessary between crops, so under certain circumstances (such as growing in polytunnels or greenhouses) growers with a faster turn-round can gain sufficient time to grow an extra crop per year, as happened with Manor Farm in 2016 (Vegetable Farmer article October 2016, p19 Ref: SBP10) and is discussed in greater detail below. Speed and ease of harvesting can also help to keep labour costs down, help a fast turnaround to plant another crop and reduce damage to plants at harvest; which can impact on saleable yield. Using Saturn Bioponics' Grower system, placing the plugs in the apparatus takes 6 seconds/plug (see Appendix 2), with harvesting taking three seconds, as it consists of simply pulling out the plant and then placing it in a harvesting cart, while trimming the plant will add up to three seconds.

The emphasis on 'saleable crop' is apparent throughout the documents and interviews; when academics refer to 'intensification' they do not pay attention to the quality of the crop produced or any wastage. In the commercial arena, crops which do not conform to the parameters specified by customers are rejected and wasted. This can be due to a number of factors, such as not being the right shape/size, contamination (e.g. soil or insects), mechanical damage and bruising. Saturn Bioponics claims that in lettuce crops, tightly controlled growing conditions led to growers participating in the trials achieving between 90-100 per cent saleable crop (CEO Saturn Bioponics). This is backed up by information revealed from interviewing the director of Valefresco, who said that waste on the field is typically 10-15 per cent, but this is reduced to approximately one per cent using the Saturn Grower (SB14). He said that the company is producing nearly '100 per cent clean', saleable crop year-round, which means no foreign bodies or diseased leaves which can cause customers to reject them. This is, therefore, contributing to achieving lower levels of waste, which, when taking into account pathogens, weeds and invertebrates can be as high as 30 per cent in some crops (Pretty and Bharucha, 2014b, Flood, 2010). Moreover, by using a growing medium rather than soil, there are no soil borne pests in the system, that do not get into the retail packaging, eliminating this commercial issue which can cause rejection and subsequent waste. Adjustments in efficiency such as looking at how to reduce man-hours for the various tasks including planting and harvesting help facilitate a rapid turnaround and therefore contribute to the production of an extra crop per season: "*In our design, we have kept in mind not only the agronomic conditions the plant needs, but also how to keep labour costs down by making planting and harvesting easy and quick for the workforce."* (CEO Saturn Bioponics).

The important role played by agronomy should not be underestimated; the right blend of nutrients needs to be provided at the right time for plants to achieve their optimum yield potential in optimal time, thereby enhancing crop efficiency. Whilst Pretty (1997) makes reference to nutrients and crop protection, successful agronomic practices include monitoring growth rates, calculating when to get the most from applications of nutrients (for example beyond an certain time in the crop cycle, there is no yield response to nitrogen applications): "*We have also been fine-tuning efficiency throughout the system; for example, water and nutrients are delivered automatically and recirculated, ensuring maximum efficiency and no waste or threats of nutrient run-off*" (CEO Saturn Bioponics, date).

As measurements were taken by Saturn Bioponics, Table 3 below not only details the higher yields, but also some of the practices which help achieve greater productivity by the use of a system such as the Saturn Grower compared with broadacre farming.

Table 3: Potential areas for contribution of Vertical Farming to productivity

Criteria	Attribute	Conventional outdoor broadacre farming	Vertical farming using Saturn Grower	Contribution
Yield per unit of land	Yield of pak choi	3.5kg/sq. m	11kg/sq. m	Higher plant density per sq.m leading to yield benefit

Input efficiency (plant protection products)	Phytosanitary standards sterilisation time	Not relevant to soil-based growing systems.	Fast crop turnaround thanks to development of methods to change water and sterilise hydroponic system using hydrogen peroxide to help eliminate pathogens	Timing and crop health benefit, resulting in yield benefit.
Input efficiency (labour)	Labour working characteristics for Harvesting and planting times	As planting and harvesting is done by hand, staff have to bend down to work at ground level.	The lowest level of the towers is 30cm above the ground the others plants are placed up to 1.50, so the labour force spends more time in a comfortable position.	Labour considerations, but this does not contribute to higher yields. However, does consideration for labour conditions one of the social aspects of sustainability.
Yield variability	Quality	Average wastage 10-12 per cent	Waste : 1-2 per cent because plugs for simple cutting at harvest reduces bruising and other mechanical damage	This may benefit both environment and commercial yields, thereby contributing to sustainable intensification.

Table 4 shows that both conventional and vertical indoor farms share a number of benefits over outdoor growing, including making crop operations easier and quicker to undertake. Thus, the real difference is arguably the higher density cropping facilitated by the Saturn Grower, which translates into higher yields.

Table 4: Potential benefits from indoor growing units and vertical farming units compared with conventional outdoor growing

	Potential benefits from indoor growing	
	Vertical Farms in greenhouse/polytunnels	Conventional growing in greenhouses/polytunnels
Yield benefit	✓	?✓ **
Water efficiency/recycling	✓	✓
Ease of planting	✓	✓
Ease of harvesting	✓	✓
Nutrient efficiency	✓	✓
Wastage (field scale)	✓	✓
Wastage transit/grading	✓	✓
Weather independent	✓	✓
Potential for biopesticide use	✓	✓

** Although growing in a protected environment can improve yields over those from broadacre, the use of vertical plane used by methods such as the Saturn Grower, improve yields much more. This is corroborated by Touliatos et al. (2016), comparing lettuce growing in an ordinary hydroponic system compared with the Saturn Grower: *The VFS (vertical farming system) produced 13.8 times more crop, calculated as a ratio of yield (kg FW) to occupied growing floor area per sq.m.*

c. Environmental impact

While considering yield increases, Godfray and Garnett (2012) and Pretty (1997) stress that producing more from the same amount of land must be done in ways that reduce the direct negative environmental impacts of food production. Pretty (2008) goes further, emphasising the importance of minimising the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers. By farming in a protected environment such as that used for the Saturn Grower by the two early adopters, there is less risk of run-off, no risk of leaching, and by the very nature of protected growing, inputs can be targeted where they are needed, thereby optimising yield and quality. However, not all the factors commonly attributed to being key to sustainable intensification are relevant in all situations (see Table 4 above). Another important objective for farming is environmental sustainability, with the focus falling on areas such as water, nutrients and wastage.

Exploring the interviews and emails with the CEO of Saturn Bioponics, it appears that the company recognises the importance of the environment (Interviews June 2014, April 2016, January 2017 (Ref: SB01,SB05,SB12)), and this is reinforced through the company's actions in working to create a system which is fertiliser efficient, water efficient, light efficient and easy to plant and harvest. Efficient use of fertiliser is of interest to growers, not only to prevent environmental damage but it is also in their own interest. Fertiliser which is not used is a wasted input cost and detracts from efficiency and profitability. Saturn Bioponics capitalises on the business benefits of fertiliser efficiency by claiming an efficiency perspective:

> "*Growers can see lower nutrient bills thanks to the controlled system being developed by Saturn Bioponics*." (Interview January 2017, Ref: SB11).

The use of organic fertiliser such as farmyard manure (FYM), which confers long-term multiple benefits for the soil structure and is often advocated by soil scientists, is not possible in a hydroponic system, which uses fertiliser processed from kelp. This has not been independently assessed for its sustainability criteria as it is more processed than FYM. Nevertheless, indoor growing can be deemed to be compliant with Pretty's sustainability criteria (2008) in terms of nutrient and water efficiency because, as with all greenhouses, an indoor system poses no danger of nutrients leaching and it is easy to recycle water using a closed system. However, caution should be taken as there are some environmental costs in the processing of the kelp fertiliser used in these situations (which are outside the scope of this study). Water efficiency plays a role too as the system works in a closed loop: "*They are proven to be 90 per cent water efficient because any water not up-taken by the plant is returned to the system to be used again*," CEO Aponic (January 2017, Ref: AP01).

In Europe, pesticide regulation is rigorous and growers are being encouraged to follow integrated pest management (IPM) approaches as increasing resistance to herbicides, fungicides and insecticides is well known (Bruce et al., 2017, Collier et al., 2016, Dewar, 2017, Oerke, 2006, Van Emden and Harrington, 2017). This is backed by legislation which ensures rigorous re-testing of products when their licence period ends at

European (European Chemicals Agency) and country level (Chemicals Regulation Division, HSE). Supermarkets, particularly in Europe, are also responding to consumer concerns by seeking to drive down pesticide use. Saturn Bioponics has worked on creating a growing environment in which the plant is as healthy as possible and best able to resist pest and disease (Interview 12 April 2016, Ref: SB05) and thus keep usage to a minimum. As the system is used in polytunnels/greenhouses, there is no risk of runoff and contamination of the environment. In addition, the company Valefresco is: "*doing its best to keep it completely chemical free, and so minimising pesticide use*" (Interview March 2017, Ref: SB13). This could be a result of the ethos of the proprietors of the company or from a push-pull situation; with the push of regulation on pesticide use together with the pull of the supermarkets who are keen on reducing maximum residue levels (MRLs) in response to customer demand, which go further than legislation on Good Agricultural Practice (GAP).

Crop health is an important factor not only for saleable yield, but care has to be taken with crop protection products to ensure there are no environmental impacts (this is also regulated by law, with only BASIS qualified agronomists being able to recommend use, with further guidance from certifying entities such as LEAF and GlobalGap*[1]. Therefore, by providing the necessary phytosanitary conditions to prevent losses from disease such as root rot, and by using internal sterilisation of the root zone with a substance which is biodegradable and not a contaminant (Saturn Bioponics, 2 February 2018, Ref: SB17) and this also contributes to the environmental profile. Healthy plants also help them achieve their genetic potential for yields.

> "*The increase in saleable yields is partly because by using Saturn Bioponics' system he [explain who the he is in these square brackets] has effectively eliminated root zone fungal disease from the system, meaning that phytophthora is not a problem*." (CEO Saturn Bioponics January 2017, Ref: SB10)

Pretty (2008) draws attention to the importance of integrating biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy (changes in plant growth as a result of chemical interactions among plants and other organisms) and competition with other plants. However, much of this is not relevant when considering protected crops.

d. Economic Sustainability

Pretty (1997) emphasises the need to clarify what is being sustained and it must be kept in mind that economic benefit is crucial to sustainability and growers need to be able sell their produce and make a respectable profit margin. Profit is an important component of sustainability, but farmers are price takers in a competitive sector and if the grower

[1] * GlobalGap is an internationally-recognised farm standards audit based on Good Agricultural Practice

cannot make sufficient profit, the business cannot be maintained. This is also, arguably, important to the practicalities of sustainable intensification as the growers play a key role; a lack of commercial growers would make providing sufficient food very hard to achieve.

The importance of economics features heavily in discussions with Saturn Bioponics as clearly any potential customer will keep this in mind when deciding whether to move to this method of growing. This is also emphasised by Pretty (1997), who reports that in projects he has found that when there are expensive inputs and technologies they do not persist. Saturn Bioponics goes further as it sees the motivation of profit to be key to commercial growers, and this can be at the expense of any environmental considerations when margins are narrow. The company refers to the business case both at the GrowQuip conference (December 2016, Ref: SBC01), asserting "*Gain in yield per square metre plus reduced costs of production result in increased profitability with a payback of between 1-3 years depending upon crop type and local market values".*
However costs and returns can vary for each grower, according to site location, contracts with suppliers and customers, thus there is no real benchmark to work from. While "*The farmer should know his or her own costs of production"* (Saturn Bioponics CEO April 2016, Ref: SB05), it is difficult to provide an accurately costed business case. Nevertheless, the costs which are reported are important because they emphasise the value of commercial data rather than the specificity of costs on a particular site and note the limits of using data from one site. Other work done on growing these crops in this way often comes from research stations and therefore lacks the practice in a commercial situation, where work is done to a tight timeline, and labour costs have to be minimised.

Nonetheless, when the business model is viewed from the point of view of commercial pak choi growers Valefresco (who have all the above mentioned pressures), the time before growers see a return on investment resulting from increased revenue from using the Saturn Grower is "*feasible"* (Interview 3 March 2017, Ref: SB13); this suggests that the returns are sufficient to warrant the wait. The return on pak choi is one of the longer periods for return on investment as it is envisaged at three years, whereas for herbs it is projected at being less than 12 months. This may be related to the high-value nature of some of the crops produced in this system: "*The potential for high-value herbs such as basil is huge, with trials producing premium quality, with significant yield improvements and a shorter crop cycle than with conventional grower*" (Saturn Bioponics,12 January 2017, Ref: SB10).

This fits with suggestions made by Pretty et al. (2016), who advocate changing land use from low value crops or commodities to those that receive higher market prices or have better nutritional content. This, therefore, is another area where we can observe linkages between Pretty's views on how sustainable intensification should look and how Saturn Bioponics' methods are developing the means of putting them into practice. What is also significant is that Valefresco is planning to increase the area using the Saturn Grower as it views the system as a success for the company's business strategy as it helps to increase profits: "*We are looking at rolling it out for all our pak choi production and are trialling it for our premium lettuce too. We are really happy with the payback figures; it makes the investment much more attractive*." (Director, Valefresco, interview (Ref: SB13).

The company sells to some of the UK's biggest processors and retailers and ultimately, if the crop does not meet customer specifications, there is no market for it. The commercial grower then either sells at a lower price than agreed in the contract with the buyer, with subsequent lower profits, or may even have to destroy the crop. However, issues with specification do not arise with the crops being grown using the Saturn Grower, as Valefresco Director reports customer enthusiasm for the reliable quality of crops grown by this method. This reliability has led to the negotiation of a new contract, and Valefresco is looking at extending the system for all their pak choi production and are trialling it for premium lettuce too, suggesting the acceptability of return on investment and the speed at which it can be achieved. "W*e sell to some of the UK's biggest processors and retailers and they absolutely love it – in fact we're negotiating a new contract off the back of it*." (Director, Valefresco, Ref: SB13).

e. Etymological differences

There are some differences in the vocabulary used by commercial growers and suppliers compared with academic debate. Content analysis has revealed that while academics talk of 'intensification', growers talk of yield and especially saleable yield. This could be due to their focus being more on the micro-scale, whereas academics are often considering more at the policy level, looking through a macro lens. Sustainability is used by both academics and growers; the growers participating in this case study recognise the need for environmental sustainability, but they see it more in terms of passing the natural capital of their land on to their descendants rather than from a more conceptual point of view.

These differences in interpretation could have been developed from the epistemological differences between the commercial world and academia, or more simply the gap between theory and practice. As scientific, reproducible measurement in commercial agriculture is not possible because of all the variables which contribute to sustainable agriculture, Pretty (1994) claims that sustainable agriculture is not an objective construct subject to independent verification. This is supported by Daston (2008) who points out that more than one variable may change at one time, and suggests that constructivist epistemologies can accommodate different points of view. While academics appear to be more aware of the complexity of the agro-ecological system, using both microscopic and macroscopic lenses, the stakeholders interviewed for this case study had a more microscopic perspective. This can be seen with the use of terminology such as 'intensification' and the big picture of what needs to be done described by the likes of Pretty (2008, 2016, 2014b, 2014a, 1997) and Godfray and Garnet (2011, 2010, 2014), whereas the practitioners in this case study talk more of 'yield', 'planting rate' and 'crop turn-round time'. This is because of the practical dimension to sustainable intensification and growers are looking for practical knowledge about growing crops which builds on what they already know. They appear to prefer to gain understanding of how the Saturn Grower works through trial and error rather than seeking practice, thus the process could be described as being technocratic. Therefore, the ability to understand grower needs is crucial to understanding their motivations; they live with the day-to-day requirement of producing higher commercial yields and providing a business which they can pass on to their children as it does not damage the environment (economic sustainability). Growers see things in terms of commercial yield (which is the crop which meets customer specification and can be sold rather than jettisoned as sub-standard) and the repeatability of obtaining high commercial yields; this is one of the perceived benefits of their technology.

4. Discussion

To move towards sustainable intensification Godfray and Garnett (2012, 2011, 2010, 2014) emphasise that much more efficient use of water, energy and other inputs (increased production must be accompanied by increased productivity. Reviewing growing methods and crop yields reported by Valefresco using the Saturn Grower, reveals that the system may make a potential contribution towards sustainable intensification at a micro-scale. This improvement in efficiency, may be attributed to the work done to ensure their system is fine-tuned. Moreover, it can be suggested that environmental sustainability also has some links to economic sustainability, and the data presented suggests this may be achieved for growers of particular crops when using vertical farming techniques. For many crops in the UK, one of the limiting factors for plant growth is lack of solar radiation for photosynthesis (Ilić and Fallik, 2017). Innovative lighting has the potential to supplement low level sunlight and may be cost effective, as it can minimise diseases such as powdery mildew in susceptible crops, thereby keeping pesticide use down and therefore follows emphasis on pest management (Pretty, 1997). It can also offer growers the potential to take advantage of selling out of season when retailers are more dependent on imports and are likely to pay a premium price for produce. This was considered by Saturn Bioponics, but work with a greenhouse company has shown that diffusing the light and reflecting it back to the plants from the floor removes the need for artificial lighting in most climates, in addition to using less energy.

There is little engagement in sustainable intensification literature between ‘total production’ and ‘commercial production’. In this study the commercial yield is deemed more important, as the total yield does not reach the consumer as it can be rejected for a number of reasons, including foreign bodies, mechanical damage, or damage due to pests and diseases. Arguably, the yield increase per unit area of land three to four times greater achieved by the growers trialling the Saturn Grower show that by using the vertical space, although varieties may be close to their genetic maximum yield, growers can still increase saleable yield. At the same time, savings in water, nutrients and energy are being achieved through use of recirculating irrigation, enabling much tighter control of resources than is possible for conventional outdoor horticulture. Minimal and more controlled use of pesticides and fungicides also lead to improved environmental outcomes. This is thanks to the elimination of root zone fungal disease and healthier, more resilient plants. Growing indoors allows for extended growing seasons and growth in extreme temperatures using targeted, energy efficient temperature control systems. Through remote control, the company can apply root zone warming or cooling. This, again allows for more crop per year. However, there is a question whether the vertical farming system can really free up land for biodiversity, although more than one crop can be grown in the same indoor system.

Additionally, one of the major challenges of field-based agriculture is soil quality. Large areas are unsuitable for growing unless the crops are provided with a protected environment. Pretty (1997) believes that human ability for innovation will make ‘substantial growth’ possible even in areas which have been degraded. This can include greenhouses, or polytunnels, plus the use of hydroponics (Pretty et al., 2018) as well as space saving innovations such as multi-level growing. As the Saturn Grower is primarily designed for indoor growing, land-type becomes irrelevant and it may bring previously uncultivated areas into production, making more use of potential resources. The potential of growing sufficient crop for market but without taking up more acreage offers the possibility of leaving land for other uses, whether other crops or for the benefits of the environment, thereby referring back to the land sparing paradigm (Firbank et al., 2013).

Sustainability is not just about the environment, there is also a need for business sustainability or financial business benefits and return on investment, including infrastructure and input costs. These areas are all referred to by Pretty (2008, 1997) and the information gathered by this study on the productivity and sustainability of methods of growing using vertical farming under the different growing and market conditions supports his argument that successful sustainable intensification is not a static process, but rather an adaptation to different conditions experienced by farmers. The motivation behind the approach to horticultural production by the case study companies (Saturn Bioponics, Valefresco and Manor Farm Fruits) tends to be practical; they are focusing on what the farmers need in agronomic terms to increase their commercial yields, without significantly upping their costs. Analysis of the information collected suggests there is a correlation between minimising inputs and environmental benefits; the fewer the inputs the better for the environment and the profit margin is higher too, providing a win-win situation. This could be a driver motivating growers to develop a philosophy that will encourage them to abide by the highest ethical and environmental dimensions, although many may need some sort of incentive, for example legislation or a financial incentive from better sales prices or longer term market linkages.

Table 5 below explores some of the potential benefits and drawbacks of using the Saturn Grower in terms of contribution to sustainable farming. These have been placed in green and amber according to their apparent contribution to sustainable intensification. Labelled as 'green' are the results from using the Saturn Grower, which can be clearly identified with sustainable intensification, amber, those which may contribute, and red, which has one element which is not environmentally sustainable (the plastic used for the towers). When looking at factors placed in the amber column, these have some benefits over conventional growing but have some drawbacks. For example, the substrate currently used by Saturn Bioponics is made of clay pebbles, which, although of natural provenance, is processed and break-down of the material after use is time consuming (and outside the scope of this study). Likewise, using kelp as fertiliser is more environmentally friendly than synthesised fertilisers, although as it is processed, it is not a natural product such as farmyard manure (FYM).

Table 5: Summary of considerations benefits and drawbacks of using the Saturn Grower compared to broadacre in terms of contribution to sustainable intensification

Factor	**Contribution towards sustainable intensification**	**Saturn Grower**	**Outdoor broadacre farming**
Saleable Yield	Higher saleable yields with the quality demanded by the sector can contribute to intensification	Yes	No,

Waste	Agronomic strategy, hygiene and ease of harvesting lead to waste levels of 1-2%, down from 10-15% , contributing to both intensification and sustainability.	Yes	Difficult to achieve
Pesticide use	Closed environment reduces the threat of pesticide run-off, contributing to sustainability.	Yes	Difficult to achieve
Water use	Controlled and recycled use of water helps optimise its use, and a reduction of 80 per cent in water use, contributing to sustainability.	Yes	Difficult to achieve
Potential to bring in new land unsuitable for outdoor cropping	Contribution to intensification.	Yes	No
Weather independent	Crops do not suffer from stresses which reduce yield (such as drought, hailstones or cold). Growing indoors can enable a lengthened growing season, contributing to intensification.	Yes	No

Substrate provenance and biodegradability	Clay balls take time to break down, but may be more environmentally friendly than other hydroponic substrates such as rockwool.	Yes	Soil-based
Biodiversity	Normally the growing environment of a glasshouse/polytunnel is set up with the ideal conditions for one crop	Yes, as with the Saturn Grower there are a number of pumps per x metres, there is the potential to grow more than one crop in each glasshouse/ polytunnel	Yes
Soil health	Not relevant to indoor cropping	No	Yes
Lighting	Natural light can be diffused to optimise growth conditions. LEDs and sodium lights can be used when natural light is insufficient.	Yes	No
Overall carbon footprint	See LEAF		

Kelp fertiliser	Choice of fertiliser can influence environmental sustainability and yield response. Organic farmyard manure is unsuitable for indoor growing as it has too variable levels of nutrients and minerals which does not lend itself to precision placement.	Yes	More options for synthetic and natural fertilisers
Carbon footprint of plastic for towers	The plastic for the towers is durable, thus will last for a long time and not need replacing for about 5 years. However, it is recyclable.	Yes	N/A

These results suggest that agri-tech developments can significantly improve farm performance, without further degrading the environment, with the hydroponic growing system used for the Saturn Grower facilitating precision farming and resource efficiency.

5. Conclusion

The data gathered illustrate the potential and actual sustainability benefits which can emerge from vertical farming and can help promote sustainable intensification, including an increase in yield per unit of land alongside reductions in negative environmental impacts. The contribution to enhanced efficiency by controlling the use of nutrients, water and pesticides by using tailored agronomic strategies helps to increase yield (intensification), which helps minimise environmental damage (sustainable). This is enhanced when the whole farm perspective is taken into consideration as land outside the direct area used for cultivation can be reassessed, and can be dedicated to environmental services, which can help to offset some of the more negative aspects of this intensive form of farming.

Therefore, on the basis that the key tenets of sustainable intensification are about producing more without damaging the environment, the case study demonstrating this particular practice of vertical farming fulfils a number of the necessary criteria, specifically contributing empirical evidence that crops can yield more while minimising damage to the environment. There are potential problems caused by conventional intensification, such as lack of local biodiversity present in land-sharing while, on the other hand, there are advocates of extensification who propose sharing more agricultural land with nature with less intensive cultivations proposed for wildlife-friendly farming (Tscharntke et al., 2012). This argument has been developed as some scholars believe that yield is negatively correlated to biodiversity (Kleijn et al., 2009, Geiger et al., 2010) and is underpinned by arguments from agroecologists who believe there is a need to move away from monocrops towards more biodiversification of cropping (Tudge and Moubarac, 2013), and that greater efficiency leads to higher demand for food, and even more pressure on non-agricultural life. However Tscharntke (2012) argues that yield and biodiversity are not necessarily correlated, nor does increased yield necessarily spare land for nature; some forms of intensification result in high losses of biodiversity with relatively small yield increases, while others can achieve larger yield increments with smaller losses in biodiversity (Kuyper and Struik, 2014).

This work has highlighted some of the difficulties practitioners have in translating the sustainable intensification paradigm into agricultural practice because of the need for social, economic, or ecological outcomes, some of which are difficult to achieve and call for trade-offs. High input: high output systems are not generally thought of as contributing to sustainability, with many academics arguing for de-intensification. However, greater understanding of the complexity of sustainable intensification las led to the suggestion that taking the whole-farm approach as adopted by LEAF could help to make a difference to eco-system services such as areas set aside for beetle banks, areas sown with flowers for pollinators etc. This is relevant to a vertical farming system which optimises rather than maximises production, as having one area for intensive cultivation such as greenhouses and polytunnels with mono-cultivations which are intensively grown, but setting aside other areas around the farm dedicated more to environmental services, such as multi-species ‘bees and seeds’ mixes, beetle banks and other environmental measures to improve the wildlife environment. This could provide a vision for contributing to sustainable intensification at farm level by using the latest technologies, as long as than other variables such as mineral fertiliser, pesticides and water use conform to best practice principles for sustainability. It appears to be aligned to weak sustainability, using man-made capital in the form of buildings, growers and equipment for fertigation. Nevertheless, by growing indoors, there is less risk of production loss from climate change and therefore could be described as climate change resilient. The analysis of information collected suggests however, while this method of vertical farming departs from agro-ecological views which argue for extending and extensifying cropping, (Tscharntke et al., 2012, Tudge and Moubarac, 2013), by intensification of the area used for growing these particular crops, it leaves other land for other environmental services.

The documented increase in yields, and the whole-farm approach discussed above help build better understanding the intentions and perspectives of organisations regarding sustainable intensification as their business develops. Market drivers emerging as crucial to farm decisions include customer specifications, and while to sell to the public strict standards have to be adhered to by law, for growers producing for the higher end markets such as Valefresco, often have further specifications, such as LEAF certifications. Further studies are needed to evaluate whether these drivers may be helpful in encouraging encourage greater adoption of a whole farm approach.

6. APPENDIX 1

6.1 Case study farm details

The case study consists of Saturn Bioponics, staff working there plus two farms working closely with them to develop the vertical farming modules; these are Manor Farm Fruits and Valefresco.

Manor Farm Fruits, a commercial soft fruit grower for British supermarkets, grows 50 hectares of soft fruit (according to Defra statistics, the average area in England dedicated to strawberries is 4.5ha). The farm also markets directly to consumers through pick-your-own; it also forms part of Berry Gardens, UK's leading berry and stone fruit production and marketing group with 30% of the UK market share (GrowQuip conference). It is important to point out here that strawberry yields are primarily determined by the plant root stock itself, where there is significant variation between varieties, root stock size and June-bearer or everbearer type.

Valefresco is salad supply business for British supermarkets including Waitrose, Tesco, Aldi, Asda, M&S, Morrisons, and Sainsbury's, Food service, wholesale and ethnic markets.

It farms a total of 408ha across two sites, of which:

1. Hampton Lucy
    a. 5ha polytunnels
    b. 17ha outdoor crop land
2. Offenham
    a. 6ha greenhousing
    b. 300ha outdoor crop land
    c. 80ha rented outdoor crop land

   Crops grown:
    d. Whole head lettuce
    e. Oriental vegetables
    f. Baby leaf (now their most important crop with year on year increases). Machine harvest outdoors.
    g. Cherry tomatoes
    h. Courgettes
    i. Wheat (for rotation purposes)

The average size of a farm growing vegetables is 170 ha (Defra statistics).

6.2 Supporting case studies

There are supporting case studies which will be included in this research:

The main supporting case study is Aponic, run by Jason Hawkins-Row. His concept is similar to that of Saturn Bioponics, in that it is for vertical farming in glasshouses and polytunnels, but the system is rather different; his innovation is simple rectangular tube with a slit for the stems, and an insert of a grip-strip for the plant stems. These tubes are then placed vertically on a simple framework or a wall and the fertigation units attached. One water pump services 100 grow-tubes, which offers 150 metres of growing space.

Table 6 Contact with case study informants

Date	Speaker	Company	Place	Code
01/08/2013	20130801 Overbury Farm	Farm Business	Interview for article	MI02
24/06/2014	CEO	Saturn Bioponics	Edgbaston, Birmingham	SB01
12/11/2014	CEO	Saturn Bioponics	Telephone call	SB02
01/01/2015	Farm Manager	Jake Freestone, Overbury Farm	Telephone call	MI04
19/08/2015	CEO	Saturn Bioponics	Email	SB03
17/1202015	CEO	Saturn Bioponics	Email	SB04
10/01/2016	20160110 Overbury Farm	Jake Freestone, Overbury Farm	Interview	MI06
12/04/2016	CEO	Saturn Bioponics	Stratford on Avon	SB05
23/04/2016	CEO	Saturn Bioponics	Telephone call	SB06
01/06/2016	Elveden Estate Farm Manager	Andrew Francis	Interview	MI09
01/09/2016	Simon Clarke	Manor Farm	Telephone call	SB07
11/10/2016	CEO	Saturn Bioponics	Email	SB08
13/12/2016	CEO	Saturn Bioponics	On-site visit, Stratford on Avon	SB09
12/01/2017	CEO	Saturn Bioponics	Email	SB10
17/01/2017	CEO	Saturn Bioponics	Telephone call	SB11
23/01/2017	Jason Hawkins CEO	Aponic	On-site visit, Cambridge	AP01

30/01/2017	Danielle Horton, Marketing Director	Urban Produce (USA)	Skype call	VFC1
27/01/2017	Robbe Jordas CEO	Robbes (Finland and Sweden)	Skype call	VFC3
27/01/2017	CEO	Saturn Bioponics	Email	SB12
20/02/2017	CEO	Urban Crops (Belgium)	Telephone call	VFC3
03/03/2017	Nick Mauro	Valefresco	Stratford on Avon	SB13
31/03/2017	Caroline Drummond	LEAF	Telephone call	OB01
13/04/2018	Rhydian Beynon-Davies	Harper Adams University/Stockbridge Technology Centre	Telephone call	TE1
01/07/2017	20170701 Elveden Estate	Andrew Francis, Elveden Estate	Interview	MI08
28/07/2017	20170601 Wantisden Farm	Tim Pratt, Wantisden Farm	Interview	MI01
07/09/2017	CEO	Saturn Bioponics	Telephone call	SB14
19/09/2017	CEO	Saturn Bioponics	Email	SB15
22/11/2017	CEO	Saturn Bioponics	Telephone call	SB16
08/12/2017	Marc Allison	Cambridge University Farm	Agronomists Conference	MI12
14/12/2017	Bryan Hanley	Knowledge Transfer Network	Telephone call	MI13
15/12/2017	Liliya Serazetdinova	Knowledge Transfer Network	Telephone call	MI14
19/12/2017	Belinda Clarke	AgriTech East	Email reply to questions	MI15
02/02/2018	CEO	Saturn Bioponics	Saturn Bioponics visit	SB17

19/02/2018	Sustainable Intensification Research Platform	Sustainable Intensification Research Platform	Webinar	SIRP1
08/08/2018	AHDB Strategy Director Rob Clayton	AHDB	Interview, Dundee Scotland	MI16
29/08/2018	Tom Webster	Grow-up Box	Telephone call	MI17
14/09/2018	CEO	Valefresco	Telephone call	SB18
13/12/2018	CEO	Saturn Bioponics	Visit: Harborne, Birmingham	SB19

Table 7: Other sources examined for case study

Date	Protagonist	Media outlet		Code
01/05/2014	20140501 Saturn Bioponics	Greenhouse Grower p8	News article (no by-line)	SBP05
01/08/2014	Overbury Farm	Food and farming entry form	Competition entry	MI03
10/01/2016	Overbury Farm	Oxford Real Farming Conference	Conference	MI05
19/07/2016	Saturn Bioponics	BBC Midlands Today https://www.youtube.com/watch?v=6a0J6Zd-R_c&feature=youtu.be	TV	SBM01
29/07/2016	Saturn Bioponics	BBC Radio 4 Farming Today	Radio	SBM03
01/10/2016	Manor Farm	Vegetable Farmer October 2016, p19	Article: By-line: Frances Wright	SBP10

21/10/2016	Saturn Bioponics	Hortidaily https://www.hortidaily.com/article/6029709/uk-commercial-pak-soi-grower-increases-yield-with-tower-system/	Internet article (no by-line)	SBP09
03/11/2016	Saturn Bioponics	World AgriTech Investment	Conference	SBC02
13/12/2016	Saturn Bioponics	GrowQuip conference	Conference	SBC01
01/03/2017	20170301	LEAF Global Impacts Report	Report	MI07
2/6/2017	Aponic	Farmers Guardian pp26-27	Clemmie Gleeson	MI07a
13/06/2017	Valefresco	https://www.worcesternews.co.uk/news/15344595.students-discover-state-of-the-art-salad-growing/	Online journal	SBPVF 01
01/09/2017	Elveden Estate	Food and farming Entry Award	Competition entry	MI10
06/10/2017	Gavin Jannaway Whitewater Farm	Mark Pettigrew Potato Industry Award	Competition Entry	MI11
01/11/2017	Sustainability key to feed growing population	Arable Technology Guide p14	Article: no by-line	MI21
	Government’s 25-year Environment Plan (2018) P36	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf		GOV1

01/01/2018	Life cycle assessment	Commercial Greenhouse Grower p30	No by-line	MI18
	Mini-revolution	Commercial Greenhouse Grower pp13-15	By-line Adrian Tatum	MI18a
01/09/2018	Crop Lighting – the next generation pp9-12 (Interview Rhydian Beynon-Davies)	Commercial Greenhouse Grower	By-line: Spence Gunn	MI18b
12/10/2018	British Crop Protection Council (BCPC) conference	British Crop Protection Council conference, speaker Christopher Wallwork (Agrii)	Presentation	MI19
28/10/2018	Opening doors to new growing technologies	Farmers Guardian p34	Article: Marianne Curtis	MI20
01/11/2018	STC Vertical Farming development	Commercial Greenhouse Grower p8	No by-line	MI18c
12/12/2018	Alex Fisher - Prosperity UK Conference	https://www.youtube.com/watch?v=I3gDO5RlH0k	Conference YouTube	MI21
25/01/2019	Valefresco	Sustainable Food Trust https://sustainablefoodtrust.org/articles/grower-nick-mauro-of-valefresco-reflects-on-brexit/	Online article	SBPVF01

7. APPENDIX 2

7.1 Costings

Saturn Bioponics' business case is looking at cost savings and profit margins:

Gain in yield per square metre + Reduced costs of production = Increased profitability

7.2 Table 8: Yield comparisons

Saturn Bioponics crop yield differences using Saturn Grower *				
Crop	Normal yield	Yield using Saturn Grower	Increase in production	Potential other benefits
Pak Choi (Based on 200,000 plants)	3 kg/m^2	Yield 11.5 kg/m^2	**Increase of 8.5 kg per m^2 = 380 per cent**	Reduced labour costs, No down time between crops + Faster growth rate = Additional 2 to 2.5 crop cycles per annum Reduced labour costs; 100% saleable yield; 0% root disease; Reduced pesticides; No ground preparation
Strawberries June bearer variety Elsanta Light	1.6 kg/m^2 @ 6. plants per m^2 in coir bag system 25	6.5 kg/m^2 @ 29 plants per m^2	Gain of 4.9 kg/m^2 => 4 x yield increase	+ Faster growth rate + Reduced water use by 80 to 85% + Reduced costs of production

Important note: the trials have been farm-scale l rather than replicated scientific trials. This usually means more to growers, as tests done in non-commercial conditions can vary widely from what farmers themselves can achieve. However, to overcome this, figures have been triangulated with independent work by Touliatos (2016)

Data was gathered from speaking with the principal players on a number of occasions both by telephone and in person, attending The GrowQuip conference at which Saturn Bioponics' CEO was making a presentation plus direct observations of the methods used for growing the crops, all of which are either in greenhouses or polytunnels.

7.3 Timeline

Table 9: Timeline of achievements

Year	Achievements
2010	Perception of opportunity for method for SI using Saturn Grower
2011	Founding and Registration of Saturn Bioponics
2012	Early development of the Saturn Grower; recruitment of biologist to help development
2013	Initial trials in greenhouse in Birmingham; Defra Innovate for Growth Winner
2014	Trials in greenhouse in Birmingham; winner of Farm Business Awards and Agritech Catalyst Awards
2015	Improvement of fruit/vegetable results in yield and supermarket specification Recruitment of growers at Manor Farm and Valefresco to test the Saturn Grower; Finalist in UK Grower Awards
2016	Landmark of discovery that the Saturn Grower achieves yields three to four times higher even under commercial growing conditions: Recruitment of new specialised staff; realisation that growers do not identify with the benefits of Saturn Grower
2017	Perception of different opportunities in hydroponic consultancy; discovery of improvement of shelf life of crops grown; move towards a new business model with just a few big customers

This is also reflected in the number of employees of the company; in the beginning, it was founder and CEO Alex Fisher together with board member Mary Stafford; as technical requirements have grown, recruitment has been made accordingly. Recognising the growing need for a marketing specialist, the latest person to join the company is an experienced agronomist capable of further adjusting the agronomy to help get an even better yield.

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