Exploring the potential of urban vertical farming: Economic and technological analyses

by

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Thesis presented in partial fulfilment of the requirements for the degree of Masters of Agricultural Sciences in the faculty of Agronomy at Stellenbosch University

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April 2019

DECLARATION

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April 2019

ACKNOWLEDGEMENTS

Momz and Pa – Emotional financial support

Friends – For ensuring that my social life did not collapse

Radical Seedlings – For providing all the plants used in this trial

Jaco – Greendrop Farms – Assisting with understanding the internal workings of Greenhouses

Martin – Technical Assistance

Welgevallen Staff – For helping with every step of the trial process

A line is simply a dot that went for a walk…

Abstract

Food security is defined as the situation in which all people are able to achieve access to sufficient, safe and nutritious food at all times in order to maintain a healthy and active lifestyle. Food security is based upon three pillars; food availability, food access and food use. The current situation of food insecurity that exists, particularly in developing nations is such that drastic measures need to be taken to resolve the perpetuating problem. An alternative to address this urgent need is the adoption of urban vertical greenhousing to ensure food insecurity becomes a problem of the past.

Financial feasibility is crucial in understanding the potential success of a venture. On paper the production system may be best practise but if it is not profitable then it will not gain traction in the real world. In order to understand the financial feasibility of a greenhouse venture, an enterprise budget was constructed and various financial indicators were calculated. The enterprise budget was constructed from data collected from a single case study of a lettuce greenhouse producer situated in the Western Cape. This was a fully functional commercial greenhouse producing for the local market. Findings from the research suggest that the investment into a greenhouse venture is a financially viable option. Thus, the return on capital investment is sufficient for the greenhouse venture to be profitable within the short term as well as be sufficient to ensure that all borrowed capital will be paid back with ease. It also suggests that the venture will not encounter cash flow problems, an issue often encountered with large investments into farming production systems. However, it must be noted that this a single isolated case study. More research needs to be conducted as to understand if greenhouses can be financially feasible regardless of where they are implemented. on the natural ecosystem.

A trial was conducted on the effectiveness of LED light as supplemental light as to improve the efficiency of urban vertical greenhousing. The trial took place using a hydroponic growth system in which lettuce plants were planted as seedlings and allowed to grow for 28 days. The trial was conducted under winter conditions in Stellenbosch. The lettuce plants were harvested and both quality measurements and nutrient analyses were taken to understand the effect that light quality (colour) and photoperiod had on lettuce growth. There were variable effects on growth and

development of lettuce crop and with regards to nutritional qualities due to photoperiod duration and light quality. It was noteworthy that when giving supplemental light careful consideration should be taken as to the balance between the length of the photoperiod and light intensity. Supplemental light should always be given as to reflect natural seasonal patterns of light. Thus, when increasing the photoperiod, light intensity should also be increased, as to ensure that proper balance is maintained within the plant.

Uittreksel

Voedselsekuriteit word gedefinieer as die situasie waarin alle mense te alle tye toegang tot genoegsame, veilige en voedsame voedsel kan verkry ten einde 'n gesonde en aktiewe lewenstyl te handhaaf. Voedsel sekuriteit is gebaseer op drie pilare; voedsel beskikbaarheid, voedsel toegang en voedsel gebruik. Die huidige situasie van voedselonsekerheid wat bestaan, veral in ontwikkelende lande, is sodanig dat drastiese maatreëls getref moet word om die voortdurende probleem op te los. 'n Alternatief om hierdie dringende behoefte aan te spreek, is die aanneming van stedelike vertikale kweekhuise om te verseker dat voedselonsekerheid 'n probleem van die verlede word.

Finansiële haalbaarheid is noodsaaklik om die potensiële sukses van 'n onderneming te verstaan. Op skrif kan die produksiestelsel die beste praktyk wees, maar as dit nie winsgewend is nie, sal dit nie traksie in die werklike wêreld kry nie.Ten einde die finansiële haalbaarheid van 'n kweekhuisonderneming te verstaan, is 'n ondernemingsbegroting opgestel en verskeie finansiële aanwysers is bereken. Die ondernemingsbegroting is opgebou uit data versamel uit 'n enkele gevallestudie van 'n blaarslaai-produsent in die Wes-Kaap. Dit was 'n ten volle funksionele kommersiële kweekhuis wat vir die plaaslike mark produseer.
Bevindinge uit die navorsing dui daarop dat die belegging in 'n kweekhuis-onderneming 'n finansieel lewensvatbare opsie is. Die opbrengs op kapitale belegging is dus voldoende om die kweekhuisonderneming op kort termyn winsgewend te maak en voldoende om te verseker dat alle geleende kapitaal met gemak terugbetaal sal word. Dit dui ook daarop dat die onderneming nie kontantvloeiprobleme sal ondervind nie, 'n probleem wat dikwels met groot beleggings in boerderyproduksiestelsels voorkom. Daar moet egter gelet word dat dit 'n enkele gevallestudie is. Meer navorsing moet gedoen word om te verstaan of kweekhuise finansieel haalbaar is, ongeag waar hulle geïmplementeer word.

Ten slotte is 'n proef gedoen met LED-lig as aanvullende lig om die doeltreffendheid van stedelike vertikale kweekhuise te verbeter. Die proef het plaasgevind met behulp van 'n hidroponiese groeistelsel waarin blaarslaai geplant is as saailinge en toegelaat was om vir 28 dae te groei. Die proef is onder wintertoestande in Stellenbosch gedoen.

Die blaarslaai is geoes en beide gehaltemetings en voedings analises is geneem om die effek wat ligkwaliteit (kleur) en fotoperiode op blaarslaai het, te verstaan. Daar is bevind dat daar varieërbare effekte was op blaarseienskappe ten opsigte van beide die fotoperiode as ligkwaliteit. Dit was opmerklik dat wanneer die aanvullende lig verskaf word, dit in gedagte geneem moet word dat die balans tussen die lengte van die fotoperiode en die ligintensiteit belangrik is. Bykomende lig moet altyd gegee word om natuurlike seisoenale patrone van lig te weerspieël. Dus, wanneer die fotoperiode toeneem, moet ligintensiteit ook verhoog word, om te verseker dat behoorlike balans in die plant gehandhaaf word.

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CHAPTER 1
General Introduction

1.1 Background

1.1.1 Food security

Be it at the private level of a breadwinner attempting to put food on the table of a single family, or at the public level of a government seeking to ensure that its people do not go hungry, achieving food security is of primary concern. Attaining food security is a goal of both developing and developed nations alike. Food security is met when all individuals, have access to sufficient safe and nutritious food (Pinstrup-Andersen, 2009).

Food security is complex by definition and cannot be constrained to the idea that it only refers to the ability to produce sufficient amounts of food (Pinstrup-Andersen, 2009). If one fifth of the world's food wastage per annum was not discarded, 900 million people would be food secure. One billion people globally are food insecure (Pinstrup-Anderson & Pandaya-Lorch, 1995) In Africa alone, one of the most food insecure continents, 200 million tonnes of food are lost to wastage per annum (Sheahan & Barrett, 2017). In developing countries an estimated 40% of total wastage is lost at post-harvest and processing levels resulting from insufficient infrastructure needed to prevent perishing. In developed countries, 40% of the food wastage occurs at consumer and retail levels, largely due to consumer standards (Food and Agriculture Organisation of the United Nations, 2017). Thus, food security is not only related to the ability to produce enough food, but is also about the ability to manage food production systems in such a way that people have consistent access to sufficient, safe and nutritious food that meets their daily dietary needs and food preferences in order for them to maintain a healthy and active life style.

1.1.2 Developing nations

Africa is a continent with boundless potential, but it still suffers from the inability to achieve food security (Food and Agriculture Organisation of the United Nations, 2017). This is despite the fact that the continent has sufficient fertile arable land. In addition, Africa's climate provides ideal conditions for diverse agricultural production systems. Despite this, Africa still has considerable high death rates as a result of starvation and malnutrition due to the inability for food to reach the desperate consumer (UNICEF DATA, 2018).

Although Africa has a rich tradition of agriculture, it remains one of the continents that struggles to achieve food security for the majority of its inhabitants. Beyond the socio-economic factors, reassessing the food production systems could address the hunger situation. The markets in need of food are often isolated and displaced from where food production takes place. This ensures that access weighs heavily on food security, perpetuating the latter definition of food security of consistent supply.

The idea to move food production closer to the market can be defined as urban and peri-urban farming. In addition, by eliminating the dependence on the natural environment, food can be grown with high efficiency closer to the market consistently throughout the year. Therefore, the question arises whether controlled climate vertical hydroponic systems could be a viable step towards food security?

1.1.3 Urban Vertical Greenhousing

Global population expansion, will coincide with migration to cities (urban areas) (Parnell & Walawege, 2011). Not only will farmed urban outskirts be in direct competition with urban development, greater amounts of agricultural products will travel greater distances increasing their food mileage. Food prices are sure to rise with added pressure on the natural environment from the supply chain. Further exacerbating the issue, is the consideration of emissions that emanate from transport and storage of produce to ensure optimal quality despite the distance. Further, nutritional quality and flavour will be sacrificed for a products shelf life.

It has become increasingly difficult for conventional agricultural methods to meet the demand of global trends. Genetically modified (GM) crops have great potential, but development is hampered over health concerns. Research has promoted production but many farmers still do not incorporate many novel management techniques.

At this backdrop, vertical farming could allow greater production efficiency that have the ability to meet demand using less production area. Through using such a production system closer to the market food supply issues can potentially be nullified in the foreseeable future. However, production systems like this often require the addition of technology as to mitigate their geographic location. For instance, supplemental light coming from light emitting diodes (LEDs) are employed to ensure optimal growth regardless of location and to extend growing period. Its effects on plant growth and development are still in its infancy.

1.2 Research Statement

Urban vertical greenhousing has the potential to alleviate the harsh reality of food insecurity, an issue, which is currently a major source of concern, with its severity predicted to rise in the foreseeable future. Of the three identified factors affecting the attainment of food security, namely climate change, urbanisation and global population trends, urban vertical greenhousing, due to the nature of the production system would be able to bypass these constraints and allow production to operate at a much higher efficiency. The production system is such that it is in close proximity with the market (urban), it can produce large quantities per square meter (vertical system), crops are grown at the perfect climatic parameters regardless of location (climate controlled), and the crops are grown in a re-circulating hydroponics system (low environmental footprint). All these advantages, when combined, provide an agricultural production system for the future.

Due to the nature of such a production system, the attainment of a sufficient supply of nutritious produce on a consistent basis that is accessible to those who need it most would be possible. Furthermore, its ability to meet the demand of the hungry would be far less influenced by the constraints that are often encountered in developing countries. Basic infrastructure often prevents the attainment of sufficient food supply. Notably, by reducing food mileage and the need for cold storage, urban vertical farming alleviates food spoilage from farm gate to consumer's plate. Such a production system can be implemented on a global scale, especially in developing nations that struggle to feed their populations. The moving of production closer to the markets will bypass the current infrastructural constraints that developing countries often suffer from. Thus, nutritious high value crops can be produced locally without the need for drastic infrastructural improvement. Food will not need storage facilities

1.3 Research aims and goals

In light of the previous discussion, the following questions were assessed:

1) Can the potential adversities resulting from relocation of food production closer to the city be avoided through implementation of relevant technologies; i.e., vertical greenhousing?
2) Can the attainment of food security be achieved in developing nations through the use of urban vertical greenhousing in a way that is financially feasible?
3) Can urban vertical greenhousing be used as an alternative crop production system in the pursuit of food security attainment given the current reality and predicted future trends?
4) What effects would newer technologies, e.g. LED supplemental lighting, have on plant morphology and nutritional quality of produce?

With regards to the research question and research statement the following goals were derived:

a) To ascertain through an enterprise budget the feasibility of undertaking the construction and running of a greenhouse venture;
b) To assess the role of supplemental LED lighting in adaptations of plant growth and development.

1.4 References

Pinstrup-Andersen, P., 2009. Food security: Definition and measurement. *Food security,* I(1), pp. 5-7.

Pinstrup-Anderson, P. & Pandaya-Lorch, R., 1995. Prospects for world food security. *Systems Approaches for Sustainable Agricultural Development,* Volume IV, pp. 89-111.

Sheahan, M. & Barrett, C. B., 2017. Review: Food loss and waste in Sub-Saharan Africa. *Food Policy,* Volume 70, pp. 1-12.

Food and Agriculture Organisation of the United Nations, 2017. *Save Food: Global Initiative on Food Loss and Waste Reduction.* [Online] Available at: http://www.fao.org/save-food/resources/keyfindings/en/ [Accessed 5 Jan 2017].

UNICEF DATA, 2018. *Malnutrition rates remain alarming: stunting is declining too slowly while wasting still impacts the lives of far too many young children.* [Online] Available at: https://data.unicef.org/topic/nutrition/malnutrition/ [Accessed 15 May 2018].

Parnell, S. & Walawege, R., 2011. Sub-Saharan African urbanisation and global environmental change. *Global Environmental Change,* 21(1), pp. 12-20.

CHAPTER 2

Literature Review

2.1 Food security

"Food security" is defined by the World Health Organization (WHO) as a situation in which all people are able to access sufficient, safe, nutritious food at all times to maintain a healthy and active lifestyle (World Health Organisation, 2016). Three pillars of food security exist: food availability, food access and food use. Food availability refers to sufficient quantities of food being available on a consistent basis. Food access deals with the ability to acquire and maintain sufficient resources to obtain appropriate foods for a nutritious diet. Food use is such that the food is used in an appropriate manner and several regions struggle to attain all three pillars at once (World Health Organisation, 2016). In a study conducted from 2010 to 2012, that almost one eighth of the world (870 million people out of 7.1 billion) were experiencing undernourishment (OXFAM Australia, 2016). This problem is highly localized, 98% of undernourished people live outside high-income countries (Food and Agriculture Organisation, 2015).

The current challenges regarding food insecurity and world hunger may not be attributed to underproduction; they stem in equal share from lack of accessibility. Every year, consumers in wealthy countries waste a total of 222 million tons of food. When compared to the total food production in sub-Saharan Africa, it equates 95% of the food produced in this area (OXFAM Australia, 2016). Globally one third of all food produced is lost to waste, this amount having the ability to feed the billion individuals experiencing daily hunger (Food and Agriculture Organisation, 2015). Food production will need to increase by 60% by 2050 to successfully feed those with access (Alexandratos et al., 2012).

The industry has to increase production and provide access in the midst of many challenges. Changing climatic patterns and environmental concerns present some of the greatest of these problems. Socio-economic issues similarly lurk as the world grows and expands. Food prices are rising as agriculture becomes a globally traded commodity with impoverished individuals spending 80% of their income on food (OXFAM Australia, 2016). The population of the lowest income countries will double by the year 2050 (United Nations, 2015).

Global food security faces three major challenges in the future (see Fig. 1) namely urbanisation rates, global population trends and climate change. Each of these three challenges has the ability to be overcome through possible adaptions to the current food production system.

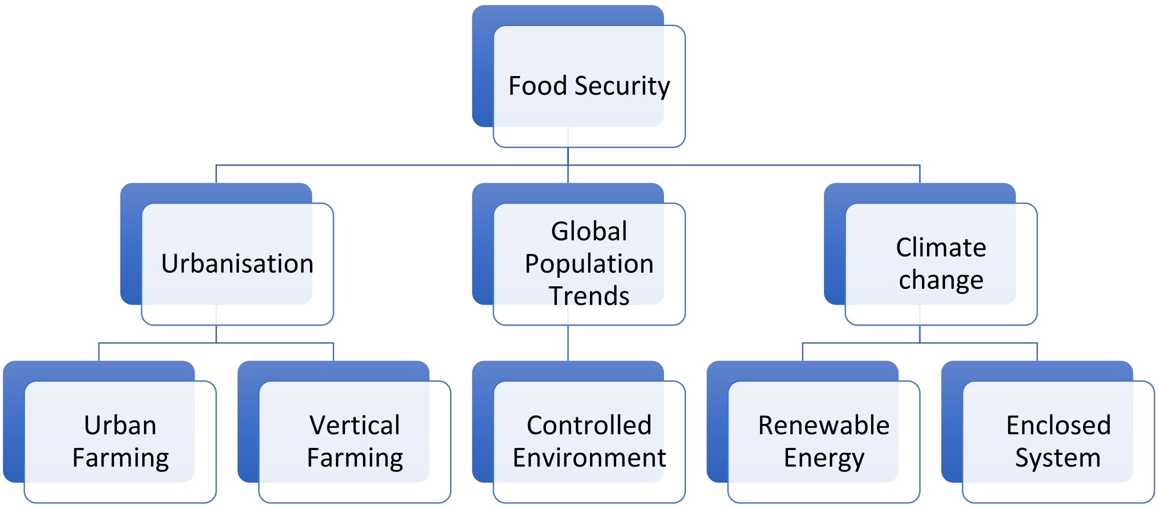

Figure 1. A diagram showing threats and solutions facing the attainment of food security

2.2 Urbanisation

Urbanisation is defined as the increase in the proportion of the population living in towns or cities (Internet Geography, 2008). This is a simplistic definition that is used to describe a highly complex process that occurs as a country undergoes the transformation of development. Urbanisation quantification is based on density or gross population size (Mcgranahan et al., 2014). Although quantification estimations differ, it is estimated that half of the world's population is already living in an urban setting (Mcgranahan et al., 2014). The United Nations Population Division (2004) notes that although urban growth rates and urbanization rates are declining globally, there is still a higher net number of people living in urban areas. The increases in the net urban populations are multifaceted, but are fundamentally described by two phenomena. The increase in urban populations is attributed to the increased migration of people from rural to urban areas, and by the increased growth of existing urban populations (Mcgranahan at al., 2014). Not only are existing urban areas seeing a net increase in people due to these phenomena, but historical rural areas are also being converted into urban areas by the same forces (Mcgranahan et al., 2014).

According to Dyson (2011), two trends follow urbanisation; namely, demographic transition and urban transition. Demographic transition is such that, as economic development in previously stable, low income populations begins to rise, the fertility and mortality rates of the population will decline at an equivalent rate. This suggests that the population will not increase exponentially. There will also be a shift in population interests from a predominantly agricultural population, living in small and dispersed rural settlements, to that of an urban population engaged in industrial and service activities (Montgomery et al., 2011). Urbanisation may lead to increased economic development, but it leads to increased inequalities in income distribution of the urban population (Kanbur et al., 2005). A growing segment of the world's impoverished population is located in an urban setting (Ravallion et al. 2007). As noted by Van Averbeke, (2007), rural poor relocate to urban areas to improve their livelihood, there is the potential of a better paying job (Van Averbeke, 2007). This leaves the job market saturated and many people with no work, resulting in conversion from rural poor to urban poor, only with different parameters (Van Averbeke, 2007).

Due to the concentrated pressure on a localized area, as a result of urbanization, the natural environment is at risk of degradation (Mcgranahan et al., 2014). Induviduals in the poorest countries have the lowest greenhouse gas emissions per person (Mcgranahan et al., 2014). This is not a result of environmentally conscious laws but relate to a lack of infrastructure that can contribute to such emissions (Mcgranahan et al., 2014). Given current trends this is sure to rise at a rapid rate, applying greater pressure to an already fragile system. As quoted from Mcgranahan et al., (2014), he has been noted to have the following requirements: "Ample water for human consumption, pastures for livestock, fields suitable for cultivation and forests for fuelwood and building materials". This perfectly summaries how agriculture plays a critical role in building a highly successful and fully-functioning city.

2.3 Global population trends

At present the global human population is estimated to exceed 7.4 billion people (WorldOMeters, 2016). If the current fertility rate trends continue as predicted, the global population will exceed 9 billion people by the year 2050 (UN-DESA, 2009). At the same time, global fertility rates are decreasing (UN-DESA, 2009), with fewer children per women being born in developed nations. Although the population is increasing at a decreasing rate in developed nations, developing nations expect a considerable growth in population from the current level.

A similar rapid increase in global population in the previous century was supported by the industrial and agricultural (green) revolutions, which allowed agricultural production to evolve with the demand (Godfray et al., 2010). Discovery of the Harber-Bosch process and mechanisation were key to the sustained supply for the growing demand (Olmstead et al., 2001). The implementation of such technologies allowed for production to move from small scale to significantly larger scale production, with lower labour requirements. Currently, we are faced with new challenges, ones that are apparent throughout the agricultural supply chain, from the planting of the seeds, to the consumption of the final product (Godfray et al., 2010). These challenges need to be met with equally radical solutions that match the revolutions of the previous century (Godfray et al., 2010). At the production level, higher yields per plant need to be achieved, through intensification, and the land used for agriculture has to grow in gross size in the next few decades to achieve the production levels needed to supply the growing population dietary needs (FAO, 2009).

The land size area, given current agricultural practise, needed to produce sufficient supply to meet population trends is estimated to be the size of Brazil (Despommier, 2013). Current global statistics estimate that 12% (roughly 1,35 billion hectares) of the total land (roughly 13.4 billion hectares) is being used for agricultural purposes (FAO, 2009). This amount is estimated to be around one third of the total land that can potentially be put under intensive agricultural production, while 4.2 billion hectares has been estimated to be able to undertake and maintain agricultural production (FAO, 2009). Of this 4.2 billion hectares, it has been noted that more than half, 2.8 billion hectares, can be found in the developing countries of the world, of which 970 million hectares are already under production (FAO, 2009). The predictions do not account for land under alternative use and if land and climatic factors are suitable for agricultural production (FAO, 2009). Agricultural production, in growing economies, will clash with urban development, and perpetuate production self-sufficiency.

As these nations grow and their economies begin to expand, while their populations increase dramatically, the competition for land, between agriculture and alternative uses, such as human settlements, will become more apparent, potentially leading to dramatic over-estimation. Secondly, the methods for deriving suitability – i.e. the parameters, which classify a piece of land as suitable for agricultural production – may be weak, with bare minimum land production potentials being used for defining land as 'suitable' (FAO, 2009). Studies have shown that almost 70% of the potentially suitable land for agricultural production, in sub-Saharan Africa and Latin America, suffers from at least one or more soil or terrain constraints (FAO, 2009). Agricultural production increases can result from expansion of land for use in agriculture and intensification of land already currently farmed. Almost 80% of the projected growth in crop production in developing countries will come from intensification, in the form of yield increases (71%) and higher cropping intensities (8%) (FAO, 2009).

2.4 Climate change and environmental degradation

In order to prevent further degradation and reverse previous damage, agriculturalists must look to systems that maximize productivity and efficiency of both land and sea, in ways that are deemed safe, so as to maintain life on earth without the consequential degradation (Beddington et al., 2012). Thus, the goal is to achieve food security for all people, but to do so within the planet's environmental boundaries. Beddington et al (2012) notes that the current and forecasted trends in population growth, changing dietary patterns, resource degradation, and climate change, point to a serious threat of not achieving the forecasted future global food production quotas. Systems need to be designed that can produce enough sustenance, continued efficiency in production, and, at the same time, avoid the adversities of both pollution and land degradation. The human population runs the risk of encountering sudden and unexpected changing climatic patterns and temperature fluctuations, as well as associated natural disaster frequency, all having a profound on agricultural production (Beddington et al., 2012).

The high levels of Greenhouse Gas (GHG) in the atmosphere have resulted in extreme weather patterns and warmer temperatures (Beddington et al., 2012). The inter-annual variability in climatic fluctuations and natural disaster occurrence leaves crop production predictions difficult (Beddington et al., 2012). Changing climates do not only affect the direct production of food through adverse yields it also has a profound effect on food quality through its vexatious contribution to post-harvest losses and the pressures of invasive species (Beddington et al., 2012). With increasing distance to market, unfit produce, as a result of pre-harvest conditions, will result in greater losses throughout the supply chain.

There are impending negative effects that climatic perturbations will have on poorer, subsistence-based communities that are farming primarily for sustenance. Such producers are under extreme pressure from climate change, not only because of its potential impact on their gross production, but also because they cannot afford to absorb such devastation (Beddington et al., 2012). Rainfall pattern changes affect a great proportion of individuals, dependent on agriculture for their livelihood. Shifting rainfall patterns over the African continent affect large communities whose agriculture is rainfed Beddington et al., 2012). These poor are still unable to afford the technologies that will assist in climate adversity avoidance (Beddington et al., 2012). Increased technological input, as to avoid climatic influences, may also increase food prices.

Climate change does not only affect the financially poor farmer, but also the financially poor consumer. If production costs were to rise, a larger portion of poorer individuals' income will need to be spent on food (Beddington et al., 2012). Production is negatively affected in gross tonnage due to weather extremes, resulting in lower yields, and subsequent lower supply (Wheeler et al., 2013). This drives food prices to rise above the norm. Climate change is a key contributor in this case, because of the increased intensity and frequency of extreme climatic events, which negatively affect the supply of food (Wheeler et al., 2013). Compounded by this, low income markets also often lack the economic capacity to absorb such shocks, and are thus subject to high domestic product volatility even considering relatively calmer global market conditions (Beddington et al., 2012).

Often, the impact of agriculture on the gross emission of greenhouse gasses (GHGs) and environmental pollution is overlooked because of the fundamental necessity of agricultural produce. In fact, agriculture is one of the major contributors to emissions and pollution, both directly and indirectly, due to inefficient farming techniques, along with the reluctance to adopt newer, more environmentally sustainable options. It has been reported that 12-14 % of global GHG emissions are a consequence of inefficient fertiliser use, from crop production and the creation of organic residues in the livestock industry (Beddington et al., 2012). Inefficient fertiliser regimes not only destroys the soil but has down stream negative externalities for natural habitats. China is considered as one of the biggest producers and users of N fertilisers, with an estimated 30-60% over-usage of the synthetic substance (Zhang et al., 2013). The same authors proposed that through the implementation of more efficient and advanced technologies, China alone could reduce their N-fertiliser emissions by 20-62%, which would result in a reduction of the contribution to global GHG emission from China of between 2-6%; a significant shift on a global scale (Zhang et al., 2013). Relatedly, the land use change from agriculture, deforestation, contributes to around 18% of global GHG emissions (Beddington et al., 2012). Activities such as transport, processing, refrigeration all contribute substantially to the total GHG emissions (Beddington et al., 2012). There is opportunity in the supply chain to actively reduce emissions through improved efficiency

Land and water use is also of concern. Agriculture is responsible for roughly 70% of the total blue water withdrawal coming from rivers and aquifers (Beddington et al., 2012). According to Beddington et al., (2012), an estimated 12 million Haof agriculturally productive land, which has the production potential to produce 20 Mt of grain, is lost each year to land degradation, as a direct result of agriculture.

All of these factors are compounding problems, exponentially harming prospects for successful crop production (Beddington et al., 2012). Bad agricultural practices do not only damage current production, but they reduce the potential for achieving maximum production in the future.

2.5 Urban farming/agriculture

Urban agriculture is defined by the United Nations Development Programme as "an industry that produces, processes and markets food and fuel, largely in response to the daily demand of consumers within a town, city, or metropolis, on land and water dispersed throughout the urban and peri-urban area, applying intensive production methods, using the reusing natural resources and urban wastes, to yield a diversity of crops and livestock's". According to Addo, (2010), urban agriculture has in been practised for a number of years by those in poorer, developing nations. It has long been involved in sustaining the livelihood of urban and peri-urban low income city dwellers in developing nations (Addo, 2010).The practice utilises empty spaces within urban and peri-urban areas, that could be previously considered dead space, or space that cannot be used for anything else (Addo, 2010). It has become a considerable economic activity in cities across the world (Addo, 2010). Globally, it is estimated that more than 800 million people are engaged in urban agriculture (Addo, 2010). Of the 800 million people involved in this economic activity, 200 million engage in it for market supplementation production, which provides a further 150 million additional employment opportunities worldwide (Addo, 2010).

In its current form, urban agriculture does face many issues, each with their own underlying causes and solutions. As the population of urban areas continue to rise, land is purchased and converted for the purposes of commercial use, thus urban agriculture is threatened by uncontrollable urban sprawl (Addo, 2010). The latter suggested that, in order for urban agriculture to be sustained well into the future, individuals need to adopt better management strategies and achieve higher productivity, that will provide an equivalent output, without polluting the soil, air, and water in the process (Addo, 2010). The practice does present many potential risks, if managed incorrectly, but the benefits are far-reaching, many of which are often underestimated and undervalued (Addo, 2010).

2.6 Concluding remarks

After the review of the current literature regarding food security it is known that the state of food insecurity remains a prominent global issue. Food security is built on three pillars, namely, food availability, food access and food use. Food insecurity does not only exist as a result of insufficient production allows the problem to be understood better. Issues surrounding food access and availability are of great concern when trying to solve the problem. Further, added pressure is exerted on food availability and access through current trends in population and climate change. In the coming years, the population will not only grow bigger, but the demographic shift from urban to rural will exert pressure on total production as well s where production is taking place. Further, climate change will result in shifting climatic patterns that will threaten current production systems already in place.

Understanding the causes of food insecurity, and the what threaten its eventual eradication, supports the idea that news production methods are needed. By farming closer to the market, with higher intensity, under a controlled environment provides a potential option in which predicted population trends and climate change can be combated to ensure optimal production. Thus, in order to understand if such an option is viable the assessment of its financial feasibility needs to be investigated. Further, by engaging in such a venture new production challenges become relevant. Thus investigation of technology that sufficiently support this type of intensification is also important.

2.7 References

Addo, K.A. 2010. Urban and peri-urban agriculture in developing countries studied using remote sensing and in situ methods. *Remote Sensing*. 2(2):497–513.
Alexandratos, N. & Bruinsma, J. 2012. *World agriculture towards 2030/2050: the 2012 revision.*
Van Averbeke, W. 2007. Urban farming in the informal settlements of Atteridgeville, Pretoria, South Africa. *Water SA*. 33(3 SPECIAL EDICTION):337–342.
Beddington, J., Asadazzama, M., Clark, M., Fernández, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., et al. 2012. Achieving food security in the face of climate change. *CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)*. (March):60. [Online], Available: www.ccafs.cgiar.org/commission.
Despommier, D. 2013.
Dyson, T. 2011. *The Role of the Demographic Transition in the Process of Urbanization*. Vol. 37.
FAO. 2009. How to Feed the World in 2050. *Insights from an expert meeting at FAO*. (1):1–35.
Food and Agriculture Organisation. 2015. *The State of Food Insecurity in the World 2015*. [Online], Available: www.fao.org/hunger/en/ [2016, March 17].
Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., et al. 2010. Food security: the challenge of feeding 9 billion people. *Science*. 327(5967):812–8.
Internet Geography. 2008. *Urbanisation*. [Online], Available: www.geography.learnontheinternet.co.uk/topics/urbanisation.html [2016, March 15].
Kanbur, R. & Venables, A.J. 2005. Spatial Inequality and Development Overview of UNU-WIDER Project Ravi Kanbur and Anthony J. Venables September, 2005. *Development*. 1–17.
Mcgranahan, G. & Satterthwaite, D. 2014. *Urbanisation concepts and trends*.
Montgomery, M.R. & Balk, D. 2011. The urban transition in developing countries: Demography meets geography. *Global Urbanization*. 89.
Olmstead, A.L. & Rhode, P.W. 2001. Reshaping the landscape: the impact and diffusion of the tractor in American agriculture, 1910-1960. *The Journal of Economic History*. 61(3):663–698.
OXFAM Australia. 2016. *Fast Facts About Global Food Production and Food Security*. [Online], Available: https://www.oxfam.org.au [2016, April 13].
Ravallion, M., Chen, S. & Sangraula, P. 2007. New evidence on the urbanization of global poverty. *Population and Development Review*. 33(4):667–701.
UN-DESA. 2009. [Online], Available: http://www.un.org/esa/population/publications/wpp2008/pressrelease.pdf.
United Nations. 2015. *World Population Prospects - Population Division - United Nations*. [Online], Available: https://esa.un.org/unpd/wpp/.
Wheeler, T. & von Braun, J. 2013. Climate change impacts on global food security. *Science (New York, N.Y.)*. 341(6145):508–13.

World Health Organisation. 2016. *Trade, Foreign Policy, Diplomacy and Health*. [Online], Available: www.who.int/trade/glossary/story028/en/ [2016, March 17].

WorldOMeters. 2016. *Current World Population*. [Online], Available: http://www.worldometers.info/world-population/ [2016, March 25].

Zhang, W., Dou, Z., He, P., Ju, X.-T., Powlson, D., Chadwick, D., Norse, D., Lu, Y.-L., et al. 2013. New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *Proceedings of the National Academy of Sciences*. 110(21):8375–8380

CHAPTER 3

Assessing the financial feasibility of a commercial greenhouse venture

3.1 Abstract

Here, the financial possibilities that are the result of setting up and producing a crop in a commercial scale greenhouse were ascertained. The information contained within this chapter is a representative example of the capital investment required to start a Greenhouse venture from the ground up as well as an overview of what returns can be expected. Most aspects of the greenhouse investigated are closely related to that which would be found in an urban area being close to the market as well as employing a vertical hydroponic production system. Lettuce is the main production crop, yielding a relatively low profit per kilogram when compared to other greenhouse grown crops. Because of this, even at low profit margins, it was demonstrated that the returns on capital can be substantial when entering into a greenhouse venture.

3.2 Introduction

When considering an investment into an agricultural venture it is important to consider not only the production returns, yield improvement, but also the return on capital investment (Nezhad & Zohoori, 2010). By comparing production returns with capital investment, the use of a budget as a decision making tool for venture implementation is crucial. A budget is a quantitative expression of plans on production inputs and outputs (Alimi & Manyong, 2000). Budgets formalise the inputs resources required and the subsequent outputs obtained (Alimi & Manyong, 2000)

An enterprise budget differs from other budget types in that it looks at a single enterprise. An enterprise budget lists all incomes and costs associated with a single farm enterprise, and gives an estimate of its profitability. An enterprise budget is developed on a per unit basis, allowing comparison between multiple enterprises on a whole farm (Alimi & Manyong, 2000). Furthermore, it is divided into three parts; incomes, costs and profit. The costs are based on variable and fixed input costs, total costs (Alimi & Manyong, 2000). Variable costs are those costs that vary with input (Garrison, et al., 2009), whereas fixed costs are not (Ali, 1994) Similarly, an enterprise budget differs from a whole farm budget in that it looks at single enterprise, not at a whole farm thus reducing the complexity of input information whilst ensuring greater focus (Penn State Extension , 2013). An enterprise budget allows a farmer undertaking a new production enterprise to better understand what is necessary in order to engage in the desired venture. Furthermore, it allows farmers to bring together production resources from a large variety of sources. Farmers are able to organise and combine the collected information and develop a typical situation (Asci, et al., 2014). Enterprise budgets ensure that farmers understand the full extent, in terms of profitability and risk, associated with entering into a new enterprise. It forms the basis on which a farmer can make an informed decision on whether an investment is worthwhile.

There are three components of a budget that are essential to its construction and consequently its accuracy. Figure 3.1 is adapted from (Hoffmann, 2010) and depicts the components needed to derive a successful budget.

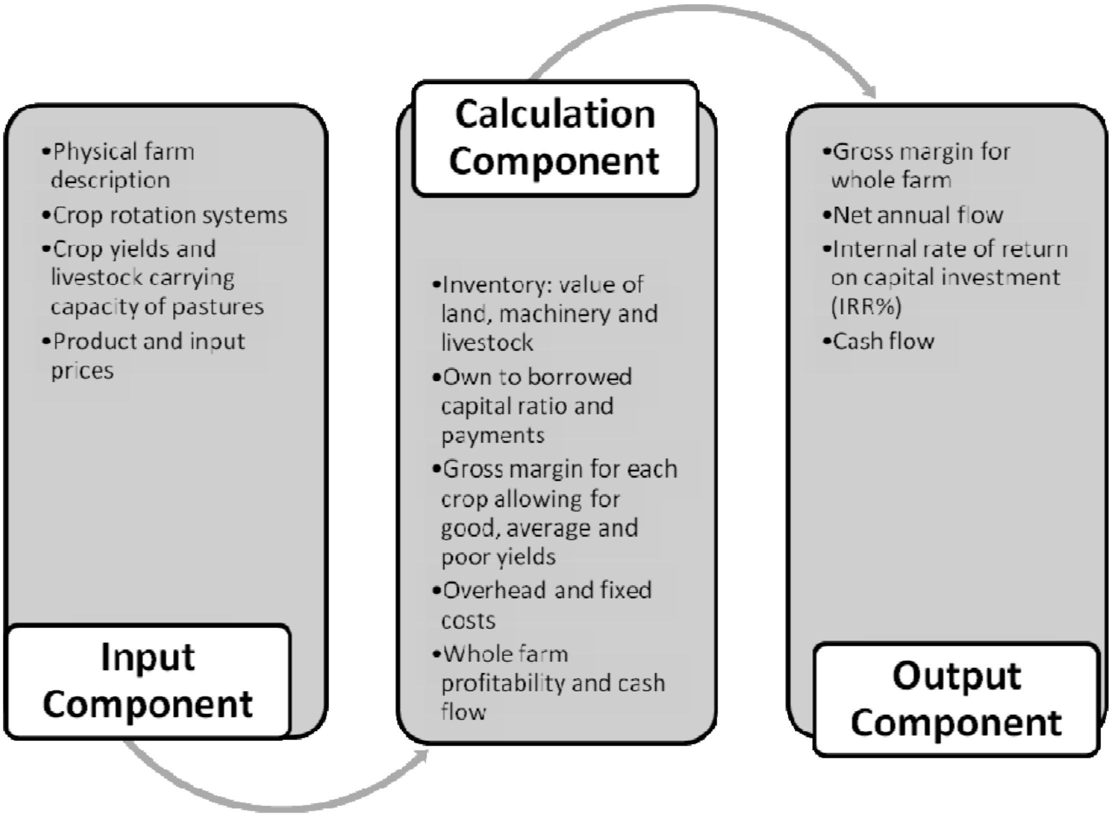

Figure 2. A graphic representation of the components of the whole-farm, multi-period budget model (Adopted from: Hoffmann, 2010).

The following chapter includes an enterprise budget for the production of hydroponically grown lettuce in a multi-span, climate controlled plastic greenhouse based in the Western Cape. The information contained within the budget was collected directly from the producer and is relevant for the year 2016. The enterprise is based on the aforementioned figure (Fig. 3.1) that has been adapted from (Hoffmann, 2010)for the purposes of this paper.

3.3 Methods and Materials

3.3.1 Farm description

The typical farm that is described in the enterprise budget is based on a case study done on a commercial greenhouse in the Western Cape. The greenhouse is located within close proximity to the main highway leading to Cape Town and is situated approximately 45km outside of Cape Town's central business district (CBD). The greenhouse is assumed to be at full production capacity, with all viable produce being sold to the market. The crop under production was lettuce. The model only determined the projected figures based on this single crop. The total area on which the greenhouse is situated is 3000 m^2. The total land area under greenhouse cover is 2750 m^2, with production only taking place on 2500 m^2. The production system is such that 22 plants.m^{-2} can be produced on the cultivated area.

The crop production system is a vertical Nutrient Film Technique (NFT) growing system. It is housed inside a standard VegTech multispan plastic greenhouse. The greenhouse is climate controlled, through the use of pad and fan cooling, as well as natural ventilation. The growth system is fully recirculating with dumping of nutrients taking place roughly every two weeks. The production system has a maximum capacity of 70 000 lettuce seedlings. Despite this, the production figures were done at a capacity of 55 000 lettuce seedlings, because some of the space was utilised for minor alternative projects being run by the farmer within the same greenhouse. Due to the nature of the production system, it is possible to plant other types of crops in this system. The climate control system and production system was determined on the basis of 2500 m^2 production area.

Included in the model was the cost of constructing a pump house, which housed the irrigation and fertigation system. The capital investment into the pump house was determined at full cost. The pump house has the ability to supplement a maximum production area of 10 000 m^2.

Production of a lettuce plant from seedling to fully marketable product was set at one month. This was the average length of time that seedlings are housed in the greenhouse until they reach a satisfactory weight for sale to the market. At this production turnaround time, 55 000 lettuce plants will be sold per month, with 12 crop cycles per year. Because of the controlled environment, it is common to yield a high level of marketable production. In this model, only 2% of the production was unmarketable, with the other 98% being sold as high quality marketable product. Although the yield per lettuce plant (in $g.plant^{-1}$), differed between summer and winter, the price was determined on a per plant basis. The high variability of lettuce price, which is governed by supply and demand, makes it near impossible to give an exact figure. Therefore, in this model, the return to a farmer per lettuce plant was determined at 40% of the retail price.

3.4 Results and Discussion

3.4.1 Financial description

The capital investment into the greenhouse venture assumed that no infrastructure existed before. The initial capital investment is presented in Tables 3.1 and 3.2. The total direct capital investment came to R 3 955 757. An additional R 791 151, determined at 20% of total direct capital investment, was included as unforeseen costs, bringing the total capital investment to R 4 746 908. Capital investment would include the construction of a greenhouse structure, an irrigation pump house and the production system for an area of 2 500 m^2. Depreciation on capital investment was done linearly, using the estimated life span of each capital investment. Total land area rented was 3 000 m^2, which housed the entire production system and relevant fixed structures needed for full production. The financing of the capital investment assumed that 50% was own capital input, with the other 50% being provided by a financial institution. Institutional capital financing back payments was determined at an 12% interest rate over a period of 20 years.

The profitability is addressed through the use of an enterprise budget and the cash flow in and out of the enterprise is addressed through the use of a cash flow budget. An enterprise budget itemises the costs incurred over an average production cycle, where as the cash flow budget analyses the cash flows in and out of the enterprise over a fixed time interval.

3.4.2 Enterprise Budget

An enterprise budget was constructed using relevant figures sourced from an already fully functional greenhouse production system. Total production area of the greenhouse amounted to 2500 m^2, growing 55 000 lettuce plants. The yield per plant was determined using long-term averages given by the farmer. Since the final plant yield varies from winter to summer, due to climate constraints, the lowest average yield, which is found in winter was used for calculation purposes.

The yield per plant was set at 80 $g.plant^{-1}$. Given summer conditions, this yield can be increased to an average of 150 $g.plant^{-1}$. The market price of lettuce is also highly variable from month to month. Thus, under the circumstances a price was fixed for the full production year. The gross return from the sale of a single price was approximated at 40% of the retail value. At the time of analysis, a retail price of R 15 was being offered, resulting in a return price per lettuce plant of R 6. Similarly, at the time of price determination, the market price of a 90g punnet of lettuce at the Cape Town market was around R 60 kg^{-1}. Because of the nature of sale at the market (90 g punnets), and the yield from a single lettuce plant being on average 100 g, returns that were determined using the proxy of 40% of retail value were similar.

Production, although highly efficient, would achieve a maximum of 98% marketable product at the end of harvest. Thus at a return of R 6 per plant and an estimated marketable production of 98%, the return to the farmer achieved monthly from the growth of 55 000 seedlings would be R 323 400. The total production costs per month for 55 000 seedlings would be R 221 726. Thus the gross return for each plant would be R 6 and the production costs per plant would be R 4,53. The resultant net profit per plant was R 1,47. The return, therefore per plant is sufficient to cover both the variable and fixed costs incurred under such a production system. The break-even price to cover the total costs would be R 4,53, where as the break-even price for variable costs being R 3,73.

Fixed costs arising from the investment into a greenhouse venture are substantial. Fixed costs represented 18,50% of the total costs. These fixed costs can be decreased through various improvements in the production system. One method of mitigating fixed costs would be to increase the production scale to full capacity, 70 000 seedlings per month. Another way would be to add additional greenhouse structures, to a maximum of 10 000 m^2 given the current fertigation system, would also ensure that the fixed costs would be reduced. The increase of yield per plant would also allow the fixed costs per plant to be reduced, and higher yields are to be expected during the summer months.

Changes in yield, resulting from improved environmental conditions, would minimally affect the variable costs when compared to the effects that they have on the fixed costs of production. Labour is by far the greatest portion of variable costs incurred. It represents approximately 42% of the total variable costs. This ensures that with slight fluctuations in labour costs per month, a drastic change in the return per marketable product can be expected.

3.4.3 Cash Flow

The cash flow analysis was generated for a single year as well as over a period of 20 years, as to satisfy the loan repayment period. A cash flow statement helps a farmer understand the cash flowing into and out of the business (Iowa State University, 2016). The results are presented in Tables 3.5, 3.6 and 3.7. The revenue per year presented is based on the assumptions made from the enterprise budget. Although yield would increase over the production year, the lowest possible yield was used as a constant, thus to avoid the influence of price fluctuations and ensure budget simplicity. Over a single production year 666 000 lettuce plant seedlings would be planted and harvested. At a 98% efficiency, a total of 646 800 seedlings would be eligible for sale at a sale price of R 6,00. It was estimated that over a 20-year period that the sale price of lettuce would rise by 5% per year and costs would rise by 3% per year. The cash flow per year was also constructed at an inflation rate of 6 and 9% (Tables 3.8, 3.9, 3.10 and 3.11). At an inflation rate of 6% and lettuce price increase, the cash flow showed a positive balance for the entire 20-year period. At an inflation rate of 9% and lettuce price increase of 5%, the cash flow was positive until the 19th year, after which it dipped into a negative balance.

Under the assumptions, the cash flow analysis showed that a positive balance could be expected from the start. Revenue received from lettuce sales at the stipulated market price would cover the costs incurred from the production of lettuce. It was determined that no supplemental financial aid would be required, past the initial investment, to ensure that cash flow returned a positive figure.

3.4.4 Financial comparison

Table 3.4 presents on overall look at the financial feasibility of undertaking a Greenhouse enterprise. It is a summary of the expected costs and returns that may be expected when undertaking such a venture. The total initial investment needed is R 4 746 908, which is considered a high capital investment. The production costs per plant was determined to be R 4,58 per plant, thus yielding a net profit per plant of R 1,42 when being sold at R 6 per plant. This ensures a net profit per year of R 916 654. By determining the net profit per year and dividing it by the total equity of the venture, a 19% return on equity can be expected. The return on equity is a measure of a business's profitability in relation to its own equity (Jagerson, 2018). This return on investment is considered high and is a very good return.

3.5 Conclusion

Although the results presented show a highly successful return on investment, the results should be understood conservatively. Although they are accurate, many hidden expenditures may exist that have not fully been incorporated into the enterprise budget, as to avoid complexity. Human nature also plays a possible role in the determination of certain returns and expenditures. Here in lies the opportunity that over or under quoting of the real value of investment, return and expenditure is to be expected. In this it is important to understand that this is a highly isolated example and does not apply to all investments into greenhouse ventures. It provides a simple initial understanding of what may be possible. More research needs to be done, which combine the results from various greenhouses in similar areas and that are comparable to the current enterprise under evaluation

Table 1. The capital investment into the construction of a 2500 m^2 greenhouse structure.

Description	***Total Cost (R)***	***Cost (per m²)***	***Estimated lifespan (years)***	***Yearly depreciation cost (R)***
Structure (7-Bay, 36m Closed Classic)	678510	271,40	50	-
Wetwalls (67.2m Wetwall Pads) + Fans (10 x EC52s)	281990	112,80	20	14099,50
Thermal Screen (SLS 30 Harmony Thermal Screen)	344680	137,87	10	34468,00
Floor Plastic	30000	12,00	5	6000,00
Drainage	123000	49,20	50	-
Leveling	116000	46,40	50	-
Electrical Work	15600	6,24	50	-
Wiring	6477,00	2,59	20	323,85
Irrigation System	140000	56,00	15	9333,33
Total	**1736257**	**694,50**		**64224,68**

Table 2. The capital investment into the construction of a pump house that will supply a 2500 m^2 greenhouse structure

Description	***Total Cost (R)***	***Estimated lifespan (years)***	***Yearly depreciation cost (R)***
Electrical	7500	20	375
Building Materials	30375	50	-
Construction	25500	50	-
Catwalk	5 250	50	-
Security	625	50	-
Irrigation Technologies	111 250	20	5 562
Total	**180 500**		**5 937**
Production System			
Description	**Total Cost (R)**	**Estimated lifespan (years)**	**Yearly depreciation cost (R)**
Vertical NFT system	1 350 000	15	90 000
Underground Piping	488000	15	32 533
Climate Control (per 2500 m^2)	201 000	15	13 400
Total	**2 039 000**		**135 933**

Table 3. The estimated expenses incurred with the production of lettuce.

Description	***Unit Cost (R/unit)***	***Monthly Cost (R/month)***	***Yearly Cost (R/year)***	***Quantity (units)***	***Total cost per year (R/year)***
Variable costs					
Seedlings	0,50	27 500		55 000	330 000
Staff		49 500		11	594 000
Manager 1		35 000		1	420 000
Manager 2		8 000		1	96 000
Security		12 000		1	144 000
Fertiliser		6 000		1	72 000
Pesticide		1200,00		1	14400
Fuel (Diesel)		4000,00		1	48000
Cleaning Agents		1 200		1	14 400
Electricity		6 000		1	72 000
Water		500		1	6 000
Maintenance		5 000		1	60 000
Insurance		6 592		1	79 115
Bank Costs		400		1	4 800
Land Rent		17 400		1	208 800
Unforeseen Expenditures		25 000		1	300 000
Total		**205 292**			**2 463 515**
Financing Cost	fixed	26 758	321 102	1	321 102
Total		**232 051**			**2 784 617**
Depreciation	fixed	20 001	240 021	1	240 021
Total		**252 053**	**3 024 638**		**3 024 638**

Table 4. Financial comparisons when undertaking an investment into a full production greenhouse.

Total initial investment for startup (R)	
Land cost	0
Fixed improvement cost	3 955 757
Miscellaneous cost	791 151
Total	**4 746 908**
Production cost of one marketable head (R,c)	
Amount Planted	660 000
Total Expenses	3 024 638
Variable/Production Costs	2 463 515
Financing Costs	321 102
Depreciation	24 0021
Production cost per plant	**4,58**
Nett profit per plant (R)	
Production cost per plant	4,58
Marketable value per plant	6,00
Nett profit per plant	**1,42**
Nett Profit for system (R)	
Nett Profit per plant	1,42
Plants per year	660 000
Percentage Marketable	98%
Marketable Plants	646 800
Total Netto Profit	**916 654,48**

Rentability on Equity (R)	
Netto profit	916 654,49
Total Equity	4796908,40
Return on Investment	**19%**

Table 5. A table showing the cash from a greenhouse venture over a single year

	Jan	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sept***	***Oct***	***Nov***	***Dec***
Opening Balance	50000	168 107	286 214	404 321	522 428	640 535	758 642	876 749	994 856	1 112 963	1 231 070	1 349 177
Cash Income	323 400	323 400	323 400	3323 400	323 400	323 400	323 400	3323 400	323 400	323 400	323 400	323 400
Cash Expenses												
Variable /Production Costs	205 292	205 292	205 292	205 292	205 292	205 292	205 292	205 292	205 292	205 292	205 292	205 292
Financing Costs												321 102
Closing Balance	168 107	286 214	404 321	522 428	640 535	758 642	876 749	994 856	1 112 963	1 231 070	1349177	1146182
Interest												

Table 6. A table showing the cash flow from a greenhouse venture over the initial 10 year period at an inflation rate of 3%

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Opening Balance	1 146 182	2 242 365	3 458 682	4 802 619	6 282 078	7 905 405	9 681 407	11 619 382	13 729 143	16 021 042
Cash Income	3 880 800	4 074 840	4 278 582	4 492 511	4 717 136	4 952 993	5 200 643	5 460 675	5 733 709	6 020 394
Cash Expenses										
Variable/ Production Costs	2 463 515	2 537 420	2 613 543	2 691 949	2 772 707	2 855 889	2 941 565	3 029 812	3 120 707	3 214 328
Financing Costs	321 102	321 102	321 102	321 102	321 102	321 102	321 102	321 102	321 102	321 102
Closing Balance	2242365	3458682	4802619	6282078	7905405	9681407	11619382	13729143	16021042	18506006
Interest										

Table 7. A table showing the cash flow from greenhouse venture over the second 10 year period at an inflation rate of 3%

	11	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Opening Balance	18 506 006	21 195 560	24 101 862	27 237 735	30 616 705	34 253 034	38 161 760	42 358 739	46 860 686	51 685 223
Cash Income	6 321 414	6 637 484	6 969 359	7 317 827	7 683 718	8 067 904	8 471 299	8 894 864	9 339 607	9 806 588
Cash Expenses										
Variable/ Production Costs	3 310 758	3 41 0081	3 512 383	3 617 755	3 726 287	3 838 076	3 953 218	4 071 815	4 193 969	4 319 788
Financing Costs	321 102	321 102	321 102	321 102	321 102	321 102	321 102	321 102	321 102	321 102
Closing Balance	21 195 560	24 101 862	27 237 735	30 616 705	34 253 034	38 161 760	42 358 739	46 860 686	51 685 223	56 850 920
Interest										

Table 8 A table showing the cash flow from greenhouse venture over the second 10 year period at an inflation rate of 6%

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Opening Balance	1146183	2242365	3384777	4574252	5811575	7097478	8432630	9817628	11252985	12739124
Cash Income	3880800	4074840	4278582	4492511	4717137	4952993	5200643	5460675	5733709	6020394
Cash Expenses										
Variable/ Production Costs	2463515	2611326	2768006	2934086	3110131	3296739	3494543	3704216	3926469	4162057
Financing Costs	321102	321102	321102	321102	321102	321102	321102	321102	321102	321102
Closing Balance	2242365	3384777	4574252	5811575	7097478	8432630	9817628	11252985	12739124	14276359
Interest										

Table 9 A table showing the cash flow from greenhouse venture over the second 10 year period at an inflation rate of 6%

	11	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Opening Balance	14276359	15864891	17504786	19195967	20938191	22731036	24573881	26465884	28405960	30392758
Cash Income	6321414	6637485	6969359	7317827	7683719	8067904	8471300	8894865	9339608	9806588
Cash Expenses										
Variable/ Production Costs	4411780	4676487	4957076	5254501	5569771	5903957	6258195	6633687	7031708	7453610
Financing Costs	321102	321102	321102	321102	321102	321102	321102	321102	321102	321102
Closing Balance	15864891	17504786	19195967	20938191	22731036	24573881	26465884	28405960	30392758	32424634
Interest										

Table 10 A table showing the cash flow from greenhouse venture over the second 10 year period at an inflation rate of 9%

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Opening Balance	1146183	2242365	3310872	4341449	5322535	6241117	7082585	7830564	8466735	8970634
Cash Income	3880800	4074840	4278582	4492511	4717137	4952993	5200643	5460675	5733709	6020395
Cash Expenses										
Variable/ Production Costs	2463515	2685232	2926902	3190324	3477453	3790423	4131562	4503402	4908708	5350492
Financing Costs	321102	321102	321102	321102	321102	321102	321102	321102	321102	321102
Closing Balance	2242365	3310872	4341449	5322535	6241117	7082585	7830564	8466735	8970634	9319434
Interest										

Table 11 A table showing the cash flow from greenhouse venture over the second 10 year period at an inflation rate of 9%

	11	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Opening Balance	9319434	9487710	9447174	9166389	8610458	7740679	6514171	4883459	2796032	193840
Cash Income	6321414	6637485	6969359	7317827	7683719	8067904	8471300	8894865	9339608	9806588
Cash Expenses										
Variable/ Production Costs	5832036	6356920	6929042	7552656	8232395	8973311	9780909	10661190	11620698	12666560
Financing Costs	321102	321102	321102	321102	321102	321102	321102	321102	321102	321102
Closing Balance	9487710	9447174	9166389	8610458	7740679	6514171	4883459	2796032	193840	-2987234
Interest	9319434	9487710	9447174	9166389	8610458	7740679	6514171	4883459	2796032	193840

3.6 References

Nezhad, M.Z., Zohoori, E. 2010. Cost-benefit analysis of greenhouse summer crops and vegetables production: a case study of Lenjan, Iran. *Green Farming,* 1(1), pp. 20-23.

Alimi, T., Manyong, V. M. 2000. *Partial budget analysis for on-farm research.* 65 ed. Ibadan: IITA.

Asci, S., van Sickle, J. J., Cantliffe, D. J. 2014. Risk in Investment Decision Making and Greenhouse Tomato Production Expansion in Florida. *International Food and Agribusiness Management Review,* 17(4), pp. 1-26.

Hoffmann, W.H., 2010. Farm modelling for interactive multidisciplinary planning of small grain production systems in south africa, stellenbosch: university of stellenbosch.

Garrison, R. H., Noreen, E. & Brewer, P., 2009. *Managerial Accounting.* 13th Edition ed. s.l.:McGraw-Hill Irwin.

Ali, H. F., 1994. A multicontribution activity-based income statement. *Journal of Cost Management,* pp. 45-54.

Penn State Extension , 2013. *Budgeting for Agricultural Decision Making,* Pennsylvania: PennState.

Iowa State University, 2016. *Unerstanding Cash Flow Analysis,* Iowa: Iowa State University Extension and Outreach.

Jagerson, J., 2018. *Investopedia.* [Online] Available at: https://www.investopedia.com/terms/r/returnonequity.asp [Accessed 1 10 2018].

CHAPTER 4

Growth response and nutritional composition of lettuce to supplemental LED lights

4.1 Abstract

For the optimal functioning of plants, the spectral quality (wavelength), quantity (photon flux) and duration (photoperiod) of light are important (Kempen, 2012). In this study, lettuce plants were grown under isolated light treatments of (1) red (R), (2) blue (B) and a combination of red and blue (R+B). Furthermore, natural light was supplemented with these three LED light treatments at either a short photoperiod (9hrs) or a long photoperiod (21hrs). The control received no LED light supplementation. Data was collected on the effects that the light colour had on the lettuce biomass accumulation, water usage, leaf morphology, leaf chlorophyll contents and leaf texture. The water usage was highest under a long photoperiod. Leaf crispness was highest under control conditions with natural light under conventional photoperiod duration. In addition, clorophyll content increased markedly under 'normal' photoperiod length with supplementary lighting of monochromatic blue (B) frequency. Root fresh weigt (FW) ws highest under monochromatic red (R) light supplementation, whereas the dry weight (DW) was the highest with a combination of R+B. Light colour and photoperiod duration was seemingly not strong enough to elicit a distinct morphological response. The effects on macro- and micro-nutrient accumulation were also studied. There were variable effects on the various macro- and micronutrients between the varied photoperiod and LED light colour treatments. Seemingly, micronutrient levels were more variable than that of macronutrients, particularly when photoperiod was extended. In addition, there were no consistent patterns of accumulation for the various micronutrients when subjected to different quality LED light supplementation. In contrast, both primary and secondary macronutrients appeared to be more affected by the combination of red + blue (R+B) LED light supplementation under prolonged photoperiod duration.

4.2 Introduction

Lettuce (*Lactuca sativa*), is a leaf vegetable crop grown in large quantities throughout the world (Mou, 2008). Among several end uses, lettuce leaves consumed fresh and that form part of culinary dishes is the most prevalent. A crucial factor determining the potential of lettuce leaf growth is the light environment to which the plants are exposed. Due to its popularity and its effective response to altered and manipulated environments it serves as a model crop for experimentation under controlled conditions (Hiroki et al., 2014). The leaves of lettuce plants, i.e., the aboveground portion, are the most important marketable part of this crop. Thus, for production purposes, the light environment in which it grows plays an important role in achieving high yields. Light quantity and quality are drivers of photosynthesis. Managing the light correctly could result in optimal production, given all other factors are not limiting (Dutta *et al.*, 2013). The most important aspects of light that need to be considered when achieving optimal light environments would be the light intensity, photoperiod and the colour ('quality') of light being supplied to lettuce plants. One way of changing the light environment is with the use of Light Emitting Diodes (LEDs) as supplemental light. These LEDs can increase the light intensity, extend the photoperiod as well as deliver varying light spectra.

All aspects of light directly affect the plants photosynthetic properties and capacity. Photoperiod extension will ensure that a plant will photosynthesize for prolonged periods. Increasing the light intensity, within a certain range, will directly increase the rate of photosynthesis. Changing the wavelength will induce varied responses pertaining to the morphology and growth habit of the leaves depending on the wavelength to which it is exposed (Dutta *et al.*, 2013). Through the use of LEDs as supplemental light it is possible to alter the light environment in terms of light intensity, photoperiod and light wavelength. Varying any of these aspects of light will alter the growth and development of lettuce plants (Cakmak et al, 2010).Growth and development alterations have a major effect on the uptake and assimilation of nutrients in the plants. Nutrients are classed into two major groups, namely, macro- and micronutrients. Macronutrients are those ions that are needed by the plant in large quantities (Shaul, 2002). Often macronutrients are referred to as essential nutrients, without them the plant is unable to achieve satisfactory growth. On the other hand, despite being required in smaller quantities, micronutrients also elicit positive plant growth responses.

Therefore, this trial sought to investigate what these aforementioned alterations would be and to what extent they can be manipulated. Furthermore, the objective of this study was to understand the effect that varying LED light colours and photoperiod treatments would have on the uptake and assimilation of nutrients in lettuce plants. Specifically, the macro and micronutrient contents of lettuce leaves were determined after a period of growth under either red, blue or red+blue (3B:9R) light at either a short (9hrs) or long (21hrs) photoperiod.

4.3 Materials and methods

4.3.1 Experimental site and setup

Trials were conducted under natural winter conditions at the Welgevallen experimental farm in Stellenbosch, South Africa. Under winter conditions the light environment was most limiting. The trial commenced with the planting of lettuce seedlings (var. 'Grand Slam-Pill') on the 7th of May 2016 and lasted for 28 days. The plants were housed in a tunnel, which did not allow for temperature or humidity control, and the climate inside matched that on the outside.

A simple non-recirculating hydroponics system was constructed to house the lettuce plants throughout their entire growth period. The nutrient solution was prepared with an EC of 1,5 and consisted of; 146,96 g of KNO_3, 84,50 g of K_2SO_4, 25,50 g of KH_2PO_4, 43,13 g of $NH_4H_2PO_4$, 323,25 g of $Ca(NO_3)2.2H_2O$ and 157,29 g of $MgSO_4.7H_2O$. and Ten grams of Hidrospoor. Each bucket held three litres of nutrient solution. Coir, as the growth medium, and the seedling was housed in a plastic net cup. Each level held 12 plants, totalling 48 seedlings per shelf.

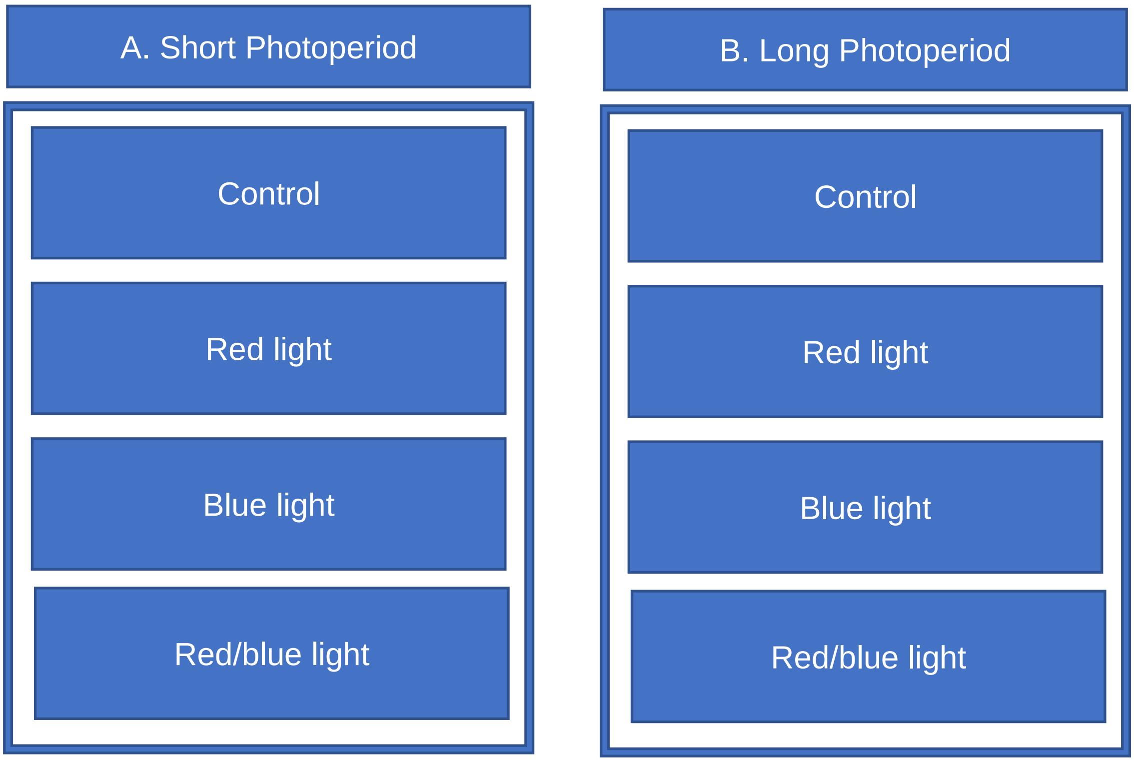

Figure 3. Schematic representation of supplemental LED light treatment. Shelf A) Short photoperiod, received 9 hours of supplemental light. Shelf B) Long photoperiod, received supplemental light for 16 hours. The levels on each shelf received a varying light colour treatment, namely, the control (no light supplementation), red light, blue light and a combination of red and blue light.

Treatments are depicted in Figure 3. Short photoperiod supplementation was for 9 hours, while long photoperiod supplementation was 21 hours. Each shelf received a 36 Watt LED light strip varying in colour, namely red (R), blue (B) and red+blue (R+B). The control shelf did not receive any additional light supplementation.

4.3.2 Data Collection

Starting with eight days after planting, total lid weight was measured every four days. Leaves were subjected; (a) to a pressure test (crispness) using an INSTRON machine, (b) Chlorophyll content test using an Opti-Sciences CCM-200 and (c) Leaf area measurements. The crop was separated into above- and belowground parts to measure both the fresh- (FW) and dry weights (DW). Bucket water content was then measured to derive the final water usage.

4.3.3 Statistical Analysis

The experiment was laid out as a Randomised Block Design (RBD) with twelve replicates per treatment combination. The data obtained from the trial was analysed using the analysis of variance (ANOVA). This was achieved by running all the trial results through Statistica (STATISTICA 11.0, Statsoft Inc., Tulsa, Oklahoma, United States of America). The main interactions that were applicable were the photoperiod and LED light treatment. The Fisher's least significant difference (LSD) ($P = 0.05$) test was used for separation of means.

4.4 Results and Discussion

4.4.1 Crop biomass

Neither the root FW (~40 g) nor DW (~8.5 g) under a long photoperiod, were significantly different from those plants under the conventional, short photoperiod duration (~39 g and ~9 g, respectively; Table 8). The highest root FW (56 g) was observed for plants subjected to supplementary red (R) LED light under an extended photoperiod duration (Table 8). There were no significant differences between the root DW of plants under conventional lighting conditions and any of the light combination treatments implored in this study. Contrastingly, the highest root DW was recorded for plants subjected to a combination of R+B light and of which the photoperiod was prolonged, which was markedly higher compared to control plants and plants exposed to monochromatic R, but not monochromatic B supplemental lighting (Table 8). The leaf FW under a long photoperiod (139 g) was lower than under control conditions (156 g). However, when lettuce crops were supplemented with either the combination of R+B or these light sources in isolation there were significant differences in leaf FW accumulation, particularly under an extended photoperiod duration (Table 8).

Increased red light supplementation increased both root -and shoot FW, while blue light had a negative correlation (Son & Oh, 2013). The FW can be highly dependent on the ambient conditions and the water status of the plant (Taiz & Zeiger, 2010).

Dry weight is often a more accurate measure of actual plant weight. An increased light intensity within a given range, as a result of supplemental light, improves total plant growth. Root growth is stimulated by carbon import from the shoot, controlled by photosynthate production of shoots (Nagel et al., 2006). Root growth manipulation is more pronounced than shoot growth to increased light intensities

(Nagel et al., 2006). It has been noted that both red and blue light supplementation are effective for increased biomass accumulation (Heo, et al., 2002; Lefsrud, et al., 2008). Results showed a similar trend, with increased biomass accumulation as a result of either red or blue LED light supplementation at a longer photoperiod. A clear difference between light colours could not be understood.

Table 8. Fresh- and dry biomass accumulation of lettuce (*Lactuca sativa*) roots and leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at P < 0.05.

PHOTOPERIOD	*** No supplement-Conventional**		**Supplementary-Conventional**		**Supplementary-Extended**	
LIGHT QUALITY	**Roots FW**	**Roots DW**	**Roots FW**	**Roots DW**	**Roots FW**	**Roots DW**
(i) Control	38.77 ± 0.66 **c**	8.80 ± 0.10 **b**	- -	- - - -	39.93 ± 1.75 **c**	8.47 ± 0.07 **b**
(ii) Red	- -	- -	50.03 ± 2.83 **ab**	8.90 ± 0.17 **b**	55.63 ± 2.83 **ab**	9.57 ± 0.24 **b**
(iii) Blue	- -	- -	47.23 ± 2.48 **ab**	8.97 ± 0.13 **b**	51.63 ± 2.48 **ab**	9.67 ± 0.52 **ab**
(iv) Red+Blue	- -	- -	42.03 ± 2.76 **bc**	9.33 ± 0.28 **ab**	49.43 ± 4.57 **a**	10.00 ± 0.15 **a**
	Leaf FW	**Leaf DW**	**Leaf FW**	**Leaf DW**	**Leaf FW**	**Leaf DW**
(i) Control	156.00 ± 5.97 **bc**	11.03 ± 0.15 **b**	- -	- - - -	139.43 ± 3.17 **b**	10.67 ± 0.12 **b**
(ii) Red	- -	- -	164.90 ± 8.71 **c**	11.00 ± 0.12 **b**	222.07 ± 6.67 **a**	13.33 ± 0.35 **a**
(iii) Blue	- -	- -	149.97 ± 9.37 **bc**	10.83 ± 0.28 **b**	193.80 ± 15.24 **a**	12.90 ± 0.78 **a**
(iv) Red+Blue	- -	- -	143.47 ± 4.31 **b**	10.90 ± 0.23 **b**	212.33 ± 5.54 **a**	12.90 ± 0.31 **a**

Table 9. Leaf morphologies of lettuce (*Lactuca sativa*) plants (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) – Red Light (R), (iii) – Blue Light (B) and (iv) – Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at P < 0.05.

PHOTOPERIOD	*** No supplement-Conventional**											
LIGHT QUALITY	**Leaf Width (W)**				**Leaf Length (L)**				**W:L ratio**			
(i) Control	121,67	±	13,74	**a**	166,67	±	16,76	**a**	0,74	±	0,11	**a**
PHOTOPERIOD	**Supplementary-Conventional**											
LIGHT QUALITY	**Leaf Width (W)**				**Leaf Length (L)**				**W:L ratio**			
(ii) Red	134,33	±	1,45	**a**	188,67	±	6,57	**a**	0,71	±	0,03	**a**
(iii) Blue	118,67	±	3,93	**a**	167,33	±	11,14	**a**	0,71	±	0,03	**a**
(iv) Red+Blue	115,00	±	4,58	**a**	160,33	±	8,84	**a**	0,72	±	0,03	**a**
PHOTOPERIOD	**Supplementary-Extended**											
LIGHT QUALITY	**Leaf Width (W)**				**Leaf Length (L)**				**W:L ratio**			
(i) Control	117,33	±	15,03	**a**	168,33	±	18,66	**a**	0,71	±	0,11	**a**
(ii) Red	136,00	±	4,00	**a**	187,33	±	16,46	**a**	0,74	±	0,09	**a**
(iii) Blue	135,67	±	11,41	**a**	180,33	±	2,33	**a**	0,75	±	0,06	**a**
(iv) Red+Blue	140,00	±	17,35	**a**	187,00	±	3,00	**a**	0,75	±	0,09	**a**

There were no apparent effects on the leaf morphology (e.g. leaf W: leaf L) of lettuce leaves subjected to the different treatments implemented in this study (Table 9). Leaf width and leaf length was unchanged when subjected to 'natural' light and even decreased marginally when exposed to monochromatic B and R+B light under the conventional photoperiod duration (Table 9). Although leaf width decreased under altered light frequencies of monochromatic R, monochromatic B and the combination of these aforementioned light sources, these changes were restored to levels of the control treatment with natural white light supplementation when photoperiod was extended.

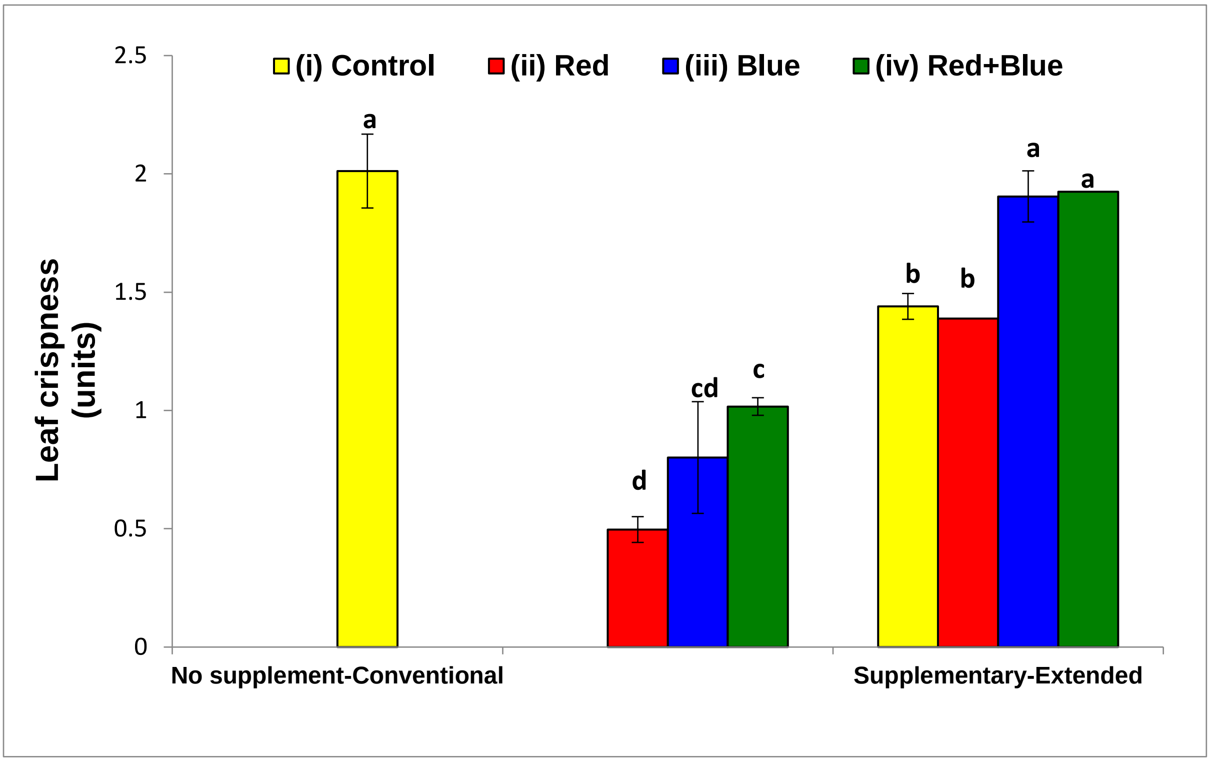

Figure 4. Leaf texture quality ('crispness') of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'natural' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at P < 0.05.

4.4.2 Leaf texture (LT) quality or crispness

The LT value of 2.01 was the highest for lettuce leaves cultivated under control conditions (Fig. 4). Lettuce leaves of crops cultivated under extended photoperiod and 'white' lighting; i.e., with no supplementary LED lighting, showed a significant loss of LT (approximately 40% less crisp) than lettuce leaves of control plants (Fig. 4). Similarly, there was a significant decline of leaf crispness for lettuces subjected to monochromatic red (R) light. In contrast, lettuce leaves supplemented with monochromatic blue light (B) and a combination of red + blue (R/B) light maintained its crispness closed to lettuce leaves of control treatments under extended photoperiod conditions (Fig. 4). The decline in leaf crispness was even more pronounced for lettuce crops cultivated under monochromatic R, B and/or a combination (R/B) thereof. Treatment with monochromatic R showed the most significant decline, with leaf crispness decreasing by up to 75% compared to leaves of crops grown under no supplementary lighting and standard photoperiod duration

(Fig. 4). Similarly, monochromatic B and the combination of R/B supplementary lighting sources showed approximately 60% and 50% decline in leaf textures, respectively in comparison to control treatments of no supplemental lighting.

Lettuce leaves have previously been shown to be more crisp under higher light intensities than when subjected to lower light intensities (Chabot 1977; Fukuda *et al.*, 2004; Fan et al. 2013). The improvement in crispness could possibly be ascribed to thicker leaves under higher light intensities. In this study it was found that the leaf texture deteriorated under prolonged exposure to light, especially when subjected to monochromatic R. Results from this study corroborates findings that showed lettuce leaf crispness to be greater under white light than under monochromatic LED lights (Lin et al., 2013b). Seemingly, extending the natural daily photoperiod with low light intensities of monochromatic supplementation could offset the increased thickness, although the light intensities were not determined during the course of this study.

4.5.2 Chlorophyll (*Chl*) contents

The *Chl* content of plants subjected to control conditions was on average 9.6%. Under extended photoperiod conditions this value decreased marginally to about 9.1% (Fig. 5). This was similar to values achieved for lettuce plants subjected to either red or blue light in isolation under the same extended photoperiod conditions (Fig. 5). Although there was an increase in *Chl* content of plants subjected to supplemental lighting of all sources, the increase was only significant for those plants exposed to monochromatic B light (Fig. 5). The *Chl* content (14%) of plants increased by approximately 50% under monochromatic B light conditions and the same conventional photoperiod duration as control plants. Under extended photoperiod conditions and supplemental lighting the *Chl* content of plants remained constant at 9.2, 8.8 and 10.5 for R-, B- and R+B light combinations, respectively compared to control conditions (9.6).

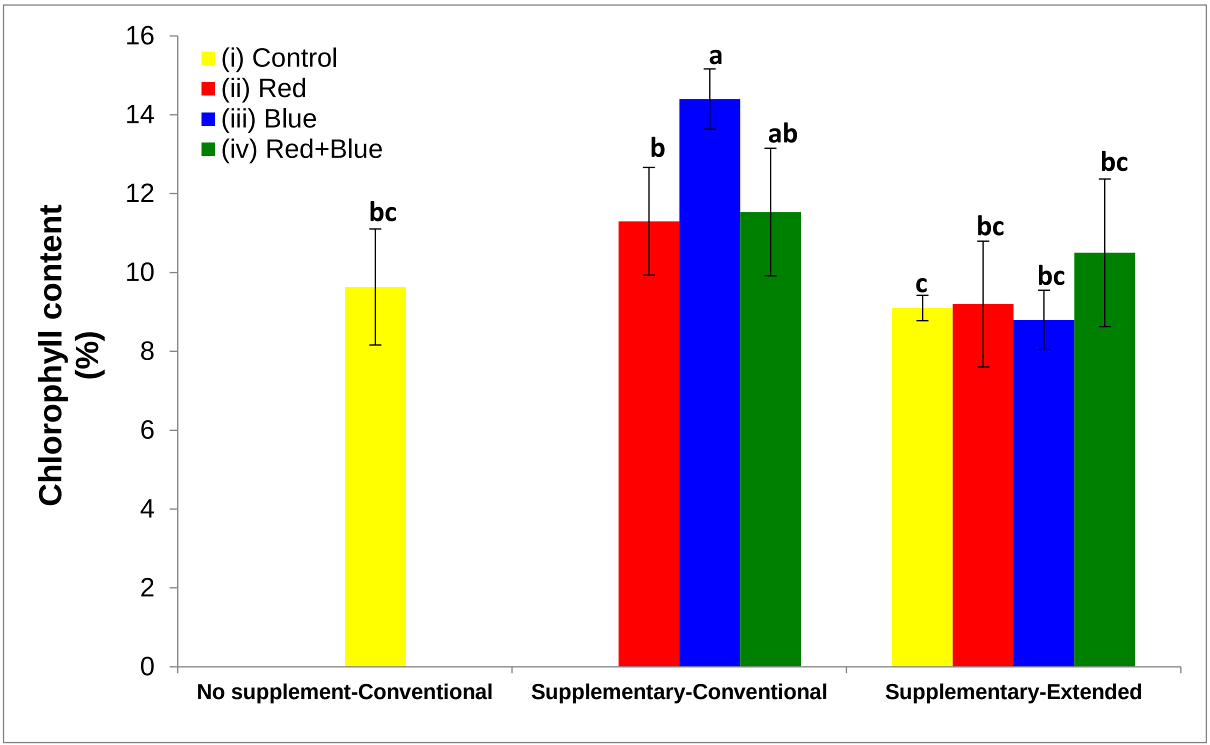

Figure 5. Chlorophyll (*Chl*) content (%) of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'natural' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at P < 0.05.

Generally, increasing light intensities increase *Chl* contents of lettuce leaves (Kang et al., 2013, Fukuda et al., 2004). However, decreased *Chl* contents were previously observed under increased light intensities (Cui et al.,1991). Seemingly, *Chl* content of leaves increase dependent on light intensities to a threshold, after which they decrease (Fu et al. 2012). Observations under conditions implemented in this study corroborated similar results reported previously where the addition of blue light as part of a light supplementation regime increased *Chl* content of lettuce leaves (Muneer et al., 2014). Similarly, Heo et al. (2002) and Lefsrud et al. (2008) found that by increasing blue light supplementation the Chl contents of lettuce leaves increased. Blue light induces stomatal opening, which leads to more CO_2 gain, which promotes photosynthetic efficiency. A greater photosynthetic ability could lead to greater production of Chl for light capture.

4.5.7 Primary macronutrients

There were no significant differences observed for the primary macronutrients nitrogen (N), phosphorus (P) and potassium (K), irrespective of photoperiod duration, with the levels of these minerals remaining constant (Fig.?). There was a significant decline of NH_4-N under conventional and extended photoperiods of monochromatic R. In addition, NH_4-N also declined markedly under prolonged photoperiod conditions when subjected to a combination of R+B light (Fig. 6A). Nitrogen forms the backbone of plant growth and development. It is an essential nutrient, it is used to form amino acids and it is a component of DNA and chlorophyll. The decrease under red light at a short photoperiod could be due to lower Chl contents, while a further decrease at longer photoperiods could be the reults of low photosynthetic rates due to low light photoperiod extension.

The levels of P remained even more consistent under the experimental conditions implored in this study, with no significant differences being observed, irrespective of photoperiod or LED light source (Fig. 6B).

Although K content showed a marginal increase under extended photoperiod conditions and normal white light supplementation, this was not significant (Fig. 6C). However, the K content increased significantly under conventional photoperiod duration, especially for lettuce crops subjected to either monochromatic R or a combination of R+B (Fig. 6C). In contrast, the leaf K content decreased markedly to its lowest levels (10.8%) under prolonged photoperiod conditions in comparison to control plants (14.8%) under 'white' light supplementation, irrespective of photoperiod duration (Fig. 6C). Potassium is known to be an important nutrient in stomatal control (Lebaudy et al., 2007). Stomatal density reaches a maximum before leaves have expanded more than 10% (Casson et al, 2008). The increase under a short photoperiod could be the result of stomata manipulation as a result of light intensity. The decrease under a long photoperiod cannot fully be explained. It is hypothesised to be the result of plant growth under low light intensities at the start and end of day.

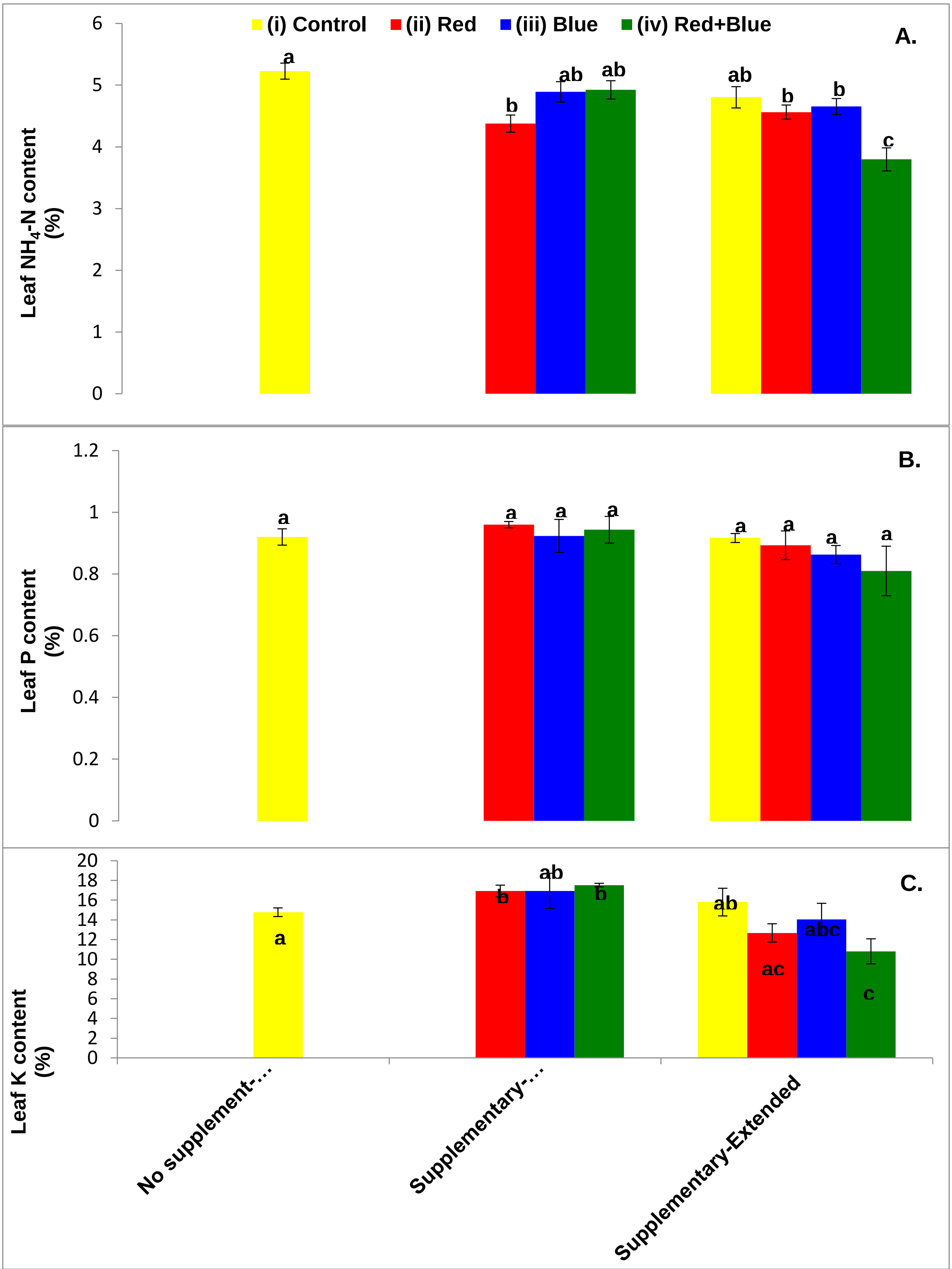

Figure 6. Content (%) of primary macronutrients (N, P and K) of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). *No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at $P < 0.05$.

4.5.4 Secondary macronutrients

Calcium (Ca) levels were largely unaffected by treatments induced in this experimental study. Neither monochromatic R nor monochromatic B independently had any effect on lettuce leaf Ca levels, irrespective of photoperiod duration (Fig. 7A). However, the Ca content was decreased significantly by a combination of R+B light under extended photoperiod conditions in comparison to control plants cultivated under 'white' light (Fig. 7A). Ca showed slight increases under a short photoperiod, but then decreased at longer photoperiods.

Magnesium (Mg) levels showed similar tendencies than Ca, and albeit that it was largely unaffected by the treatments, a significant decrease was observed between lettuce crops subjected to a combination of R+B under conventional and extended photoperiod conditions (Fig. 7B). Similarly, there was a marked decline in Mg levels between lettuce crops exposed to 'white' light and those exposed to a combination of R+B under extended photoperiod conditions (Fig.?B). Magnesium forms an integral part of the chlorophyll molecules in leaves (Cakmak et al, 2010). Thus, Mg contents are closely proportional to chlorophyll contents of leaves (Shaul, 2002). Within a range, increasing light intensities increase chlorophyll content (Zhang *et al.*, 2016). Under long photoperiods leaf expansion is greater, resulting in a lower relative content of Mg as when compared to the conventional photoperiod.

Unlike the other two divalent cations, sulphate (SO_4-S) showed an increase, particularly under prolonged photoperiod conditions and when subjected to a combination of R+B LED light sources. Neither monochromatic R nor B had any influence on SO_4-S levels in lettuce leaves (Fig. 7C).

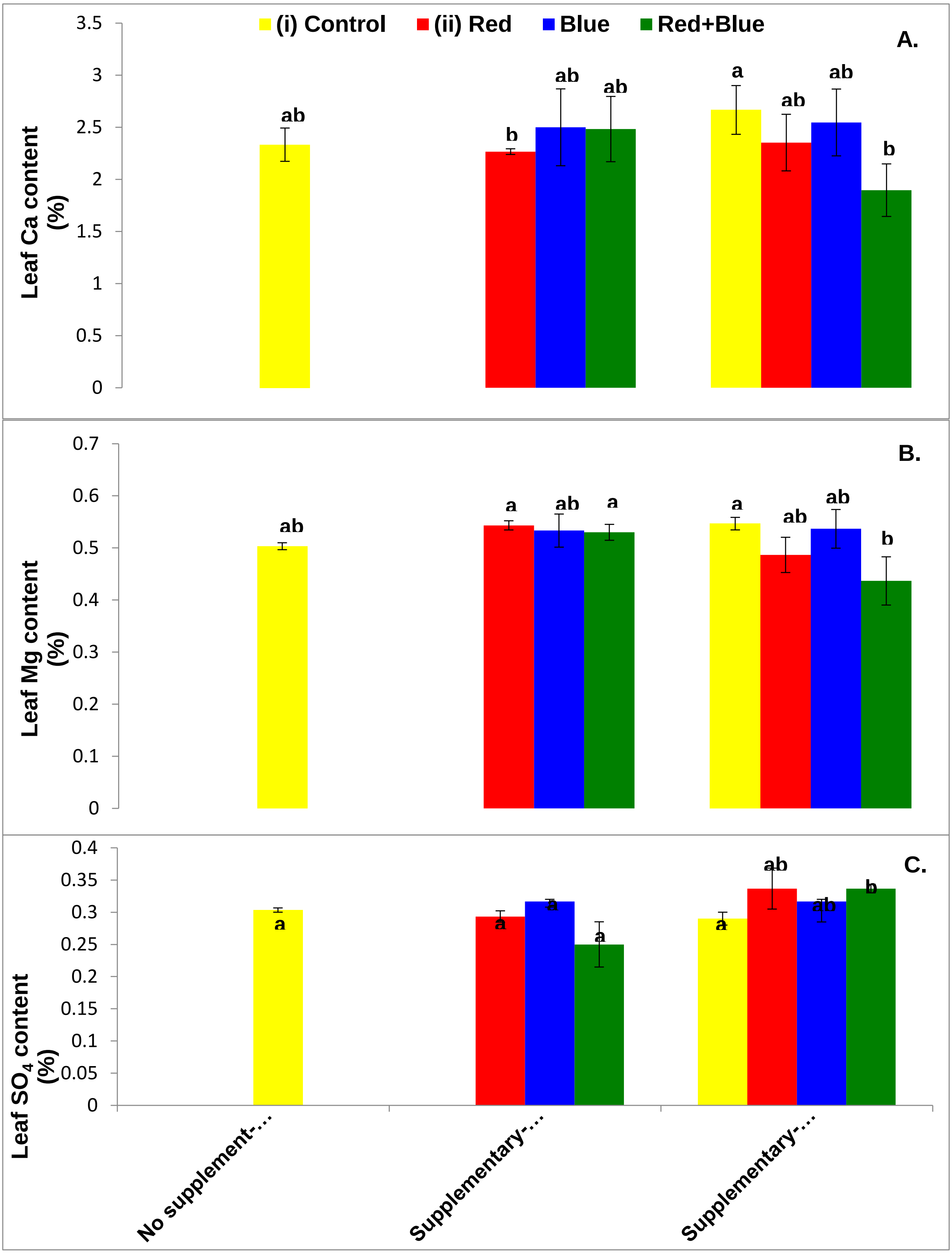

Figure 7. Content (%) of secondary macronutrients (Ca, Mg and SO_4) of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at $P < 0.05$.

4.5.8 Micronutrients

The sodium (Na) content of lettuce leaves from control plants (2013 $mg.kg^{-1}$) subjected to white light and conventional photoperiod duration remained constant when compared to lettuce crops grown under white light supplement (1883 $mg.kg^{-1}$) and prolonged photoperiod (Fig. 8A). Furthermore, there were no differences observed for lettuce crops exposed to monochromatic LED lights and/or a combination of R+B lights of any kind under the experimental conditions imposed in this study (Fig. 8A). However, when photoperiod was extended, the leaf Na contents of lettuce crops exposed to either monochromatic R or monochromatic B in isolation increased markedly when compared to control plants subjected to white light, irrespective of the photoperiod duration (Fig. 8A). There were no such responses observed; i.e, no significant differences for lettuce crops exposed to a combination of R+B LED light sources, for either photoperiod duration. The difference in Na contents can be attributed to greater shoot/leaf biomass accumulation resulting from photoperiod extension and light intensity increases.

Furthermore, the manganese (Mn) content of lettuce plants subjected to a longer photoperiod was increased markedly when compared to control plants supplemented with white light under conventional photoperiod duration (Fig. 8B). A similar significant increase of Mn levels was observed for plants subjected to monochromatic R LED light compared to control plants cultivated under white light and conventional photoperiod duration (Fig. 8B). Under prolonged photoperiod conditions the combination of R+B LED light sources caused a significant decrease in Mn levels (67 $mg.kg^{-1}$) in comparison to control plants (82 $mg.kg^{-1}$) under the same conditions.

There was no apparent changes, other than a significant increase in lettuce leaf boron (B) levels under extended photoperiod conditions and subjected to monochromatic B LED light, in comparison to B levels of control plants and plants exposed to monochromatic R under conventional photoperiod duration (Fig. 8C).

The iron (Fe) content of lettuce leaves subjected to a prolonged photoperiod were unchanged from control plants receiving white light under conventional photoperiod duration (Fig. 9A). Iron accumulated to its highest levels (355 $mg.kg^{-1}$) under monochromatic B light and extended photoperiod conditions. This was significantly higher than the Fe levels of plants subjected to monochromatic R light and the combination of R+B light supplement, but only under extended photoperiod conditions (Fig. 9A).

Overall, there was a decreasing trend for aluminium (Al) content accumulation in lettuce leaves, with only the Al content of those plants subjected to a combination of R+B light showing similar levels to control conditions for both the conventional and extended photoperiods (Fig. 9B). For instance, where plants were subjected to monochromatic R or B independently, Al levels declined markedly, particularly when photoperiod duration was extended (Fig. 9B). This was also the case for the Al content of plants subjected to the combination of R+B, specifically under extended photoperiod conditions, which also decreased markedly in comparison to control treatments exposed to white light. Plant biomass under both a short and long photoperiod had significantly higher leaf biomass than the control, suggesting that greater biomass accumulation results in a decrease in Al content of leaves. Aluiminium seems to be a beneficial element that occurs in plants, its function is still not clearly understood.

Plants subjected to control conditions under white light supplementation showed an increase in copper (Cu) accumulation under prolonged photoperiod conditions, but this was not significant (Fig. 9C). However, there was a significant decrease in Cu levels of plants exposed to isolated light supplementation of either R or B under conventional photoperiod conditions. This trend of lower Cu levels subsided for monochromatic B light supplementation when Cu levels accumulated to similar levels than control plants, whereas Cu levels also decreased significantly to its lowest level (0.5 $mg.kg^{-1}$) when plants were subjected to the combination of R+B LED lighting sources (Fig. 9C).

Leaves of lettuce crops supplemented with white light accrued more zinc (Zn) when photoperiod was extended (Fig. 9D). There were no noticeable changes in Zn levels of plants exposed to either monochromatic R or B and the combination of the two LED light sources under conventional photoperiod duration. However, Zn levels (19 $mg.kg^{-1}$) decreased significantly in comparison to control conditions (51 $mg.kg^{-1}$) and monochromatic B (60 $mg.kg^{-1}$) under a prolonged photoperiod duration when plants were subjected to the combination of R+B (Fig. 9D).

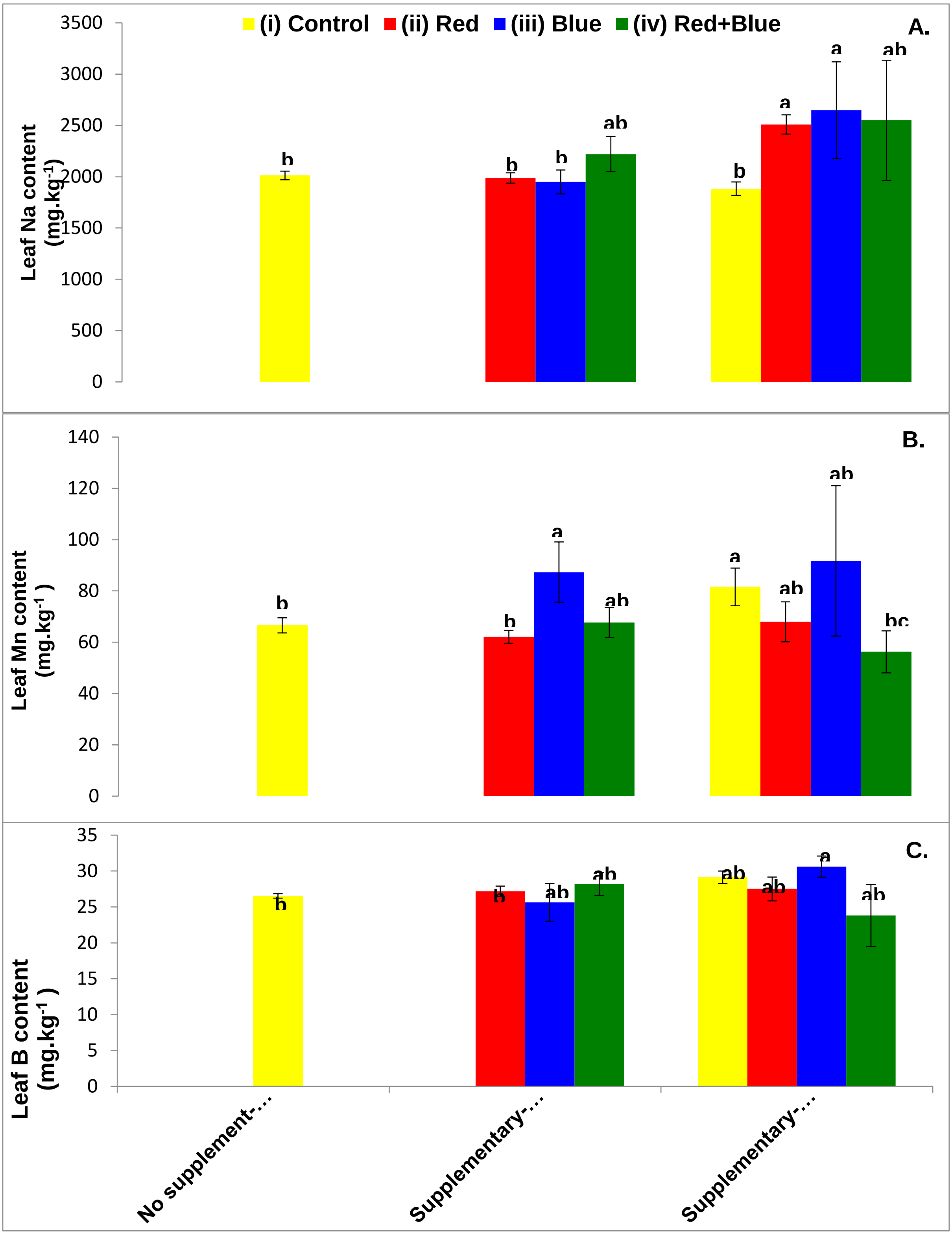

Figure 8. Content (mg.kg^{-1}) of 'non-metal' micronutrients A. Sodium (Na); B. Manganese (Mn) and C. Boron (B) of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at P < 0.05.

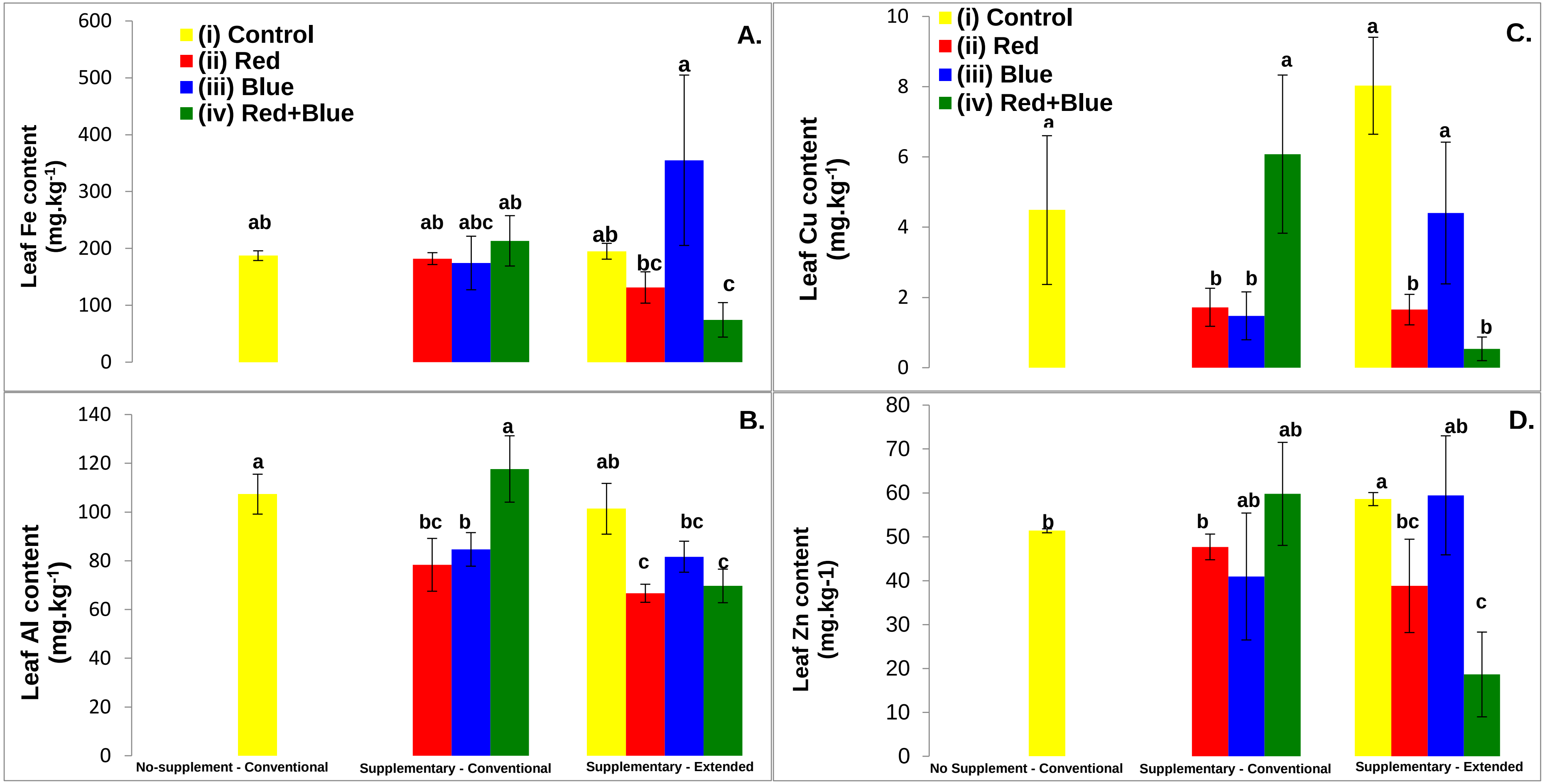

Figure 9. Content (mg.kg^{-1}) of 'metal-like' micronutrients A. Iron (Fe); B. Aluminium (Al); C. Copper (Cu) and D. Zinc (Zn) of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at $P < 0.05$.

4.5.1 Water Usage (WU)

The water usage (WU) averaged about 1650 ml.container^{-1} for lettuce plants cultivated under control conditions; i.e. no supplemental lighting and a photoperiod of 9 h. Water usage was decreased marginally by 12% under supplementary lighting and extended photoperiod conditions, respectively when compared to aforementioned control conditions (Fig. 10). Furthermore, with supplemental lighting under conventional photoperiod conditions the decrease ranged between 4% (red light supplement) and 6% (blue light supplement), respectively, whereas the WU decrease was more pronounced when plants were subjected to a combination of R + B light; i.e., 16%.

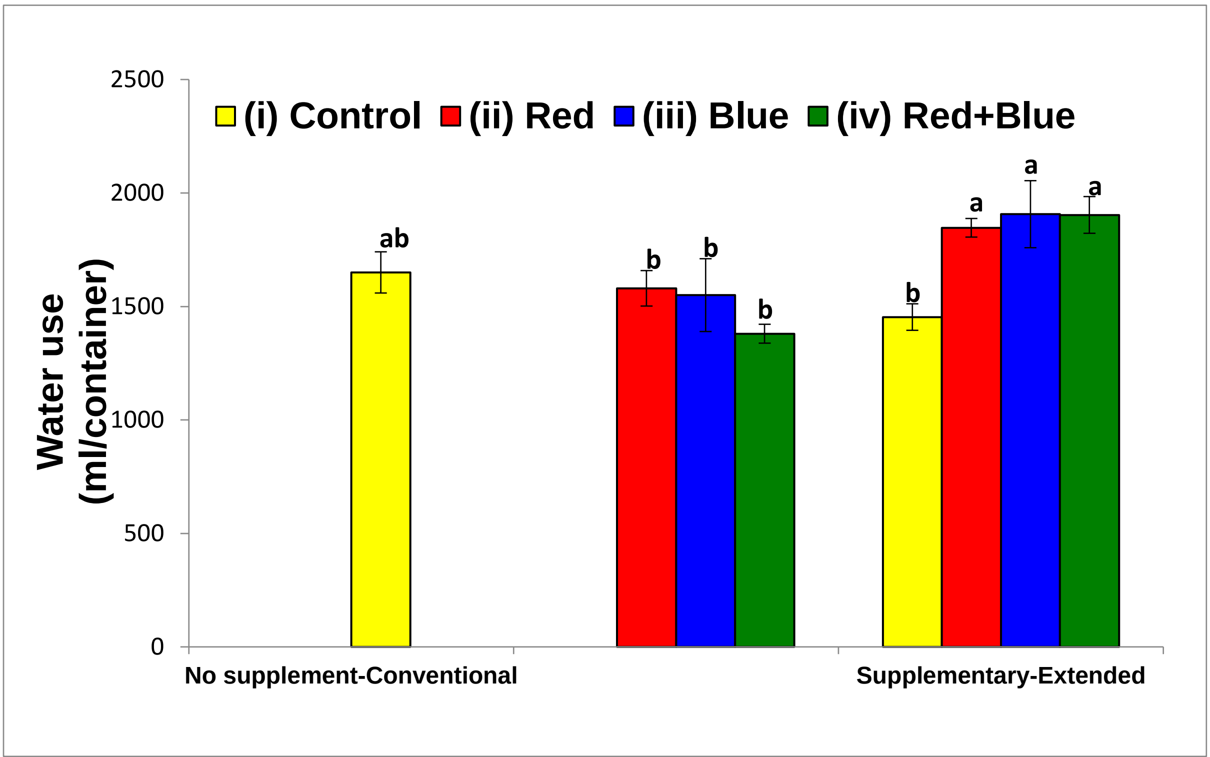

Figure 10. Water usage (WU; ml.container^{-1}) of *Lactuca sativa* leaves (n = 12) subjected to both a short- or long photoperiod duration and LED light colour. Plants were exposed to; (i) Control (No supplemental light), (ii) Red Light (R), (iii) Blue Light (B) and (iv) Red+Blue Light (R+B). **No-supplement-Conventional was exposed to 'normal' white light and not to any other colour LED light supplements*. Means for each treatment effect followed by different letters are significantly different at $P < 0.05$.

In contrast, there was an increase between 12% (red light supplement) and 16% (blue light supplement) when lettuce plants were subjected to these aforementioned lighting sources under extended photoperiod conditions in comparison to control conditions

(Fig. 10). Under conditions of a combination of R+B supplementary lighting the increase in WU was about 15%. The lowest WU of 1380 ml.container^{-1} was observed under conventional photoperiod conditions with a combination of red + blue light. The highest WU of 1907 ml.container^{-1} was observed under blue light supplementation (Fig. 10).

4.6 Discussion

Manipulation of the light environment is a common practice in industry, particularly when natural light is limiting. The implementation of High Pressure Sodium (HPS) lamps has previously been utilised to improve the light environment (Islam, 2012). However, such lamps are usually limited in the wavelength frequency that it emits, invariably only being able to supply white light at a one specific intensity. In addition, HPS lamps suffer from an inefficient conversion of electrical energy to light energy. Thus, light emitting diodes (LED) have since emerged as more effective alternatives to HPS lamps and other light sources. These light sources achieve close to 80% efficiency in converting electrical energy into light energy. Moreover, LED lights can be customised to emit specific frequency wavelengths which coincides with the photosynthetically active radiation (PAR) range of where plants actively photosynthesise and that is conducive to biomass accumulation overall (Tennessen et l., 1994). Seemingly, light frequencies in the red and blue range are the most efficient drivers of photosynthesis.

From the results it is clear that the supplementation of light has an effect on lettuce growth. Lettuce crop growth responses are mainly attributed to the distinct light frequencies resulting from supplemental light. Generally, monochromatic R light supplementation elicited a more pronounced growth response, particularly with regards to FW accumulation, irrespective of the photoperiod duration. This also translated into a higher DW accumulation, but only for lettuce leaves. Furthermore, R light is considered the most efficient wavelength for eliciting greater biomass accumulation because it is a key driver of photosynthesis. Results from this study corroborated findings from a previous study (Shimizu et al., 2011).

Contrastingly, the roots of lettuce plants subjected to monochromatic B light and/or a combination of R+B accrued higher DW. It is well established that the growth of roots and shoots in plants is governed by a ratio, and they maintain a dynamic balance, which reflects the relative abundance of aboveground resources in relation to the root-zone resources (Plants in Action, 2016). Similarly, B LED light supplementation accumulated higher levels of chlorophyll under conventional photoperiod conditions, whilst remaining unaffected under prolonged photoperiods. These higher levels of chlorophyll accrued under B light illumination could be to dissipate energy deliverance to the leaf surface of affected plants, since it is known that energy-dense B light energy could be lost through dissipation and fluorescence (Lee et al., 2015). Thus, increasing the *Chl* content may be a means to maximise the efficiency in absorption and to optimise photosynthesis.

The various light frequencies and photoperiod duration the plants were subjected to in this study invariably caused differences in lettuce crop nutritional quality. Some minerals, most notably N and K were reduced markedly under prolonged photoperiod durations, particularly under mixed light supplementation of R+B. This was also the case for Ca and Mg under similar conditions when compared to the control treatment under extended photoperiod conditions. In contrast, there were no such apparent effects on P in lettuce crops, irrespective of light frequency or photoperiod duration. Potassium is pivotal to the regulation of stomatal aperture (Lebaudy, Véry & Sentenac, 2007). By controlling the opening and closing of stomata it influences the regulation of turgor, leaf gaseous exchange and long distance nutrient flow, transpiration stream regulation. The reason for the K percentage decrease under a longer photoperiod can be attributed to the morphological characteristics of lettuce leaves under this light treatment. It was found by (Gay & Hurd, 1975) that stomatal density reaches a maximum before leaves have expanded more than 10%. Casson & Gray (2008) also noted that mature leaves determine stomatal density of leaves six days before the unfolding of a new leaf blade. Thus, although stomatal density would be equivalent under both a short and long photoperiod, the greater expansion of lettuce leaves under a long photoperiod would result in a dilution effect. An equivalent stomatal density, and subsequently K percentage, distributed across a greater leaf area would result in a perceived lower percentage. It is proposed that when maintaining a given light intensity, while the biomass increases simultaneously, the plants demand for nutrients to support the plant processes will remain constant but will be diluted across the increased biomass.

Furthermore, the extension of the photoperiod will undoubtedly increase the WU of plants due to the increased demand for CO_2 and plant nutrients as result of improved growth (Araújo et al., 2011).

It is apparent that photoperiod and light colour/frequency can have a significant effect on the nutrient contents of lettuce leaves; yet, the effects were not as explicit. All responses elicited in terms of nutrient contents of lettuce leaves could be to some extent be ascribed to the morphological responses that resulted from supplemental light. However, the supplemental light used might not have been strong enough; i.e., the ideal light intensity, to elicit distinct growth responses from lettuce plants. Yet, it can be concluded that light can be used to manipulate growth, even at low levels of supplementation. Light colour treatments effectiveness may be more pronounced at greater levels and the isolated effects are well documented. It is proposed that when additional light is supplemented that care should be taken such that the increased light intensity is in balance with the length of the photoperiod. For optimal supplementation a regime that similarly follows the trends of seasonal photoperiod and light intensity patterns is recommended.

Further research, using stronger LED lights, into natural light supplementation for plants grown under Western Cape climatic conditions is required. A greater consideration of these environmental aspects being provided to plant growth will allow a farmer to improve growth and yield, whilst not negatively affecting the lettuce leaf quality.

4.7 References

Araújo, W.L., Fernie, A.R. & Nunes-Nesi, A. 2011. Control of stomatal aperture. *Plant Signaling & Behavior*. 6(9):1305–1311.

Chabot, B.F. & Chabot, J.F. 1977. Effects of Light and Temperature on Leaf Anatomy and Photosynthesis in Fragaria vesca. *Oecologia*. 26(4):363–377.

Cui, M., Bogelmann, T.C. & Smith, W.K. 1991. Chloropyll and light gardients in sun and shade leaves of Spinacia oleracea. *Plant, Cell and Environment*. 14:493–500.

Dougher, T.A.O. & Bugbee, B. 2004. Long-term blue light effects on the histology of lettuce and soybean leaves and stems. *Journal of the American Society for Horticultural Science.* 129(4):467–472.

Dutta Gupta, S., Jatothu, B., Massa, G.D., Kim, H.H., Wheeler, R.M., Mitchell, C.A., Morrow, R.C., Olle, M., et al. 2013. Importance of "blue" photon levels for lettuce seedlings grown under red-light-emitting diodes. *HortScience*. 43(1):43–52.

Fan, X.-X., Xu, Z.-G., Liu, X.-Y., Tang, C.-M., Wang, L.-W. & Han, X. 2013. Effects of light intensity on the growth and leaf development of young tomato plants grown under a combination of red and blue light. *Scientia Horticulturae*. 153:50–55.

Fu, W., Li, P. & Wu, Y. 2012. Effects of different light intensities on chlorophyll fluorescence characteristics and yield in lettuce. *Scientia Horticulturae*. 135:45–51.

Fukuda, N., Nishimura, S. & Fumiki, Y. 2004. Effect of supplemental lighting during the period from middle of night to morning on photosynthesis and leaf thickness of lettuce (Lactuca sativa L.) and Tsukena (Brassica campestris L.). In Vol. 633 *Acta Horticulturae*. 237–244.

Gaudreau, L., Charbonneau, J., Vezina, L.P. & Gosselin, A. 1994. Photoperiod and photosynthetic photon flux influence growth and quality of greenhouse-grown lettuce. *HortScience*. 29(11):1285–1289.

Hiroki, R., Shimizua, H., Ito, A., Nakashima, H., Miyasaka, J. & Ohdoi, K. 2014. Identifying the optimum light cycle for lettuce growth in a plant factory. *Acta Horticulturae*. 1037:863–868.

Kang, J.H., KrishnaKumar, S., Atulba, S.L.S., Jeong, B.R. & Hwang, S.J. 2013. Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system. *Horticulture, Environment, and Biotechnology*. 54(6):501–509.

Lin, K., Huang, M., Huang, W., Hsu, M., Yang, Z. & Yang, C. 2013a. The effects of red , blue , and white light-emitting diodes on the growth , development , and edible quality of hydroponically grown lettuce (Lactuca sativa. *Scientia Horticulturae*. 150:86–91.

Lin, K.-H., Huang, M.-Y., Huang, W.-D., Hsu, M.-H., Yang, Z.-W. & Yang, C.-M. 2013b. The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. var. capitata). *Scientia Horticulturae*. 150:86–91.

Mou, B. 2008. Lettuce. In Vol. 1 *Vegetables I*. 75–116.

Muneer, S., Kim, E., Park, J. & Lee, J. 2014. Influence of Green, Red and Blue Light Emitting Diodes on Multiprotein Complex Proteins and Photosynthetic Activity under Different Light Intensities in Lettuce Leaves (Lactuca sativa L.). *International Journal of Molecular Sciences*. 15(3):4657–4670.

Nagel, K.A., Schurr, U. & Walter, A. 2006. Dynamics of root growth stimulation in Nicotiana tabacum in increasing light intensity. *Plant, Cell and Environment*. 29(10):1936–1945.

Runkle, E. 2017. *Effects of blue light on plants*. [Online], Available: http://flor.hrt.msu.edu/assets/Uploads/Blue-light.pdf.

Son, K.H. & Oh, M.M. 2013. Leaf shape, growth, and antioxidant phenolic compounds of two lettuce cultivars grown under various combinations of blue and red light-emitting diodes. *HortScience*. 48(8):988–995.

Taiz, L. & Zeiger, E. 2010. Plant Physiology, Fifth Edition. *Cell*. 1:782. [Online], Available: http://www.amazon.com/dp/0878938567.

Wojciechowska, R., Długosz-Grochowska, O., Kołton, A. & Żupnik, M. 2015. Effects of LED supplemental lighting on yield and some quality parameters of lamb's lettuce grown in two winter cycles. *Scientia Horticulturae*. 187:80–86.

Zeiger, E. & Helper, P.K. 1977. Light and Stomatal Function : Blue Light Stimulates Swelling of Guard Cell Protoplasts. *American Association for the Advancement of Science*. 196(4292):887–889. [Online], Available: url: http://www.jstor.org/stable/1744100.

Cakmak, I. & Yazici, A.M. 2010. Magnesium: A Forgotten Element in Crop Production. *Better Crops*. 94(2):23–25.

Casson, S. & Gray, J.E. 2008. Influence of environmental factors on stomatal development. *New Phytologist*. 178(1):9–23.

Fu, W., Li, P. & Wu, Y. 2012. Effects of different light intensities on chlorophyll fluorescence characteristics and yield in lettuce. *Scientia Horticulturae*. 135:45–51.

GAY, A.P. & HURD, R.G. 1975. THE INFLUENCE OF LIGHT ON STOMATAL DENSITY IN THE TOMATO. *New Phytologist*. 75(1):37–46.

Knecht, G.N. & O'Leary, J.W. 1972. The Effect of Light Intensity on Stomate Number and Density of Phaseolus vulgaris L. Leaves. *Botanical Gazette*. 133(2):132–134. [Online], Available: http://www.jstor.org/stable/2473811.

Lebaudy, A., Véry, A.A. & Sentenac, H. 2007.

Mou, B. 2008. Lettuce. In Vol. 1 *Vegetables I*. 75–116.

Shaul, O. 2002. Magnesium transport and function in plants: the tip of the iceberg. *Biometals : an international journal on the role of metal ions in biology, biochemistry, and medicine*. 15(3):309–323.

Zhang, H., Zhong, H., Wang, Ji., Sui, X. & Xu, N. 2016. Adaptive changes in chlorophyll content and photosynthetic features to low light in Physocarpus amurensis Maxim and Physocarpus opulifolius "Diabolo". *PeerJ*. 4:e2125.

CHAPTER 5

General Summary

5.1 Synopsis

From the literature review of the current state of global food security it was found that gross production is not the outright issue at the core of the problem. Food availability and accessibility have been understood to exert greater pressure in achieving a food secure population. In light of the current state of food security added pressure will be exerted by predicted trends in global population trends, urbanisation and climate change. It was thought that a drastic change in current production techniques is required to combat future trends. It was hypothesised that by moving production into a controlled environment, with a higher level of intensification, would be a viable solution.

In the subsequent chapters following the initial literature review, the financial and technological feasibility was analysed. By understanding the financial and technological feasibility of a greenhouse venture conclusions were able to support the idea that such a production system could employed as a way to ensure global food security in light of the future challenges. The financial feasibility, in the form of a budget, showed that although the initial capital investment was high, the return on investment made the production system profitable. This shows that, if managed correctly, such a production system can be financially feasible. When compared to open field ventures, the start initial investment was higher, but it out performed the open field system in the long run. Further, the technological feasible was determined through a trial involving LED lights. This trial showed that, even at low levels of supplemental LED lighting, growth could be improved.

Overall, it is clear that greenhouse production systems can manage the current and future trends in population and climate change. The financial feasibility ensures that the investment would be an attractive one. The returns allow a consistent cash flow, yielding good consistent profits, as well as ensuring that the initial capital investment will be paid back within four years. Further, being able to feed more individuals, it allow for the economic upliftment of areas where such a venture would be implemented. The technological feasibility study showed that relevant technologies can be employed to maintain optimal production. Issues surrounding production intensification and production relocation closer to the market can be curbed with the use of LED lights.

Overall, this study only touched on minor details surrounding the assessment of food insecurity and investigation into a solution to solve it. More research is needed to understand if greenhouse production systems can be developed with a lower capital investment, and if these production systems can be as profitable and yield as high production as the ones discussed previously. Moreover, due to the continued uncertainty on how to combat the contradictions involved in maintaining desired contents of nutrients in lettuce plants more research needs to be conducted. A perfect balance between light intensity and photoperiod needs to be found in which all nutrients are assimilated in optimum quantities in lettuce leaves.