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The Production of Seed Potatoes by Hydroponic Methods in Brazil

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ABSTRACT

In recent years, hydroponics has proven to be a very successful strategy for the production of pre-basic seed potatoes. Hydroponic techniques are much more efficient than the more traditional methods of cultivation of seed potatoes (i.e. in fields, planting beds or containers) and productivity can be three times greater (15 *vs.* 5 tubers/plant, respectively). Hydroponic methods not only facilitate the adequate supply of nutrients to the plants but also permit multiple harvesting of mini-tubers, a procedure that can be performed at specified intervals throughout the production cycle. The number of mini-tubers obtained via systematic harvesting is high in comparison with a single harvest strategy and the product obtained will be of uniform size. Since hydroponic cultivation avoids attack by pests and the dissemination of pathogens, the resulting tubers are normally disease-free. The main aspects concerning the production of seed potatoes are presented in this review.

Keywords: agricultural, biotechnology, nutrition, potato seed tubers, *Solanum tuberosum*

CONTENTS

INTRODUCTION

The potato (*Solanum tuberosum* L.) is the fourth most important culture worldwide (after corn, rice and wheat) and is so basic to the human diet that the United Nations and the Food Agriculture Organisation declared 2008 to be "The International Year of the Potato". Although the potato is rather poor in essential nutrients, it is highly valued as a source of complex carbohydrates with the added advantage of a low fat content. Moreover, many different types of traditional dishes can be prepared using the potato on account of its mild flavour and aroma (Pereira 2008).

Since the potato is widely appreciated and accepted by most cultures, the vegetable could contribute to the reduction of hunger in many parts of the world. However, in order to meet the increasing demands of a growing population, the efficiency of production must be improved. One of the main constraints in the culture of potato is the cost of producing seed tubers since this can account for between 30 and 50% of the total production expenses depending on the country or region. A further limitation is the long asexual (vegetative) propagation cycle during which infection by viruses or bacteria can give rise to degenerative diseases. In tropical climates, in which both temperature and humidity are high, leaf diseases are further aggravated by the rapid proliferation of aphids that are responsible for the transmission of pathogenic micro-organisms and the consequent reduction in crop yield can be extensive.

Research institutes around the world have dedicated a great deal of effort into improving the vigour and quality of seed potato tubers and, consequently, maximising production efficiency and increasing crop yield. The application of biotechnological techniques such as tissue culture and hydroponics have resulted in increased yields, reduced production costs, a lower incidence of disease and diminished use of agrochemicals. Thus, by curbing or eliminating the occurrence of pests and pathogens, these techniques have contributed to the preservation of the environment. In this context, several countries, including Brazil and Russia, are currently stimulating and financing programmes associated with the hydroponic cultivation of seed potatoes. Within this context, the present review describes the main developments in the use of hydroponics for the production of high quality seed potatoes in Brazil.

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Invited Mini-Review

OVERVIEW OF THE PRODUCTION OF SEED POTATO TUBERS

The initial process in potato cultivation involves the commercial multiplication of pathogen-free tubers to be employed as seed potatoes (Filgueira 2003). According to Daniels (2000), the quality of seed potatoes is crucial in achieving satisfactory productivity, and thus cultivation, harvesting and storage must be conducted under rigorous conditions in order to prevent infection by viruses, bacteria, fungi and other pests. For this reason, good quality seed potatoes can only be guaranteed if regular inspections are carried out during all stages of production in order to ensure minimal levels of infection. Furthermore, seed potatoes must be collected at the appropriate time and should present excellent physiological characteristics such as turgidity and firmness. Old and wrinkled tubers should not be cultivated because the resulting plants are likely to be less vigorous and present shorter vegetative cycles. In Brazil, basic, registered and certified tubers can only be produced by specialised growers recognised by the Secretaries of Agriculture of the various states.

According to Pereira and Daniels (2003), an average of *ca.* 15% of the world potato production is preserved as seed potatoes, but in those countries in which the productivity of potatoes is high, this percentage is often much lower (typically around 10%). In Brazil, some 13% of the potatoes produced are employed as seed, but only 20 to 30% of these are considered to be quality seeds (i.e. certified seed or similar). On the other hand, Chile and The Netherlands export 15 and 25%, respectively, of their production as seed potatoes. Moreover, according to the Ministry of Agriculture and Commerce of the United States, 10% of the potatoes harvested in the USA are exported as seed potatoes, thus demonstrating the strength and efficiency of potato production in that country. Part of this success is due to the remote locations and the rigorous climates of the producing areas, aspects that are not favourable to attack by pests. In these regions, winters tend to be long and cold and the culture periods are characterised by sunny days and fresh nights, which facilitate the emergence of vigorous and prolific plants. In contrast, in tropical climates the multiplication of pathogens and their vectors is favoured, and the only way to control the dissemination of diseases is through the application of agrochemicals, a procedure that increases production costs significantly.

Although it is difficult to describe the ideal qualities of seed potatoes, a first rate batch should be in accordance with the following specific criteria (Rowe 1993): (i) tubers should be genetically pure; (ii) seeds should be certified for tolerance against the main pest-borne diseases; (iii) seeds should be certified for tolerance against physiological diseases and mechanical injuries; (iv) root-associated bacteria, latent infections and root nematodes should be absent; (v) tubers should exhibit vigorous sprouting; (vi) tubers must be free of soil particles; and (vii) inspection labels should confirm previous certification.

The nomenclature of seed potatoes varies depending on the country of origin. The European Union adopts the clone criteria (1 to 6 years old) with categories S, SE, E, B and C (Beukema and Van der Zaag 1990). South Africa adopts the generation criteria (1 to 3), whereas Canada classifies the seeds as pre-elite, elite I, II and III. Brazil adopts the American system in which seed potatoes are grouped into four classes (genetic, basic, registered and certified) that vary with respect to their tolerance to diseases. Genetic seed potatoes are those obtained by vegetative multiplication of a cultivar, under the responsibility of a breeding institute, and maintained with a high degree of genetic purity. Basic seed potatoes originate from genetic seeds via vegetative multiplication, and are produced under the responsibility of a breeding or authorised institute in order to ensure the health status and specified levels of tolerance to diseases. Within these classifications, generally three multiplications are allowed by the majority of Brazilian states (Brazilan Ministry of Agriculture 1998). Certified potato seeds are those obtained via vegetative multiplication from basic (national or imported) or previously certified seeds; further multiplication of such tubers is not allowed since these are the seeds that are made available to potato farmers.

Between genetic and basic seeds there is an intermediary type known as pre-basic seeds. Such seeds originate from genetic seeds following various cycles of multiplication carried out by the breeding institute, and are submitted to various indexing tests in order to certify the absence of viruses. The standard biotechnological methods for producing pre-basic seed potatoes (mini- and micro-tubers) are multiplication through tissue culture, in planting beds or pots, or by hydroponics. Pre-basic seeds are supplied to the recognised growers of basic seeds and undergo further multiplication cycles (three cycles in total), after which the seeds are commercialised by potato farmers for supply to the consumer market. The sequence of cultivation of seed potatoes from pre-basic material is thus: pre-basic » basic » registered » certified » consumption. Pre-basic potato seeds are cultured under shade conditions and after three generations each tuber will produce one box of certified seed potatoes (Dr. Marcos Paiva, Multiplanta-Tecnologia Vegetal, Andradas-MG Brazil, pers. comm.).

Mini- and micro-tubers, obtained via biotechnological approaches, constitute excellent pre-basic seeds since they are disease-free, present excellent physiological characteristics and exhibit higher multiplication rates compared with tubers produced in the field. Moreover, in a potato breeding programme, the number of multiplications needed in the field can be significantly reduced if mini- or micro-tubers are employed (Struik and Lommen 1999).

IN VITRO MICROPROPAGATION

The tissue culture technique employed in the micropropagation of potatoes consists in the aseptic cultivation of cells or fragments of plant tissues and organs in an artificial medium under controlled temperature and light conditions. Vigorous and disease-free potato plants can be obtained in the laboratory using these methods, and are then transferred to hydroponic conditions for the production of seed potato tubers. The culture of stem apices, erroneously known as meristem culture (Torres *et al.* 1998), is the technique most commonly employed in the regeneration of virus-free plants (Kane 2000). One of the advantages of this method is the maintenance of genotype identity since meristem cells preserve their genetic stability more uniformly (Murashige 1974; Grout 1990).

Four fundamental steps are involved in the *in vitro* culture of potatoes (Fortes and Pereira 2003), namely: (i) preparation of explants - selection of apical shoots from plants grown in green houses, separation of shoots into small pieces and surface sterilisation; (ii) establishment of cultures - isolation of stem apices and inoculation onto appropriate medium for differentiation and growth over a period of 40-60 days; (iii) multiplication and rooting - inoculation of shoots onto semi-solid or liquid media (most cultivars do not require growth regulators); and (iv) acclimatisation of plants - transfer of propagules into polystyrene trays containing sterilised substrate and maintenance under green house conditions for approximately 10 days. After the acclimatisation period, plants are normally transferred to the sites of production of seed potato tubers. At this stage the shoots can be excised from the plants in order to reinitiate the micropropagation process.

Fig. 1 illustrates stages 1 to 10 of the micropropagation of potato plants leading not only to the formation of multiple new plants but also to the production of seed potato mini- and micro-tubers that can be cultivated directly in the field The productivity of micro-tubers *in vitro* can be rather low with values of 1.85, 2.07 and 2.52 being reported for cultivars 'Jaerla', 'Spunta' and 'Kennebec', respectively (Grigoriadou and Leventakis 1999). However, plants can be induced to produce a higher number of micro-tubers through

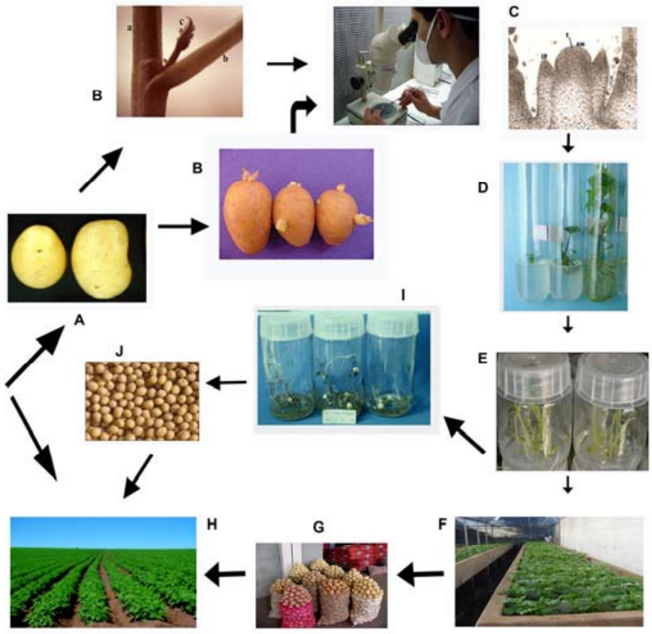

Fig. 1 *In vitro* micropropagation of potatoes. Disease-free tubers produced in the greenhouse (**A**) are induced to produce shoots (**B**), which are then washed in running water for 3-4 h and subsequently disinfected with hypochlorite solution (0.5-1.0 % active chlorine; 20 min) in order to eliminate superficial contamination. The stem apices are inoculated onto semi-solid Murashige and Skoog (1962) medium (**C**) for growth (**D**) and multiplication (**E**). Some cultivars develop well in the absence of plant growth regulators and in liquid medium. The propagules are then transferred to hydroponic systems, planting beds or containers (**F**) in order to produce seed potatoes (**G**), which are then cultivated in the field (**H**). The plants multiplied *in vitro* (**I**) can also be induced to produce micro-tubers (**J**) for cultivation in the field (**H**). Figure: Ricardo Monteiro Corrêa; MultiPlanta Tecnologia Vegetal, 2008.

manipulation of the growth conditions (i.e. alteration of the nutrient balance and/or photoperiod). Currently, in many countries, such micro-tubers are employed exclusively for the preservation of germplasm and for plant improvement since the technologies available and local climatic conditions (particularly in the tropics) are not favourable to the culture of small tubers.

Fig. 2 displays details of the systematic production (multiple harvesting) of mini-tubers from the *in vitro* micropropagation of plants to the harvesting of tubers from pots maintained in the green house. However, the multiple harvesting of seed potatoes following cultivation of plants in pots can present some disadvantages including damage caused to the plant roots due to the multiple harvestings and the dissemination of diseases occasioned by the favourable microclimate provided by irrigation, which is normally by aspersion. Within this context, hydroponics represents a valuable strategy by which to circumvent such problems since the micropropagated and acclimatised plants are not transferred to the soil, as is the case with planting beds or pots, but to a nutrient solution.

THE USE OF HYDROPONICS

In its basic form, hydroponics consists in culturing plants in a nutrient solution containing balanced amounts of the essential components that are necessary for plant growth and development. The use of hydroponics for commercial applications commenced in the 1930s, although reports regarding the culture of plants in liquid medium date back to the seventeenth century. During World War II, hydroponics was largely employed in the USA for the production of fresh vegetables under adverse conditions. With respect to the production of seed potatoes, hydroponics has been used in many countries including Brazil, Russia, Belgium and The Netherlands. There are many advantages attached to the use of hydroponics in the culture of pre-basic seed potatoes over more conventional methods, and these include: (i) very high rates of tuber multiplication (Muro 1997; Ranalli 1997; Rolot and Seutin 1999; Medeiros 2001; Factor *et al.* 2007; Corrêa *et al.* 2008); (ii) absence of risk of tuber contamination by soil pathogens (Rolot and Seutin 1999; Corrêa *et al.* 2008); (iii) lower incidence of physiological diseases; (iv) elimination of the need for soil sterilisation; and (v) facile systems management (Ranalli 1997).

Fig. 2 Systematic production of seed potato mini tubers. Initially the semi-solid medium [normally Murashige and Skoog (1962) supplemented with 0.6% agar] used for plant micropropagation is prepared and autoclaved at 120°C and 1 atm for 20 min (**A**). The shoots or stem apices are inoculated into flasks (200-300 mL; 20-30 mL of medium) or into test tubes (75 × 25 mm i.d.; 10-15 mL of medium) under sterile conditions (**B**). After 30 days in culture, the regenerated plants are multiplied in liquid medium (15-20 mL) under controlled conditions (25 ± 1°C; 8 h photoperiod) in the growth room (**C**). The propagules are transferred to polystyrene trays containing sterile substrate (**D**) for acclimatisation. The acclimatised plants are transplanted to planting beds (**E**) or containers (**F**) in the green house. After 30 days, the seed potato mini-tubers are harvested (**G** and **H**), stored in order to induce sprouting (**I**) and subsequently cultivated. Photos: Ricardo Monteiro Corrêa.

Types of hydroponic systems

The main hydroponic systems presently available for the cultivation of leafy vegetables and potatoes are the nutrient film technique (NFT), the deep flow technique (DFT) and aeroponics. The NFT system consists of a series of PVC or asbestos-cement growing channels, arranged on wooden benches with a 1-4% slope, through which a thin film of nutrient solution (1 cm deep) flows over the roots of appropriately spaced plants. The solution is collected in a tank located at the lowest end of the bench and is subsequently pumped back to the top of the channels by a submersible pump, thus allowing the constant recirculation of the nutrient solution. In this system, the surface of the roots is also exposed to the air while the nutrient solution circulates.

NFT is widely used in the culture of leafy vegetables because the installation is straightforward and cheap. The alternative DFT hydroponic system consists of a tank containing the nutrient solution (5-20 cm deep), and the plants are placed on a platform with the roots completely immersed in nutrient. Recirculation occurs through a typical entry-exit mechanism with the aid of a pump. Aeroponics is a more costly and complex hydroponic system that involves growing plants in an air or mist environment. A typical system would consist of PVC tubes (200 mm diameter) maintained in the vertical position and containing lateral holes through which the plants are anchored by foam compressed around the lower stem such that the roots are suspended in the internal part of the tube and the leaves and crown protrude outside the tube. The root zone inside the tube is then sprayed for short periods with atomised nutrient solution, whilst the leaves on the outside of the tube receive appropriate light conditions. The application of DFT and aeroponics is less common than NFT but has increased recently.

Although all three hydroponic systems can be used for the culture of seed potatoes, NFT is the most common employed. Medeiros *et al*. (2002) have described two different NFT systems for producing seed tubers and have reported on their advantages and limitations. The first system consisted of 6 cm deep channels, constructed from asbestos-cement roofing material and covered by polyethylene membranes, spaced 18 cm from each other and resting on wooden platforms with a 4% slope. The second system was similar to the asbestos-cement model but consisted of two overlapping articulated PVC channels that had been fabricated especially for the purpose. The fixed upper channels comprised 25 cm orifices spaced 15-20 cm apart in which the plants were placed, while the lower channels were movable in order to allow observation of the tubers as they formed and product harvesting.

The channels were covered by a polyethylene film in order to prevent exposure to light. Although the asbestos-cement model required a smaller installation area, the tubers produced were of variable size (some weighing more than 250 g) and could, therefore, only be planted directly in the field to produce potatoes for consumption. The PVC model demanded a larger installation area but had the advantage of allowing easy access to the plants and harvesting of the tubers when they achieved the desired size. Not only was productivity of the PVC model (35 tubers/plant) some 2.5-fold greater than that of the asbestos-cement model (14 tubers/plant), but systematic multiple harvesting allowed the collection of uniform sized product.

A comparison of NFT, DFT and aeroponic techniques regarding the productivity of basic seed potato mini-tubers from cvs. 'Monalisa' and 'Ágata' per unit area of installation (Factor *et al*. 2007) revealed that the aeroponic system (875 tubers/m^2) was 255 and 91% more efficient than the NFT (246 tubers/m^2) and DFT (458 tubers/m^2) systems, respectively. Such significant differences were attributed to the diverse plant densities supported by the three systems, these being 6.25 (NFT), 11 (DFT) and 17 (aeroponics) plants/m^2.

Nutrient solutions

Supplementation of the hydroponic solution with mineral nutrients is very important with regard to the quality and productivity of mini-tubers. The primary macronutrients required are nitrogen, phosphorus and potassium. Nitrogen is important for the synthesis of protein and chlorophyll and is, therefore, essential for the development of leaf area and productivity. Phosphorus is a component of the phosphorylated nucleotides involved in metabolic processes that require energy transfer such as absorption of nutrients and plant growth.

Potassium is not only an activator of enzyme reactions, but also participates in the redistribution of photo-assimilates to the sink areas and increases plant tolerance against pests and diseases. There is evidence that the yield of seed potato tubers is increased following the application of phosphate fertilisers, whereas the effect of nitrogen- and potassium-based fertilisers is not so clear-cut (Nava *et al*. 2007).

Magnesium and calcium are essential secondary macronutrients. Magnesium is not only a component of the chlorophyll molecule, but is also the most important cofactor for plant enzyme activity. Calcium is a component of cell wall pectates and is responsible for the integrity of cell membranes. Furthermore, root growth and function depend on the presence of calcium.

Micronutrients are those elements that are absolutely vital for plant metabolism, although the amounts required are minute. Boron is responsible for sugar transport, cell wall synthesis, the metabolism of RNA and growth regulators (indole-3-acetic acid), and for root growth. According to Cakmak (1997), boron deficiency negatively influences the effect of potassium fertilisers and releases sucrose and amino acids from plant tissues thus stimulating the proliferation of pests and pathogens by increasing the availability of nutrients. Iron, zinc and copper are enzyme activators during plant growth. Additionally, copper plays a role in the protection of plants against diseases.

The efficiency and superior productivity exhibited by hydroponics are dependent on the constant availability of nutrients, the possibility of multiple harvestings and the prevention of root injury (Calldevilla and Lozano 1993). Whilst nutrients are not replaced in substrate-based multiplication systems, in hydroponics the concentrations of macro and micronutrients, together with the pH of the system, are maintained within optimum limits throughout the various production cycles.

Two reports are available concerning the production of mini-tubers from cvs. 'Monalisa' and 'Ágata' in similar NFT systems at densities of 6.25 plants/m^2 but with different concentrations of nutrients (**Table 1**). Corrêa and co-workers (2005) employed a nutrient system based on the formula of Medeiros *et al*. (2002) and obtained yields of 443 and 439 tubers/m^2, respectively, from the two cultivars. These values were much greater than that (246 tubers/m^2) claimed by Factor *et al*. (2007) who employed a modified nutrient solution (Medeiros *et al*. 2002; Rolot and Seutin 1999) containing higher amounts of some key nutrients.

Table 1 Nutrient solutions used in the production of seed potato tubers in two published studies.

Reference	**Macro and micro nutrients (mg L^{-1})**												
	NO_3^{2-}	**NH_4^+**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Cu**	**Mo**	**Mn**	**Zn**	**B**
Corrêa *et al*. 2005*	160	12	42	239	152	11.2	40	1.68	0.24	0.032	1.28	0.6	0.8
Factor *et al*. 2007**	145	29	40	295	162	40	64	2.0	0.05	0.05	1.0	0.3	0.3

* Medium according to Medeiros *et al*. (2002)
** Medium according to Rolot and Seutin (1999) and modified by Medeiros *et al*. (2002)

The differences in productivity observed in hydroponic systems might also be due to variation in region and season of cropping, since temperature is a factor that influences considerably the formation of tubers. Moreover, day length and nitrogen levels are involved in the control of endogenous growth regulators and, consequently, in tuberisation (Krauss 1985; Jackson 1999). High levels of nitrogen can reduce the levels and inhibit the activities of endogenous growth regulators (Krauss 1985; Stallknecht 1985), while there is some evidence that excess use of nitrogen fertiliser in the field can delay the formation of tubers by reducing the translocation of carbon from leaves to roots and by increasing nitrogen flow to new leaves instead of tubers (Oparka 1987). Hence, in hydroponics it is important to adjust the levels of nitrogen, as well as other nutrients, in order to maximise the yield of tubers. A study of the effect of varying the concentration of ammonium nitrate (in the range 0-400 mg kg^{-1}) on tuber production (Fontes *et al.* 2008) revealed that excessive concentrations of fertiliser diminished the dry mass of tubers proportionally. Since nitrogen is involved in the production of dry matter, the quantities supplied must be based on the requirements of the cultivar and on the stage of cultivation. Typically, levels of nitrogen that are too low result in diminished numbers of tubers, whereas excessive nitrogen delays tuberisation and prolongs the culture cycle, thus diminishing productivity (Oparka *et al.* 1987).

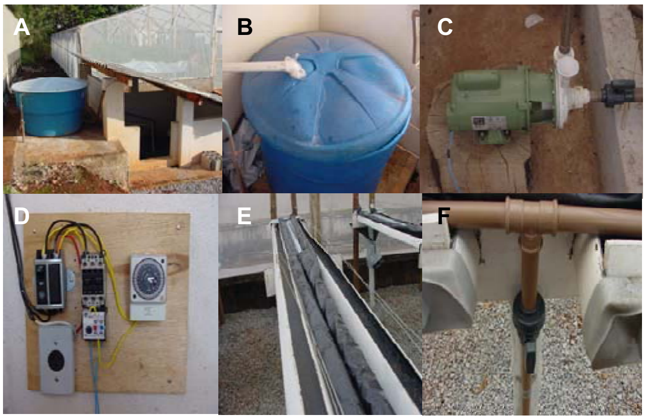

Fig. 4 Structure of the NFT hydroponic unit installed at the Universidade Federal de Lavras for the cultivation of seed potatoes from cvs. 'Monalisa' and 'Ágata'. The green house (protected with anti-aphid netting) and the reservoir of nutrient solution (2000-5000 L) are close to each other (**A**). The pump and the small tank of nutrient solution (2000 L) are inside the pump house (**B**). The pump, placed below the level of the tank, is covered with PVC (**C**) and attached to the control unit and timer (**D**). The cultivation channels (**E**), supported by wooden benches, are 4 m long and receive the nutrient solution through tubes connected to the pump (**F**). Photos: Ricardo Monteiro Corrêa.

Design and installation of an NFT hydroponic working unit

The location at which an NFT unit is to be constructed should be level, well-drained and with easy access. The hydroponic unit itself should be constructed inside a green house, various models of which are available depending on the needs and financial resources of the grower. The most common type of structure employed takes the form of a ground-to-ground arc style shelter with a roof of polyethylene film (100-150 µm) and walls made of anti-aphid netting to prevent interaction between the crop and insects. **Fig. 3** shows the installation of the green house located in the campus of Universidade Federal de Lavras (UFLA), which shelters the NFT unit used in the production of seed potatoes from cvs. 'Monalisa' and 'Ágata'. The productivity of the system shown is very high (typically 15 tubers/plant).

Since good quality water is essential in hydroponics, the microbiological and physicochemical (pH, hardness, Salinity, level of dissolved minerals, electrical conductivity etc) characteristics of the local water supply should be determined. Water containing chlorine or pathogenic micro-organisms and water exhibiting a high electrical conductivity is inappropriate for hydroponics. The construction of an artesian well must be considered when alternative sources of quality water are unavailable. Although many farmers use asbestos-cement tiles, specific PVC channels are the most common employed. Typically channels 3-6 m long, 15 cm wide and 7 cm high are attached to benches with a slope of (typically) 4%. A smaller declination is not recommended since this would not support a sufficient flow of nutrient solution, which should normally fall within the range 1 and 2 L min^{-1}.

Fig. 3 The NFT hydroponic unit installed at the Universidade Federal de Lavras for the cultivation of seed potatoes from cvs. 'Monalisa' and 'Ágata'. The benches are made of treated eucalyptus wood (**A**) and the 30 day old plants are supported by wire within the PVC channels (**B**). The mini tubers are ready for harvesting after 30 days of cultivation (**C** and **D**). Photo: Ricardo Monteiro Corrêa.

The reservoir (2000-5000 L) containing the nutrient solution should be fabricated from plastic or glass fibre and placed outside the green house, below the level of hydroponic system, and protected by a brick shelter in order to maintain the temperature below ambient level. Reservoirs larger than 5000 L are not recommended because of the difficulty in managing such large volumes of solution. A smaller tank (1000-2000 L) connected to and placed above the main reservoir is useful for replenishing the PVC channels with nutrient solution.

The nutrient solution is pumped from the reservoir to the cultivation channels using a centrifugal pump of variable potency (0.5-2.0 hp). The pump should be covered with PVC in order to avoid oxidation and to prolong its working life. The pump must be placed as near as possible to the reservoir and primed prior to use. It is necessary to attach the pump to a timer in order to allow intermittent irrigation, for example, 15 min of irrigation followed by a 15 min break. During the night, the break interval may be increased to 2-3 h. **Fig. 4** shows details of the pumping system employed in the NFT unit installed at UFLA.

The nutrient solution must be monitored throughout the cultivation process in order to ensure the proper growth and development of the plants. However, it is only feasible in practice to measure the total concentration of the salts rather than their individual concentrations. Monitoring is accomplished using a conductimeter and a pH meter. Conductivity should remain within the limits of 2-3 mS cm^{-1}, while pH should be in the range 5.5-6.0. Values of nutrient pH above 6.0 may result in a reduction in the absorption of micronutrients and infection by *Streptomyces scabies*, which is a common potato disease. It is possible that the concentration of salts could become unbalanced during the cultivation process due to differential absorption of nutrients by the roots. In order to overcome this problem the nutrient solution in the reservoir should be completely replaced every 30 days.

It is worth noting that plants subjected to hydroponic conditions tend to grow rather rapidly and should be supported firmly within the channels. This can be accomplished using cheap materials such as wire or netting, although more efficient, but more complex, approaches are available.

Harvesting of seed potatoes

The productivity of seed potatoes formed under hydroponic conditions is highly influenced by the method of harvesting. Mini-tubers can be harvested at the end of the culture cycle (single harvesting) or systematically throughout the cultivation period (multiple harvesting). Multiple harvesting is useful for obtaining small uniform tubers (3-4 cm) in great quantities, which can be subsequently commercialised as seed potatoes. Single harvesting permits the growth of tubers over a prolonged period of time, and the resulting tubers are bigger (up to 10 cm) but irregular and cannot be used as seeds.

The discrepancy between the sizes of tubers obtained through single and multiple harvesting can be explained by the principles of tuberisation. The earliest tubers to form exert dominance over the later tubers and, hence, at the end of the cultivation cycle the tubers produced all have dissimilar sizes. In contrast, multiple harvesting performed at fixed intervals, eliminates the dominance of the primary tubers and results in more uniform tubers. The systematic approach is based on the source (aerial parts) and sink (tubers) relationship, i.e. after a harvest, the photoassimilates that would have been used to augment the size of the harvested tubers are rerouted to form new tubers.

The advantage of multiple harvesting is exemplified by the cultivation of cvs. 'Monalisa' and 'Ágata' using the NFT hydroponic system (Corrêa *et al*. 2005). In this case, single harvesting yielded far fewer tubers (19 tubers/plant) compared with multiple harvesting (43 tubers/plant) and, although the single-harvest tubers were bigger and heavier, the productivity of the multiple harvest system was 126% greater.

When multiple harvesting is employed, the intervals between harvestings can also exert a significant influence on the total yield obtained. In the case of mini-tubers derived from cvs. 'Monalisa' and 'Ágata', the yields were, respectively, 47 and 39 tubers/plant when harvesting was carried out every 15 days, but fell to just 31 and 29 tubers/plant when harvesting occurred less frequently (i.e. every 30 days) (Corrêa 2005).

The removal of tubers from plants cultivated hydroponically is facilitated by facile access to the PVA channels. Furthermore, the integrity of the roots of plants grown hydroponically is preserved during harvesting unlike those of plants cultivated in pots or in the field. Generally the unsettling of the roots is a stressful event from which plants may not fully recover and this may lead to a reduction in the number of tubers produced in subsequent harvestings (Corrêa 2005).

Although the adoption of a multiple harvesting approach for plants cultured in solid substrate is not really practical, Lommen (1995) has reported that the number of tubers obtained by multiple harvesting of potato plants grown in pots was greater in comparison with that achieved through single harvesting. This author also observed that early tuberisation yielded numerous and vigorous tubers but that the roots were injured during the various harvestings and this reduced the growth of plants and the formation of tubers in late tuberisation. Despite the damage caused to the roots, however, multiple harvesting improved the number of tubers by 100 to 250% (Lommen and Struik 1992). Medeiros *et al*. (2002) reported that multiple harvesting yielded 5 tubers/plant grown in the field, compared with plants grown under hydroponic conditions in which the yield was approximately 15 tubers/plant depending on the cultivar and the management approach. The effects of single and multiple harvestings from hydroponic and planting bed grown plants are illustrated in **Fig. 5**.

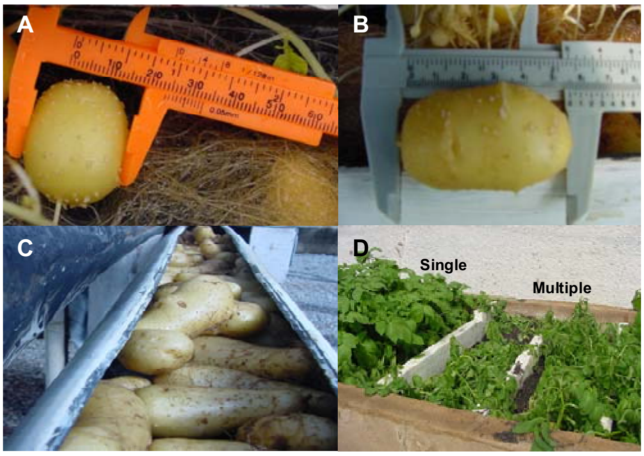

Fig. 5 Harvesting of seed potato tubers 15 days - 'Agata' (**A**); 30 days - 'Monalisa' (**B**) after cultivation of plants in the NFT hydroponic; single harvesting hydroponic (**C**) and single *vs* multiple harvesting in beds, installed at the Universidade Federal de Lavras. Photos: Ricardo Monteiro Corrêa.

FINAL CONSIDERATIONS

Hydroponics is an alternative method for obtaining high yields of seed potatoes and, as such, may play a key role in satisfying the demands of a growing market. Although the installation of a hydroponic unit represents a high capital expenditure, the initial costs can be spread over numerous production cycles. An alternative strategy to facilitate the commercialisation of such a unit and to maximise profits would be for producers to organise themselves into cooperatives.

Hydroponics may also offer an attractive solution to the problems that will be caused by increasing controls over the use of water in agriculture and concerns over the excessive exploitation of soils by rotation of short term crops such as potatoes. The recirculation of water in a hydroponic system is economical in terms of preventing waste and in avoiding the need for the application of insecticides. However, some improvements to the systems currently in use need to be made, including: (i) the development of alternative nutrient solutions containing, for example, more appropriate concentrations of potassium and boron, which are elements involved in the translocation of photoassimilates from source to the sink tissues; and (ii) more efficient management of the plant material with especial emphasis on alternative methods of supporting the aerial parts of plants grown hydroponically.

The hydroponics system in Brazil are similar to those found in other countries since the nutrient solution is used practically the same. The type of installation material, however, can be very diverse and their costs depend on the region, climate and availability of raw material for building the greenhouses.

In Brazil the hydroponic for potato seed tubers is usually made with low cost materials such as treated eucalyptus wood and double-face plastics. Many Brazilian Centers such as Embrapa Clima Temperado, Universidade Federal de Lavras and Instituto Federal de Educação Ciência e Tecnologia de Minas Gerais campus Bambuí the hydroponics have used for potato seed tuber multiplication obtaining excellent results. The great benefit of this system is that tubers can be harvested in batches as its reach the right size. Thus, 3 to 5 harvests can be obtained per crop cycle.

In order to increase the yield of potato seed tubers in Brazil, new studies have been carried out in focusing on mineral nutrition, cultivars, and alternative hydroponics.

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