ISSN 1808-3765

EXPERIMENTAL STRUCTURE FOR EVALUATION OF BRACKISH WATER USE IN LETTUCE HYDROPONIC PRODUCTION

Tales Miler Soares; Sergio Nascimento Duarte; Ênio Farias de França e Silva; Ralini Ferreira Mélo; Cristiano de Andrade Jorge; Áureo Santana de Oliveira
Departamento de Engenharia Rural, Escola Superior de Agronomia Luiz de Queiroz, Universidade de São Paulo, talesmiler@bol.com.br

1 ABSTRACT

Despite the usual utilization of hydroponic systems in agricultural research, such management systems do not always use the same techniques commercially feasible, leading to few pragmatic results for farmers. This is an important observation because in Brazil the majority of hydroponic vegetable production uses the nutrient film technique (NFT). Therefore, research must be carried out in NFT systems to find out its contribution on horticulture and environmental protection studies. The salt tolerance of plants may be greater in hydroponics systems than it turns out to be under conventional soil-based systems. The possibility of use of brackish water in soilless cultivations can be seen as a new perspective on Brazilian semi-arid agriculture, besides contributing to the improvement of the agricultural environment safety. In order to test the hypothesis of a positive effect of high irrigation frequency of hydroponic system on the salt tolerance of plants, a structure with 40 experimental units was constructed . Each experiment unit was designed to represent a hydroponic NFT system. This paper presents and describes the experimental structure built. Preliminary findings from lettuce cultivation suggest that the experimental structure is feasible for scientific investigations.

KEY WORDS: soilless, salinity, electrical conductivity, vegetables, NFT.

SOARES, T.M.; DUARTE, S.N.; SILVA, E.F.F.; MÉLO, R.F.; JORGE, C.A.; OLIVEIRA, A.S. ESTRUTURA EXPERIMENTAL PARA AVALIAÇÃO DO USO DE ÁGUAS SALOBRAS NA PRODUÇÃO HIDROPÔNICA DE ALFACE

2 RESUMO

Apesar do uso da hidroponia ser comum em pesquisas, nem sempre essas adotam as mesmas técnicas comercialmente viáveis, o que leva a resultados pouco pragmáticos aos agricultores. Essa é uma observação importante, pois, no Brasil na maioria dos cultivos hidropônicos comerciais de hortaliças folhosas se utiliza a técnica do fluxo laminar de nutrientes (NFT). Nesse sentido, as pesquisas devem ser conduzidas no sistema NFT para demonstrar sua contribuição em horticultura e estudos de proteção ambiental. A tolerância das culturas à salinidade deve ser maior em sistemas hidropônicos do que em sistemas convencionais de cultivo. A possibilidade de uso de águas salobras na hidroponia pode contribuir para uma nova perspectiva à agricultura do semi-árido brasileiro, colaborando, inclusive, para uma maior segurança ambiental. A alta freqüência da irrigação em sistemas hidropônicos aumenta a tolerância das plantas à salinidade. Para testar a hipótese de um efeito

Recebido em 15/05/2007 e aprovado para publicação em 10/10/2008
DOI: http://dx.doi.org/10.15809/irriga.2009v014n1p102-114

positivo da alta freqüência de irrigação dos sistemas hidropônicos sobre a tolerância à salinidade, foi construída uma estrutura com 40 parcelas. Cada parcela foi projetada para representar individualmente um sistema hidropônico NFT. No presente artigo é apresentada e descrita a estrutura experimental montada. Resultados preliminares com a cultura da alface indicam que a estrutura experimental é viável para investigações científicas.

UNITERMOS: hidroponia, salinidade, condutividade elétrica, hortaliças, NFT.

3 INTRODUCTION

In many cases, research involving different irrigation depths or different nutrient doses in fertigation become operationally complicated and onerous when two or more factors compose the treatments (factorial experiments), because the number of reservoirs, registers and other hydraulic accessories is high when the two basic statistical experimentation principles are respected, such as: the randomization and replication of treatments.

For that reason, researchers are compelled to carry out their experiments in less usual statistical configurations, as the split plot and split block, which lead to less precision on comparisons of main treatments, besides the same disadvantages found in factorial experiments (Pimentel-Gomes & Garcia, 2000; Ferreira, 2000; Banzatto & Kronka, 1989). On the other hand, other researchers sacrifice the principles stated above, leading to results that could permit important inferences, but which do not authorize the categorical conclusions. Another important aspect related to the subject is the involvement of only a reduced number of research groups in that investigation object.

Experiments concerning the brackish water use may have the same trouble. And, when installed in hydroponic system with closed circulation, as in Nutrient Film Technique (NFT) (Cooper, 1975), become more complex, since reservoirs of each treatment must be independent, in order to preserve the treatments. Moreover, the use of only one pump system for all experimental units is just possible if treatments are not imposed concomitantly, which may not be interesting to the research. Another complexity to management, with only one pump, is the necessity of cleaning the system after application of each treatment. The alternative of using one pump for each treatment implicates in costs related to accessories and pipelines which will extend to each replication. And, in this case, variables as pH, electrical conductivity, specific nutrients concentration and water consumption, are evaluated just as a function of only one average value, damaging the statistical analysis. This design may also lead the loss of the treatment, not only to the missing plot, if nutritive solution is spoiled for any reason, which can mean a great statistical damage or even the investigation unfeasibility.

Dealing with soilless and research, Martinez (1997) alerts that although cultivation in water, sand or grinded quartz is very usual in plant nutrition research, the techniques used in experiments are not attractive for marketable production. This is an important observation, since in Brazil most of commercial hydroponic cultivations of lettuce and other vegetables use the NFT technique (Furlani, 1999; Rodrigues, 2002). For that reason, to become more commercially pragmatic the scientific research on hydroponic should be carried out under structures which might reproduce the NFT cultivation system.

For the same cultivar and under the same soil type condition, it is possible to obtain different values of salt tolerance as a function of water management strategies for crop production systems. This distinction in plant tolerance is informed by Ayers & Westcot (1999). Particularly for investigations on the use of brackish waters in NFT systems, it would be an equivoque not only extrapolate the salt tolerance found in the soil, but also those from other hydroponic systems. For example, it was confirmed that there are differences in lettuce production as a function of solution oxygenation process (Tesi et al., 2003), which must be dependent of hydroponic system type.

The building of a low cost experimental structure, which agrees commercial arrangement and statistical requisites, is a critical point in research on NFT systems when the treatments are applied via nutritive solution. The objective of the current manuscript was to discuss and present the construction of an experimental structure to carry out research involving the use of brackish waters for lettuce production under NFT hydroponic systems.

The subject is justified pertinent to the investigations proposed under the hypothesis that crops salinity threshold under a NFT hydroponic cultivation system may be greater than that reached under conventional cultivation conditions (Duarte et al., 2006). This hypothesis considers the larger and more constant water availability to plants in hydroponic production systems, with small or inexistent matric potential contribution, which may represent more water and nutrients uptake and, hence, less negative effect on marketable yield in relation to soil cultivation. If proved the technical feasibility of brackish water use in a NFT system, it may be viable to construct evaporation ponds for the effluent emission. If proved the economic and environmental feasibility, it will be available an agricultural alternative for farmers inserted in Brazilian semi-arid.

2 MATERIAL AND METHODS

2.1 Location and environmental characterization

The experimental structure was built into an arched and single span greenhouse installed at the geographic coordinates 22° 42’ 89,4” S, 47° 37’ 46,2” W, altitude 540 m at the Department of Rural Engineer of the Escola Superior de Agricultura ‘Luiz de Queiroz’, in Piracicaba, State of São Paulo, Brazil. The greenhouse was east/west oriented, measuring 17.80 m x 7.0 m, with an eave height of 3.0 m and arc height of 1.35 m (Figure 1a), and covered with a transparent and low density polyethylene film with ultra-violet protection and 0.10 mm thick. The lateral walls were protected with black shade cloth (50 %) and equipped with movable curtains made of a polyethylene film and used for temperature management.

The greenhouse ground was covered with a black geotextile membrane (bidim OP-20) in order to keep lifetime expectancy of the pumping system and also to improve phytosanitary conditions. According to the Köppen climate classification, Piracicaba climate is humid subtropical with rainy summer and dry winter seasons (Sentelhas, 1998).

With the aim to reduce greenhouse internal temperature under hot day conditions, a thermo-reflective screen was installed at 2.70 m high, with a 50 to 54 % shade and holes measuring 2.5 x 10 mm (Figure 1b). According to the screen manufacturer (Polysack, 2006), percentages of reflection, diffused light and energy save were: 50 %, 65 % and 20 %, respectively. Two vents, one in the front and other in the rear end of the greenhouse were located in such a way as to remove the warm air raised in the environment due the convection process.

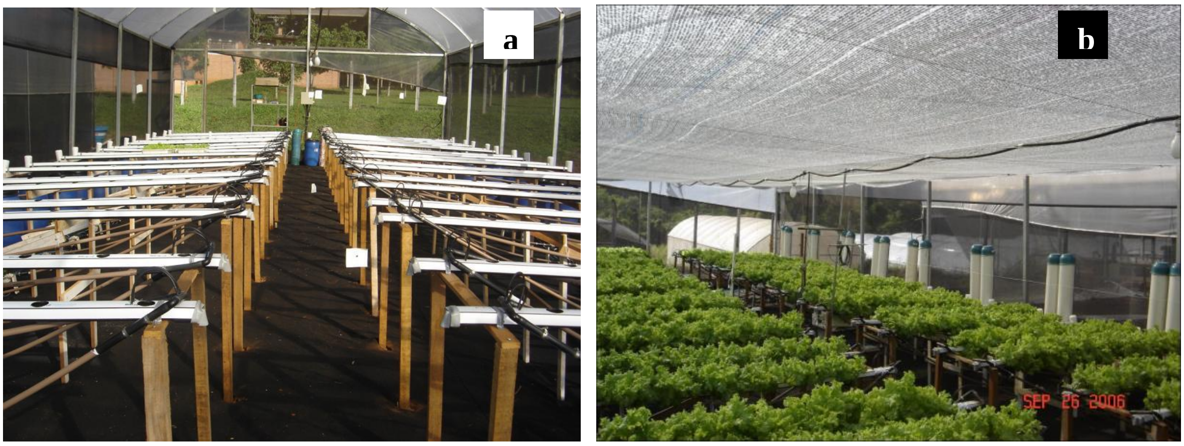

Figure 1. General view of the greenhouse before the installation of the experiments (a), and during the crop cultivation protected by a thermo-reflective screen (b).

2.2 Hydraulic and electrical components

A hydroponic structure with 40 experimental units was built (Figure 1). Each experimental unit represents an independent NFT hydroponic system, composed of one polypropylene reservoir with a full capacity of 60 L; one circulating electrical-pump system (model EBD250076, self-ventilated, driven by a single phase motor, voltage 127 V, frequency o 60 Hz, rated current of 2 A and flow of 27 L min^{-1}), with plastic internal parts to avoid corrosive effects of nutrition solution (Figures 2a and 2b); and one trapezoidal hydroponic gully channel made of polypropylene, ultra-violet protected, with a 75 mm commercial diameter, 2.8 m length and holes (radius of 2.5 cm) spacing 0.30 m (Figure 3a).

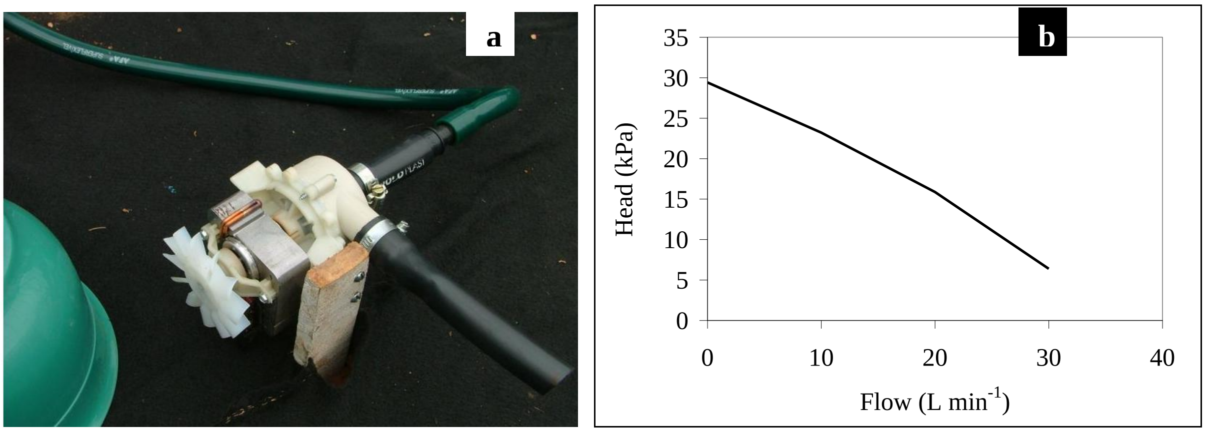

Figure 2. Electro-pump for nutrient solution circulation (a) and its flow x pressure curve (b).

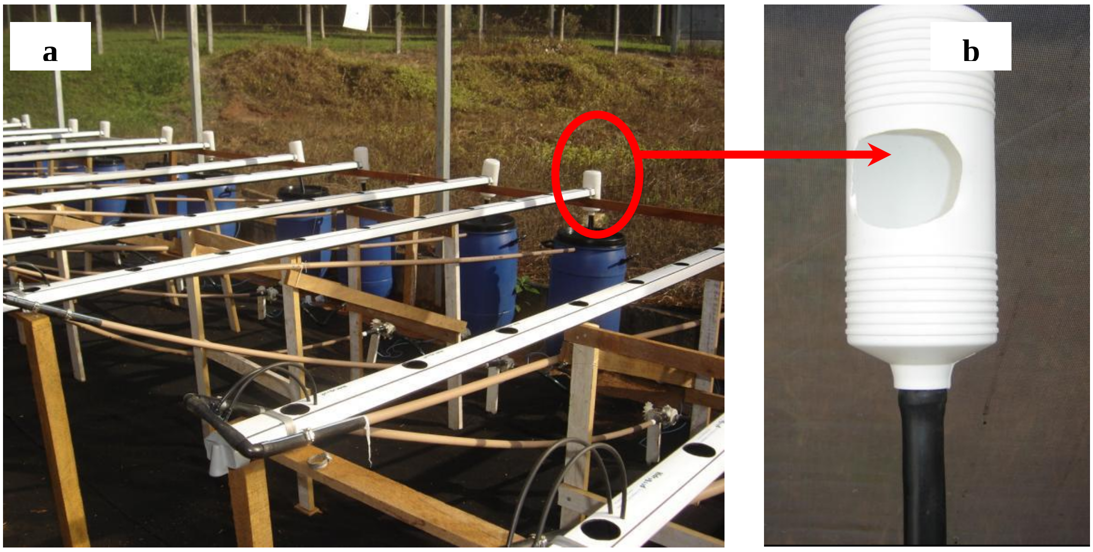

Figure 3. Gullies sustained on four support points (a) and bottle adapted as end cap (b).

The gullies were installed at 0.85 m height on four support points, laid on a 3.3 % slope down in which the circulating solution flows. At the end of the gullies, where solution admission happens, a cap was installed to preclude algal growth due the solar radiation incidence, and to avoid solution losses. In order to drive the solution back to the reservoir a white bottle was coupled to the gully lower end (Figure 3b). Gullies were mounted two by two above wood beam, spacedat the 0.53 m distance. A passageway to facilitate transit and operating process was projected between the gully pairs (Figure 3a). The gullies spacing and the passageway width were also planed to avoid competition among plants from different treatments. Gullies simulating borders were not used.

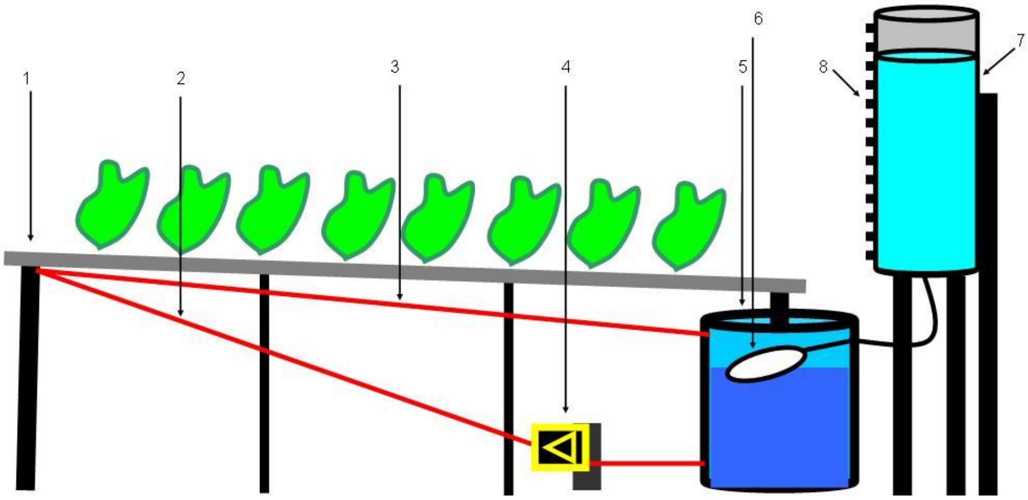

Figure 4. Design of the hydroponic gully equipped with an automatic supply tank. Legend: 1 - hydroponic gully; 2 - PVC pipeline to conduct nutrient solution to injection system; 3 - PVC pipeline to drain nutrient solution to the reservoir; 4 - electro-pump; 5 - nutrient solution reservoir; 6 - ball-cock valve; 7 - graduated and automatic supply tank; 8 – transparent microtube.

Nutrient solution was pumped into a 20 mm PVC pipeline (Figure 4) to the highest end of the gully. Height difference between the electro-pump (affixed on a wooden stick) and injection system was 0.76 m. The injection system was composed of two emitters connected to the pipeline by flexible microtubes (Figures 5a and 5b), presenting an average flow of 1.6 L min^{-1} (at 45 L reservation). Nutrient solution excess returns to the reservoir by a PVC pipeline, in which the end was connected to a 90º plain elbow with the purpose trying to improve the solution aeration.

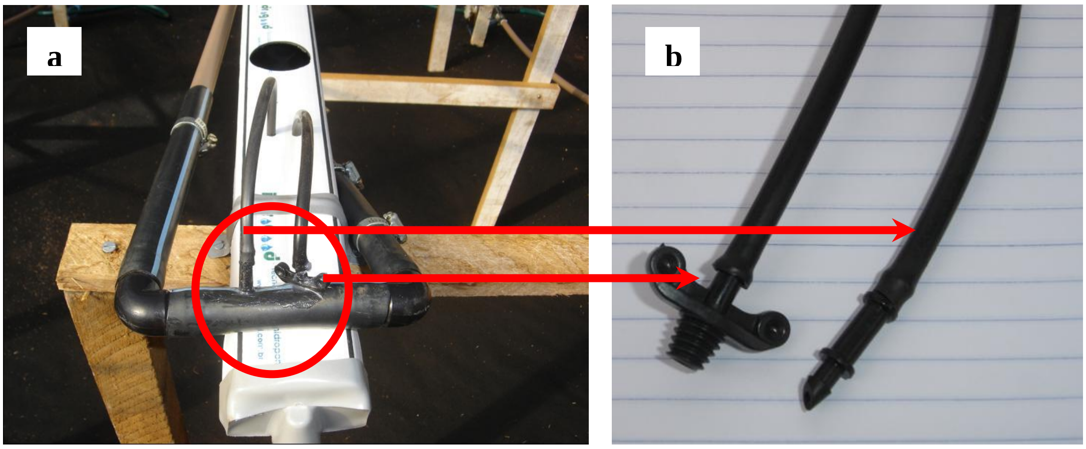

Figure 5. Nutrient solution injection system (a) and its emitter types (b).

Electric-pump was gravity fed, with the flow dependent on the total static head (lift height) and solution depth in the reservoir (Figures 2b and 6). Figure 6 shows the gully flow variation as a function of the maintained solution volume in the reservoir, considering a head pressure of 0.76 m. That curve was built for a 0.13 m height difference between pump's axis and reservoir bottom. For any solution depth above 20 L in the reservoir, gully flow was always maintained for recommended intervals (Martinez, 2006; Staff, 1997; Teixeira, 1996) for lettuce, which ranges from 1.5 to 2.0 L min^{-1}.

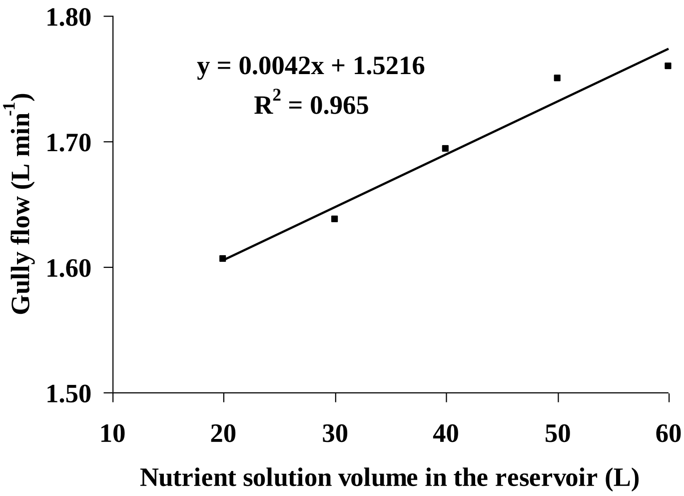

Figure 6. Registered flow in the gully as a function of nutrient solution volume in the reservoir.

Figure 7. Driven and oxygenation of nutrient solution by a 90° plain elbow.

Automatic water supply tanks were individually mounted for each plot (Figures 4 and 8) using a PVC pipe of 200 mm of diameter. This system permits the automatic water inflow to the nutrient solution reservoir by means of a ball-cock valve, keeping a constant volume. Supply tank was equipped with a ruler set up to the side of a transparent micro-tube, that allows for the calculation of water consumption per plant (equation 1).

$$V_{ETC} = \frac{(Lf - Li) \times \pi \times D^2}{4 \times n \times \Delta T} \quad (1)$$

where: V_{ETC} = water consumption, m^3 $plant^{-1}$ day^{-1}; Lf = current height of water in the tank, m; Li = initial height of water in the tank, m; D = reservoir internal diameter, m; ΔT = time interval between the measurements, day; n = number of plants per gully.

Figure 8. Hydroponic gullies connected to their respective automatic supply tanks.

To evade the eventual problems with nutrient solution returns below the gully, due to its curvature caused by the increase of the plant weight, a PVC ring was locked up to the gully drainage end (Figure 9). This ring intercepts and drives along the nutrient solution, avoiding its loss and allowing for the water consumption evaluation and the concentration differences of treatments.

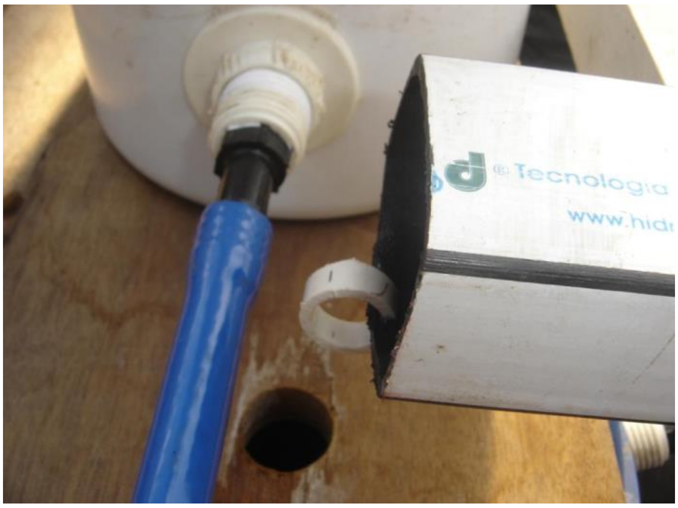

Figure 9. Details of the PVC ring used to avoid nutrient solution losses.

The electrical network was dimensioned to operate all plots simultaneously. In the control panel a contactor CWM50 (220V) was connected to three 30 A switches (Figure 10a). Each switch energizes one line (two 4mm wires), which starts a set of 13 or 14 pumps through the line derivations in a 2.5 mm wire (Figure 10b).

Figure 10. Control panel of the hydroponic system (a) and electro-pumps connected to an electrical network (b).

In the control panel a digital timer (220 V), with electrical autonomy of 24 hours, programmable for 720 events, was installed to provide the switching on and off of the contactor in minimum intervals of one minute. During the conduction of the experiments the follow daily programming was kept: irrigations at each 15 minutes from 6:00 AM to 11:00

AM; steady irrigation episodes from 11:00 AM to 2:00 PM; irrigations at each 15 minutes from 2:00 PM to 7:00 PM; 15 minutes irrigations at 9:00 PM, 11:00 PM, and 02:00 AM. The time was checked out on a daily basis in the timer in order to guarantee the programming proposed to collect the experimental data.

3 RESULTS AND DISCUSSION

In agricultural experimentation, practice indicates that rarely reasonable results are reached in tests with less than 20 experimental units. Another useful suggestion is to use at least 10 degrees of freedom for error (Pimentel-Gomes & Garcia, 2000). Table 1 shows that the error freedom degree reached the allowable limit recommended in three different test types with the experimental structure built to assess the brackish water use. For calculation purposes, all 40 plots were considered useful experimental units. Six levels of water salinity were simulated, using or not the local control represented by four blocks. In the factorial experiment, three levels (or types) of another interest factor were assumed. For simulations of simple experiments, in completely randomized designs or randomized blocks, or even factorial randomized in blocks, the freedom degrees of error were higher than the minimum value ($FD_{error} > 10$) recommended by Pimentel-Gomes & Garcia (2000), which results in a less experimental error and, therefore, a higher precision of the statistical analysis applied to the experimental data.

Table 1. Freedom degrees (FD) of error and other variation sources obtained in different experiment types carried out under the experimental structure built

Completely randomized design	**FD**
Water salinity	5
Error	**34**
Total	39
Randomized in blocks	**FD**
Water salinity	5
Block	3
Error	**31**
Total	39
Randomized in blocks with double interaction	**FD**
Water salinity	5
Factor B	2
Interaction	10
Block	3
Error	**19**
Total	39

From the built structure, it was reached what could be ideal in NFT hydroponic experiments: independent plots and a high freedom degree of error. However, to provide such autonomy, it was used for each plot a reservoir (60 L) with dimensions smaller than the usual ones and, for that reason, the nutrient solution was more exposed to temperature oscillations. In commercial cultivation, reservoir must store at a maximum volume of 5,000 L and at a minimum 500 L (Furlani, 1998). However, caution with solution temperature must be reiterated. Moreover, spacing between plots, higher than the commercial ones, allows more incident solar radiation on the gullies, depicting a possible contribution for nutrient solution warming. Burying the reservoir under the ground as a preventive action was not accepted in the current study because the electro-pump was operated only by gravity feed.

The nutrient solution heating was detected during the tests (Figure 11). This warmth process was mostly related to the energy exchange between the solution and the gully than to the reservoir exposure to the sun light. In fact, the nutrient solution heating did occur not only by the great contact surface when the whole system is computed, but also as a function of the heated atmosphere confined into the gully walls. Therefore, in further investigations, in order to minimize the temperature increase in hot days, measures must be taken to mitigate air temperature under greenhouse conditions.

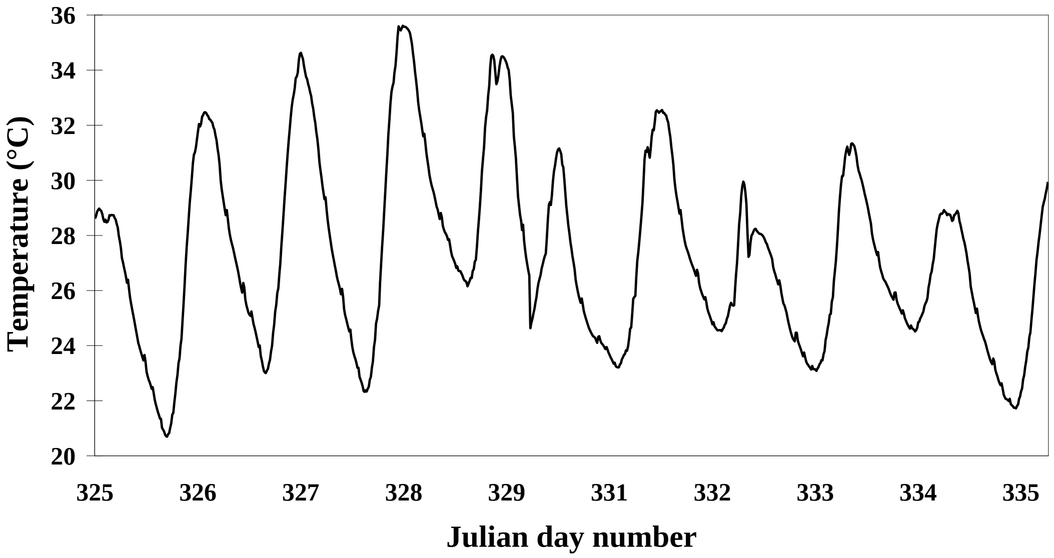

Figure 11. Nutrient solution temperature throughout the day from November 21st, 2006 to December 1st, 2006.

Despite the reservoir capacity of 45 L, aiming at approaching the research to commercial features, in some experiments the volume of nutrient solution will be kept at 24 L, correspondent to a 3 L available solution per plant. Teixeira (1996) suggested the use of 1.5 to 2.0 L per plant, whereas Furlani et al. (1999) recommended a minimum volume of 0.5 to 1.0 L. A 3 L volume per plant would be used to guarantee a minimal flow in the gullies (Figure 6) and to avoid solution heating. For this reason, the automatic supply tanks (installed to maintain a 45 L volume) were employed only in tolerance studies, under the conditions which salinity must be constant. In other experiments a more simple method for use of brackish waters by farmers will be proposed, without any additional management technique. Therefore, the nutrient solution salinity will be increasing in time. In this case, storing a 24 L volume of nutrient solution turns out to be justified as an attempt to simulate the same nutritional depletion rates of available volume per plant.

Some experiments carried out reveal the utilization feasibility of the experimental structure in study for evaluation of brackish waters under hydroponic systems (Soares, 2007). In relation to the salt tolerance for NFT hydroponic system, the lettuce salinity threshold was estimated in 4.03 dS m^{-1}. Under the same experimental conditions, the salt tolerance for soil cultivation was estimated in 2.51 dS m^{-1}. Figure 12 shows a visual contrast of two lettuce plants (cv. Veronica), one exposed to a salinity of 9 dS m^{-1} throughout all the growing season, and the other exposed to a nutrient solution of 2 dS m^{-1}. Despite the reduced size, plants exposed to salt stress did not show other symptoms that could damage their marketable value. Such effect on the crop physiology was observed in other trials in such a way as to reinforce the veracity of the hypothesis that a higher salt-tolerance may be obtained under hydroponic system as opposed to conventional soil management practices.

Factors, such as solution oxygenation, reduced length of gully (3 m) and high volume of available nutrient solution per plant may have contributed for the results obtained herein. Those factors may be inherent to the experimental structure proposed, typifying some migration to commercial design, where gully length may reach up to 15 m and less nutrient solution per plant is available. On the other hand, those factors indicate the need for further research involving them into brackish water exploitation approaches under NFT system.

Figure 12. General aspect of lettuce plants exposed to a salinized solution of 9 dS m^{-1} (on the left) in comparison to a non-salinized nutrition solution of 2 dS m^{-1} (on the right).

Apart from the costs of greenhouses, the total investment with the mounted experimental structure was estimated in US$ 6,800.00, of which approximately 64 % were obtained from partner corporations. For researches that have not water consumption as a response variable, automatic supply tanks may be removed. In this case, the structure would be estimated in US$ 4,977.00 (at exchange rate of R$ 2.2/US$).

Studies concerning several disciplines of agriculture sciences could be proposed with the experimental structure. The current report may to foment more researchers to build experimental NFT hydroponic systems, considering the low costs of the experimental structure and the first obtained results. Investigations carried out on this structure may help to increase the use of hydroponics systems, especially in Brazil where the lack of research is a constraint to hydroponic projects. Results obtained from this structure would be more consistent and data extrapolations from soil cultivation conditions would be unnecessary.

The experimental NFT hydroponic systems may be particularly useful for studies on the brackish waters use. Based on the current manuscript, other research groups built experimental structures in Northeast Region of Brazil (Ibimirim, State of Pernambuco; Cruz das Almas, State of Bahia), where the surface water is scarce and the groundwater is usually brackish.

4 ACKNOWLEDGMENTS

Authors wish to thank the following corporations for their generous support and colaboration help: Tigre, Metalcorte/Eberle, Hidrogood and Hanna Instruments. Special thanks are also devoted to “Coordenação de Aperfeiçoamento de Pessoal de Nível Superior” (CAPES) for the support provided by means of the PROAP (Programa de Apoio à Pós-Graduação).

5 REFERENCES

AYERS, R. S.; WESTCOT, D. W. **A qualidade da água na agricultura**. 2. ed. Campina Grande: UFPB, 1999. 153 p. (Estudos FAO Irrigação e drenagem, 29).

BANZATTO, D. A.; KRONKA, S. N. **Experimentação agrícola**. São Paulo. Jaboticabal: FUNEP, 1989. 247 p.

COOPER, A. S. Crop production in recirculating nutrient solution. **Scientia Horticulturae**, Amsterdan, v. 3, p. 251-258, 1975.

DUARTE, S. N. et al. Produção hidropônica de alface utilizando águas salinas. In: CONGRESSO BRASILEIRO DE ENGENHARIA AGRÍCOLA, 35., 2006, João Pessoa. **Anais**... Jaboticabal: Sociedade Brasileira de Engenharia Agrícola, 2006. CD ROM.

FERREIRA, P. V. **Estatística experimental aplicada à agronomia**. Maceió: EDUFAL, 2000. 422 p.

FURLANI, P. R. Hydroponic vegetable production in Brazil. **Acta Horticulturae**, Leuven, n. 481, p. 777-778, 1999.

FURLANI, P. R. **Instruções para o cultivo de hortaliças de folhas pela técnica de NFT**. Campinas: IAC, 1998. 30 p.

FURLANI, P. R. et al. **Cultivo hidropônico de plantas**. Campinas: IAC, 1999. 52 p. (Boletim técnico, 180).

MARTINEZ, H. E. P. **Manual prático de hidroponia**. Viçosa: Aprenda Fácil, 2006. 271 p.

MARTINEZ, H.E.P. **O uso do cultivo hidropônico de plantas em pesquisa**. 2. ed. Viçosa: Editora UFV, 1997. 47 p. (Cadernos didáticos, 1).

PIMENTEL-GOMES, F.; GARCIA, C. H. **Curso de estatística experimental.** 14. ed. Piracicaba: ESALQ, 2000. 477 p.

Aluminet 50-I. Polysack Plastic Industries. Disponível em: <http://www.polysack.com/index.php?goto=bep&page_from=104>. Acesso em: 5 set. 2006.

RODRIGUES, L. R. F. **Técnicas de cultivo hidropônico e de controle ambiental no manejo de pragas, doenças e nutrição vegetal em ambiente protegido**. Jaboticabal: FUNEP, 2002. 762 p.

SENTELHAS, P. C. **Estimativa diária de evapotranspiração de referência com dados de estação meteorológica convencional e automática**. 1998. 97 p. Tese (Doutorado em Irrigação e Drenagem) - Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, 1998.

SOARES, T.M. **Utilização de águas salobras no cultivo da alface em sistema hidropônico NFT com alternativa agrícola condizente ao semi-árido brasileiro**. 2007. 272 p. Tese (Doutorado em Irrigação e Drenagem) - Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, 2007.

STAFF, H. **Hidroponia**. Cuiabá: SEBRAE/MT, 1997. 86 p.

TEIXEIRA, T. N. **Hidroponia:** uma alternativa para pequenas propriedades. Guaíba: Agropecuária, 1996. 86 p.

TESI, R.; LENZI, A.; LOMBARDI, P. Effect of salinity and oxygen level on lettuce grown in a floating system. **Acta Horticulturae**, Leuven, n. 609, p. 383-387, 2003.