Investigation of the transpiration process in spinach

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Introduction

According to some predictions, Mars will be inhabited before 2050 [1]. However, a successful permanent habitation of Mars or the Moon requires life support systems which can be reliable, predictable, autonomous and able to produce food, water and oxygen. Physicochemical systems (like the ones in the International Space Station [2]) are robust technologies to recover oxygen and water but not able to produce food [3]: in order to have this capability, biological processes are required. In this case, they are called bioregenerative life support systems. These systems are capable to convert metabolic wastes into oxygen, potable water and edible biomass [4]. The European project developing this type of technology is the MELiSSA (Micro-ecological Life Support Systems Alternative) project. MELiSSA is using microorganisms and higher plants to produce O_2 and food, remove CO_2 and recycle water. However, these systems are strongly influenced by environmental conditions (like gravity, temperature, O_2 and CO_2 level, pressure, relative humidity, etc.), and to be able to precisely control these systems, fundamental understanding and mathematical description of all processes involved is required. One of the process that needs to be better understood is transpiration: in fact, water transpired from plants is considered as a source of potable water for the astronauts.

Transpiration

Transpiration is defined as the loss of water from the plant in the form of water vapour. However a small amount of water vapour may be lost through lenticels. The largest proportion by far (more than 90%) escapes from leaves [5]. Transpiration is influenced by many factors such as air, relative humidity, which, when below 50%, significantly increases the transpiration process [6]; ambient temperature affects the rate in two ways: An increased rate of evaporation and decreased relative humidity outside the leaf will increase the water potential gradient; wind speed, which influence the rate of water vapour diffusion between the substomatal air chamber and the ambient atmosphere; the light necessary for photosynthesis, whose products affect the osmotic potential of stomata cells [6], number of leaves, water supply, and nutrient solutions compositions.

Plants selection

To prepare an experiment two kind of plants classified as leaves plant was taken into consideration – Lettuce and Spinach.
Spinach (*Spinacia oleracea L.*) is a leafy green plant. It is one of the cool-season vegetables and can be grown in temperate areas all year around with a short growth period of 30–50 days [7]. Spinach is a rich source of calcium, magnesium, phosphorus, potassium, and zinc. Vitamins which can be found in spinach are: vitamin C, vitamin A, vitamin E, folic acid, niacin, and vitamin K. Total lipid content of Spinach is 0.39%. [8]. Spinach has a high moisture (91.4%) and dietary fiber content (2.2%). Spinach caloricity is 23 kcal per 100 g [9].
Lettuce (*Lactuca sativa*) is low in calories with around 95% water content. Lettuce is the most popular salad vegetable [16]. It is a good source of potassium, calcium, phosphorous, and iron. It also contains significant amount of folate, vitamin A, vitamin K, beta-carotene, and vitamin C. Lettuce caloricity is 17 kcal per 100 g [10]. Lettuce has a short growth period - ca. 28 days [3]. Because spinach has bigger tolerance for the salinity, and bigger range of accepted temperature and humidity, this crop was chosen as a test plant for the experiment. In addition, compared to lettuce, spinach contains more vitamins, minerals, fats and protein [8-10].

Experiment setup

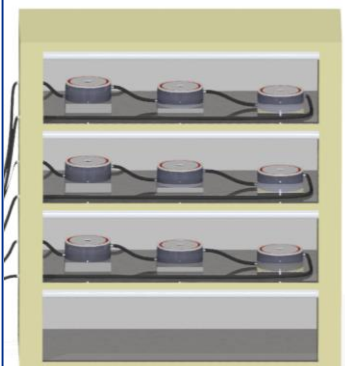

Fig. Environmental chamber scheme

The first phase involves performing an experiment without plants to check the accuracy of the tested system, calculate the water balance of the chamber, determine the sources of measurement errors, their size and to create a chamber model.
During the experiment 3 shelves inside the chamber will be used. On every shelf 3 pots will be located. The distance between shelf and the lightning system is ca. 35 cm. The first and second pot are positioned higher compared to the third to provide gravity flow.

The whole system works as a closed loop, and water is recirculated. To check the water balance three scales will be used to measure:

- the mass of water in the tank with nutrient solution,
- the mass of water in the fogging tank,
- the mass of water removed from the chamber by condensation.

According to the plants and chamber limitations, in order to avoid a significant reduction of the yield, the range of the parameters which are tested during both phases of the experiment are:

- temperature (15 – 28 ˚C) [11,12-15]
- humidity 50 – 90% [11,12-15]
- salinity of the nutrient solution <220 mS/m² [12]
- air flow 1 – 2 m/s

In the second phase, seeds are germinated in incubator. When the length of the plants' roots is at least half of the height of the pot, they are moved to the hydroponic system inside the growth chamber. Inside the system plants are placed in special pots with perlite. The roots zone is separated from the steam, to prevent water from evaporating from the pots, with the aid of Kapton tape and Parafilm™. The chamber experiment is carried out in the same way as the first phase of the experiment. The parameters of the nutrient solution are presented in the table below.

Parameter	Range	Unit
pH	5.5 – 6.5	-
EC	1300 – 2200	µS/cm
Nutrient solution oxygenation	7 – 10	ppm
CO_2 level	1000 – 1500	ppm

Summary

The experiment is still in the first phase. The first data about the chamber leakage and the accuracy of the humidity and temperature stability were collected. After that, using the data collected in second phase of the experiment, the average amount of water evaporated from plants depending on the average amount of biomass increase will be calculated. After creating the model, it will be experimentally verified to check the accuracy of this model.

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