AROMATIC PLANT CULTURE IN OPEN-AIR HYDROPONICS

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Additional index words: Essential oil, substratum, nutrient solution, rose geranium, (*Pelargonium roseum* Willd.), soilless culture

Abstract

Starting from 1965 physiological, agrochemical basis and effectiveness of a number of valuable aromatic plant (*Pelargonium roseum, Cymbopogon citratus, Ocimum gratissimum, Vetiveria zizanioides, Nepeta transcaucasica* etc.) soilless cultivation has been studied at the Institute of Hydroponics Problems (Armenia).

The possibility, high efficiency and economical benefit of shifting from labour-consuming, expensive traditional culture of aromatic plants, to industrial production in open-air and greenhouse hydroponic fields, over the surfaces unfit for traditional agriculture, has been proved.

Experiments have shown that hydroponically grown aromatic plants have higher productivity, in addition to accumulate 3-6 times more essential oil per unit of feeding surface, compared with field grown ones. The root environment of hydroponic plants is abundantly provided with water, nutrients and air, with a corresponding increase of the metabolic and absorbing activity of roots, which, in its turn, initiates development of plant overground part with increasing biological and economical productivity several folds. It is shown that this is accompanied by some physiological and biochemical changes in the plant, e.g. some increase of chlorophyll and essential oil content, drastic increase of hydroponic field photosynthetic potential, early development of maximal assimilation surface, etc. Besides, water and labour expenses per tonne of crops significantly decrease, efficiency of sun energy increases, and finally, hard and labour consuming work such as cultivation, loosening, weeding, irrigation etc. are eliminated.

So, new, progressive and automated biotechnology of phyto-stuff production comes to substitute conventional agrotechnics.

1. Introduction

One of the new, progressive ways of the plant productivity increase is the development of a new branch of biological industry, i.e. the biotechnology of soilless cultivation of plants in a completely or partly controlled environment. This will allow to discover all potential opportunities of plants and to make a good use of the lands abandoned by traditional agriculture.

Soilless cultivation is now developing fairly fast in many countries of the world (Japan, the Netherlands, France, Italy, Sweden) where, in addition to research centres, there are big hydroponic farms.

The importance of soilless culture in land-starved arid regions like Armenia is quite obvious. The existence of large territories of saline lands leads to the necessity of the soilless cultivation organization.

Taking into account that hydroponic installations need large initial capital investments, it was thought that it is better to produce in open-air hydroponic conditions

Proc. WOCMAP-2
Agr. Production, Post-Harvest Techniques, Biotechnology
Eds. G. Giberti *et al.*
Acta Hort. 502, ISHS 1999.

more expensive, valuable plants (aromatic, medicinal, dye-bearing), which occupy comparatively small areas and are capable of giving great profits.

From this point of view experiments on aromatic plant production which are of great interest, were started in 1965 and carried out for the first time in the Soviet Union and probably in the world, at our Institute of Agrochemical Problems and Hydroponics of the Armenian Academy of Sciences.

The experiments were aimed to find out the feasibility and efficiency of valuable aromatic plant soilless production. Our experiments had the object to study the agrochemical, physiological, biochemical characteristics of hydroponic cultures. Our studies allowed to prove the possibility of yield increase by means of mineral nutrition, root environment, water-air regime, etc. improvement and to development of soilless biotechnology of some valuable aromatic plants.

The main object of our studies were the industrial culture of rose geranium, 8 hybrids of geranium with high essential-oil content and some other aromatic plants - i.e. citric sorghum, eugenol basil, vetiveria and others. All these aromatic plants, except geranium and basil, were for the first time introduced in our republic.

2. Materials, Methods, Experiments

The experiments have been carried out at the experimental hydroponic station of the institute and in our scientific-industrial hydroponic station in Echmiadzin.

Hydroponic ferro-concrete vegetation installations 10-40 m^2 were filled by different local substrates - gravel, volcanic slag, pumice stone crumbs and their mixtures (3:1). The diameter of pieces was 2-20 mm.

Plants were subirrigated by 0.15% nutrient solution suggested by academician G.S. Davtyan. The nutrient solution was supplied by means of automatically regulated pump equipment through the pipes. When a certain level of solution was reached, the work of the pump automatically stopped and the solution returned into the reservoir through the same pipes. So, our substrate was periodically enriched by water solution of nutrients.

After discharge of each portion of the concentrated solution there was a pause for 2-3 days, during which the subsoil waters were supplied. This was done in order to protect the substrate from salinization. The solution was supplied with a frequency of 1-2 per day in spring, 2-3 times per day in summer and once per day in autumn.

Prior to experiments the substrates were treated by 2% solution of formalin or 0,05% solution of permanganate.

A simultaneous planting of the same plants in an experimental, brown, carbonate, cultural-irrigated soil with clay and loamy mechanical composition served as a control plot. The humus content in arable layer was 1.4-1.8%, pH of water extraction was 8.2-9.0.

The soil control was fertilized by 30-40 t/ha of dung and N(300)P(120)K(60) kg/ha. It should be noted that P(120)K(60) were supplied before planting in the field and N - after planting twice per 100 kg/ha. The care of the control plants included weeding (8-10 times) and 12-15 times watering during the vegetation period.

The replication was 4-10 fold.

All the necessary analyses were carried out by traditional methods.

3. Results and Discussions

Researches for many years have shown that in the case of soilless cultivation of rose geranium (*Pelargonium roseum* Willd.) in 4 experimental substrates different yields of green mass can be obtained (for details see table 1). Here different weather conditions have also to be taken into account.

The comparison of 4 experimented substrates has shown that, for growing rose geranium, it is advisable to use gravel or gravel mixture with porous materials in 3:1 ratio. The advantages of these substrates are the following: 1. they are "warm" substrates; 2. the temperature regime and substrat humidity can be easily regulated by adjusting the frequency of nutrient solution supply; 3. gravel and gravel mixtures are not weathered , i.e., they can be used for many years. Previous experiments have indicated that under hydroponic conditions the harvest of green mass increases 5-6 times if compared with soil method.

The trials have shown that the hydroponic method of phytostuff production ensures the production of planting material with a stronger fibril root system, thicker stalks and better branching, in comparison with the convenient one. The productivity of hydroponic saplings increases by 13% as compared with soil grown ones.

The numerous analyses have shown that by its physical and chemical characteristics the essential oil of rose geranium, produced under hydroponic conditions exceeds to some extend the quality of the essential oil of rose geranium grown in the soil, mainly due to the higher content of more valuable primary alcohols (geraniol, citronellol), which determine the quality of rose geranium essential oil. (see table 2).

Under hydroponic conditions the plants of rose geranium grow and develop more intensively and in 30-40 days they outstrip the development of soil grown plants. It is known that approximately 98% of the essential oil of rose geranium is extracted from the leaves. Our studies have shown that the end of August, i.e. the period of heavy growth of the plant coincides with the maximum accumulation of essential oil in the leaves. This fact makes it possible to obtain under open-air hydroponics two harvests instead of one. The first, at the end of August and the second, at the end of October. In this case the total yield of essential oil increases by 20-25% if compared with a single harvest. So, according to our experiments, we can conclude that in the Ararat valley of Armenia in open-air hydroponics it is possible and advisable to get double harvest.

The trials have indicated that the optimal density of rose geranium planting is 40 x 40 cm. In this case, the plant productivity exceeds by 15-25% those of all other tested plant densities. The density of planting has a certain effect on rose geranium essential oil contents. The decrease of planting density leads to the reduction of citronellol content, and to the increase of the complex ether citronellilformiate contents. This can be explained by the fact that the biosynthesis of citronellol is proceeding intensively on the stage of most intensive growth of rose geranium, which can be observed under high density of planting. All mentioned above coincides with the conclusion of Prof. Nizherdadze and his co-workers.

The choice of rose geranium as the object of research was not an ocasional one. High yield of green mass, valuable essential oil, high rooting, comparative disease resistance make the culture of rose geranium favourable for soilless cultivation. Nevertheless, it has to be noted that the plant essential oil -bearing glandules contain comparatively little amount of essential oil.

That is why in different institutions of our country - in Sukhumi, Pakhtaabad (The Tajikistan) and Armenia the highly oil-bearing hybrids of geranium have been raised.

Beginning from 1970, the investigations were carried out to establish the efficiency of soilless cultivation of these hybrids. The data of table 3 show that the yield of rose geranium overground mass exceeds significantly all the hybrids harvest, whereas the contents of essential oil, obtained from the hybrids, exceed 1,5-3 times those obtained from rose geranium.

The most productive hybrids are Sukhumi No. 7, the Tajic C18K4. P/2K-37-2 and Aist -4.

The results of gas-liquid chromatography have shown that all the experimented hybrids differ from rose geranium by their higher contents of primary alkohols on the one hand , and by the lower contents of menthon on the other hand. Besides this, oil, obtained from rose geranium, contains about 21% of complex oil --citronellilformiate, whereas the oil obtained from the hybrids either contains it in a little amounts or does not contain it at all.

Concerning the example of rose geranium, as the most valuable essential-oil bearing plant, the numerous experiments were carried out to study the physiological, biochemical, agrochemical characteristics of the plants under open-air hydroponic conditions. We have made a close study of oil contents changes during a day and during the vegetation period, intensity of photosynthesis, the character of dry matter accumulation, chlorophylls "a" and "b" and tocopherol accumulations, dynamics of nutrients accumulation and removal, effects of light, different doses of N P K, volume of root inhabiting medium on the productivity of rose geranium on the physical and chemical characteristics of the essential-oil obtained from it, and finally, the character of changing in the contents of the nutrient solution during the plant growth.

Along with rose geranium and its high oil-bearing hybrids, experiments were carried out on a number of other aromatic plants. Among them - citric sorghum (*Cymbopogon citratus* Stapf), eugenol basil (*Ocimum gratissimum* L.), common basil (*Ocimum basilicum* L.), vetiveria (*Vetiveria zizanioides* Stapf), mint (*Mentha piperita* L.), catmint (*Nepeta transcaucasica*), worm-wood (*Artemisia annua L.*).

In the experiments with these aromatic plants, different substrates have been tested. Density and dates of planting, seasonal dynamics of essential oil accumulation were determined. In other words we have reached the stage of introduction of these plants in national economy.

The data of table 4 have shown that in open-air hydroponic conditions the essential-oil output of these plants increases 2,5-6 times per a unit of area. At the same time we must note that all these hydroponic essential oils can even exceed those from soil grown ones.

Economical efficiency of aromatic plant hydroponic cultivation is shown on the example of rose geranium and its highly oil-bearing hybrid C18K4. It was established that in hydroponic production of rose geranium, the labour cost was reduced 1,6 times per hectare.

The reduction of green mass cost price leads to the increase of net profit. The period of paying off is about 6,2 years for rose geranium and 3,8 years for hybrid C18K4.

On the bases of our many year experiments and studies we have come to the following conclusions:

1. In open-air hydroponic conditions no principal changes are observed in the growth, development of the plants and essential oil biosynthesis, though there are some changes in vegetation period. In July, August and early September the number of young leaves rich in essential oil, total leafing, essential-oil content and output increases. At the end of vegetation season, the leaves grow old rapidly, the intensity of biosynthesis and essential oil output diminished. The biosynthesis of essential oil depends on the light, temperature, air humidity. There is a correlation between essential oil biosynthesis and dry matter accumulation.

2. Optimum of light intensity for intensive biosynthesis of essential oil does not coincide with the optimum of growth intensity and plant productivity.

3. Under hydroponic conditions, the plant reaches the assimilative surface much more earlier than in soil. And the photosynthetic potential of the whole hydroponic plantation

increases 3.5 times. That is one of the main reasons for multiple increase of soilless plant productivity.

4. The reduction of the root inhabiting medium volume under constant frequency of feeding, leads to the inhibition of plant growth and productivity. This can be partly compensated by the increase of the frequency of the nutrient solution supply. This can serve a way of plant productivity increase from an unit of area.

5. The most favourable conditions for citronellol and geraniol biosyntheses can be guaranteed by using Davtyan solution. The changes of the nutrient element dosis inhibit the citronellol and geraniol syntheses and promote citronellilformiate synthesis. The quality of undesirable menthon amounts in all trials is lower than admitted by the State standards.

6. The nutrient solution content, electroconductivity, total concentration, pH etc. have undergone changes in the process of circulation. These changes are mainly connected with nutrient solution uptake, different physical-chemical secondary processes, precipitation of some nutrient ions, etc. As far as the number of absorbed anions exceeds the number of absorbed cations, the nutrient solution pH has also a tendency to increase. The inverse correlation between the nutrient solution EC and pH was established ($r = -0.70 \pm 0.12$).

7. The nutrient solution circulation regime prevents salinization of substrate. With the help of EC measuring, the optimum duration of washing and the nutrient solution supply regime can be determined.

8. The overground mass of rose geranium exceeds all the experimental hybrids harvest. But the content of essential oil in hybrids exceed 1,5-3,0 times those obtained from rose geranium. All the hybrids differ from the plants of rose geranium by higher content of citronellilformiate.

9. Experiments of many years have shown the feasibility, efficiency and prospects of soilless cultivation of citric sorghum, eugenol and common basil, mint, vetiveria, and other essential-oil bearing plants. The tested aromatic plant productivity under hydroponic conditions exceeds those of soil grown ones. The quality of hydroponic essential oil is by no way inferior, but rather superior to those from the soil.

10. The economic evaluation of the results of our investigations has shown the efficiency and expediency of soilless cultivation of aromatic plants and advantages of gravel hydroponics.

11. On the bases of the results of our investigations it is recommended to build hydroponicums on lands abandoned by traditional agriculture. These hydroponicums will be aimed at industrial cultivation of valuable aromatic plants and to obtain expensive essential oil, used in medicine, food and perfumery production. Due to all this, Armenia will become a new producer of valuable products and will save the country from importing all these products with foreign currency.

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Table 1 - The productivity of rose geranium under open-air hydroponics

Substrates	Saplings	Yield, t/ha (on area of hydr. instal.)	Content of essential oil, %	Output of essential oil, kg/ha	On the whole area of hydroponicums	
					Yield, t/ha	Output of ess. oil, kg/ha
Gravel	Hydroponic	143	0.123	177	95	118
	Soil	127	0.107	137	85	91
Gravel + volc. slag	Hydroponic	129	0.121	157	86	105
	Soil	117	0.118	139	78	93
Gravel+ pumice	Hydroponic	140	0.122	170	93	113
	Soil	138	0.104	144	92	96
Volcanic slag	Hydroponic	125	0.136	169	83	113
	Soil	124	0.120	149	83	98
Soil (control)	Hydroponic	26	0.115	30	26	30
	Soil	21	0.109	23	21	23
$LSD_{0.5}$		28				

Table 2 - Physical and chemical characteristics of the essential oil of rose geranium grown under open-air hydroponic conditions

Substrates	Contents in % according to the data provided by Gas Fluid Chromotography				
	Citronellol	Geraniol	Total primary alcohols	Isomenthon	Citronellil-formiate
Gravel	41.0	10.9	51.9	7.3	14.3
Gravel+slag	46.8	10.1	55.9	8.4	14.3
Gravel+pumice	40.8	9.5	50.3	6.6	13.5
Volcanic slag	45.2	10.8	56.0	7.8	15.3
Soil (control)	12.0	8.8	50.8	5.6	13.9

Substrates	Specific weight	Coefficient of refraction
Gravel	-12.0°	1.4545
Gravel+slag	-10.0°	1.4640
Gravel+pumice	-11.3°	1.4630
Volcanic slag	-13.0°	1.4639
Soil (control)	-12.5°	1.4628

Table 3 - Productivity of highly oil-bearing hybrides of geranium. Chemical composition of their essential oils (Substrate-- volcanic slag)

Hybrids	Yield t/ha	Ess.oil contents, %	Ess. Oil Output, kg/ha	Contents of chemical components, %				
				Menthon	Leralool	Citronellil-formiate	Citronellol	Geraniol
Rose geranium	136	0.115	157	10.8	6.4	20.6	48.1	6.2
No 7	58	0.321	186	—	3.5	—	62.0	33.4
No 24	55	0.285	157	1.7	8.1	—	77.0	2.9
C18K4	80	0.336	269	4.3	3.2	—	68.6	23.3
16K — 5	105	0.179	206	5.6	—	2.0	52.5	39.5
P/2K-37-2	81	0.319	258	5.3	—	—	73.5	21.2
the Tajik-15	37	0.330	122	3.9	—	2.6	58.1	34.0
Aist — 4	98	0.354	347	4.3	—	—	67.0	11.6
$LSD_{0.5}$	27							

Table 4 - Essential oil productivity and quality under different conditions of growth

Cultures	Growth conditions	Yield, t/ha	$LSD_{0.5}$	Essential oil content, %	Essential oil output, %	Content of the main component
Citric Sorghum						citral
	Hydroponics	49.7	13.2	0.370	184	86
	Soil	9.3		0.326	30	84
Eugenol basil						eugenol
	Hydroponics	57.3	14.6	0.229	131	83
	Soil	10.8		0.327	35	82
Common basil						metilchavicol
	Hydroponics	141.0	24.3	0.057	81	70
	Soil	26.0		0.069	18	68
Peppermint						menthol
	Hydroponics	177.3	27.0	0.162	287	53
	Soil	33.0		0.219	72	46
Vetiveria						vetivon
	Hydroponics	5.2	—	0.782	41	11
	Soil	1.4		1.160	16	4
Catmint						citronellol
	Hydroponics	63.1	23.5	0.121	77	47
	Soil	15.7		0.19	21	34
Wormwood						artemisiaketon
	Hydroponics	48.4	1.8	0.238	119	42
	Soil	16.0		0.250	40	50