A COMPARISON OF LIVING SOIL METHODOLOGIES IN RELATION TO PLANT HEALTH AND YIELD IN A CONTROLLED ENVIRONMENT FOR CANNABIS

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Abstract: There currently exists many different methodologies for growing cannabis in controlled environments, however there is very little published research on the subject in regards to cannabis cultivation. Conventional approaches using bottled nutrients have a higher cost of production, which has become a challenge cultivators as the market price of cannabis has dropped dramatically.[1] With an estimated revenue of 9 billion in legal cannabis sales in 2017 and estimated revenue of 11 billion for 2018, the emerging market is growing rapidly.[2] Many of the current methods involving hydroponic cultivation have a large carbon footprint and negative environmental impact due to the use of fossil fuels. These methods typically only allow for the media to be used one or two times before being disposed of, which contributes to leaching of phosphates and other nutrients into our groundwater.

The need for more sustainable and earth-friendly methods of cultivation is important from a social perception, environmental, and economic perspective.

Methodology:
For this study an enclosed indoor space was outfitted with three 4' x 12 ' soil beds each containing different organic living soil recipes.

Soil Bed #1: **S2S** comprised of Peat Moss, Pumice, Compost, Worm Castings, Blood Meal, Feather Meal, Alfalfa Meal, Kelp Meal, Insect Frass, Fish Bone Meal, Bone Meal, Bat Guano, Seabird Guano, Soft Rock Phosphate, Potassium Sulfate, Langbeinite, Greensand, Azomite, Oyster Shell Flour, Gypsum, Basalt Rock Dust, Glacial Rock Dust, Iron Sulfate, Copper Sulfate, Nutrisorb, Fossilized Carbon Complex, Diatomaceous Earth

Soil Bed #2: **KIS Organics Biochar Soil** comprised of biochar, spaghnum peat moss, fish compost, earthworm castings, volcanic pumice, glacial rock dust, basalt, soft rock phosphate, oyster shell flour, alfalfa meal, fish bone meal, crustacean meal, kelp meal, neem cake, karanja cake, fish meal, feather meal, steamed bone meal, agricultural lime.

Soil Bed #3: **XXX Soil Mix** comprised of Peat Moss, Coconut Coir, Perlite, African Night Crawler Worm Castings, Composted Porcine Manure, Glacial Rock Dust, Basalt Rock Dust, Oyster Shell Flour, Insect Frass, Fishbone Meal, Certified Organic Alfalfa Meal, Gypsum, Limestone Flour, Bone Meal, Feather Meal, Mined Potassium Sulfate, Blood Meal, Rock Phosphate, Fossilized Carbon Complex, Kelp Meal, Bat Guano/ Mineralized Phosphate amended with 10% Biochar and a blend of compost at 2% by volume.

All soil was mixed on-site to ensure accuracy. Each bed was planted with clones containing 1/3 Cookies and Cream cultivar (CNC) and 2/3 Gorilla Glue #4 cultivar (GG).

Environmental Controls:

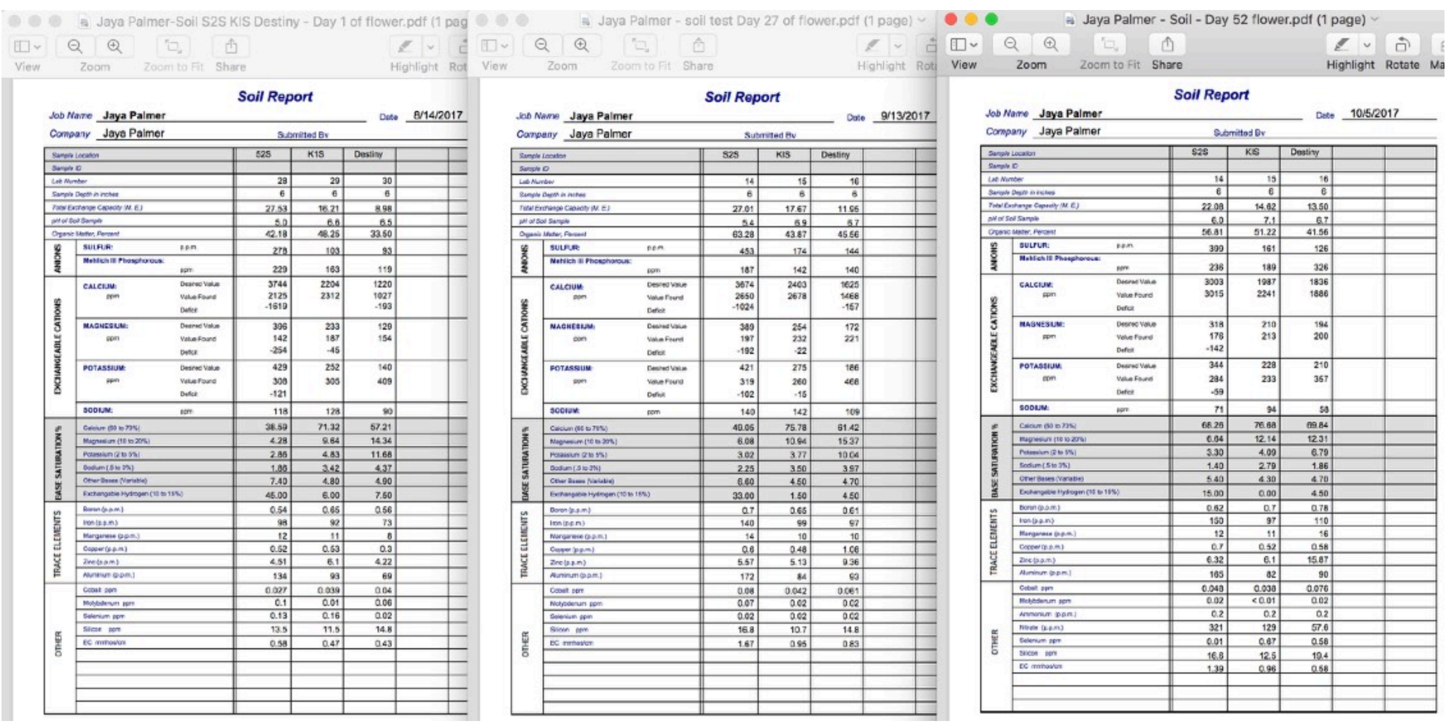
82F (27.7 C) daytime temperature, 76F (24.4 C) nighttime set point
75rH daytime, 64rH nighttime set point
1500 ppm CO_2 set point
Dehumidifiers on 15 minute increment timers so they would turn on 30 mins before lights out.
1000 pfd average at canopy height
Lighting controller would turn off half the lights 15-30 mins before the other half so temp would drop slowly and not spike humidity.
Humidifier on another 15min increment timer so it would turn off 30 mins before lights turned off.
Plants were watered using Blumat irrigation and set to maintain moisture content in the soil at 100 mbar.

Equipment:
Three rolling beds on v-casters and v-track, each 4'x12'.

LED lighting from Fluence Biotechnology (**https://fluence.science/**). There were 12 VYPRxPlus lights over a 12' x 12' canopy with each light covering a 3' x 4' footprint. We chose Fluence based on the existing body of research supporting their lights as well as the higher efficiency of LED lighting in comparison to HPS, double-ended HPS and LEC technology.

Two 12k BTU Air Conditioning Units; 200 pint Ideal-Air Humidifier; Atlas 8 Digital CO_2 Controller; 2 - 70 pint Dehumidifiers; Helios 12 Light Controller

Soil Testing: We used three types of soil tests to evaluate the nutrient and mineral levels in the media. The Meilich III test and saturated paste test from Logan Laboratories and a Soil Savvy (artificial resin) test from UniBest. The Meilich III test is an acid extraction that is helpful in determining what nutrients and minerals are in the media but it does not show what is currently available for uptake for the plant. The Saturated Paste Tests and Soil Savvy test are two different testing methodologies designed to show what is currently available for plant uptake.



Jaya Palmer-Soil S2S KIS Destiny - Day 1 of flower.pdf (1 pag

Soil Report

Job Name: Jaya Palmer — Date: 8/14/2017
Company: Jaya Palmer — Submitted By

Sample Location			S2S	K1S	Destiny
Sample ID					
Lab Number			28	29	30
Sample Depth in inches			6	6	6
Total Exchange Capacity (M. E.)			27.53	16.21	8.98
pH of Soil Sample			5.0	6.6	6.5
Organic Matter, Percent			42.18	48.25	33.50
ANIONS	SULFUR:	p.p.m.	278	103	93
	Mehlich III Phosphorous:	ppm	229	163	119
EXCHANGEABLE CATIONS	CALCIUM: ppm	Desired Value	3744	2204	1220
		Value Found	2125	2312	1027
		Deficit	-1619		-193
	MAGNESIUM: ppm	Desired Value	396	233	129
		Value Found	142	187	154
		Deficit	-254	-45	
	POTASSIUM: ppm	Desired Value	429	252	140
		Value Found	308	305	409
		Deficit	-121		
	SODIUM:	ppm	118	128	90
BASE SATURATION %	Calcium (60 to 75%)		38.59	71.32	57.21
	Magnesium (10 to 20%)		4.28	9.64	14.34
	Potassium (2 to 5%)		2.86	4.83	11.68
	Sodium (.5 to 3%)		1.86	3.42	4.37
	Other Bases (Variable)		7.40	4.80	4.90
	Exchangable Hydrogen (10 to 15%)		45.00	6.00	7.60
TRACE ELEMENTS	Boron (p.p.m.)		0.54	0.65	0.56
	Iron (p.p.m.)		98	92	73
	Manganese (p.p.m.)		12	11	8
	Copper (p.p.m.)		0.52	0.53	0.3
	Zinc (p.p.m.)		4.51	6.1	4.22
	Aluminum (p.p.m.)		134	93	69
OTHER	Cobalt ppm		0.027	0.039	0.04
	Molybdenum ppm		0.1	0.01	0.06
	Selenium ppm		0.13	0.16	0.02
	Silicon ppm		13.5	11.5	14.8
	EC mmhos/cm		0.58	0.47	0.43

Jaya Palmer - soil test Day 27 of flower.pdf (1 page)

Soil Report

Job Name: Jaya Palmer — Date: 9/13/2017
Company: Jaya Palmer — Submitted By

Sample Location			S2S	KIS	Destiny
Sample ID					
Lab Number			14	15	16
Sample Depth in inches			6	6	6
Total Exchange Capacity (M. E.)			27.01	17.67	11.96
pH of Soil Sample			5.4	6.9	6.7
Organic Matter, Percent			63.28	43.87	45.66
ANIONS	SULFUR:	p.p.m.	453	174	144
	Mehlich III Phosphorous:	ppm	187	142	140
EXCHANGEABLE CATIONS	CALCIUM: ppm	Desired Value	3674	2403	1625
		Value Found	2650	2678	1468
		Deficit	-1024		-157
	MAGNESIUM: ppm	Desired Value	389	254	172
		Value Found	197	232	221
		Deficit	-192	-22	
	POTASSIUM: ppm	Desired Value	421	275	186
		Value Found	319	260	468
		Deficit	-102	-15	
	SODIUM:	ppm	140	142	109
BASE SATURATION %	Calcium (60 to 75%)		40.06	75.78	61.42
	Magnesium (10 to 20%)		6.08	10.94	15.37
	Potassium (2 to 5%)		3.02	3.77	10.04
	Sodium (.5 to 3%)		2.25	3.50	3.97
	Other Bases (Variable)		6.60	4.50	4.70
	Exchangable Hydrogen (10 to 15%)		33.00	1.50	4.50
TRACE ELEMENTS	Boron (p.p.m.)		0.7	0.65	0.61
	Iron (p.p.m.)		140	99	97
	Manganese (p.p.m.)		14	10	10
	Copper (p.p.m.)		0.6	0.48	1.08
	Zinc (p.p.m.)		5.57	5.13	9.36
	Aluminum (p.p.m.)		172	84	93
OTHER	Cobalt ppm		0.08	0.042	0.061
	Molybdenum ppm		0.07	0.02	0.02
	Selenium ppm		0.02	0.02	0.02
	Silicon ppm		16.8	10.7	14.8
	EC mmhos/cm		1.67	0.95	0.83

Jaya Palmer - Soil - Day 52 flower.pdf (1 page)

Soil Report

Job Name: Jaya Palmer — Date: 10/5/2017
Company: Jaya Palmer — Submitted By

Sample Location			S2S	KIS	Destiny
Sample ID					
Lab Number			14	15	16
Sample Depth in inches			6	6	6
Total Exchange Capacity (M. E.)			22.08	14.62	13.50
pH of Soil Sample			6.0	7.1	6.7
Organic Matter, Percent			56.81	51.22	41.56
ANIONS	SULFUR:	p.p.m.	390	161	126
	Mehlich III Phosphorous:	ppm	236	189	326
EXCHANGEABLE CATIONS	CALCIUM: ppm	Desired Value	3003	1987	1836
		Value Found	3015	2241	1886
		Deficit			
	MAGNESIUM: ppm	Desired Value	318	210	194
		Value Found	176	213	200
		Deficit	-142		
	POTASSIUM: ppm	Desired Value	344	228	210
		Value Found	284	233	367
		Deficit	-59		
	SODIUM:	ppm	71	94	58
BASE SATURATION %	Calcium (60 to 75%)		68.26	76.68	69.84
	Magnesium (10 to 20%)		6.64	12.14	12.31
	Potassium (2 to 5%)		3.30	4.09	6.79
	Sodium (.5 to 3%)		1.40	2.79	1.86
	Other Bases (Variable)		5.40	4.30	4.70
	Exchangable Hydrogen (10 to 15%)		15.00	0.00	4.50
TRACE ELEMENTS	Boron (p.p.m.)		0.62	0.7	0.78
	Iron (p.p.m.)		150	97	110
	Manganese (p.p.m.)		12	11	16
	Copper (p.p.m.)		0.7	0.52	0.58
	Zinc (p.p.m.)		6.32	6.1	15.87
	Aluminum (p.p.m.)		165	82	90
OTHER	Cobalt ppm		0.048	0.038	0.076
	Molybdenum ppm		0.02	< 0.01	0.02
	Ammonium (p.p.m.)		0.2	0.2	0.2
	Nitrate (p.p.m.)		321	129	57.6
	Selenium ppm		0.01	0.67	0.58
	Silicon ppm		16.8	12.5	10.4
	EC mmhos/cm		1.39	0.96	0.58

Saturated Paste Report

Job Name **Jaya Palmer** Date 10/5/2017

Company Jaya Palmer Submitted By

			S2S	KIS	Destiny		
Sample Location			S2S	KIS	Destiny		
Sample ID							
Lab Number			110954	110955	110956		
Water Used			DI	DI	DI		
pH			6.0	7.1	6.7		
Soluble Salts		ppm	2,062	1,334	835		
Chloride (Cl)		ppm	250	411	120		
Bicarbonate (HCO3)		ppm	63	83	61		
ANIONS	SULFUR	ppm	221.4	154.1	117.5		
	PHOSPHORUS	ppm	7.59	0.89	1.73		
SOLUBLE CATIONS	CALCIUM	ppm	451.40	232.50	104.80		
		meq/l	22.57	11.63	5.24		
	MAGNESIUM	ppm	45.95	40.23	25.21		
		meq/l	3.83	3.35	2.10		
	POTASSIUM:	ppm	157.80	127.70	172.30		
		meq/l	4.10	3.32	4.48		
	SODIUM	ppm	39.53	58.64	28.29		
		meq/l	1.72	2.55	1.23		
PERCENT	Calcium		70.06	55.77	40.17		
	Magnesium		11.89	16.08	16.10		
	Potassium		12.72	15.91	34.30		
	Sodium		5.33	12.23	9.43		
TRACE ELEMENTS	Boron (p.p.m.)		0.13	0.04	0.07		
	Iron (p.p.m.)		0.4	0.21	0.42		
	Manganese (p.p.m.)		0.13	0.02	0.03		
	Copper (p.p.m.)		< 0.02	< 0.02	< 0.02		
	Zinc (p.p.m.)		0.04	< 0.02	< 0.02		
	Aluminum (p.p.m.)		1.38	0.96	1.15		
OTHER							

Logan Labs, LLC

Soil Report

Job Name **Jaya Palmer** Date 1/5/2018

Company Jaya Palmer Submitted By

			S2S	KIS	Destiny		
Sample Location			S2S	KIS	Destiny		
Sample ID							
Lab Number			29	30	31		
Sample Depth in inches			6	6	6		
Total Exchange Capacity (M. E.)			18.14	10.46	9.29		
pH of Soil Sample			5.6	7.5	6.8		
Organic Matter, Percent			48.83	67.72	30.84		
ANIONS	SULFUR:	p.p.m.	303	215	109		
	Mehlich III Phosphorous:	ppm	78	109	153		
EXCHANGEABLE CATIONS	CALCIUM: ppm	Desired Value	2467	1422	1263		
		Value Found	1937	1659	1333		
		Deficit	-530				
	MAGNESIUM: ppm	Desired Value	261	150	133		
		Value Found	153	137	127		
		Deficit	-107	-12	-6		
	POTASSIUM: ppm	Desired Value	282	163	144		
		Value Found	243	63	214		
		Deficit	-39	-100			
	SODIUM:	ppm	123	103	72		
BASE SATURATION %	Calcium (60 to 70%)		53.39	79.32	71.74		
	Magnesium (10 to 20%)		7.05	10.96	11.35		
	Potassium (2 to 5%)		3.43	1.53	5.91		
	Sodium (.5 to 3%)		2.94	4.30	3.39		
	Other Bases (Variable)		6.20	3.90	4.60		
	Exchangable Hydrogen (10 to 15%)		27.00	0.00	3.00		
TRACE ELEMENTS	Boron (p.p.m.)		0.77	0.73	0.83		
	Iron (p.p.m.)		84	75	96		
	Manganese (p.p.m.)		7	11	15		
	Copper (p.p.m.)		0.96	2.43	2.55		
	Zinc (p.p.m.)		10.18	8.9	11.81		
	Aluminum (p.p.m.)		115	59	79		
OTHER	Cobalt ppm		0.098	0.206	0.293		
	Molybdenum ppm		0.17	0.06	0.04		
	Ammonium (p.p.m.)		0.5	0.2	0.2		
	Nitrate (p.p.m.)		112.6	39.2	20.6		
	Selenium ppm		0.71	0.02	0.07		
	Silicon ppm		6.3	11.7	15.5		
	EC mmhos/cm		1.72	0.64	0.65		
	Media Weight %		11.8	15.8	15.7		

Logan Labs, LLC

Saturated Paste Report

Job Name **Jaya Palmer** Date 1/5/2018

Company Jaya Palmer Submitted By

			S2S	KIS	Destiny		
Sample Location			S2S	KIS	Destiny		
Sample ID							
Lab Number			114371	114372	114373		
Water Used			DI	DI	DI		
pH			5.6	7.5	6.8		
Soluble Salts		ppm	2,217	982	662		
Chloride (Cl)		ppm	456	322	193		
Bicarbonate (HCO3)		ppm	29	102	49		
ANIONS	SULFUR	ppm	298	203.3	142.5		
	PHOSPHORUS	ppm	11.8	1.12	2.03		
SOLUBLE CATIONS	CALCIUM	ppm	471.60	188.30	78.28		
		meq/l	23.58	9.42	3.91		
	MAGNESIUM	ppm	59.06	29.58	20.38		
		meq/l	4.92	2.47	1.70		
	POTASSIUM:	ppm	119.60	22.12	108.00		
		meq/l	3.11	0.57	2.81		
	SODIUM	ppm	69.78	66.86	44.26		
		meq/l	3.03	2.91	1.92		
PERCENT	Calcium		68.07	61.29	37.85		
	Magnesium		14.21	16.05	16.42		
	Potassium		8.97	3.74	27.12		
	Sodium		8.76	18.92	18.61		
TRACE ELEMENTS	Boron (p.p.m.)		0.25	0.2	0.46		
	Iron (p.p.m.)		0.19	0.15	0.24		
	Manganese (p.p.m.)		0.28	0.02	0.02		
	Copper (p.p.m.)		< 0.02	< 0.02	0.02		
	Zinc (p.p.m.)		0.23	0.03	< 0.02		
	Aluminum (p.p.m.)		1.04	0.77	0.64		
OTHER							

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Day 53 of flower

Day 63 of flower

Results:

Yield expressed in lbs. per 16 square feet

Cultivar	S2S	KIS Organics	XXX
Gorilla Glue #4	2.13	2.76	2.65
Gorilla Glue #4	2.62	3.22	2.99
Cookies and Cream	1.44	1.95	1.53

**Average yield across all cultivars was 2.475 lbs. per 4'x4' area*

Yield expressed in grams per square feet

Cultivar	S2S	KIS Organics	XXX
Gorilla Glue #4	60	78	75
Gorilla Glue #4	74	91	85
Cookies and Cream	41	55	43

**Average yield across all cultivars was 66.88 grams per square foot*

Discussion:
While the overall yields show promise, replication of these trials would be needed to draw further conclusions. Furthermore, based on the soil tests, additional trace mineral applications could have potentially improved overall plant health and yield even though deficiencies weren't visually apparent.

Soil S2S was mixed using target ranges to match the macro nutrient levels in the KIS Organics soil, however guaranteed analysis on guanos was not reliable and resulted in very imbalanced soil. For future trials it would be pertinent to test the various fertilizer inputs due to the variance in manufacturing and processing.

It is also important to note that soil testing can show variability across laboratories and samples and the goal is not a perfectly balanced soil test but rather healthy plants. The soil test is just a tool to allow us to see potential deficiencies and excesses. In this study we had quite a bit of variability in test results, however there was much less variability that was visible when viewing the plants. This further demonstrates the ability of the plant to regulate it's own nutrient demand when given traditionally "excessive" levels of nutrients in organic, biologically-active soils.

As we learn more and improve these processes, it seems likely that living soils offer the ability to match or beat hydroponic yields with less input and labor cost, a smaller carbon footprint, and in a manner that would allow for the final product to be certified organic based on current National Organic Program standards.

Citations/Resources:

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