

Standard hydroponic formulations from the scientific literature

When researchers started looking into growing plants without soil, they started to look for mixtures of nutrients that could grow plants successfully so that these formulations could be used to study other aspects of plant physiology. If you have a mixture of nutrients that you know grows a plant without major issues, then you can use that as a base to study other things, for example how plants react to some exogenous agent or how changes to temperature or humidity affect the uptake of certain nutrients (see this paper for a view into the history of hydroponics and standard solutions). The establishment of these standard solutions was one of the great achievements of botanists during the twentieth century, which allowed thousands of detailed studies on plants to be carried out. In this post, we're going to be talking about these standard solutions and why they are a great place to start for anybody seeking to formulate their own nutrients.

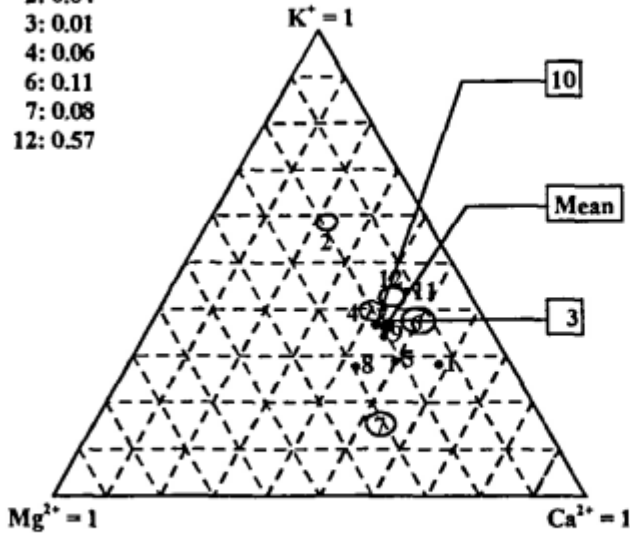
ppm (mg/L)	1	2	3	4	5	6	7	8	9	10	11	12
K	132.93	187.28	241.24	312.79	236.15	237.33	89.54	157.57	261.57	302.23	430.08	312.79
Ca	136.27	36.07	149.09	163.52	200.39	160.31	161.11	120.23	184.76	172.34	220.43	160.31
Mg	19.69	18.71	37.19	49.34	48.61	24.31	55.90	48.61	49.10	50.55	36.46	34.03
N as NH4+	0.00	4.90	2.10	18.91	0.00	28.01	19.61	0.00	0.00	0.03	0.01	17.51
Na	0.00	0.23	1.15	0.46	0.00	0.46	0.00	2.07	0.46	0.69	8.74	0.69
Fe	36.86	2.79	4.02	0.00	1.44	1.12	1.12	5.03	1.34	1.90	7.10	0.84
Mn	0.00	0.62	1.23	0.00	0.50	0.11	0.14	0.40	0.62	1.98	2.40	0.55
Cu	0.00	0.06	0.01	0.00	0.02	0.03	0.00	0.02	0.01	0.10	0.04	0.04
Zn	0.00	0.01	0.01	0.00	0.05	0.13	0.13	0.05	0.11	0.10	0.12	0.03
N as NO3	123.82	77.46	161.50	226.63	210.10	196.09	112.75	112.05	167.80	201.28	241.62	224.11
P	103.45	42.74	64.74	40.89	30.97	61.95	71.24	61.95	30.66	59.78	69.69	38.72
S	25.97	27.90	54.51	65.09	64.13	32.07	96.84	64.13	111.59	67.98	87.22	44.89

Cl	0.00	0.00	0.00	0.00	0.64	1.77	0.00	0.53	0.00	0.00	13.47	0.00
B	0.00	0.28	1.19	0.00	0.46	0.27	0.10	0.40	0.43	0.30	0.34	0.27
Mo	0.00	0.41	0.00	0.00	0.01	0.05	0.00	0.03	0.05	0.19	0.06	0.34

Summary of standard nutrient formulations found in [this article](#) with the concentrations translated to ppm. The numbers in the list correspond to the following: 1. Knop, 2. Penningsfeld North Africa, 3. Pennings-Feld Carnations, 4. Gravel Culture Japan, 5. Arnon and Hoagland 1940, 6. Dennisch R. Hoagland USA, 7 Shive and Robbins 1942, 8. Hacsalyo 1961, 9. Steiner 1961, 10. Cooper 1979, 11 Research Centre Soil-less culture, 12. Naaldwijk cucumber.

One of the best places to find a comparison between these standard solutions is [this paper](#). In it, the authors explore the relationships between the different solutions and how they are similar or diverge. In the table above, you can see a summary of the elemental nutrient concentrations found in this paper for the 12 standard solutions they compare (the paper states them in mmol/L but I have changed them to ppm as these are more commonly used units in the field nowadays). As you can see, some of the older solutions miss some elements or contain much smaller amounts of them – as they were likely present in the media or other salts as impurities – while more recent standard solutions do contain all the elements we now understand are necessary for plant life.

NH₄⁺ proportion:
 2: 0.04
 3: 0.01
 4: 0.06
 6: 0.11
 7: 0.08
 12: 0.57

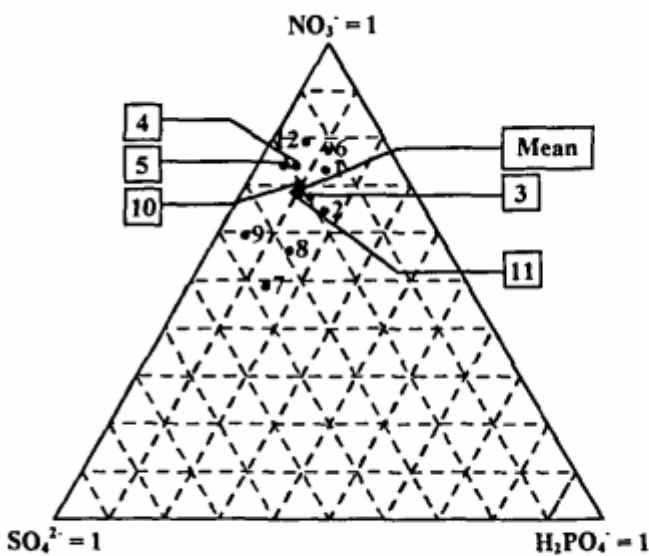


Standard solutions:

1. Knop
2. Penningsfeld N. Africa
3. Penningsfeld Carnations
4. Gravel culture, Japan
5. Arnon and Hoagland
6. Dennish R. Hoagland
7. Shive and Robbins
8. Hacskalyo
9. Steiner
10. Cooper
11. Res. Centre Soil. Cult.
12. Naaldwijk, cucumber

FIGURE 1. Cation composition of the standard solutions.

Figure showing the Ca/Mg/K ratio represented in a three axis plot. Taken from the paper mentioned above.



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FIGURE 2. Anion composition of the standard solutions.

Figure showing the N/S/P ratio represented in a three axis plot. Taken from the paper mentioned above.

It is interesting to note that all of these solutions have been successfully used to grow plants, so their convergent aspects might show us some of the basic things that plants require for growth. As they highlight on the paper, the

K/Mg/Ca ratio for most of these solutions is rather similar, as well as the N/S/P ratios. This means that most of these authors figured out that plants needed pretty specific ratios of these nutrients and these ratios are sustained with minor variations through the 12 solutions, developed across a span of more than 100 years. All the solutions developed from the 1940s have similar final concentrations and their starting pH is almost always in the 4-5 range, due to the presence of acid phosphate salts like monopotassium phosphate.

Nonetheless, there are several things that improved in the solutions as a function of time. The first is the inclusion of higher concentrations of all micronutrients with time, as macronutrient salt quality increased, the media sources became more inert and the need to add them to avoid deficiencies became apparent. The need to chelate micronutrients also became clear with time, as solutions starting with Hoagland's solution in the 1940s started using EDTA to chelate iron, to alleviate the problem of iron phosphate precipitation in hydroponic solutions. This is clearly shown in the table below, where the authors show how the first three solutions had almost or all of their Fe precipitate out, while the newest solutions, like Cooper's developed in 1979, had less than 5.5% of its Fe precipitated.

Standard solution	% Fe precipitated as Fe ₂ (PO ₄) ₃	% Cu complexed with chelate	% Zn complexed with chelate	% Mn complexed with chelate
1. Knop 1865	100	-	-	-
2. Penningsfeld North Africa	99.9	-	-	-
3. Penningsfeld Carnations	99.9	-	-	-
4. Gravel culture Japan	-	-	-	-
5. Arnon and Hoagland 1940	87.8	40.3	6.4	0.3
6. Dennisch R. Hoagland	4.0	97.5	97.5	0.1
7. Shive and Robbins 1942	99.9	-	-	-
8. Hacsalyo 1961	4.0	99.3	42.4	0.2
9. Steiner 1961	4.9	99.5	48.8	0.2
10. Cooper 1979	5.5	98.3	22.4	0.1
11. Res. Centre Soil. Cultures	6.9	100	99.2	7.7
12. Naaldwijk cucumber	4.5	96.5	7.8	0

This table shows the precipitated Fe and chelated portions of the micro nutrients in all the standard solutions.

The natural question when reading about standard solutions is: which one is the best one to use? Sadly, I don't think there's a simple answer. There have been multiple studies comparing standard solutions (see [this one](#) for an example). What ends up happening most of the time is that, while most of the solutions manage to grow healthy crops, one of the solutions happens to be more fit to the idiosyncrasies of the study because its conditions are better aligned with those that the authors developed the solutions under. A study revealing a solution to be better than another to grow plants under a given set of conditions does not imply that this solution will be the best one for all plants under all conditions. For this reason, the optimization of nutrient solutions to particular conditions using tissue analysis is still pursued in order to maximize yields.

My advice would be to view the above solutions as well researched starting points for your hydroponic crops. These solutions, especially the ones developed after 1940, will do a good basic job growing your plants. If you're interested in

making your own solutions, starting with a solution like the Hoagland, Steiner, or Cooper solutions is a great way to begin making your own nutrients. Once you have a basic standard solution working for you, you can then tweak it to maximize your yield and improve your crop's quality.