Aquaponics vs hydroponics, which is best and why?

In hydroponic culture, plants are grown with the help of a nutrient solution that contains all the substances required for plant growth. In these systems, the nutrient solution is prepared using externally sourced chemicals, which can be of a synthetic or natural origin. On the other hand, in aquaponics, a plant growing system is coupled with an aquaculture system – a system that raises fish – so that the plants feed on the waste coming from the fish. In theory, aquaponics offers the benefits of a simplified, closed system with an additional upside – the ability to produce fish – while a hydroponic system requires a lot of additional and more complicated inputs. Through this post, we will use the current peer-reviewed literature to take a deep look into aquaponics vs hydroponics, what are the advantages and disadvantages and why one might be better than the other. A lot of the information below has been taken from this 2019 review on aquaponics (9).

Basic process diagram of an aquaponic setup (from here)

Complexity

An aquaponic system might seem simpler than a hydroponic system. After all, it is all about feeding fish regular fish food and then feeding the waste products to plants. However, it is actually not that simple, since there are substantial differences between the waste products of fish and the nutritional needs of plants. One of the most critical ones is nitrogen.

This element is excreted by fish in its ammoniacal form but plants require nitrogen in its nitrate form. This means that you need to have a biofilter system containing bacteria that can turn one into the other. Furthermore, the chemical conditions ideal for nitrification are basic, while plants prefer solutions that are slightly acidic. This mismatch in the optimal conditions of one system compared to the other makes the management of an aquaponic system substantially more complicated than the management of a traditional hydroponic system (1).

Furthermore, plant macronutrients like Potassium and Calcium and micronutrients like Iron are often present at low levels in aquaponic solutions. Plants that have higher demands for these elements, such as large flowering plants or some herbs, might have important deficiencies and issues when grown in an aquaponic system (2, 3). This means that supplementation is often required in order to achieve success with these crops. Achieving ideal supplementation rates often requires chemical analysis in order to properly gauge the amounts of these elements that are required.

Additionally, aquaponic systems require additional area for fish and a lot of additional labor to manage the fish, the biofilters, and other sections of the facility that would not exist under a purely hydroponic paradigm. This article (16), better describes some of the economic and practical tradeoffs in terms of complexity when going from a hydroponic to an aquaponic facility.

Yield and quality

Given the above, it could be easy to think that yields and quality of products coming from aquaponics would be worse. However, the evidence points to the contrary. Multiple studies looking at aquaponics vs hydroponics quality and yields have shown that aquaponics products can be equivalent or often superior to those produced in hydroponic environments (4, 5, 6, 7, 8). A variety of biological and chemical factors present in the aquaponic solution could offer bio-stimulating effects that are not found in traditional hydroponic solutions. For a detailed meta-analysis gathering data from a lot of different articles on aquaponics vs hydroponics see here (14).

The best results are often found with decoupled aquaponic systems. In these systems, the aquaponic system is treated as separate aquaculture and hydroponic systems. The nutrient solution is stored in a tank that is used by the hydroponic facility as its main feedstock to make nutrient solution. Its chemistry is then adjusted before it is fed to the hydroponic system.

An aquaponic setup growing leafy greens

Growing Systems

Traditionally, Nutrient Film Technique (NFT) systems have been preferred in commercial hydroponic culture due to their high yield and effectiveness. However, aquaponic systems do better with setups that can handle large levels of particulates, due to their presence in the aquaponic nutrient solution. For this reason, deep water culture (DWC) is the preferred method for growing in commercial hydroponic systems. This is also because dark leafy vegetables are the most commonly grown products in aquaponic setups and DWC setups are particularly well suited to grow this type of plants.

Sustainability

Aquaponic systems are, on average, more sustainable than hydroponic systems in terms of fertilizer usage. When comparing Nitrogen and Phosphorus usage between a hydroponic and an aquaponic crop, it seems to be clear that aquaponic crops are much more efficient (12). An aquaponic crop can offer the same quality and yield with drastically lower fertilizer use and carbon dioxide emissions due to these facts (13).

The aquaponic closed system diagram, taken from here

The economics

Due to the poor nutritional characteristics of the aquaponic solutions for flowering plants, most aquaponic growers have resorted to the growing of leafy greens. A 2017 study (10) showed that profits from growing basil were more than double of those attained by growing Okra, due to the fact that basil could be grown with little additional supplementation while Okra required significant modification of the aquaponic solution to fit the plants' needs.

Due to the fact that large flowering plants require large amounts of mineral supplementation in order to be grown successfully in aquaponics, they are seldom grown in aquaponics setups. Since leafy greens eliminate the need for such supplementation, can be grown faster, and suffer from substantially less pest pressure, it is a no-brainer in most cases to grow leafy greens instead of a crop like tomatoes or peppers. However, high-value crops like cannabis might be attractive for aquaponics setups (10, 11).

Aquaponics often require economies of scale to become viable. The smallest scale aquaponic setups, like those proposed by FAO models, can offer food production capabilities to small groups of people, but suffer from a lack of economic viability when the cost of labor is taken into account (12). It is, therefore, the case that, to be as profitable as hydroponics, aquaponic facilities need to be implemented at a relatively large scale from the start, which limits their viability when compared with hydroponic setups that can offer profitability at lower scales. As a matter of fact, this 2015 study (15) showed that most aquaponic farms were implemented at relatively small scales and had therefore low profitability values.

Nonetheless, aquaponics does offer a much more sustainable way to produce food relative to conventional hydroponic facilities and does offer economic advantages, especially in regions where low water and fertilizer usage are a priority (14).

Which one is best then?

It depends on what your priorities are. If you want to build a setup with few uncertainties that can deliver the most profit at the smallest scale, then hydroponics is the way to go. Aquaponic setups have additional complexities, uncertainties, needs of scale, and limitations that hydroponic crops do not have. Building a hydroponic commercial setup is a tried-and-tested process. Hydroponics offers predictable yields and quality for a wide variety of plant products. There is also a wide industry of people who can help you achieve this, often with turn-key solutions for particular plant species and climates.

On the other hand, if you want to build a setup that is highly sustainable, has as little impact as possible on the environment, has very low fertilizer and water use and can deliver the same or better quality as a hydroponic setup, then aquaponics is the road for you. Aquaponics has significantly lower impact – as it reduces the impact of both plant growing and fish raising – and can deliver adequate economic returns if the correct fish and plant species are chosen.

In the end, it is a matter of choosing which things are most important for you and most adequate for the circumstances you will be growing in. Sometimes, limited fertilizer and water availability, coupled with higher demand for fish, might actually make an aquaponic setup the optimal economic choice versus a traditional hydroponic setup. However, most of the time a purely economic analysis would give the edge to a hydroponic facility.

If you are considering building an aquaponic system, a decoupled system that produces Tilapia and a deep water culture system producing dark leafy greens seems to be the most popular choice among commercial facilities.

Which do you think is better, aquaponics or hydroponics?

The ultimate EC to ppm chart and calculator

Electrical conductivity (EC) meters in hydroponics will generally give you different types of readings. All of these readings are conversions of the same measurement – the electrical conductivity of the solution – but growers will often only record one of them. The tools presented in this page will help you convert your old readings from one of these values to the other, so that you can compare with reference sources or with readings from a new meter. In this page you can figure out the scale of your meter, convert from ppm to EC and from EC to ppm.

The TDS reading of different meters will be done on different scales, so it is important to know the scale of your meter in order to perform these conversions. These scales are just different reference standards depending on whether your meter is comparing the conductivity of your solution to that of an NaCl, KCl or tap water standard. To learn more about how TDS scales work I would suggest you watch my youtube video on the subject. **To compare the readings from different meters, always compare the EC (mS/cm) reading, do not compare ppm readings**

unless you are sure they are in the same scale.

My go-to EC meter recommendation is the Apera EC60

To figure out the scale of the meter, measure the EC (mS/cm) and TDS (ppm) of the exact same solution with your meter. After this, input the values in the first calculator below. You can then use this scale value to convert between EC and ppm using the other two calculators below. If you already know the scale of your meter you can use the other two calculators and skip the first step. The meter scale will usually be 500, 600 or 700.

Figure out the Scale of the Meter

TDS (ppm) reading:

EC (mS/cm) reading:

Calculate

Meter scale:

Convert ppm to EC

TDS (ppm) reading:

Meter scale:

Calculate

EC in mS/cm:

Convert EC to ppm

EC reading mS/cm:

Meter scale:

Calculate

TDS (ppm) reading:

Create a table for reference

Meter scale:

Generate Table

If you would like to learn more about EC readings in hydroponics I would suggest reading the following posts on my blog:

- Comparing the conductivity of two different solutions
- Improving on HydroBuddy's theoretical conductivity

model, the LMCv2
- FAQ – Electrical Conductivity (EC) in Hydroponics

Using electro-degradation to enhance yields in recirculating hydroponics

The efficient use of nutrient solutions is a very important topic in hydroponics. Although some commercial growers use run-to-waste systems where solutions are not recirculated, the economics of fertilizer use often demand re-circulation in order to enhance nutrient utilization and maximize growing efficiency. However one of the biggest problems found when circulating nutrient solution continuously is the build-up of plant exudates, which can be toxic and detrimental to plant growth.

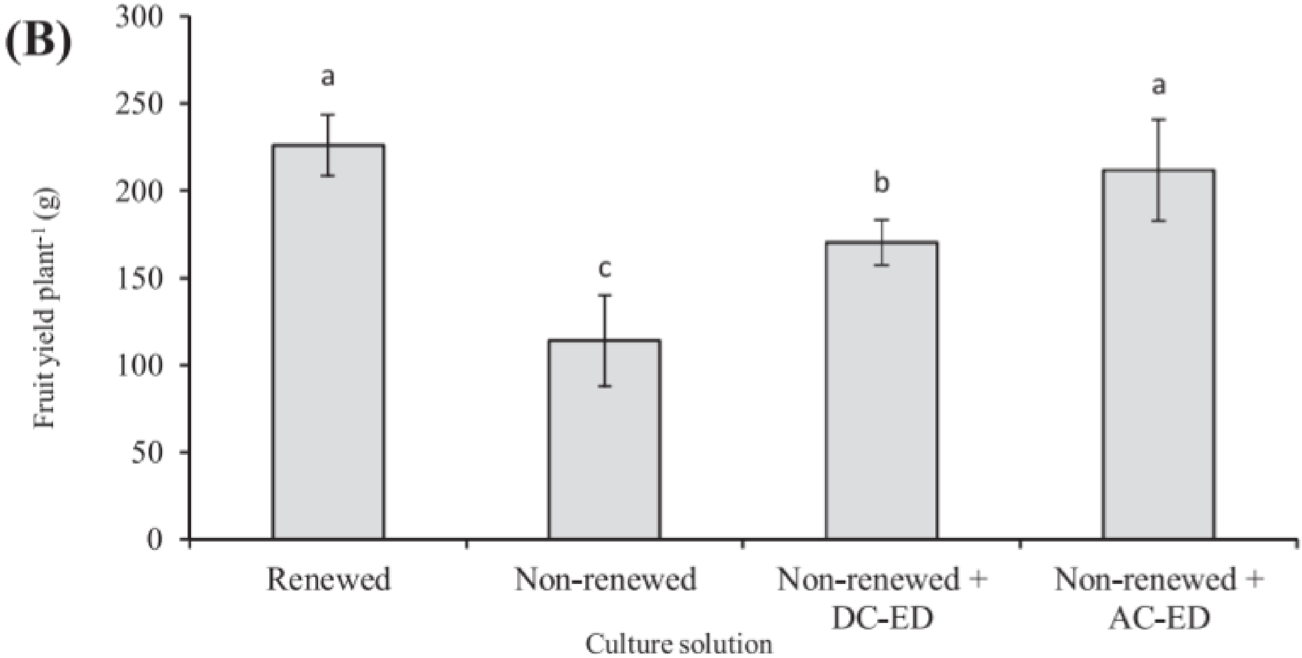

Image taken from this article

Several solution for this have been studied historically, most commonly the use of filtration systems – such as activated charcoal cartridges – to capture these exudates and prevent their accumulation. The problem with this approach is that activated carbon – or other filters – are not neutral to some of the components of nutrient solutions and might disproportionately and efficiently capture metal chelates and eventually cause nutrient deficiencies. There are some ways around this – such as changing the formulations or replenishing solutions after filtering – but both are far from ideal.

More recently a paper has been published showing how electro-degradation can actually alleviate this problem by destroying these exudates – which are commonly organic acids – in nutrient solutions. The paper talks about how they used this technique to treat recirculating solutions in strawberry, eliminating autotoxicity and increasing fruit yields substantially.

The technique is very simple, basically using either a DC or AC current passed through an electrode that the solution circulates through, destroying the problematic molecules in the process. The first image in this post clearly shows how not renewing the solution causes important problems with yields that are completely removed by the use of the AC based electro degradation.

Table 1
Changes in mineral nutrients after application of electro-degradation of nutrient solution in no plant experiment. Electro-degradations were applied in 10 l of 25% standard "Enshi" nutrient solution with 400 μM L^{-1} benzoic acid for 24 h. (Experiment II).

Electro-degradation	NO_3^- (ppm)	$P_2O_5^-$ (ppm)	K^+ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Fe^{3+} (ppm)
Control[a]	687	37.5	7.9	49.9 a[d]	16.2	3.5 a
DC-ED[b]	658	35.8	7.6	41.6 b	13.8	2.2 b
AC-ED[c]	669	37.5	7.2	52.6 a	15.4	3.4 a
Significance	NS	NS	NS		NS	

[a] Electro-degradation was not applied.
[b] Electro-degradation was applied using "Direct Current".
[c] Electro-degradation was applied using "Alternate Current".
[d] Means within a column followed by different letters are significantly different and NS indicate non-significant according to the Tukey's test at $P < 0.05$.

Image taken from this article

Another advantage of this technique is that – contrary to filtering techniques – there is little loss in the amount of nutrients in solution when performing the AC electro-degradation. Since the oxidation/reduction of the metal chelates used is highly reversible, the actual concentration of these elements in solution remains practically the same after treatment. You can see this in the image above, where there is no statistically significant change for the concentration of nutrients in solution.

The paper concludes suggesting a treatment of 24 hours (for 300L in the experiments) every three weeks, to completely recover from the exudates present in solution. For this AC application they used a frequency of 500Hz at 14V with an electrode area of around 53 square centimeters, made of titanium metal. For this process you need an inert metal or conductive material that will not react at the potential values used. You can buy titanium metal tubes – which are not expensive – to build an anode/cathode pair to carry out this experiment. *Note that the frequency and voltage characteristics are vital so using a proper power supply to generate them is of the highest importance.*

The above technique is novel and easy to build for treating commercial hydroponic solutions. It is far easier and economic compared with filtering techniques and can be applied from smaller to larger scale growing operations.

A simple Arduino based sensor monitoring platform for Hydroponics

Last time I posted about automation I talked about how I use an Arduino to automate the monitoring and management of my home hydroponic system. Today I want to talk about how you can build an Arduino based station to monitor the most important variables of your hydroponic crop without having to solder anything, use complicated bread board setups or learn to how to do any coding. I will walk you through some of the steps to build the system, talk about the parts you need and show you the code you need to run to have this setup work.

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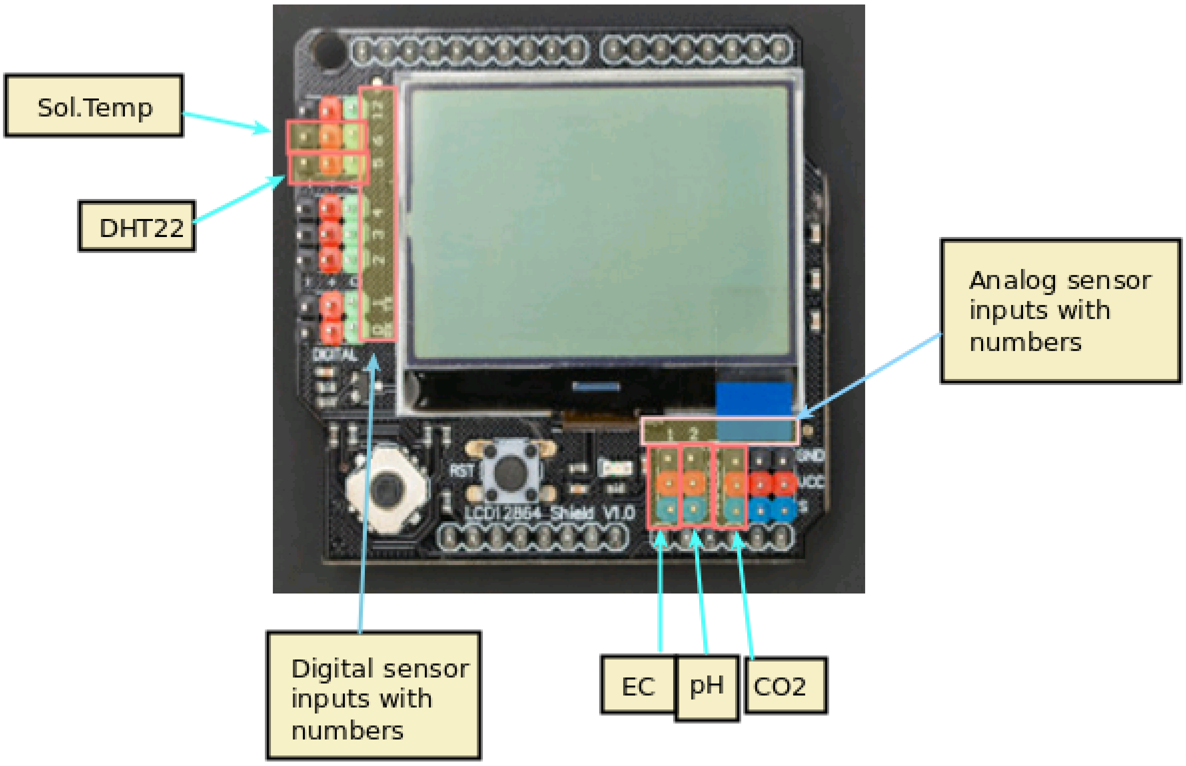

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A basic sensor monitoring application for hydroponics should be able to get the most critical information needed to grow a crop successfully. The basic variables you would want to monitor to achieve this goal would be: temperature, humidity, carbon dioxide concentration, pH and electrical conductivity. An Arduino micro-controller can help you achieve all these goals at a reduced cost when compared with commercially available monitoring solutions of the same quality.

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- Arduino UNO R3 – 23.90 USD
- LCD 12864 screen shield – 24.05 USD
- DHT22 temperature and humidity sensor – 9.50 USD
- Gravity pH sensor – 56.95 USD
- Gravity EC sensor – 69.90 USD
- Gravity CO2 sensor – 58.00 USD

–

The list above contains all the pieces you need to get this to work. This includes the Arduino plus an LCD display that we will use to be able to read the information we obtain from the sensors. I have included links to the pieces at the dfrobot site (one of my favorite sources for DIY electronics) but you can definitely get them elsewhere if you prefer. The pH sensor included here is of industrial quality while the EC sensor has a lower quality level. However I have been able to use both for extended periods of time without anything else than a calibration around once every 2 months. If you want you can also purchase an industrial quality EC probe if you find the prove from the included Gravity kit to be insufficient for your needs.

The cool thing about this setup is that the LCD screen already contains all the connections we need for the sensors. The bottom part contains numbered analog inputs while the left part contains numbered digital inputs. In this setup we have two digital sensors – the DHT22 humidity/temperature sensor and the solution temperature sensor that comes with the EC sensor – and three analog sensors, which are pH, EC and CO_2. I have put some text on the image to show you exactly where you should connect the sensors according to the code, make sure the orders of the colors on the wires match the colors on the connector in the LCD screen. The Arduino code contains some defines with the pins for each sensor so you can just change those numbers if you want to connect the sensors in different places.

–

```
//Libraries
#include <DHT.h>;
#include <U8glib.h>
#include <stdio.h>
#include <OneWire.h>
#include <Wire.h>
#include <Arduino.h>
#include <Adafruit_Sensor.h>
```

```
//PINS
#define DHT_PIN        5          // DHT pin
#define DHTTYPE        DHT22      // DHT 22  (AM2302)
#define PH_PIN         2          //pH meter pin
#define CO2_PIN        3          //ORP meter pin
#define EC_PIN         1          //EC meter pin
#define DS18B20_PIN    6          //EC solution temperature
pin

// AVERAGING VALUES
#define MEDIAN_SAMPLE 8
#define MEASUREMENTS_TAKEN 100

// EC - solution temperature variables
#define StartConvert 0
#define ReadTemperature 1

// EC values // CHANGE THESE PARAMETERS FOR EC PROBE
CALIBRATION
#define EC_PARAM_A 0.00754256

//pH values // CHANGE THESE PARAMETERS FOR PH PROBE
CALIBRATION
#define PH_PARAM_A 1.0
#define PH_PARAM_B 0.0

#define XCOL_SET 55
#define XCOL_SET2 65
#define XCOL_SET_UNITS 85

//--------------------------

DHT dht(DHT_PIN, DHTTYPE);
U8GLIB_NHD_C12864 u8g(13, 11, 10, 9, 8);
unsigned long int avgValue;
float b, phValue;
int buf[MEASUREMENTS_TAKEN],tmp;
int chk;
float hum;
float temp;
unsigned int AnalogAverage = 0,averageVoltage=0;
```

```
float solution_temp,ECcurrent;
unsigned int levelAverage;
float co2;
OneWire ds(DS18B20_PIN);

//-------------------------

void draw() {
  u8g.setFont(u8g_font_04b_03);
  u8g.drawStr( 0,11,"Temp:");
  u8g.setPrintPos(XCOL_SET,11);
  u8g.print(temp);
  u8g.drawStr( XCOL_SET_UNITS, 11,"C" );
  u8g.drawStr(0,21,"Humidity:");
  u8g.setPrintPos(XCOL_SET,21);
  u8g.print(hum);
  u8g.drawStr( XCOL_SET_UNITS,21,"%" );
  u8g.drawStr(0,31,"pH:");
  u8g.setPrintPos(XCOL_SET,31);
  u8g.print(phValue);
  u8g.drawStr(0,41,"EC:");
  u8g.setPrintPos(XCOL_SET,41);
  u8g.print(ECcurrent);
  u8g.drawStr( XCOL_SET_UNITS,41,"mS/cm" );
  u8g.drawStr(0,51,"Sol.Temp:");
  u8g.setPrintPos(XCOL_SET,51);
  u8g.print(solution_temp);
  u8g.drawStr( XCOL_SET_UNITS,51,"C" );
  u8g.drawStr(0,61,"CO2:");
  u8g.setPrintPos(XCOL_SET,61);
  u8g.print(co2);
  u8g.drawStr( XCOL_SET_UNITS,61,"ppm" );
}

float TempProcess(bool ch)
{
  static byte data[12];
  static byte addr[8];
  static float TemperatureSum;
  if(!ch){
          if ( !ds.search(addr)) {
```

```
                ds.reset_search();
                return 0;
            }
            if ( OneWire::crc8( addr, 7) != addr[7]) {
                return 0;
            }
            if ( addr[0] != 0x10 && addr[0] != 0x28) {
                return 0;
            }
            ds.reset();
            ds.select(addr);
            ds.write(0x44,1);
    }
    else{
            byte present = ds.reset();
            ds.select(addr);
            ds.write(0xBE);
            for (int i = 0; i < 9; i++) {
              data[i] = ds.read();
            }
            ds.reset_search();
            byte MSB = data[1];
            byte LSB = data[0];
            float tempRead = ((MSB << 8) | LSB);
            TemperatureSum = tempRead / 16;
      }
            return TemperatureSum;
}

void calculateAnalogAverage(int pin){
 AnalogAverage = 0;
  for(int i=0;i<MEASUREMENTS_TAKEN;i++)
  {
    buf[i]=analogRead(pin);
    delay(10);
  }
  for(int i=0;i<MEASUREMENTS_TAKEN-1;i++)
  {
    for(int j=i+1;j<MEASUREMENTS_TAKEN;j++)
    {
      if(buf[i]>buf[j])
```

```
      {
        tmp=buf[i];
        buf[i]=buf[j];
        buf[j]=tmp;
      }
    }
  }
  avgValue=0;
              for(int        i=(MEASUREMENTS_TAKEN/2)-
(MEDIAN_SAMPLE/2);i<(MEASUREMENTS_TAKEN/2)+(MEDIAN_SAMPLE/2);i
++){
    avgValue+=buf[i];
  }
  AnalogAverage = avgValue/MEDIAN_SAMPLE ;
}

void read_pH(){
  calculateAnalogAverage(PH_PIN);
  phValue=(float)AnalogAverage*5.0/1024;
  phValue=PH_PARAM_A*phValue+PH_PARAM_B;
}

void read_EC(){
  calculateAnalogAverage(EC_PIN);
  solution_temp = TempProcess(ReadTemperature);
  TempProcess(StartConvert);
  averageVoltage=AnalogAverage*(float)5000/1024;
  float TempCoefficient=1.0+0.0185*(solution_temp-25.0);
                                                              float
CoefficientVolatge=(float)averageVoltage*TempCoefficient;
  ECcurrent=EC_PARAM_A*CoefficientVolatge;
}

void read_CO2(){
  float voltage;
  float voltage_difference;
  calculateAnalogAverage(CO2_PIN);
  voltage = AnalogAverage*(5000/1024.0);
  if(voltage == 0)
  {
    co2=-100.0;
```

```
  }
  else if(voltage < 400)
  {
    co2=0.0;
  }
  else
  {
    voltage_difference=voltage-400;
    co2=voltage_difference*50.0/16.0;
  }
}

void setup()
{
    pinMode(13,OUTPUT);
    Serial.begin(9600);
    dht.begin();
    u8g.setContrast(0);
    u8g.setRot180();
    TempProcess(StartConvert);
}

void loop()
{

  digitalWrite(13, HIGH);
  delay(800);
  digitalWrite(13, LOW);
  hum = dht.readHumidity();
  temp= dht.readTemperature();
  read_pH();
  read_EC();
  read_CO2();

  u8g.firstPage();
    do  {
      draw();
    }
      while( u8g.nextPage() );
}

_
```

After you connect the sensors you can then upload the code above using the Arduino IDE to your Arduino via USB. You will need to install the following Arduino libraries to get it to compile and upload:

–

- AdaFruit unified sensor driver
- AdaFruit DHT sensor library
- OneWire library
- U8glib library

–

After you upload this to your Arduino it should start and show you a screen with the temperature, humidity, pH, EC and carbon dioxide readings. The carbon dioxide concentration might show as -100 in the beginning, which simply means that the sensor is heating up (it requires a few minutes before it can start giving readings).

It is also worth noting that you should calibrate your pH sensor. To do this you should read the pH of a 7.0 buffer (M7) – record the value you get – and then repeat the process with a pH 4.0 buffer (M4). You can then change the PH_PARAM_A and PH_PARAM_B values in the code (right at the beginning) to make the sensor match your measurements. The PH_PARAM_A parameter should be equal to 3/(M7-M4) while PH_PARAM_B should be 7-M7*PH_PARAM_A. If you ever need to recalibrate set PH_PARAM_A to 1 and PH_PARAM_B to 0 and repeat the process. For the EC sensor you should perform a calibration using the 1.412 mS/cm solution that comes with the sensor and then change EC_PARAM_A so that your sensor matches this reading (1.412/(MEC/0.00754256)).

With this new monitoring station you should now have a powerful tool to monitor your hydroponic system and make sure everything is where you want it. Of course making the arduino intereact with a computer to record these values and then implementing control mechanisms using fans, peristaltic pumps, water pumps, humidifiers/dehumidifiers and other appliances is the next step in complexity.

A Step Forward : Moving from AllHydroponics to ScienceinHydroponics.com

Through the past few weeks I have been meditating about the current limitations of the blogger platform and how it makes my writing and customization options smaller and the look of my blog less professional. Due to the fact that I intend to start writing more and expanding this blog it becomes evident that I will need a much more powerful blog hosting platform and blogger seems to be limiting instead of helping my efforts in this regards. For this reason I have taken the decision to move my blog from its current blogspot home to a new self-hosted domain which I will use from now on to post new articles and releases of hydrobuddy.

This new website – scienceinhydroponics.com – will be the new home of my blogging effort in the area of hydroponic crop production and research. I will stop posting new articles on blogger and the old blogger website will start redirecting to the new wordpress based blog today. The idea of this new blog is to allow me to customize my website as much as I want and to be able to exploit the full potential of my web presence through the use of a self-hosted domain. In the future I hope that this move forward will make my content more professional and my efforts more worth-while. Future versions of hydrobuddy will now be released and maintained on the new wordpress blog and the previous blogger implementation will not be maintained anymore.

Of course if you have linked to my old blog the pages will not be deleted but they will cause automatic redirection towards my new domain. However the RSS feed will stop being updated so feel free to subscribe through my new blog's RSS feed (links available on the top right corner of the blog). There are also now several buttons you can use in the bottom of each page to share the contents of the posts on facebook, twitter, etc and a Printer friendly function that will allow you to easily print my blog's contents without any of the menus, etc. I hope that you will greatly enjoy this new blog which is a milestone achievement for me and the start of a new era for me as a much more professional blogger :o)

Feel free to leave any comments or suggestions ! :o)

Ion Selective Electrodes in Hydroponic Culture

Currently, hydroponic growers rely on a combination of electrical conductivity and pH measurements in order to assess the quality and durability of their hydroponic nutrient solutions. However, many are unaware that hydroponic gardening can be much furtherly enhanced by the addition of ion selective electrodes.
In a certain sense, all hydroponic gardeners have used an ion sensitive electrode since the pH meter they use to measure the concentration of $H_3O(+)$ ions is actually selective to that ion. Imagine if every time you read pH you had interference from all the other ions present inside the hydroponic solution.

Nonetheless, there are currently a large variety of ion selective electrodes available and many of them can be used in hydroponic gardening to accurately control the concentration of several elements.

For example, ion selective electrodes with very good selectivity and little interference exist for the nitrate ion. These type of electrodes can be purchased from many manufacturers but can be easily found here. For just 229 USD, the grower is able to accurately control the amount of nitrate ions present inside the hydroponic solution independently from other nutrients.

By measuring the potential difference given by the electrode when the solution is prepared, the grower is able to easily detect and graph changes within a certain growing period. Best of all, since the ion selective electrode gives a real measure of ion concentrations, the grower is able to resupply spent nitrogen without unbalancing the hydroponic growing solution.

Ion selective electrodes exist for a variety of ions including nitrate, ammonia, phosphate, potassium, iron and copper. This technology will prove to be the future of hydroponics as it will guarantee the grower the ability to accurately control and resupply the exact amount of nutrients needed by his or her growing plants. These electrodes can also be easily wired to computer software in order to monitor nutrient use 24/7 (below a display of several ion selective electrodes)