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RESEARCH ARTICLE

TRANSPIRATION DYNAMICS OF PEPPER (*CAPSICUM CAPSAULARIS*) IN RESPONSE TO ATMOSPHERIC DROUGHT AND SOIL TYPE UNDER SEVERAL VAPOUR PRESSURE DEFICIT (VPD) LEVELS.

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Vapour pressure deficit, Transpiration rate, Water-use efficiency, Days after sowing, Water holding capacity

Abstract

Vapour pressure deficit (VPD) is considered as an important environmental factor that affect transpiration rate (TR) in plants. In this study, transpiration rate were observed in Pepper (*Capsicum capsaularis*) in 3 different soil conditions (organic, sand and mineral) subjected to low (0.10-1.5) and high VPD (2.50-3.90). The highest transpiration rate noted in mineral soil (2.08) but organic one showed more exponential results under high VPD (3.29), comparing lower leaf area to other soil conditions. The lowest TR indicated in sands (0.17) with lower VPD level and large leaf area. The results showed that sand has the lowest transpiration rate and organic soil has the highest transpiration rate. Adding more substrate will be better to compare the transpiration

Introduction:-

Plants lose a copious amount of water by transpiration. Plants take up and transpire a great deal of water by their rooting system. The speed and amount of water moving from the root to shoot in turn determine the concentration of solutes arriving at the shoot (Markhart and Smith 1990).

VPD is a good indicator of plant stress, brought about by either excessive transpiration of water (high VPD values) or the inability to transpire adequately (low VPD values). VPD alone does not provide a perfect model of crop water stress. However, if the measurements of VPD calculation are taken in a manner that provides an accurate representation of the current crop conditions, it could be used to influence key environmental control management decisions. Saturated vapour pressure are increasing exponentially with increasing temperature to impact on plant growth (Sinclair *et al*., 2007). Temperature and vapor pressure deficit (VPD) effects on plant growth are almost always confounded in experiments because VPD is increasing with the decreasing temperature. Increasing VPD rate raise up the atmospheric demand, and consequently higher plant transpiration (Sinclair *et al*., 2007). A large number of researchers showed that higher leaf to air, VPD decreased stomatal conductance (Bunce 2006, Lopez-Berenger *et al*., 2006). Stomatal closure limits the transpiration rate and sometimes a decrease at high VPD (Oren *et al*., 2001). Therefore, stomatal closure restricts the corresponding decrease in plant water potential and prevents excessive water loss.

Different types of soil play a distinguishing role in the plant's ability to extract water. It is noted that water holding capacity depends on soil texture and the effects of soil organic matter are strongest in more sandy soils (Hudson

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1994; Minasny *et al*. 1999; Rawls *et al*. 2003). Texture, structure and porosity influences the movement and retention of water in the soil, which subsequently aff ects the plants transpiration (Moyano *et al.* 2013).

The original intent of this experiment was to study the effect of transpiration rate, as manipulated by several vapor pressure deficit levels in combination with different soil conditions. Pepper (C3) showed substantial differences in their rate and sensitivity to the VPD and limitations in transpiration rate at high VPD. Most of the studies have been conducted in a specific growth phase of the crop, while there is little information on transpiration rate over the plants ontogeny but these studies has been conducted for checking the soil effects on plant transpiration rate.

Objectives:-
To measure the effect of transpiration rate on Pepper (C3) plants in response to changes the atmospheric vapour pressure deficit.

Hypothesis:-
The hypotheses are
Soil has the effects on transpiration rate

Materials and Methods:-

The experiment was carried out during the summer season under greenhouse conditions (22-35 °C; light: dark = 16:8 hours).

Plant material:-
Pepper (*Capsicum capsaularis*) seeds were used to getting seedlings. This was needed at least 6-8 hours of sunlight per day. Support each pepper plant with a stake, to help bear the weight of the broad leaf and fruits.

Plants growing strategy:-
The whole experiment was split into three sub divisions

1. Pepper plants were raised in three (organic, mineral and sand) different conditions in controlled environments.
2. Transpiration rates were measured in the climate chamber and biomass harvested.

Table 1:- Species and their photosynthetic metabolism, life form, substrate and corresponding family of Pepper plant

Species	Photosynthetic metabolism	Life form	Substrate	Family
Capsicum capsaularis	C3	Perenial Dicotyledonous	Organic soil Sand Mineral soil	Piperaceae

Soil properties:-
Pepper was raised in three different (organic, mineral and sand) conditions in controlled environment. Each soil has different properties (Table 1)

Table 1:- Guinea grass in different substrates

Species	Soil type	Soils description
Capsicum capsaularis	Organic soil	Its contain more than 20% organic carbon Fine textured soil High water retention capacity
	Sand	less nutrient and Low water holding capacity large particles (2.0 mm -0.05 mm)
	Mineral soil	Derived from minerals or rocks and containing little humus or organic matter Less than 20% of carbon contend

Seedling were raising in three different soil conditions:-
Three seeds of pepper were placed in three (mineral, sand and organic) different soil conditions in each and every pot. One week after germination, the pots were thinned to single germinated seedling. (Figure 1).

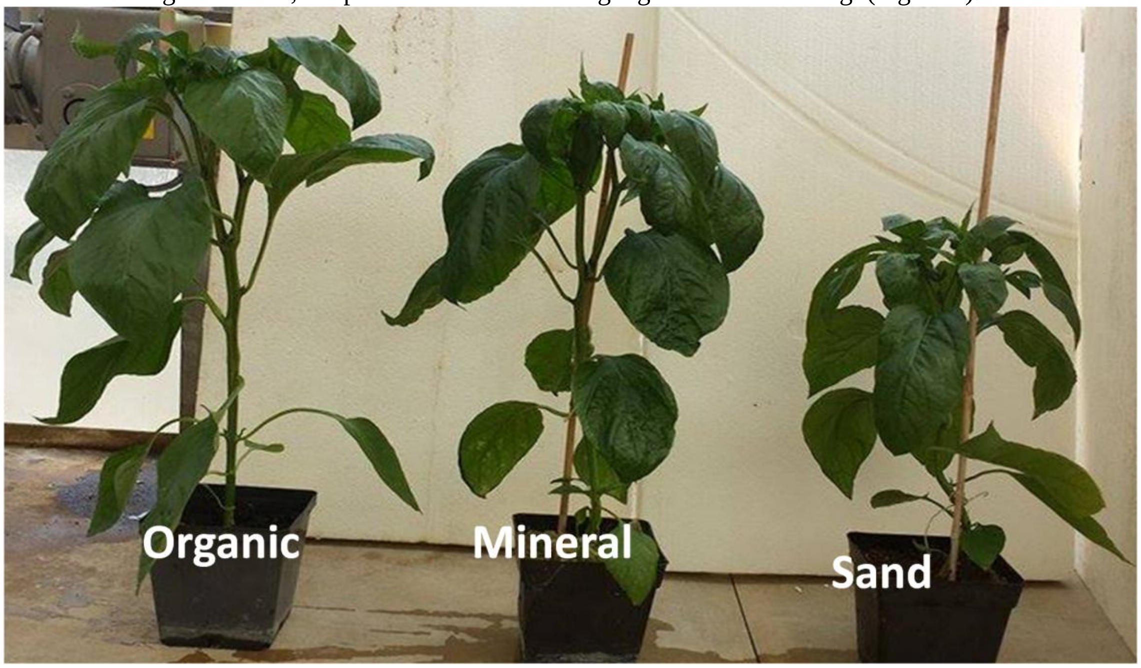

Fig 1:- Pepper (C3) plants are growing in three different soil conditions (organic, mineral and sand respectively).

Technical set-up for climate chamber:-
The plant transpiration rate was measured in a climate chamber (80×80×100cm) with PVC transparent side and top elements. LED light was installed 15cm away from the top of the climate chamber for providing photosynthetic photon flux (PPF) at 600µmol $m^{-2}s^{-1}$at the bottom and 1200 µmol $m^{-2}s^{-1}$ near the top. Uninterrupted air flow through the VPD chamber excluded the possibility of carbon dioxide deficit in the chamber. The temperature and the relative humidity were recorded every minute for calculating the accurate atmospheric VPD by using Tinytag data loggers (Type-TV4505, Gemini Data Loggers., UK). Four individual balances (KERN KB 2400-2N d=0.01g, with a maximum load of 2400g) arranged symmetrically in order to maintain equal light conditions which are connected to a PC for every minute weight information with GrassLog software version 0.1. Four box fans are installed on the top of the chamber for mixing the inside air by continuously adjustable intensity.

A desiccant dehumidifier (Consorb DC-10, Seibu Giken, Sweden) was used to generate dry air at a flow rate of max. 190 m^3/h. The air flow at 60 m^3/h was simultaneously used to counterbalance temperature losses of the wet air produced by ultrasonic nebulizers (Fogstar 100, Seliger GmbH, Germany). Both air streams were saturated before entering the chamber from a side entrance. The speed of each air stream was adjustable with throttle flaps placed inside PVC tubes before mixing.

The actual atmospheric VPD was measured by calculating the recorded every 60 seconds relative humidity and temperature. Different humidity levels were reached by adjusting throttle flaps of wet and dry airstreams while targeting four VPD levels between 0.40 and 3.80.

Plant transpiration rate measuring in the climate chamber

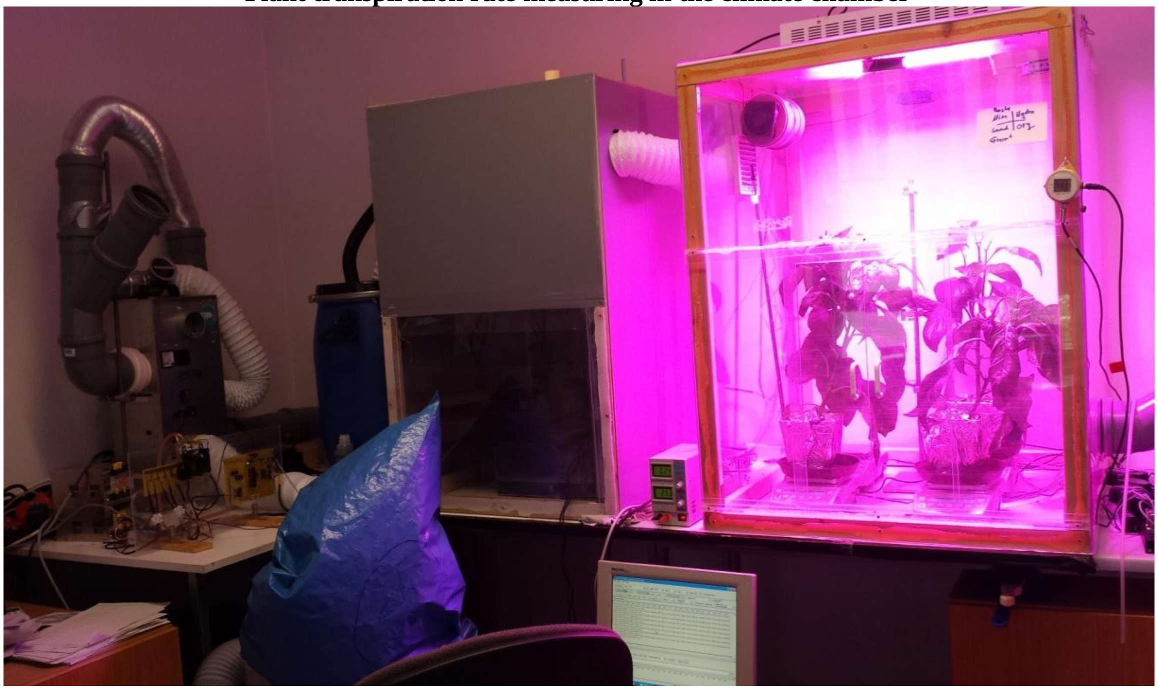

Figure 2:- Transpiration rate measuring in climate chamber

Figure 2. Showing the transpiration rate measurement in climate chamber. The pot was covered with aluminum foil to reduce evaporation. VPD was maintained approximately 0.5 kPa and increased stepwise to almost 4.0 kPa. After the equilibrium condition in the chamber, the entire unit of plants and pot were weighed on a balance. Plant transpiration rates were recorded based on the mass loss. Four humidity levels in the chamber were established by adjusting the humid and dry air. Transpiration rate were started to measure from low VPD to higher VPD. Transpiration rates were recorded over 20 minutes for each VPD levels with an interval of 5 minutes for adjusting VPD until the starting of the higher VPD levels. The measurements for each replicate consisted of four VPD levels for around 2 hours in total.

Determination of transpiration rate and dry biomass:-

After measuring the transpiration rates, plants were clipped at the stem base and separated into shoot and root. The total leaf area was measured in green house by using LI-3100 area meter. Every pot was immersed in water to remove sand, soil and inert materials. Roots were further washed, cleaned and sealed separately in leveled paper bags .Whole plant tissues were dried in an oven at 70^0C for 48 hours to get the constant weight.

Statistical Calculation:-

Transpiration rate calculation:-

Plant transpiration rates (TR) were calculated per unit of leaf area (mmol $H_2Om^{-2}s^{-1}$), based on their pot weight changing in every minute's interval.

TR = {(W0-W1)/18} / Time × Leaf Area

W0 = the initial weight

W1 = weight after 60 seconds

VPD were calculated by using recorded temperature and relative humidity. The data were analyzed by plotting TR against VPD using Software package SAS.

Root-Shoot ratio calculation:-

Root dry weight (g) was divided by Shoot dry weight (g) in each and every replication.

$$\text{Root} - \text{Shoot ratio} = \frac{\text{Root dry weight (g)}}{\text{Shoot dry weight (g)}}$$

Normalizing transpiration rate to VPD:-
VPD in the chamber were manipulated by manually through adjusting the relative humidity while keeping the temperature constant. Therefore, the exact VPD couldn't be fixed at exactly 0.5, 1.90, 2.90, 3.70 KPa. All the TR values were plotted against their respective VPD to produce regression line compare with TR and VPD.

Results:-

Root-Shoot ratio:-

Table 3:- Root-Shoot ratio (root dry weight (g) / shoot dry weight (g)) in three soil conditions respectively).

Soil condition	Root/Shoot
Organic	0.3053
Mineral	**0.4365**
Sand	0.2798

Table 03 showed that root-shoot ratio was higher in mineral soil and lower in sand. In organic condition the ratio is in between two of them. Root-shoot ration is higher in mineral and transpiration rate also higher but less exponential then organic condition with their increasing VPD.

Transpiration rate measurement in different soil condition:-
Transpiration rate were measured in different soil condition in the climate chamber and three exponential lines were indicated different transpiration rate in the figure 03, 04 and 05.

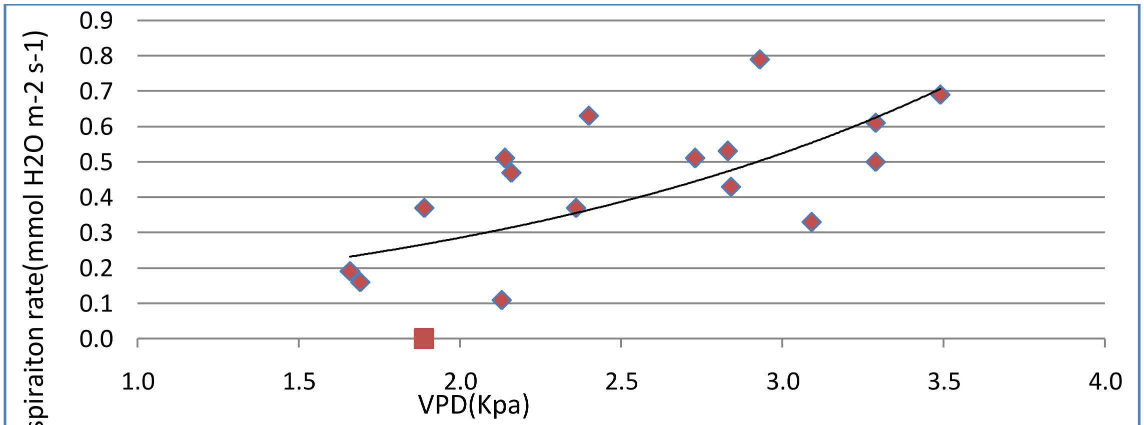

Fig: 03 Transpiraiton rate against VPD in Organic condition

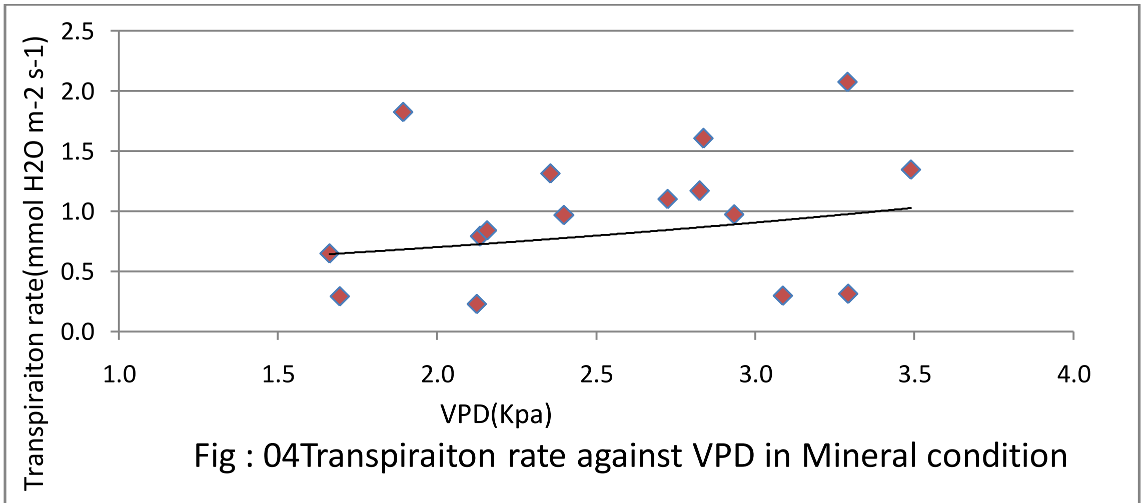

Fig : 04Transpiraiton rate against VPD in Mineral condition

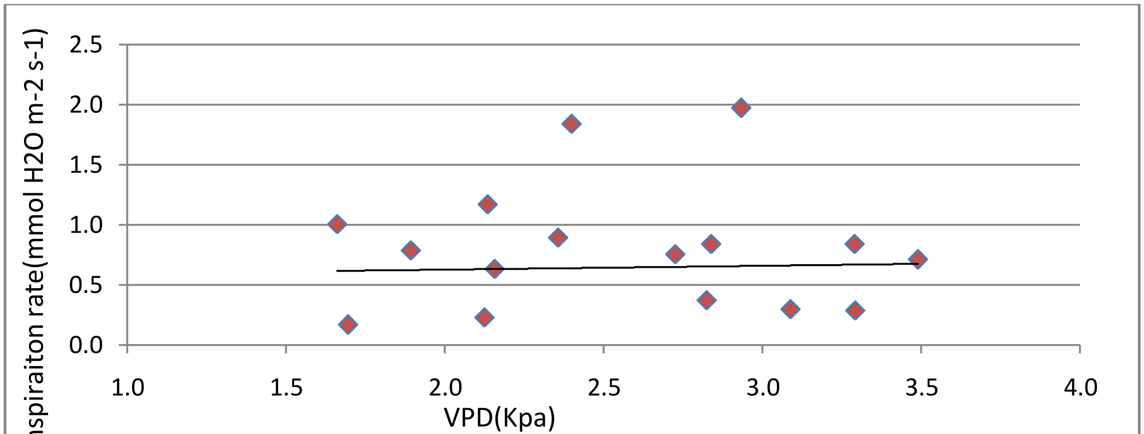

Fig: 05 Transpiraiton rate against VPD in Sand condition

Figure 03 showed that, transpiration rate were gradually increasing with their increasing VPD Exponential line of transpiration rate showed organic condition that, it's increasing with the increasing VPD. Figure 04 indicated that, transpiration rate in mineral soil were increasing but the line were less exponential compare to the organic condition. In figure 05 showed that, transpiration rate were vibrating the same way with their increasing VPD.

Table 4:- Analysis of variance

Analysis of variance	VPD	TR
Organic	2.558	0.4502
Mineral	2.557	0.9860
Sand	2.557	0.7997
P value at 0.05	0.002	0.687
Sig. Level	NS	NS
CV (%)	0.05	53.29

Table 04 showed that, transpiration rate of each and every substrate is not significant with their respective VPD. The organic one indicated more transpiration compare to the other soil condition.

Discussion:-

Biomass measurement in relation to transpiration rate:-

The rate of water supply to the plant shoot is dependent on both the conductance of water in the soil and in the roots (Hogg and Hurdle, 1997; Meiner and Grantz, 1990). In that case, the organic soil has the huge possibility for water, root conductance and transpired more water than the mineral soil followed by sand. The fine textured soil has the more ability to preserve and continuous water supply around the root zones compare to the sandy soil.

Root-Shoot ratio:-

The rate of transpiration tends to increase with higher root-shoot ratio (Devlin, 1975). He also mentioned that it is expected that a plant with a higher root: shoot value will tend to transpire faster than another plant with a lower root to shoot. In this experiment it's observed that, the root-shoot ratio was higher in mineral soil. Higher leaf area against root volume compare to the others could be the reason (Table 03).

Soil properties in terms of transpiration rate:-

Soil texture highly influences water infiltration, pH, permeability and water holding capacity. Soil texture refers to the composition of the soil in terms of the proportion of small, medium and large particles (clay, silt and sand respectively) in a specific soil mass. Brady (1990) mentioned that sandy soils have low porosity and the movement of air and water is rapid. Soil porosity refers to the space between soil particles, which consists of various amounts of water and air. A fine soil has smaller but more numerous pores than a coarse soil. A coarse soil has bigger particles than a fine soil, but it has less porosity or overall pore space.

Smettem and Collis-George (1985) reported that a single continuous pore of 0.3 mm diameter can conduct more water than the rest of a 100 mm diameter sample. Water can be held tighter in small pores than in large ones, so fine soils can hold more water than coarse soils.

In that case, available water was higher in organic and mineral soil and transpires more water than the sandy soils (appendix 03). Naiman *et al.*, (1994) also mentioned that higher levels of organic matter result in a greater number of cation exchange sites which tend to decrease the pH. He also added sandy soils with a low CEC are generally unsuited for septic systems since they have the little adsorptive ability and there is potential for groundwater. The main effect of soil pH is on the availability of plants nutrients which have the specific preference range of soil pH. So pH could be varied and it might have the effects on nutrients absorption, even extra nutrients was supplied in sand and mineral growth medium for equal plant growth but the effects still unclear.

In this study, transpiration difference was isolated by comparing similar size individual pot weight in each plant. Results showed that organic substrate transpire much of water by generating the shoot biomass. (Fig: 03).

Measurement of 55 days old Pepper (C4) plant showed large leaf area in mineral soil condition but the effect of less transpiration rate. Plants may sense different soil condition and hence send inhibitory signals to the shoots which harden the plants against the consequences of a degrading environment, especially if the plants water supply is at risk. Transpiration rate can be interpreted as anticipated rates to the soil becoming too dry. Since different substrates condition varying degree of the inhibitory signals may affect and different stomatal conductance, cell expansion, cell division and the rate of leaf appearance.

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Conclusion:-
In the present study, its shows different rate of foliar transpiration over its ontogeny under lowers to higher VPD levels. Although little or no change in leaf appearance was shown in this study, differences were observed in overall plant leaf area under low and high VPD. But the results showed that leaf area expansion is a key difference to high VPD. Under high VPD, higher TR was associated with lower leaf area expansion rates as shown in the results for Pepper (C3) plant. Including by more substrates and growth stages should be the preference for further research. Checking the rewetting data could be the possible way to know plant recovering and soil texture.

Including by more substrates and growth stages would be the preference for further research. Checking the rewetting data could be the possible way to know plant recovering. Tying a small around among the all exposed leaves would be the way in order to obtain the exact amount transpired from the water source into the atmosphere. This will be able to provide more details on the exact time and amount of water was transpired.

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Appendix 01:-

Nutrient solution preparation:-

A number of chemical with their exact amount were added for stock solution

Table 2:- Nutrient solution preparations for hydroponic system

label	Chem. substance	Conc. stock	Molecular weight	Sample weight per 1L stock	Sample weight per 2L stock	Final conc.	Dil. factor	ml of stock for 1L final solution
A	K_2So_4 KCL	0.35M 0.05M	174.26g 74.55 g	60.99 g 3.73 g	121.98g 7.45g	0.7mM 0.1 mM	500	2 2
B	KH_2PO_4	0.1 M	136.09 g	13.61 g	27.22g	0.1 mM	1000	1
C	$MgSO_4*7H_2O$	0.5 M	246.48 g	123.24 g	246.48g	0.5 mM	1000	1
D	$Ca(NO_3)_2*4H_2O$	1 M	236.15 g	236.15 g 472.30 g	472.30g	2.0 mM	500 1000	2 1
E	$MnSO_4*H_2O$ $ZnSO_4*7H_2O$ $CuSO_4$ or $CuSO_4*5H_2O$ $(NH_4)_6Mo_7O_{24}*4H_2O$	0.5mM 0.1 mM 0.2 mM 0.01mM	169.09 g 287.54 g 159.60 g 249.68 g 1235.86 g	84.51mg 28.75 mg 31.92 mg 49.54 mg 12.36 mg	169.02mg 57.51mg 63.87mg 99.88mg 24.72mg	0.5µM 0.1 µM 0.2 µM $1*10^{-8}$M	1000	1
F	H_3BO_3	10 mM	61.83 g	618.3 mg 309.1 mg	1.237g 618.3mg	10 µM 20 µM	1000 500	1 2
G	FeNaEDTA	50 mM	367.05 g	4.6g 5.5g	in 250ml in 300 ml	50 µM	1000	1