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Study of effect of artificial light and percentage of CO_2 on plant growth of *Triticum Turgidum* and *Aristida Purpurea* in artificial ecosystem

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ABSTRACT

Crop growth experiments in the soil-based closed ecological facility, Laboratory Biosphere, were conducted in artificial ecosystem. Wheat (Triticum Turgidum) and a perennial plant i.e Indian wild grass (Aristida Purpurea) are allowed to grow in the plant trays. The required optimum light intensity is obtained by planning and executing a batch of multivariate experiments. The duration of the exposure of the plant to the artificial light radiation is followed as per natural schedule of the day. The growth rate for the grain crop plant is observed over a period of 87 days during tillering, jointing, booting and heading, anthesis, milk, dough and ripening stages respectively and the growth rate for the perennial plant is observed over a period of 30 days under various experimental conditions. A series of multi-factorial experiments are planned and conducted by considering the following conditions. 1) 0.4% CO_2 is maintained with Artificial light 2) 0.04% CO_2 is maintained with Artificial light 3) 0.4% CO_2 is maintained with Natural light and 4) 0.04% CO_2 is maintained with Natural light. On comparing the growth rates of grain crop plant under different physical conditions it is found that the growth rate is high under artificial lighting when 0.4% of CO_2 is maintained. The next high value of growth rate is observed for the same light with 0.04% of CO_2. However the growth rate under natural light is found to be more when 0.4% CO_2 is maintained than 0.04% of CO_2. On considering the growth rate under the artificial light with 0.4% CO_2 as 100 then the growth rate of the same plant when 0.04% CO_2 used is found to be 17% less. Similarly the growth rate under natural light and 0.4% CO_2 is found to be 32% less. On comparing the same with natural light at 0.04% of CO_2, it is observed 40% less. The growth rate under natural light at 0.4% CO_2 decreases by 11.8% when the concentration reduces to 0.04%. Under low pressure conditions the growth rate under artificial light is 27.7% high compared to the rate using natural light. Figure 13 shows that the crop growth is faster using an artificial source of light than the natural source. In particular if the plant subjected to artificial lighting at high pressures the growth is significantly high compared to all other combinations of type of light and amount of CO_2.

KEYWORDS

Closed ecological system;
Bio-regenerative;
Wheat;
Perennial plant;
Light efficiency;
Crop yields;
Life-support.

INTRODUCTION

This work essentially deals with the ways in which artificial ecosystems can help the human living at an extraterrestrial places by incorporating plant growth mechanism into it for survival. Artificial ecosystems are more productive, less diverse compared to natural ecosystems. They seem to be pragmatic with defined goals and set to demonstrate the maintenance of coherence and unity[1]. According to Thomas Malthus the population of the earth is increasing at a geometric rate, while food production is increasing only at an arithmetic rate. If the current growth rate of 1.2% remains unchanged, the world population would grow from its current 6.6 billion to 9.3 billion over the next 40 years (2050). Distribution of resources has always been unequal, and continues to be an issue now and in the future[2]. The earth currently produces 2,264 million metric tons of cereals, which is the staple food of the world. If each person consumes 2,000 calories per day, 2,264 million metric tons of cereal will support a little bit over 10 billion people. Currently, around half of all arable land in the world is producing crops. Vegetables and fruits are also produced on arable land. If we clear-cut all the forests and jungles, we could double our theoretical food production but ultimately leading to deforestation. There are a number of adverse effects of deforestation, such as soil erosion, disruption of the water cycle, loss of biodiversity, flooding and drought, climate change. Due to these changes we may face acute shortage of water and severe drought in future. Artificial systems like Green houses, biospheres using a range of techniques like hydroponics and aquaponics give us scope to tune to the above problems. Plants "see" light differently than human beings do. As a result, lumens, lux or footcandles should not be used to measure light for plant growth since they are measures used for human visibility. More correct measures for plants are PAR watts, PPF PAR and YPF PAR, although each in itself does not tell the whole story. In addition to quantity of light, considerations of quality are important, since plants use energy in different parts of the spectrum for critical processes[3]. Artificial light sources can be employed in such a way so that the suitable wavelengths and intensities of light are utilized to enhance the productivity using a lesser cultivation area[4]. Various exploration missions to Moon and Mars raised the hopes of the possibility of living outside the earth. Biomes and space stations can be constructed using advanced techniques like cloning and hydroponics and a new life structure can be started on either of the planets in 20 to 25 years time from now[5,6].

METHODOLOGY AND EXPERIMENTATION

A glass Chamber (Figure 1) having dimensions of 1m x1m x 1m is taken as an ecosystem for the plant growth under artificial conditions. The bottom of the chamber is divided into 9 compartments of equal size such that the size of each compartment is 12'x12'x 6' (1 square foot). At each run required number of plants can be subjected for experimentation. Plant trays having a depth of 6'(15 cm) are incorporated. Cleaned and processed coconut dust, vermicompost and bio compost in a ratio of 1:1:1 (33% each) is taken as a soil medium. An inlet is provided for the supply of water to this arrangement by using plastic hoses 5mm diameter via drip irrigation. The schedule of irrigation is followed as per the norms of Indian council of Aricultural research. Grain crop plant i.e wheat (Triticum Turgidum) and a perennial plant i.e Indian wild grass (Aristida Purpurea) are allowed to grow in the plant trays. The glass Chamber is also provided with another inlet having a controlling valve through which CO_2 can be pumped into it. The pressure measurements are used to regulate the $CO_{2.}$ One of the faces of the chamber is provided with an outlet which is connected to an impinger consisting KOH solution. To measure the rate of flow of the air through the chamber a Rota meter is used. On the top of the chamber an artificial light source of a CFL is arranged.

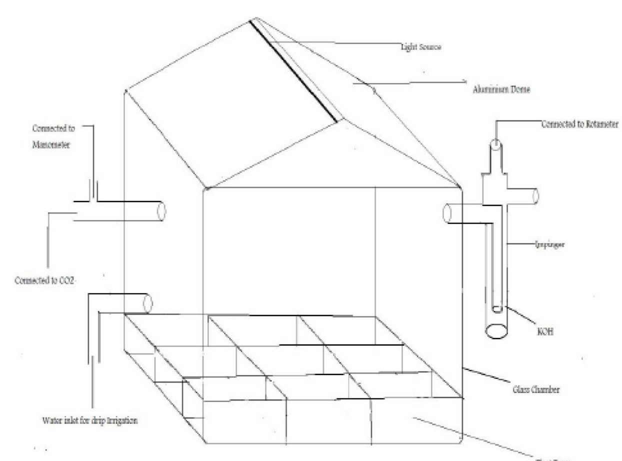

Figure 1 : Experimental arrangement for creating an artificial ecosystem

The duration of the exposure of the plant to the artificial light radiation is followed as per natural schedule of the day.

After soaking the seeds initially for a period of 24 hours in water, they sowed into the soil mixture which is maintained with appropriate nutrient levels. (Krishiseva.com) Graded Plants of Triticum Turgidum (wheat) after the seedling stage i.e., after 20 days of sowing and Aristida Purpurea (Indian wild grass) are planted separately in the plant trays of two different glass chambers after measuring their initial height. The growth rate for the grain crop plant is observed over a period of 87 days during tillering, jointing, booting and heading, anthesis, milk, dough and ripening stages respectively and the growth rate for the perennial plant is observed over a period of 30 days under various experimental conditions.

Initially, the required optimum light intensity is obtained by planning and executing a batch of multivariate experiments i.e., by using the different light sources of different intensities. After optimizing the intensity required, a series of batch experiments are being conducted by taking 1plant/compartment, 2plants/compartment,4 plants/compartment and then 6 plants/compartment and after optimizing the number of plants for each compartment, a series of multi-factorial experiments are planned and conducted by considering the following conditions.

1. 0.4% CO_2 is maintained with Artificial light
2. 0.04% CO_2 is maintained with Artificial light
3. 0.4% CO_2 is maintained with Natural light
4. 0.04% CO_2 is maintained with Natural light

The CO_2 level in the chamber is measured by using the alkalinity titration method.

RESULTS AND DISCUSSION

Optimization of light intensity

The following data represents the variation of crop yield for various intensities of the artificial light used. The same grain crop plant (Triticum Turgidum) is used for two trial runs and in both the trials the variation is found to be almost the same under the given conditions. (TABLE 1 and 2) The measurement of light intensity is made using a quantum light meter.

The two curves relating the productivity (P) in (mol/m^2/day) and the light intensity (I) in (gm/m^2/day) (Figure 2 and 3) show that the crop productivity increasing linearly with the light intensity, however reach an optimum value from where the productivity remains almost unaltered with further increase in the intensity of light as shown. These two graphs actually give the optimum light intensity (in mol/m^2/day) under suitable conditions for a particular type of a plant. From the above two variations it is quite evident that the productivity of the crop is directly related to the light intensity below the optimum value,

i.e., $\mathbf{P \propto I}$

or $\mathbf{P = k\,I}$

where k is a characteristic constant of proportionality which is dependent on factors like type of the plant, amount of nutrient supply, available CO_2 to the plant and physical conditions like pressure and temperature. The value of this characteristic constant k can be estimated from the slope of the curve which is found to be Therefore the empirical equation is found to be 0.46 (approx) for the type of the grain crop plant (Triticum Turgidum) used here. However the average value of k may in general vary between 0.4 and 0.5 for other grain crop plants.

TABLE 1 : Productivity Vs light intensity for Triticum Turgidum–Trial I

Light Intensity (mol/m^2/day)	Productivity (gm/m^2/day)
10	3.6
20	9
30	14
40	19
50	22.5
60	25.2
70	28
80	30
90	31.5

TABLE 2 : Productivity Vs light intensity for Triticum Turgidum–Trial II

Light Intensity (mol/m^2/day)	Productivity (gm/m^2/day)
10	3.2
20	8.5
30	14
40	19
50	23
60	27
70	29.1
80	30.7
90	31.7

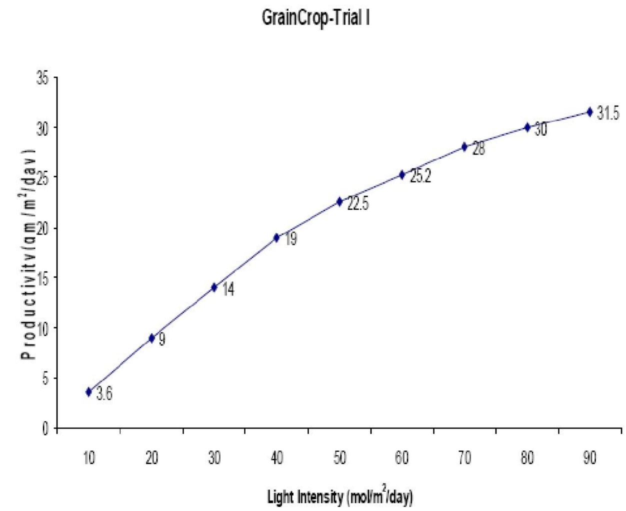

Figure 2 : Yield Vs light intensity for a grain crop-Trial I

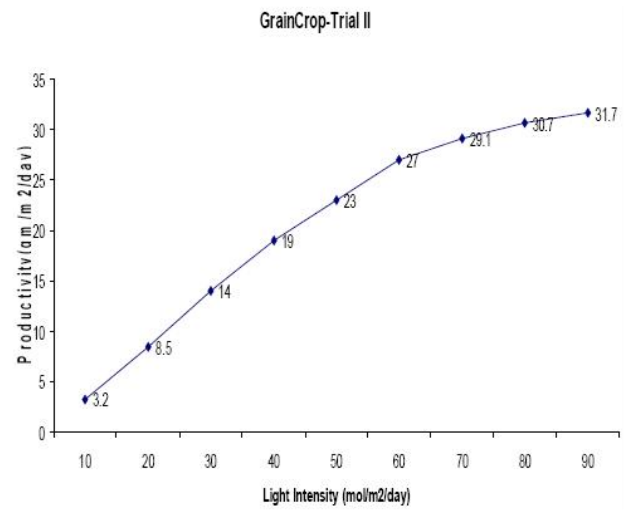

Figure 3 : Yield Vs light intensity for a grain crop-Trial II

Optimizing the no of plants per compartment

The above variation describes the optimization of plant number per unit cultivating area (TABLE 3 & Figure 4). This model shows an increase in the product in grams per and is maximum when 4 plants are taken per square foot area. With further increase in plant number for the same area of cultivation the yield per plant declines showing the optimum value of the plant number to be cultured in square feet area, as four only.

TABLE 3 : Plant yield/compartment in an artificial ecosystem

S.No	No.of Plants/sq.ft	Total Yield (gm)	Yield/Plant (gm)
1.	1	12	12
2.	2	35	17.5
3.	4	89.6	22.4
4.	6	122	20.34

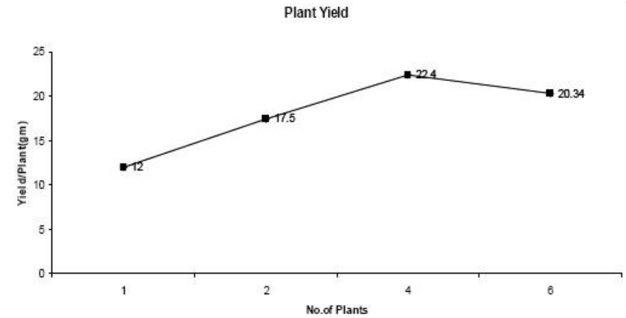

Figure 4 : Yield per plant in an artificial ecosystem

Growth rate

Let us now examine the behaviour of the grain crop plant (Triticum Turgidum) under four different cases involving the physical parameters like light and pressure.

The plot in Figure 5 is the variation between the average growth of the given grain crop plant per day under artificial lighting and high pressure conditions. The entire plot can be chiefly divided into 3 parts, part 1 in the initial phase (first 15-20 days) where the slope is smaller, part 2 where the growth rate suddenly rises accomplishing a high slope value in the middle period (20-70 days approx) and part 3 being the low growth phase at the end (71-90days). This variation is a sigmoidal curve with not much of an appreciable change in the growth rate during the initial 18-20 days of the observation. The growth rate is much more significant during the middle period of 50 days where stages of jointing, booting and heading are countered. The slope of the graph during this period is very high indicating a high growth rate of the plant. Its value is found to be 113.25(approx). The last 20 days of observation deals with the stages from anthesis to ripening. The slope falls to a very low value in this period from a high value of the previous stage indicating a low growth rate.

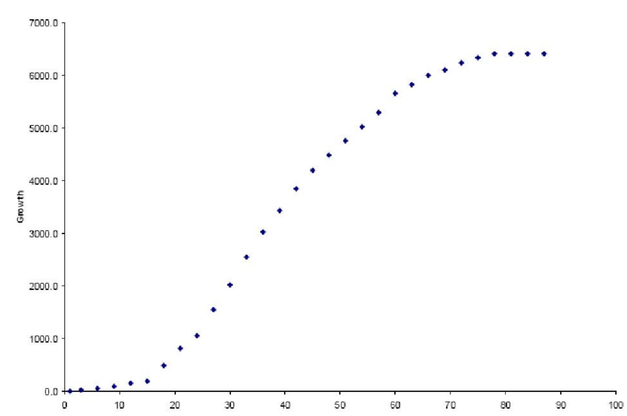

Figure 5 : Growth rate of a grain crop plant under artificial light and high pressure

The plot (figure 6) shows the variation between the average growth of the given grain crop plant per day under artificial lighting and low pressure conditions, which is again a sigmoid (figure 7) with no appreciable growth during the initial phase of 20 days. The growth rate is similar to that of the previous curve during the middle period of 50 days showing a significant jump in the slope value which is found to be 105.3 (approx). During the stages of anthesis, milk, dough and ripening i.e., the last 20 days of observation, the slope falls to a very low value compared to the previous stage.

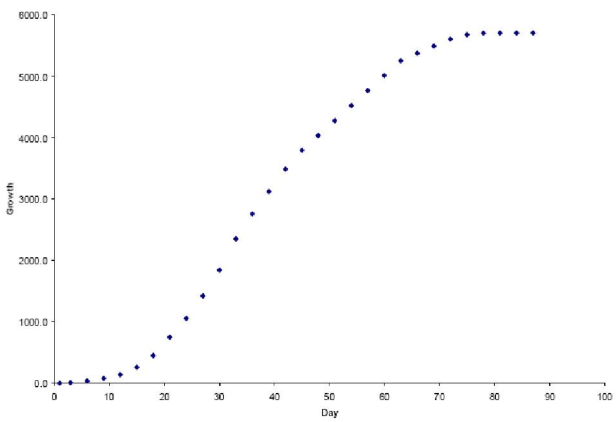

Figure 6 : Growth rate of a grain crop plant under artificial light and low pressure

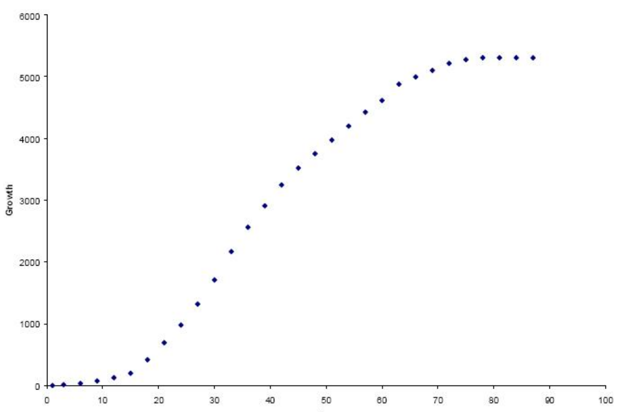

Figure 7 : Growth rate of a grain crop plant under natural light and high pressure

As shown in figure 8, the third plot in this series shows the variation between the average growth of the given grain crop plant per day under natural lighting and high pressure conditions, which is sigmoidal with a low growth factor during the initial phase of 20 days. The growth rate is similar to that of the previous curves during the middle period of 50 days showing a slope value of 98.1(approx). The slope of this curve is significantly lower to what has been found for the variations under artificial lighting. During the last stages of anthesis to ripening i.e., in the last 20 days of observation, the growth rate is very low compared to the previous two stages.

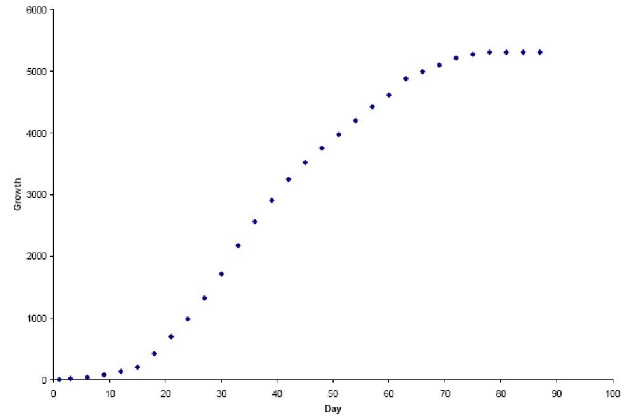

Figure 8 : Growth rate of a grain crop plant under natural light and low pressure

The plot (figure 9) in this series shows the variation between the average growth of the given grain crop plant per day under natural lighting and low pressure conditions. This is also a sigmoidal graph showing a low growth rate in the initial phase of tillering i.e., in the 20 days of observation. During the middle phase of jointing, booting and heading processes the growth rate increases as shown in figure 9. The slope during the central period of 50 days the growth varies having a slope value of 95.4(approx). The slope of this curve under the conditions of low pressure and natural lighting is significantly lower when compared to all the three previous graphs i.e., shows a lower growth rate in the middle period. For the last stages of anthesis to ripening i.e., in the last 20 days of observation, the growth rate is very low compared to the previous two stages as can be seen in any sigmoidal variation.

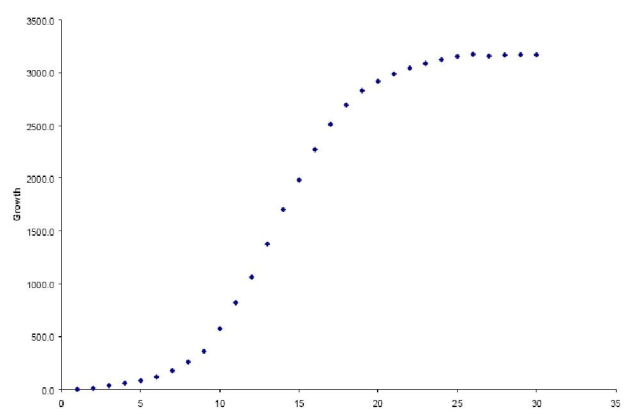

Figure 9 : Growth rate of a perennial plant under artificial light and high pressure

Let us now examine the behaviour of the perennial plant (Aristida Purpurea) subjected to observation under four different sets of conditions involving the two physical parameters, light and pressure.

The plot (figure 10) is the variation between the average growth of the perennial plant under observation per day, under artificial lighting and high pressure conditions. The entire plot can be chiefly divided into 3 parts, part 1 in the initial phase (first 5-8 days) where the slope is smaller, part 2 where the growth rate suddenly rises accomplishing a high slope value in the middle period (9-20 days approx) and part 3 being the low growth phase at the end (21-30days) very similar to the one in case of a grain crop plant. This variation is also a sigmoidal curve with not much of an appreciable change in the growth rate during the initial 5-8 days of the observation. The growth rate is much more significant during the middle period of 10-12 days. The slope of the graph during this period is very high indicating a high growth rate of the plant. Its value is found to be 234.4(approx). The last 8-10 days of observation shows a very low value of slope compared to the first two stages.

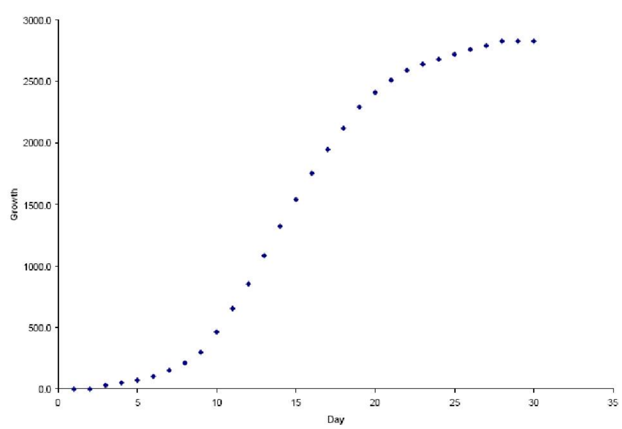

Figure 10 : Growth rate of a perennial plant under artificial light and low pressure

The plot (figure 11) is the variation between the average growth of the perennial plant under observation per day, under artificial lighting and low pressure conditions. This variation shows a sigmoidal curve with very less alteration in the growth rate during the initial 5-8 days of the observation. As observed in all the previous cases the growth rate is much more significant during the middle period of 10-12 days. The slope of the graph during this period is very high indicating a high growth rate of the plant, but low compared to the previous case as in 3.2.4.1. The value of the slope calculated is 194.6 (approx). The last 7 days of observation shows a low value of slope compared to the first two stages.

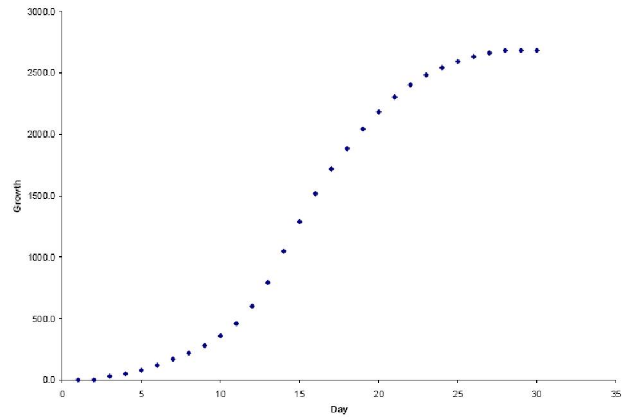

Figure 11 : Growth rate of a perennial plant under natural light and high pressure

Plot (figure 12) is the variation between the average growth of the given perennial plant per day, under natural lighting and high pressure conditions. This variation shows a sigmoidal curve with very less alteration in the growth rate during the initial 5-8 days of the observation. As observed in all the previous cases the growth rate is much more significant during the middle period of 10-12 days. The slope, however during this period is very high indicating a high growth rate of the plant, having a value of 182.3 (approx). The last 5-6 days of observation shows a fall in the value of slope compared to the first two stages.

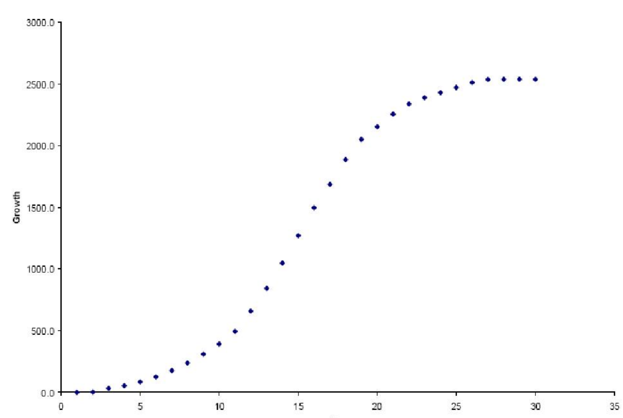

Figure 12 : Growth rate of a perennial plant under natural light and low pressure

The fourth plot in this series is the variation between the average growth of the given perennial plant per day, under natural lighting and low pressure conditions. It can be seen from figure 3-13 that this variation shows another sigmoid with a slight change in the slope during the initial 5-8 days of the observation. As observed in all the previous cases the growth rate is much more significant during the middle period of 10-12 days, i.e., from 10th day to 22nd day. The slope in this case shows a high of 176.2 (approx) indicating a high growth rate during this phase, but comparatively lower to values in all the three previous cases. The last 5-6 days of observation shows a fall in the value of slope compared to the first two stages as usual.

The scale of measurement adopted in this particular work is the *Zadoka Scale* of reference. The TABLE 4 shows the duration of different processes during the growth of the plant. After sowing and germination the next process to follow is tillering for a grain crop plant. It is significant to note that this process fastens the plant growth if the plant is made to grow under artificial light at high pressure. This is in support to the earlier work done by Jochem Evers, which enunciates that tellering process ceases early under specific light conditions. It is also evident through this experiment that the process of ripening occurs early when the plant is subjected to artificial lighting conditions compared to any other case.

TABLE 4 : Comparison of duration of stages under various conditions.

Stage	Zadoka Scale (days)			
	AL-HP	AL-LP	NL-HP	NL-LP
Tillering	22-26	20-29	20-29	20-29
Jointing	27-37	30-36	30-38	30-39
Booting	38-46	37-49	39-47	40-49
Heading	47-55	50-58	48-58	50-59
Anthesis	56-68	59-67	59-69	60-69
Milk	69-76	68-77	70-78	70-79
Dough	77-81	78-86	79-89	80-89
Ripening	82-92	86-95	90-99	90-99

AL-HP: Artificial lighting and high pressure; AL-LP: Artificial lighting and low pressure; NL-HP: Natural lighting and high pressure; NL-LP: Natural lighting and low pressure

CONCLUSION

On comparing the growth rates of grain crop plant under different physical conditions it is found that the growth rate is high under artificial lighting when 0.4% of CO_2 is maintained. The next high value of growth rate is observed for the same light with 0.04% of CO_2. However the growth rate under natural light is found to be more when 0.4% CO_2 is maintained than 0.04% of CO_2.

On considering the growth rate under the artificial light with 0.4% CO_2 as 100 then the growth rate of the same plant when 0.04% CO_2 used is found to be 17% less. Similarly the growth rate under natural light and 0.4% CO_2 is found to be 32% less. On comparing the same with natural light at 0.04% of CO_2, it is observed 40% less. The growth rate under natural light at 0.4% CO_2 decreases by 11.8% when the concentration reduces to 0.04%. Under low pressure conditions the growth rate under artificial light is 27.7% high compared to the rate using natural light. The figure 13 shows that the crop growth is faster using an artificial source of light than the natural source. In particular if the plant subjected to artificial lighting at high pressures the growth is significantly high compared to all other combinations of type of light and amount of CO_2.

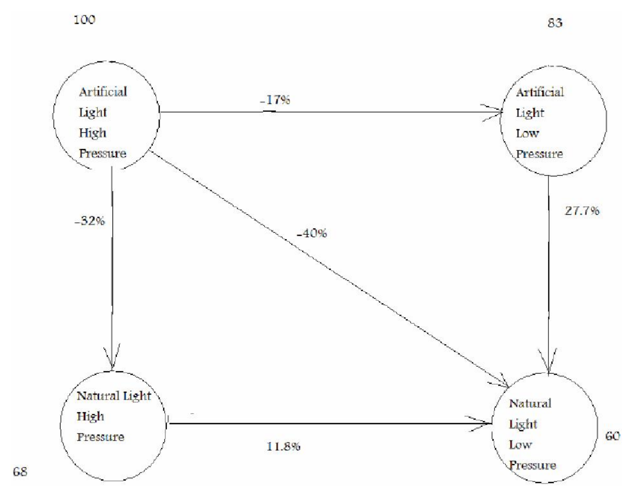

Figure 13 : Relative growth of plants under different physical conditions

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