# The Effect of EC Levels of Nutrient Solution on the Growth, Yield, and Quality of Tomatoes (*Solanum Lycopersicum*) under the Hydroponic System

R. A. Bustomi Rosadi[*1], Masateru Senge[2], Diding Suhandy[3], Ahmad Tusi[4]

[1,3,4]Department of Agriculture Engineering, Faculty of Agriculture, University of Lampung, Bandar Lampung, Indonesia
[2]Faculty of Applied Biological Science, Gifu University, Gifu, Japan

[*1]bustomirosadi@yahoo.com; [2]senge@gifu-u.ac.jp; [3]diding2004@yahoo.com; [4]atusi@unila.ac.id

***Abstract*- The objective of this research was to investigate the effect of EC (electric conductivity) levels of nutrient solution on the growth and yield of tomatoes under the hydroponic system. This research was conducted in a plastic house on the experimental farm of Lampung University, Lampung in Indonesia from April to July 2009. The EC treatments to nutrient solutions were S1 (1 dSm$^{-1}$), S2 (2 dSm$^{-1}$), S3 (3 dSm$^{-1}$), S4 (4 dSm$^{-1}$), and S5 (5 dSm$^{-1}$) arranged in a completely randomized design with four replications. The results showed that the highest yield was under S3 (120.8 g/plant), followed by S2 (96.6 g/plant), S1 (89.7 g/plant), S4 (88.4 g/plant), and S5 (75.5 g/plant). The yields of tomato responded to EC levels of nutrient solution in the two ranges of lower and higher EC than 3 dSm$^{-1}$. The yield increased as EC of nutrient solution increased from 0 to 3 dSm$^{-1}$ probably, due to increase of nutrients. On the other hand, the yield decreased as the EC of nutrient solution increased from 3 to 5 dSm$^{-1}$ probably, due to increase of water stress. So, it can be concluded that the salinity threshold of the tomatoes was 3 dSm$^{-1}$. On the other hand, the highest SSC (soluble solid content) was recorded under S5 (7.34 brix), followed by S4 (6.93 brix), S3 (6.44 brix), S2 (6.26 brix), and S1 (6.11 brix). It means that the S5 treatment was the best quality. Among the range of treatments, treatment S3 (3 dSm$^{-1}$) gave the highest yield, but lower SSC than S4 (4 dmS$^{-1}$) and S5 (5 dSm$^{-1}$).***

***Keywords- Salinity; Hydroponics; Deep flow techniques; Tomato; Water stress***

## I. INTRODUCTION

Tomatoes, the biggest hydroponically produced crop on a worldwide scale, are complex in their physiology and response to crop management techniques. Obtaining economic yields of high-quality fruit while minimizing the use of pesticides and other agrochemicals has put commercial tomato growers under increasing pressure, and many are now looking to modified hydroponic systems where higher profits are possible [1].

Many hydroponic systems can be used in growing tomatoes. But according to [1], nutrient film technique (NFT) and deep flow technique (DFT) are used in many commercial and amateurish tomato production systems. DFT is less common than NFT for hydroponic tomato production and relies on a similar system of channels that are filled with a deep flow of nutrient solution rather than a thin film. DFT systems rely on the introduction of oxygen along the entire length of each growing channel so that oxygenation rates in the root zone are continually kept high enough for good root growth. As with NFT, the nutrient solution recirculates continuously and EC, pH and often temperature levels are adjusted at the main nutrient reservoir [1]. Plants require 16 elements for growth and these nutrients can be supplied from air, water, and fertilizers. The 16 elements are carbon (C), hydrogen (H), oxygen (O), phosphorus (P), potassium (K), nitrogen (N), sulfur (S), calcium (Ca), iron (Fe), magnesium (Mg), boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), and chlorine (Cl). The key to successful management of a fertilizer program is to ensure adequate concentrations of all nutrients throughout the life cycle of the crop. Inadequate or excessive amounts of any nutrient result in poor crop performance [2]. When tomatoes are grown hydroponically, the EC of the nutrient solution usually employed (7.0 mM $K^+$, 4.0 mM $Ca^{2+}$, 2.5 mM $Mg^{2+}$, 1.5 mM $NH^{4+}$, 12.0mM $NO_3^-$, 1.5 mM $PO_4^{3-}$, 4.0 mM $SO_4^{2-}$ plus micro elements) ranges between 2.0 and 2.5 dSm$^{-1}$ ([3]; Cuartero and Soria, 1997 as in [3]).

Tomato is moderately tolerant to salinity (Fisher, 1967 as in [5]). Bernstein (1964) as in [5] estimated that 50 per cent yield reduction was obtained at an electrical conductivity of soil extract (ECe) of 8 dSm$^{-1}$ at 25°C. But according to Hoffman et al. (1980 in [6]), tomato is moderately sensitive to salinity with salinity threshold of 3.0 dSm$^{-1}$, and according to Maas (1986 in [4]), tomato is classified as being “moderately sensitive” to salinity, which means that it tolerates an EC of the saturated soil extract up to about 2.5 dSm$^{-1}$ without any yield reduction. Saranga et al. (1991 in [4]) found a threshold between 2.0 and 2.5 dSm-1 and a reduction in yield from 9% to 10% with an increase of 1 dSm$^{-1}$ beyond the threshold. But Ehret and Ho (1986 in [4]) reported no significant yield reduction above 7 dSm$^{-1}$ perhaps, due to the low light intensity and high relative humidity in their experiments.

Crop salt tolerance is generally assessed as the relative yield response to increasing root zone salinity, expressed as soil or irrigation water electrical conductivity. In contrast to the general response, where the yield declines after the tolerance threshold is represented by a single regression line with a species-specific slope (Maas 1990 in [7]). Reference [7] identified two well defined linear functions with different slopes within this region. In the first region, between 2.5 and 9.6 dSm$^{-1}$ EC, the slope was 6 % per $dSm^{-1}$, whereas after 9.6 $dSm^{-1}$ EC the yield reduction per unit increase in salinity was 1.4 %. According to [4], yields are reduced when plants are grown with a nutrient solution of 2.5 $dSm^{-1}$ or higher, and above 3.0 $dSm^{-1}$ an increase of 1 $dSm^{-1}$ results in yield reduction of about 9-10 %. At low solution electrical conductivity (ECs), yield reduction is caused mainly by reduction in the average fruit weight, whilst the declining number of fruits explains the main portion of yield reduction at high ECs.

Water stress technique has been used as a method to improve the quality of fruits, such as in tomato production. Water stress was induced by increasing salinity of nutrient solution. The simplest way of increasing the flavor constituents of tomato fruit is to increase the EC of the nutrient solution [1]. According to [8], irrigation with saline water can significantly improve fruit quality in term of SSC, perhaps, acidity of field grown processing tomatoes without depressing marketable yields. Imposing water stress during fruit growth and fruit ripening stages or from flowering onward reduced marketable yield and water use efficiency, and increased fruit soluble solids and colour relative to the fully irrigated treatment [9].

Based on the above explanation, it is clear that the tomato plant was moderately sensitive, but the salinity threshold of nutrient solution of tomato changed between 2 and 6 $dSm^{-1}$. So, there is a need to know the proper value of salinity threshold of tomato in water stress application in order to maximize the positive outcome, which is improving the SSC value, and minimize negative outcome, which is decreasing yield of tomato. In order to know the optimal condition of the water stress application, this research was conducted to know the effect of salinity (in term of EC) on the growth, yield and quality of tomato fruits under the hydroponic system.

## II. MATERIAL AND METHODS

This research was conducted in a plastic house of the experimental farm in Lampung University, Lampung in Indonesia from April to July 2009. Tomato cultivar used was Permata. The elevation of the site was 43 m above sea level. The average air temperature was 26.3°C and the relative humidity was 60.8 %.

The salinity treatments to the nutrient solutions were S1 (1 $dSm^{-1}$), S2 (2 $dSm^{-1}$), S3 (3 $dSm^{-1}$), S4 (4 $dSm^{-1}$), and S5 (5 $dSm^{-1}$) arranged in a completely randomized design with four replications. The hydrophonic system used in this experiment, was Deep Flow Technique (DFT) in small bucket (10 litres volume) combined with aerator to ensure that oxygenation rate in the root zone was good. DFT system relies on the introduction of oxygen along the entire length of each growing channel so that oxygenation rates in the root zone are continually kept high enough to ensure root growth. To maintain the salinity of the treatment, the nutrient solution was changed weekly to the basic salinity the same as the initial salinity of the treatment. For example, the nutrient solution of treatment S2 (2 $dSm^{-1}$) was maintained at 2 $dSm^{-1}$ from week I (after transplanting to the hydroponic system) until harvest time. When the EC of the nutrient solution increased to around 2.10 $dSm^{-1}$ on average, the nutrient solution was replaced with a new nutrient solution of the same salinity level of the treatment, which was 2 $dSm^{-1}$.

Before transplanting to the DFT hydroponic system, tomato seeds were seeded in small plastic boxes for three weeks, and then the tomato seedlings were transplanted into the plastic buckets with soil medium until 6 weeks old. At seven weeks, the tomato plants were transplanted to the DFT hydroponic system with 1 $dSm^{-1}$ salinity. Each bucket contained two plants. The treatments were applied one week after transplanting to the DFT hydroponic system. The nutrition used in this research, was nutrition package of Joro A & B Mix. Joro A package contained 12 kg $KNO_3$, 16 kg $Ca(NO_3)_2$, 350 g Fe(EDTA), and Joro B package contained 15 kg $KH_2PO_4$, 7.5 kg $MgSO_4$, 5 kg $K_2SO_4$, 60 g $MnSO_4$, 50 g $ZnSO_4$, 50 g Borat acid, 50 g $CuSO_4$, 1 g NaMo. Each package was diluted in 100 liter of water, and mixed. For example, to make the nutrient solution of 2 $dSm^{-1}$ (S2), 3.3 liter of Joro A and 3.3 liter of Joro B solutions were mixed in 1000 liter of pure water. With the same way, to make the nutrient solution of the treatments are as follows (see Table 1):

TABLE 1 THE PORTION OF JORO A AND JORO B TO MAKE THE NUTRIENT SOLUTION AS A TREATMENT [10]

| **Treament** | **EC ($dSm^{-1}$)** | **Joro A (litre)** | **Joro B (Litre)** | **Water (Litre)** |
|---|---|---|---|---|
| S1 | 1 | 1,7 | 1,7 | 1000 |
| S2 | 2 | 3,3 | 3,3 | 1000 |
| S3 | 3 | 5,7 | 5,7 | 1000 |
| S4 | 4 | 7,8 | 7,8 | 1000 |
| S5 | 5 | 9,9. | 9,9 | 1000 |

Source: 1. Reference [11] http://joronet.net/produk/pupuk/abmix.htm

2. Based on laboratory experiment

Agronomic variables evaluated in this research were plant height, number of leaves, flowers and fruits, yield, and soluble solid content (SSC) as a quality indicator. The plant height was measure as the average of two plants in the bucket. The number of flower was the total number of flower per bucket, the yield was the total fruit weight per bucket, and the SSC was the value of the fruits sample (five fruits per bucket). Statistical analysis using F-test at 5% significant level, followed by LSD (Least Significant Different) test at the same level was carried out.

## III. RESULTS AND DISCUSSIONS

The effect of salinity on the plant height is shown in Table 2. It can be observed that, the tomato plants were stressed under treatments S4 and S5 from week I and that of treatment S3 started from week III. The plant height of treatment S2 (167.5 cm) was the highest at week IV, followed by treatment S1 (163.8 cm); however there was no significant difference between these two treatments. Both of these treatments were significantly different ($p<0.05$) from treatments S3 (143.3 cm), S4 (129.0 cm), and S5 (120.8 cm). The above results shows that the plant height was significantly affected by water stress due to the high salinity of treatments (S3, S4, S5), but was not affected by the low salinity treatments (S1, S2).

TABLE 2 THE EFFECT OF SALINITY ON THE PLANT HEIGHT (IN CM) OF TOMATO PLANTS DURING THE WEEKS VIII TO XI

| Salinity level | Week | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | VIII | | IX | | X | | XI | |
| S1 (1 $dSm^{-1}$) | 92.50 | a | 122.75 | a | 145.25 | ab | 163.75 | a |
| S2 (2 $dSm^{-1}$) | 91.40 | a | 123.50 | a | 150.50 | a | 167.5 | a |
| S3 (3 $dSm^{-1}$) | 89.75 | a | 115.75 | a | 135.00 | b | 143.25 | b |
| S4 (4 $dSm^{-1}$) | 76.25 | b | 98.75 | b | 115.50 | c | 129.00 | c |
| S5 (5 $dSm^{-1}$) | 74.63 | b | 91.00 | b | 106.25 | c | 120.75 | c |

Note: it means followed by different small letters (a-c) in the same column in each week after transplanting under different salinity levels are significantly different according to LSD test ($p<0.05$).

The effect of salinity on the number of leaves is shown in Table 3. It can be observed that, there was no effect of salinity on the number of leaves. The mean number of leaves under treatment S2 (20.5) was the highest at week IV, followed by S1 (19.5), S4 (19.0), S3 (18.8), and S5 (16.8).

TABLE 3 THE EFFECT OF SALINITY ON THE NUMBER OF LEAVES OF TOMATO PLANT DURING THE WEEKS VIII TO XII

| Salinity level ($dSm^{-1}$) | Week | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | VIII | | IX | | X | | XI | | XII | |
| S1 (1 $dSm^{-1}$) | 12.00 | a | 14.25 | a | 16.75 | a | 19.50 | a | 21.00 | a |
| S2 (2 $dSm^{-1}$) | 12.25 | a | 15.50 | a | 17.75 | a | 20.50 | a | 22.00 | a |
| S3 (3 $dSm^{-1}$) | 13.50 | a | 15.25 | a | 17.75 | a | 18.75 | a | 19.00 | ab |
| S4 (4 $dSm^{-1}$) | 12.00 | a | 14.00 | a | 17.00 | a | 19.00 | a | 21.50 | a |
| S5 (5 $dSm^{-1}$) | 11.25 | a | 13.25 | a | 16.25 | a | 16.75 | a | 17.25 | b |

Note: it means followed by different small letters (a-c) in the same column in each week after transplanting under different salinity levels are significantly different according to LSD test ($p<0.05$).

Table 4 shows that the effect of salinity on the number of flowers, especially at week IV and V, treatment S2 was not significantly different from the other treatments, except treatment S1. The number of flowers of treatment S2 (19.0) was the highest at week V, followed by treatment S3 (18.3), S4 (18.3), S5 (16.8), and S1 (10.5). Treatment S1 was the smallest among all the treatments due to its lowest nutrient content. It could be said that treatment S1 was stressed by low nutrition.

TABLE 4 THE EFFECT OF SALINITY ON THE NUMBER OF FLOWERS OF TOMATO DURING THE WEEKS X TO XII

| Salinity level ($dSm^{-1}$) | Week | | | | | |
|---|---|---|---|---|---|---|
| | X | | XI | | XII | |
| S1 (1 $dSm^{-1}$) | 1.50 | b | 5.75 | a | 10.50 | b |
| S2 (2 $dSm^{-1}$) | 7.00 | a | 13.75 | a | 19.00 | a |
| S3 (3 $dSm^{-1}$) | 12.25 | a | 17.25 | a | 18.25 | a |
| S4 (4 $dSm^{-1}$) | 10.75 | a | 15.25 | a | 18.25 | a |
| S5(5 $dSm^{-1}$) | 9.75 | a | 13.25 | a | 16.75 | a |

Note: it means followed by different small letters (a-c) in the same column in each week after transplanting under different salinity levels are significantly different according to LSD test ($p<0.05$).

Based on Table 5, it was known that the effect of salinity on the number of fruits, especially at week IV and V, the number of fruits of treatment S3 was not significantly different, compared to the other treatments except treatment S1. The number of fruits under treatment S3 (18.0) was the highest at week V, followed by S2 (17.5), S4 (16.5), S5 (15.5), and S1 (10.3). It can be observed from Table 5 that the number of fruits generally decreased at the harvest time (week VII), compared to week V, because most of the small fruits felled down and number of fruits of the plants under high salinity treatments (S4, S5) and low nutrient conditions (S1, S2) decreased more sharply than the middle salinity condition (S3).

TABLE 5 THE EFFECT OF SALINITY ON THE NUMBER OF FRUITS OF TOMATO DURING THE WEEKS X TO XII

| Salinity level ($dSm^{-1}$) | Week | | | | | |
|---|---|---|---|---|---|---|
| | X | | XI | | XII | |
| S1 (1 $dSm^{-1}$) | 1.50 | b | 5.75 | a | 10.25 | b |
| S2 (2 $dSm^{-1}$) | 7.00 | b | 13.75 | a | 17.50 | a |
| S3 (3 $dSm^{-1}$) | 12.25 | a | 17.25 | a | 18.00 | a |
| S4 (4 $dSm^{-1}$) | 10.75 | a | 15.25 | a | 16.50 | a |
| S5(5 $dSm^{-1}$) | 9.75 | a | 13.25 | a | 15.50 | a |

Note: it means followed by different small letters (a-c) in the same column in each week after transplanting under different salinity levels are significantly different according to LSD test ($p<0.05$).

Table 6 shows that the yield of treatment S3 was significantly different, compared to the other treatments except treatment S2. The yield of treatment S3 (120.8 g/plant) was the highest, followed by S2 (96.6 g/plant), S1 (89.7 g/plant), S4 (88.4 g/plant), and S5 (75.5 g/plant). S3 treatment was significantly different, compared to S4 and S5 treatments, but there was no significant difference, compared to S2 treatment. It means that S4 (EC=4 $dSm^{-1}$) treatment was on a stress condition. Therefore, the EC at 3 $dSm^{-1}$ (S3 treatment) was a treshold salinity.

TABLE 6 THE EFFECT OF SALINITY ON THE NUMBER OF FRUITS, YIELD, AND SOLUBLE SOLID CONTENT (SSC) OF TOMATO PLANT

| Salinity level ($dSm^{-1}$) | Week XII | | | | | |
|---|---|---|---|---|---|---|
| | Total fruit Number | 5 % | Yield (gr) | 5 % | SSC (brix) | 5 % |
| S1 (1 $dSm^{-1}$) | 5.50 | b | 89.65 | b | 6.11 | d |
| S2 (2 $dSm^{-1}$) | 7.25 | b | 96.57 | a | 6.26 | d |
| S3 (3 $dSm^{-1}$) | 10.00 | a | 120.82 | a | 6.44 | c |
| S4 (4 $dSm^{-1}$) | 6.50 | b | 88.39 | b | 6.93 | b |
| S5(5 $dSm^{-1}$) | 6.25 | b | 75.54 | b | 7.34 | a |

Note: it means followed by different small letters (a-c) in the same column in each week after transplanting under different salinity levels are significantly different according to LSD test ($p<0.05$).

Based on Table 2 to Table 6, it can be observed that the treatments S4 and S5 were under water stress condition due to the high salinity (4 $dSm^{-1}$ and 5 $dSm^{-1}$, respectively) from week I after transplanting to the hydroponic system, and continued to be stressed until the harvest time based on the plant height and yield results (fruit weight). Treatment S3 started to be under stress condition from week III according to the plant height data, but recorded the highest yield and was significantly different from the other treatments except treatment S2. Based on Table 6, it can be seen that the yield responsed to EC levels of nutrient solution under the two lower and higher $EC_s$ than 3 $dSm^{-1}$. The yield of tomatoes increased as EC of the nutrient solution increased from 0 to 3 $dSm^{-1}$ probably, due to increase of nutrients. On the other hand, the yield decreased as EC of the nutrient solution increased from 3 to 5 $dSm^{-1}$ probably, due to increase of water stress. So, it can be concluded that the salinity threshold of the tomato was 3 $dSm^{-1}$. It means that the result of this experiment was the same with the statements as in [4], Maas Hoffman (1977 in [7]), and [7]. According to Hoffman et al. (1980 in [6]), the salinity threshold of tomato was 3 $dSm^{-1}$ and according to Maas (1986 in [4]), the salinity threshold of tomato (based on saturated soil extract) was about 2.5 $dSm^{-1}$. It means that this experiment was good enough for estimating the salinity threshold of tomatoes under the specific conditions examined here (using mixed nutrition solution of Joro A and joro B).

The relationship between the EC levels of the nutrient solution ($EC_s$) and the yield were expressed by the following two quadratic relationships.

1) between 0 to 3 $dSm^{-1}$ $y = 8.65x^2 - 19.1x + 100$

2) between 3 to 5 $dSm^{-1}$ $y = 9.75x^2 - 101x + 335$

Where, Y = Yield (gr) and X = $EC_s$ ($dSm^{-1}$)

The relationships are very different, compared to the result of Maas and Maggio as mention before; that is single linear line and two linear functions with different slopes. The differences in the results are perhaps due to the different salinity method. Maas and Maggio measured the salinity by saturated soil extract method which was known as $EC_e$, and this experiment measured the salinity of nutrient solution which was known as $EC_s$. Based on the curve above (Fig. 1), it was known that the yield increased sharply from 8% to 25% with the increased of 1 $dSm^{-1}$ below the "threshold (3 $dSm^{-1}$)", and the yield decreased sharply from 10% to 50% with an increase of 1 dS $m^{-1}$ beyond the "threshold (3 $dSm^{-1}$)".

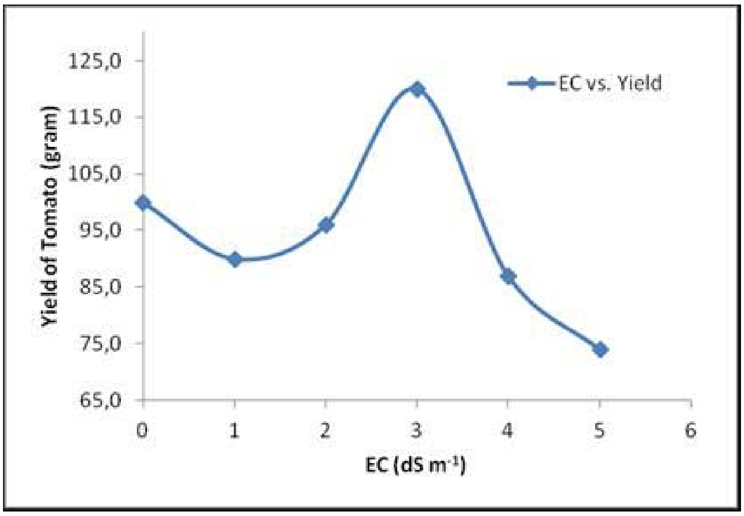


Fig. 1 The relationship between the EC nutrient solution and yield of tomato

The effect of salinity on the SSC value is shown in Table 6. It can be observed that increasing the salinity level relates to increasing the SSC or increasing the quality of tomato fruits. The SSC of treatment S5 (7.43 brix) was the highest, followed by treatment S4 (6.93 brix), treatment S3 (6.44 brix), treatment S2 (6.26 brix), and treatment S1 (6.11 brix). Treatments S4 and S5 were actually under stress condition from week I (after transplanting to the hydroponic system), and continued to be stressed until harvest time, but the quality of tomatoes of these treatments as shown by SSC results, were significantly different from treatment S3 and the quality of tomatoes of treatments S4 and S5 were better than treatment S3. It means that the result of this experiment was the same with the result of the experiments conducted by [5, 8, 9], and [10] as mentioned before that tomatoes grown under water stress condition will produce fruits with high SSC value.

## IV. CONCLUSIONS

1. The plant height was significantly affected by water stress due to high salinity of nutrient solution (S3, S4, S5), but was not affected by low nutrient solution (S1, S2).

2. The number of leaves was not significantly affected by EC levels of nutrient solution, but number of flowers was significantly affected by low nutrient (S1).

3. The number of fruits generally decreased at the harvest time (week VII) compared to week V, because most of the small fruits felled down, and number of fruits of the plants under high salinity (S4, S5) and low nutrient conditions (S1, S2) decreased more sharply than the middle salinity condition (S3).

4. The treatment S3 started to be in stress condition at week III according to the plant height results, but its yield was the highest and significantly different ($p<0.05$)from the other treatments except S2 treatment.

5. The yield of tomatoes increased as EC of nutrient solution increased from 0 to 3 $dSm^{-1}$ probably, due to increase of nutrients. On the other hand, the yield decreased as EC of nutrient solution increased from 3 to 5 $dsm^{-1}$ probably, due to increase of water stress. So, it can be concluded that the salinity threshold of the tomato was 3 $dsm^{-1}$. under the specific conditions examined here (using mixed nutrition solution of Joro A and Joro B)

6. Increasing the salinity level relates to increasing the SSC or increasing the quality of tomato fruit.

7. Among the range of treatments, treatment S3 (3 $dsm^{-1}$) gave the highest yield, but lower SSC than S4 (4$dms^{-1}$) and S5 (5$dsm^{-1}$).

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