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“Achieving Resilient and Environmentally Sustainable Animal Industry in the post COVID-19 Pandemic Era”
# TABLE OF CONTENT

## PREFACE ........................................................................................................................................... i

## TABLE OF CONTENT .......................................................................................................................... ii

## WELCOME SPEECH ............................................................................................................................ iv

Welcome Message from Rector ....................................................................................................................... v

Welcome Message from Dean ........................................................................................................................... vi

## PROCEEDINGS .................................................................................................................................... 1

The Impact of COVID-19 Pandemic on Poultry Production: Challenges and Prospects
  A. Jalaludeen and Stella Cyriac .......................................................................................................................... 2

Sustainability of Sheep and Goat Production in Asian Countries
  A. K. Thiruvengadavan and J. Muralidharan .................................................................................................... 10

Electrical Conductivity of Milk: Measurement and Analysis of Mastitis Detection Performance on Dairy Cattle
  T. E. Susilorini, G. Emerald, and Kuswati ....................................................................................................... 21

Analysis of Critical Point Amplification of DNA Microsatellite of Capra hircus
  D. Wulandari, I. L. Murtika, F. E. Wardani, A. Furqon, W. A. Septian, T. E. Susilorini and S. Suyadi ................................................................................................................... 27

Case Study of Critical Point on RFLP (Restriction Fragment Length Polymorphism)
  F. E. Wardani, D. Wulandari, I. L. Murtika, A. Furqon, W. A. Septian, T. E. Susilorini, A. Rachmawati and S. Suyadi ................................................................................................................... 34

Observational Study on Critical Point of Polymerase Chain Reaction (PCR) Process of Mitochondrial DNA
  I. L. Murtika, D. Wulandari, F. E. Wardani, A. Furqon, W. A. Septian, T. E. Susilorini, A. Rachmawati and S. Suyadi ................................................................................................................... 41

Estimation of Heritability for Body Weight Using Fullsib and Halfsib Method in Etawah Grade Goat
  V. M. A. Nurgiartiningsih and C. Safina ........................................................................................................ 46

5 Ways to Improve Farmer Management Skills of Joper Parent Stock in Berline Farm, Ngajum, Malang
  M. H. Natsir, V. M. A. Nurgiartiningsih, O. Sjoefjan, W. Firdaus, and Y. F. Nuningtyas ............................................................................................................................... 52

The Potential of Antioxidant Activity and the Characteristics of Fingerroot Extract
  (Boesenber gia pandurata Roxb. Schlecht.) with Nanoencapsulation Technology
  N. N. N. Nida, Z. Zuprizal and B. Ariyadi .................................................................................................. 56

Nutritional Content, Gross Energy and Density of Banana Corn Evaluation from Nanotechnology and Re-binding as A Hybrid Duck Feeds
  O. Sjoefjan, M. H. Natsir, Y. F. Nuningtyas, E. A. Putra, and D. N. Adli ........................................................................................................................................................................... 62

The Effect of Corn Substitution with Re-Binding Banana Hump Flour in Feed on Internal Organs, Abdominal Fat Percentage and Size of Caeca in Hybrid Ducks
  O. Sjoefjan, M. H. Natsir, Y. F. Nuningtyas, T. S. Wardani, and D. N. Adli ........................................................................................................................................................................... 67

The Effect of Corn Substitution with Palm Kernel Meal with Addition of Enzyme Mananase in Feed on Carcass Weight, Carcass Percentage, Pieces of Carcass Hybrid Ducks
  O. Sjoefjan, M. H. Natsir, Y. F. Nuningtyas, F. R. Amalia, and D. N. Adli ........................................................................................................................................................................... 72
Ruminal Degradation of Selected Local Feeds in Dairy Cattle Using In Sacco Techniques
A. Rosmalia, I.G. Permana, Despal, and R. Zahera .......................................................... 77

The Effect of Fresh Dayak Onion (Eleutherine palmifolia L. Merr) and Storage Time on Rejected-Duck Nuggets N. Hidayat................................................................................. 83

Effect Ozonation on the Physicochemical and Penicillin-G Residues in Dairy Milk D. Suprapto, L. E. Radiati, C. Mahdi, and H. Evanuarini................................................................. 91


Water Requirements in Hydroponic and Aquaponic Maize Fodder Production Hermanto, S. Chuzaemi, B. A. Nugroho and I. Subagiyo ................................................................. 103

The Fermentation Quality of Agricultural Waste-based Complete Feed Silage Treated with Cellulase and its Effect on Productivity of Kacang Goats B. Santoso, T. W. Widayati, and B. T. Hariadi ................................................................................................................................. 110

Water Requirements in Hydroponic and Aquaponic Maize Fodder Production

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Abstract

The experiment was conducted in a greenhouse. A layer of maize seeds were placed on planting tray (25 x 10 x 5 cm³) with perforated bottom so that the roots grew down into pan containing growing medium solution. The media used were pure water, hydroponic nutrient solution 1000 ppm, 2000 ppm, pond water of Tilapia and Catfish. On each media, maize seed were planted at 3 densities i.e. 100; 150 and 200 seeds per tray and each was harvested at 7; 14; 21; 28 and 35 days of age. Each was replicated 3 times. Batch irrigation method was used. The results showed that the 1000 and 2000 ppm solution medias gave similar fodder Dry Matter (DM) yields that significantly higher (P<0.01) than those grown on other types of media. The density of 100 seeds per tray gave highest DM conversion of seeds to forage. The ratio of DM yields of root : shoot at 7 days was 84 : 16 and at 35 days was 39 : 61. The amount of water required to produce per kg fodder DM was significantly affected by the treatments. At the age of 7 days, the need for water/solution to produce 1 kg of fodder DM was 10.2 ± 2.62 l and it became inefficient at 35 days of age i.e. 200.2 ± 27.85 l / kg fodder DM. It was concluded that although highest conversion of seed to fodder DM was obtained at low seed density, less water is required to produce maize fodder under the 200 seed density/tray at 7 days of harvest age.

Keyword : hydroponic; aquaponic; water requirement, fodder, maize

INTRODUCTION

Production of ruminant livestock is often limited by the incontinuity of good quality forage supply that naturally depends on the availability of land and its fertility, availability of water supply and season. Irrigated fertile land, however, is commonly prioritized for food crops production. The ruminant production, hence, have to move towards crop-livestock integration systems where low quality crop residues are used as animal feed. Feeding of maize stover to ruminant livestock, for instance, is practised by the smallholder farmers in the area of intensive agriculture systems in Indonesia. According to Umiyasih dan Angraeney (2005), the Dry Matter (DM) production of maize stover ranged from 2.19 to 3.2 t/ha/harvest.

Water is vital in crop production. Field studies, however, found that only 2 - 3% of irrigation water is actually used for the crop growth while the rest just moist the soil and large amount are lost due to evaporation (Al-Karaki and Al-Momani, 2011). In order to increase efficiency of water used in crop production, hydroponic technology has been suggested (Adjlanea et al., 2016). The water commonly used in hydroponic are pure water or plant nutrient solutions. Alternatively, the water may sourced from an aquaculture installation and as such the technology is called as aquaponic. The roots of the crop in the ponds' water acting as filter that absorb the fish waste as nutrients for the crops’ growth and thus keep the fish pond health. Both crop and fish is produced by the aquaponic technology with one production input only i.e. the fish feed (Rakocy et al, 2007). The technical features of growing crop/s on hydroponic and aquaponic systems are the same except the types of solution used ie. the hydroponics uses pure water and/or nutrient solutions while aquaponics uses fish pond water. They are containing different types and
concentrations of nutrients available for the plant to grow. Further information about how much would they be needed for maize fodder production is still hardly found.

Beside of growing crops, the hydroponic and aquaponic are potential for fodder production. Chavan and Kadam (1989) outlined the advantages of hydroponic fodder production systems that include environmentally friendly because it does not use pesticides, does not require land management, does not depend on the season, saves water use because the water is recirculate and is able to produce good quality fodder in only short of time on pure water or plant nutrients solution. It is commonly reported that hydroponic fodder is best produced using pure water media and harvested at young age. Dung, Godwin and Nolan (2010) for instance, suggested to harvest barley fodder between 5 to 8 days after the seed nutrient/s deposit were exhausted for the purpose of germination and early growth of the seedlings. Rodriguez-Muela, Rodriguez, Ruiz, Flores, Grado dan Arzola (2004) mentioned that 6 to 10 kg fresh fodder can be produced from 1 kg of seed planted hydroponically. However, Tudor, Darcy, Smith and Shallcross (2003) reported that there were 12 to 20 percent lost of seed Dry Matter (DM) if the fodder were harvested at young age. This study, hence, hypothesized that allowing more DM fodder accumulation by extending harvest age could reduce the DM lost.

On the basis of above, this experiment was designed to study the requirement of different water/solution types on maize fodder production under different seed densities and harvest ages.

MATERIALS AND METHODS

This research was conducted in the greenhouse of Animal Husbandry Field Laboratory, Faculty of Animal Science, Brawijaya University located at Dusun Semanding, Sumber Sekar Village, Dau District, Malang Regency. The analysis of DM was carried out at the Laboratory of Animal Nutrition and Forage, Faculty of Animal Science, Universitas Brawijaya. The greenhouse used is a permanent building, floor area 8 x 8 m², wall height 4 m consisting of 2 m brick wall and 2 m woven wire for air circulation that can be opened and closed with a plastic sheet. Roof height 4.5 m and made of glass. The greenhouse is equipped with planting tables, fish ponds, electricity facilities. A well is also available as water source. Tilapia and catfish ponds made of plastic drums are available in the greenhouse. Temperature, humidity and intensity of solar radiation in the greenhouse were measured every 2 hours at 8.00; 10.00; 12.00; 14.00 and 16.00.

The seeds of the Bisi 18 maize variety final stock were used. These were taken from the middle part of sun dried cob and clean from dirt. The average weight of the seed was 32.07 ± 0.059 grams per 100 seeds. Their germination rate as measured prior to the experiment was 90.6 ± 4.16 % on day 5. Seed sample was taken for DM content analysis.

This experiment followed the nested completely randomized design consisting of 3 factors. The first factor include 5 types of solution ie. M1= pure water; M2= hydroponic nutrient solution of 1000 ppm; M3= hydroponic nutrient solution of 2000 ppm; M4= Tilapia pond water; M5= Catfish pond water. The second factor include 3 levels of maize seed densities ie. K200 = 200 seeds/250 cm²; K150 = 150 seeds/ 250 cm²; K100 = 100 seeds/250 cm². The third factor include 5 harvest ages ie. W07= 7 days; W14= 14 days; W21= 21 days; W28= 28 days; W35= 35 days. Each treatment was replicated 3 times. The data collected were subjected to the Analysis of Varians in which the density of the maize seeds was nested in solution, the harvest age was nested in the seeds density and the solution. Duncan Multiple Range Test was employed to test average differences.

The maize seeds were immersed in 70°C water for 12 hours prior to be spreaded to form a layer of seeds on a perforated tray of 25 x 10 x 5 cm³. The average number of seed in K200 treatment was equivalent to 8,000 seeds/m² or 2.6 kg dry seeds. The seeds of K150 and K100 respectively equivalent to 1.95 and 1.30 kg dry seed. The trays containing seeds were stacked up (15 trays/stack), covered with black plastic and every 2 hours were sprayed with water to let them germinated. On day three, their roots had grown so they were
unstacked and each was placed on a pan containing growing media in which the roots were dipped. This became day one of the experiment. The growing media pan (the same size as above) contained 500 ml water/solution according to treatments that was replaced with new one at every 24 hours. Prior to the replacement, the volume and weight of the water/solution remained on each tray was measured. Started from the experiment day 14, the volume of the water/solution was lifted up to 700 ml/tray.

Daily water consumption is the daily differences between the water given in the morning and the remaining water in the next morning. Total water/solution consumption is the amount of water/solution consumed until the fodder is harvested. Production of fodder DM was measured as weight of fodder DM at harvest divided by the DM weight of the seeds were planted. This also representing seed-fodder DM conversion efficiency. Water used efficiency (ml/g DM) is the total water/solution consumption divided by the resulted fodder DM weight. The fodder production is comprised edible materials including roots and shoots. The DM analysis was made according to the AOAC (1995) procedure.

RESULTS AND DISCUSSION

3.1. Greenhouse environmental conditions

The light intensity, temperature and humidity in the greenhouse during period of this experiment are shown in Table 1.

Table 1. Light intensity, temperature and humidity in the greenhouse during the experimental period

<table>
<thead>
<tr>
<th>Time</th>
<th>Light intensity (lux)</th>
<th>Temperature (°C)</th>
<th>Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>7,643.64 ± 4,509.32</td>
<td>24.90 ± 1.78</td>
<td>49.06 ± 3.56</td>
</tr>
<tr>
<td>10</td>
<td>12,483.44 ± 3,358.52</td>
<td>31.36 ± 2.10</td>
<td>49.39 ± 3.84</td>
</tr>
<tr>
<td>12</td>
<td>12,266.33 ± 3,464.37</td>
<td>32.88 ± 2.08</td>
<td>47.48 ± 3.66</td>
</tr>
<tr>
<td>14</td>
<td>6,422.73 ± 3,679.43</td>
<td>31.67 ± 1.52</td>
<td>48.84 ± 3.87</td>
</tr>
<tr>
<td>16</td>
<td>1,853.97 ± 1,113.88</td>
<td>28.68 ± 1.43</td>
<td>54.13 ± 5.81</td>
</tr>
</tbody>
</table>

Table 1 shows that variables of the environmental condition in the greenhouse varied between times in the day. Highest variation was found on light intensity, from 1,853.97 at 4 pm to 12,483.44 at around 10 am. The widely ranged coefficient of variation (cv) ie from 27% (at 10 am) to 60% (at 4 pm) indicated high variations of light intercepted in the greenhouse also occurred between days. The resulted temperature was also varied between times in a day, lowest at 8 am and highest at noon. The cv of average temperature at each time, however, was far below that of light intensity; highest (7%) at 8 am and lowest (4.8%) at 2 pm indicating the relatively low temperature variation between days during the experimental period. The humidity was relatively stable from 8 am to 2 pm and increased at 4 pm. Variation between days was also relatively small, ranged from 7.2% at 8 am to 10.7% at 4 pm.

The daily temperature range in the greenhouse (Table 1) was higher as compared to the recommended room temperature for fodder production given by Starova (2015) ie between 19 to 22°C. However, the range of the greenhouse temperature in this experiment is considered suitable for growing maize as that defined by Azraji, Mejaya and Yasin (2007) ie. between 27 to 32°C.

Humidity in the greenhouse (Table 1) was also lower compared to that recommended by Starova (2015) ie. 60%. Such low humidity and high temperature are potentially increase
water/solution evaporation, plant transpiration and seed germination failures (Van de Venter and Hoffman, 1988). However, ideal environmental condition in the greenhouse, unlike in a growth chamber, is difficult to control. Such natural environmental greenhouse conditions was also supported by Adebiyi et al. (2018).

3.2. Fodder production

Production of maize fodder under different types of media, seed densities and harvest ages are shown in Table 2. Each of these variables were significantly (P<0.01) affect fodder production.

Table 2. Maize fodder production on various media types, seed densities and harvest age.

<table>
<thead>
<tr>
<th>MEDIA DENSITY</th>
<th>CUTTING AGE</th>
<th>W07</th>
<th>W14</th>
<th>W21</th>
<th>W28</th>
<th>W35</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 K200</td>
<td></td>
<td>927</td>
<td>836</td>
<td>831</td>
<td>928</td>
<td>932</td>
<td>951</td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>1,087</td>
<td>970</td>
<td>974</td>
<td>1,257</td>
<td>1,172</td>
<td></td>
</tr>
<tr>
<td>M2 K200</td>
<td></td>
<td>1,002</td>
<td>999</td>
<td>1,080</td>
<td>1,466</td>
<td>1,295</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>850</td>
<td>830</td>
<td>899</td>
<td>1,336</td>
<td>1,376</td>
<td>1,180</td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>978</td>
<td>1,063</td>
<td>1,173</td>
<td>1,444</td>
<td>2,040</td>
<td></td>
</tr>
<tr>
<td>M3 K200</td>
<td></td>
<td>844</td>
<td>845</td>
<td>962</td>
<td>1,082</td>
<td>1,471</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>959</td>
<td>845</td>
<td>989</td>
<td>1,407</td>
<td>1,508</td>
<td>2,126</td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>1,064</td>
<td>996</td>
<td>1,323</td>
<td>1,686</td>
<td>2,257</td>
<td></td>
</tr>
<tr>
<td>M4 K200</td>
<td></td>
<td>968</td>
<td>793</td>
<td>901</td>
<td>1,006</td>
<td>1,239</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>801</td>
<td>712</td>
<td>838</td>
<td>949</td>
<td>1,118</td>
<td>999</td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>1,033</td>
<td>954</td>
<td>1,006</td>
<td>1,246</td>
<td>1,276</td>
<td></td>
</tr>
<tr>
<td>M5 K200</td>
<td></td>
<td>970</td>
<td>843</td>
<td>940</td>
<td>1,053</td>
<td>1,181</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>850</td>
<td>804</td>
<td>875</td>
<td>1,114</td>
<td>1,232</td>
<td>1,032</td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>1,048</td>
<td>962</td>
<td>1,066</td>
<td>1,230</td>
<td>1,306</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows that pure water (M1) as a growing medium was able to maintain the life of maize fodder up to 35 days although there was no significant increased in fodder DM biomass (P>0.01) from day 7 to 35. This suggest that pure water media produced maize fodder optimally at 7 days. Such finding is in line with the findings of Chavan and Kadam (1989) as well as Pandey and Pathak (1991). Lamganibi and Surve (2017) reported that 8 days is the most optimal time to harvest hydroponic maize fodder using water media without nutrients because extending the harvest time does not increase and even tends to decrease biomass DM production. Data in Table 2 also shows that at 7 days the seed DM weight was converted to 1.07 total fodder DM i.e. a conversion efficiency of 1.07 at 100 seeds/250 cm² density which is close to the finding of Naik et al. (2015) and Jemimah et al. (2018)

A significant increase of fodder DM biomass on media other than M1 were found started at 28 to 35 days. At harvest day 7, growing media other than M1 also convert seed DM to fodder DM and conversion efficiency more than one was found at the lowest seed density (K100) under all types of media, except the M2. The latter gave conversion efficiency more than one at highest seed density studied i.e. K200. Conversion efficiency more than 2 were obtained on M2 and M3 growing medias at lowest seed density (K100) and harvest day of 35. The overall features suggest that seed densities higher than 100 seeds/250cm² will reduce the DM conversion of seeds to plant biomass. Perhaps higher seed densities than
the K100 limit the space for plant growth. Such limitation can cause the leaves are not fully open due to the dense population and moreover obstructing optimum photosynthesis as is the case with plant growth under shade. Bewe and Hunter (1986) had found that shade can inhibit maize production because the rate of plant photosynthesis is reduced and will have an impact on decreased plant productivity.

The total DM produced as discussed above comprised roots and shots. Ratio of these components was mainly affected by the harvest age as depicted in Figure 1.

![Figure 1. Ratio of roots and shoots in dry matter at different harvest ages.](image)

At harvest age of 7 days, the proportion of roots DM from total fodder DM is high (84%) and it decreases with the increasing age of the plant. It became 35% of the fodder DM harvested at 35 days. High proportion (70%) of roots from total fresh maize fodder harvested at 8 day was also reported by Jemimah et al. (2018). These findings signaled that roots are the major provider of fodder quality harvested at young age.

3.3. Water used efficiency

The analysis of variance found that each treatments in this experiment is very significantly affect water used efficiency (P<0.01). Data on the amount of water consumed to produce per gram fodder DM under different types of media, seed densities and harvest ages are presented in Table 3.

Table 3 shows that water used efficiency significantly increases (P<0.01) with the increasing harvest age. At harvest age of 7 days, dependent to types of media and seed densities, between 7 to 15 l of water (average of 10.2 ± 2.62 l) were consumed to produce 1 kg of maize fodder DM while at harvest age of 35 the water consumed ranged from 151 to 266 l (average of 200.2 ± 27.85 l) to produce 1 kg maize fodder DM. This suggest that extending harvest age lead to higher water consumption and moreover ineffeciency of water used.

Data in Table 3 shows that higher water used efficiency occurred at high seed densities (K200) than at low seed density (K100). Apart from consumed by the plants the water may lost due to evaporation and transpiration, especially in hot and dry environment. Water evaporation at low seed density could be higher than at high seed density. This may because the plants grow more sparsely at low seed density compared to that at higher seed densities thus, more spaces available for water to evaporate. It was also observed that larger leaves area of individual plant at low seed density may contribute to higher water losses due transpiration.
Table 3. Water consumption to produce one gram of maize fodder under different types of media, seed densities and harvest ages

<table>
<thead>
<tr>
<th>MEDIA</th>
<th>DENSITY</th>
<th>CUTTING AGE</th>
<th>W07</th>
<th>W14</th>
<th>W21</th>
<th>W28</th>
<th>W35</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>ml / g DM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>K200</td>
<td>7.10 a</td>
<td>42.23 b</td>
<td>94.99 c</td>
<td>138.43 a</td>
<td>198.48 e</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>9.07 a</td>
<td>44.01 b</td>
<td>85.22 c</td>
<td>122.24 d</td>
<td>194.70 e</td>
<td>97.77 x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>10.33 a</td>
<td>52.23 b</td>
<td>109.29 c</td>
<td>140.16 c</td>
<td>218.08 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td>K200</td>
<td>7.03 a</td>
<td>44.75 b</td>
<td>95.71 c</td>
<td>121.30 c</td>
<td>198.89 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>9.29 a</td>
<td>50.38 b</td>
<td>130.09 c</td>
<td>142.24 c</td>
<td>195.64 d</td>
<td>110.81 y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>15.20 a</td>
<td>67.22 b</td>
<td>157.78 c</td>
<td>212.26 d</td>
<td>214.34 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td>K200</td>
<td>7.73 a</td>
<td>46.59 b</td>
<td>88.19 c</td>
<td>138.95 d</td>
<td>151.44 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>8.66 a</td>
<td>49.82 b</td>
<td>97.74 c</td>
<td>122.14 c</td>
<td>177.66 e</td>
<td>91.83 x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>11.71 a</td>
<td>55.87 b</td>
<td>101.63 c</td>
<td>150.53 d</td>
<td>168.83 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M4</td>
<td>K200</td>
<td>8.02 a</td>
<td>47.30 b</td>
<td>95.67 c</td>
<td>144.00 d</td>
<td>170.27 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>13.18 a</td>
<td>60.34 b</td>
<td>114.25 c</td>
<td>167.62 d</td>
<td>202.54 e</td>
<td>106.61 y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>12.17 a</td>
<td>52.18 b</td>
<td>115.37 c</td>
<td>165.16 d</td>
<td>231.04 e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M5</td>
<td>K200</td>
<td>8.25 a</td>
<td>53.41 b</td>
<td>108.59 c</td>
<td>160.47 d</td>
<td>200.09 e</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K150</td>
<td>11.33 a</td>
<td>62.77 b</td>
<td>130.81 c</td>
<td>168.65 d</td>
<td>215.70 e</td>
<td>121.14 z</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K100</td>
<td>14.18 a</td>
<td>70.77 b</td>
<td>141.75 c</td>
<td>204.41 d</td>
<td>265.95 e</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( ^a-c \): Different superscripts on the same line show very significant differences (\( P < 0.01 \))

\( ^w-z \): Different superscripts in the AVERAGE column show very significant differences (\( P < 0.01 \))

Among the types of growing media, highest water consumption to produce 1 g fodder DM is found at M5 followed by M2 and M4. Lowest water consumption to produce a gram fodder DM and thus highest water used efficiency occurred at both the M1 and M3. The M3 solution consumption was actually higher than that at M1. However, the M3 enabled high production of fodder DM, may due to its high nutrients concentration hence the water used efficiency of M3 was similar to the M1 where water consumption and growth of the plants were lower as compared to at M3.

**CONCLUSION.**

The need for water in hydroponic maize fodder production is affected by the types of media, harvest age and seed density. Low seed density gave good DM conversion although the water used efficiency is lower than at high seed density. Delaying harvest age to produce more maize fodder DM increases the need for water, thus it is necessary to consider the economic aspect between using hydroponic and aquaponic solutions that utilize fish pond water.
REFERENCES


