

*Full Length Research Paper*

# **Water use efficiency and fodder yield of maize (*Zea mays*) and wheat (*Triticum aestivum*) under hydroponic condition as affected by sources of water and days to harvest**

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This study was conducted at Soilless Culture Unit, Azemor Agribiz Limited, Ibadan to evaluate the effects of sources of water (fish hatchery wastewater (FHW), borehole water (BW) and nutrient solution (NS)) and days to harvest (8, 10 and 12 days after sowing (DAS)) of two forage crops (maize (*Zea mays*) and wheat (*Triticum aestivum*)) for green fodder production and water use efficiency under hydroponic conditions. The experiment was conducted under average room temperatures of 25.27° and 27.92°C and humidity of 82.8% and 64% in the morning and evening, respectively. The results showed that the pH of the irrigation water samples ranged from 6.20 to 6.70 while the nitrogen and P contents varied from 0.01 - 0.02 %. Maize crop used more water efficiently on the 10 DAS using NS and wheat at 8 DAS using BW, while total water use (lt/kg fresh matter) was lowest on the 10th DAS using NS and BW to produce maize and wheat fodder, respectively. Generally both crops used less than two liters of water to produce 1 kg green fodder. A fresh yield (t ha<sup>-1</sup>) of 60.42 was recorded in maize using NS as against 58.38 recorded in wheat using BW. Dry matter yield (t ha<sup>-1</sup>), DM% of fresh fodder and green fodder (kg tray<sup>-1</sup>) were highest using NS in maize but not for wheat using NS. In conclusion maize crop can be considered the better choice for production of hydroponic green fodder with better water efficiency and yields using nutrient solution.

**Key words:** Hydroponic, days to harvest, fish hatchery wastewater, borehole water and nutrient solution, maize, wheat

## **INTRODUCTION**

Green fodder which forms an essential component and natural diet for ruminant livestock is of low quality and quantity during the dry season, leading to overall poor

performance of ruminants. Consequently, for improving livestock products, quality green fodder should be fed more often to animals (Dung et al., 2010). The natural

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pasture supplies most of the feed resources for ruminants. As the gap between the demand and supply of green fodder for ruminant livestock increases, an alternative complementing fodder production method that would enhance fodder and livestock production is hydroponics.

A hydroponic system can be used for green fodder production of many forage crops in a clean environment free from chemical substances including but not limited to insecticide, herbicides, fungicides, and artificial growth enhancers (Tudor et al., 2003; Al-Hashmi, 2008). The technique guarantees high fodder yield, year round production and least water demand (Cuddeford, 1989; Al-Karaki, 2011). Unlike conventional fodder production system that use run-to-waste irrigation practices, recirculation system is used in the hydroponic fodder production, therefore decreasing the waste of water. Tudor et al. (2003) reported that hydroponic fodder production needs only about 2-3% of that water used under field conditions to produce the same amount of fodder. Under this system, fodder can be produced within a short growth period 7 to 10 days, on a small piece of land. Fodder produced is of a high quality, higher in proteins, fiber, vitamins, and minerals. These aforementioned exceptional characteristics of hydroponic system, in addition to others make it one of the most important techniques currently in use for green forage production in many countries especially in arid and semiarid regions of the world. Therefore, the objectives of this study were to evaluate fodder yield and water use efficiency of maize (*Z. mays*) and wheat (*T. aestivum*) under hydroponic condition as affected by sources of water and days to harvest.

## MATERIALS AND METHODS

### Experimental site

The experiment was conducted in the Hydroponic Fodder Unit of Azemor Agribiz Ltd, KM 15, Ibadan-Ife Expressway, Ibadan, Nigeria located on latitude 7.38°N and longitude 3.95°E. Ibadan has a tropical wet and dry climate, with a lengthy wet season and relatively constant temperatures throughout the course of the year. The wet season runs from March through October, with rainfall peak in August. This peak nearly divides the wet season into two different wet seasons. November to February forms the dry season in the city, during which Ibadan experiences the typical West African harmattan wind. The mean total rainfall for Ibadan is 1420.06 mm, falling in approximately 109 days. There are two peaks for rainfall, June and September. The mean minimum and maximum temperatures were 21.42 and 26.46°C, respectively, while the relative humidity was 74.55% (Wikipedia, 2017).

### The hydroponic system

The hydroponic fodder system consists of an enclosure made of planks covered with mesh net (2 mm) and mosquito net to prevent rodents and insects, respectively as well as allowing cross ventilation. The length, breadth and height of the house were 930, 960 and 240 cm, respectively. The roof was made of white translucent polyethylene materials which only permit the light

penetration and not the sun rays thereby providing the needed light for photosynthetic activities as well as reducing the heat absorption thus supporting enabling conditions for seed germination, growth and development. The house has a dwarf wall of 1.5 m made of bricks, plastered with strong concrete floor.

The house consist of sixteen units of metal shelves (coated with aluminum to prevent rusting) each 140 cm in length, a width of 92 cm, and a height of 220 cm (Plate 1). Each shelf was divided into five layers at 30 cm interval, each layer accommodated five trays; thus each shelf contained 25 trays making a total of 400 trays in the hydroponic system. Each of the trays made of aluminum material was 108.3 cm in length, a width of 26 cm, and a depth of 5 cm. The trays were perforated at the bottom to allow for dropping of water from the upper trays to the lower ones. This did not only reduce stress during watering but also prevented waterlogging. The 400 trays can produce approximately 2,400 kg of green fodder per growth cycle (8 – 10 days), depending on crop, variety, and growth conditions with a minimum of 6 kg seed per tray. By estimation, a total of 60,000 kg of green fodder was attainable per year at 25 growth cycle/year. The experiment was conducted under absolute ambient climatic conditions.

### Plant material

Two fodder crops were evaluated in this trial: Maize (*Z. mays*) and wheat (*T. aestivum*). Seeds of these crops were obtained from ACE Feed Mill in Ibadan. The seeds were subjected to germination (by placing the seeds on moist cotton-wool) test to check for their viability before sowing.

### Irrigation water

Three sources of irrigation water were used in this trial. These were: fish hatchery wastewater (FHW), nutrient solution (NS) and borehole water (BW). Fish hatchery wastewater was sourced from the main hatchery located beside the hydroponic building. Nutrient solution was constituted using 'BIC Concept' hydroponic liquid solution A and B at 1 and 2.5 mL<sup>-1</sup>, respectively. Borehole water was obtained from the main water source of the farm. The borehole water is safe for drinking and used for the fish culture without any recorded detrimental effect, hence it can be concluded to be free from harmful minerals.

### Treatment of seeds before planting

Seeds of maize and wheat were cleaned from debris and other foreign materials and weighed. The seeds were sterilized by soaking for 30 min in a 20% sodium hypochlorite solution (household bleach) to control the formation of mould. Planting trays were also cleaned and disinfected. The seeds were thoroughly washed from residues of the bleach and re-soaked overnight (about 12 h) in borehole water before sowing.

### Seed sowing and irrigation

Trial seeds of the two crops were sown in the planting trays, which were lined with aluminum sheets and perforated at the bottom to allow for drainage of excess water during irrigation. The seeding rate used in this experiment was 2 kg seed tray<sup>-1</sup>. This rate was based on the size and weight of the seeds. The trays were labeled accordingly and stacked on the shelves. Treatments meant for the same irrigation water (but of different days to harvest) were randomly stacked together on the same shelf. Trays were irrigated



**Plate 1.** The shelves and the trays used for hydroponic fodder production.

manually with experimental water (allotted to each treatment) twice daily (7.00 am and 7.00 pm) at a fixed rate of  $600 \text{ mL tray}^{-1} \text{ day}^{-1}$  which was enough to keep the seeds/seedlings moist.

#### Nutrient composition of the irrigation water

Water from the three sources was analyzed for the type and quantity of the nutrient present in each of them. In addition, the pH of the water was measured daily and recorded.

#### Experimental design and procedure

This experiment involved two fodder crop species namely: Maize (*Z. mays*), and wheat (*T. aestivum*), three sources of irrigation water: fish hatchery wastewater (FHW), nutrient solution (NS) and borehole water (BW); and three days to harvest: 8, 10 and 12 days after sowing (DAS). The experiment was therefore a  $2 \times 3 \times 3$  factorial. The treatments in trays were randomly arranged on the shelf and well labeled. Each treatment was in five replicates; hence 90 aluminum trays were used in this trial.

#### Data collection

The experiment was terminated at 8, 10 and 12 DAS when the fodder was ready for harvest. At harvest, the entire mat of the fodder (comprising the root and the green leaves) was lifted and removed from the tray. At each harvest, fresh yield from each tray was weighed in kg and used to extrapolate for the fresh yield in tons per hectare. A representative fresh fodder sub-sample (300 g) from each tray was taken for the evaluation of the parameters listed below:

**Total green and dead fodder yields:** The representative green fodder sub-sample (300 g) taken from each tray was separated into the dead/yellow (if any) and green fodder. Each unit was weighed, recorded, and packaged separately in labeled appropriate envelopes. The summation of the two sub-units amounted to the total biomass yield per tray/treatment.

$$\% \text{ Green fodder proportion} = \frac{\text{fresh fodder weight}}{\text{weight of sub - sample}} \times 100$$

$$\% \text{ Dead fodder proportion} = \frac{\text{dry fodder weight}}{\text{weight of sub - sample}} \times 100$$

**Total water use and water use efficiency:** Total quantities of water added and drained from each tray throughout the course of experiment were recorded daily to compute the total volume of water use and water use efficiency. The total volume of water used by plants (liters/tray) was computed according to the equation:

$$\text{Total volume of water used} = \text{Total volume of water added in irrigation} - \text{Total volume of water drained from the trays}$$

At each watering, a known quantity of water was used to irrigate the seeds. The water drained from each tray was collected in an empty tray placed directly under each planting tray, measured, and recorded to compute for total water use and water use efficiency.

Water use efficiency (WUE) was computed according to the equation:

$$WUE = \frac{\text{Total green fodder produced (kg/tray)}}{\text{total water used (liter/tray)}}$$

#### Statistical analysis

All data were subjected to two-way analysis of variance (ANOVA) in a Randomized Complete Block Design (RCBD) using statistical package SAS, 2012 version 9.4 while significant means were separated and compared using Duncan's Multiple Range Test (Duncan, 1955) at 5% level of significance.

#### Experimental model

$$Y_{ij} = \mu + T_i + G_j + (TG)_{ij} + \sum_{ij}$$

**Table 1.** pH and mineral composition of different sources of irrigation water.

Parameter	Borehole water	Nutrient solution	Fish hatchery wastewater
pH	6.40	6.20	6.70
% N	0.01	0.02	0.01
P (mg kg <sup>-1</sup> )	0.01	0.01	0.02
K (mg kg <sup>-1</sup> )	23.50	558.43	60.13
Ca (mg kg <sup>-1</sup> )	6.40	230.46	8.50
Mg (mg kg <sup>-1</sup> )	14.07	18.50	19.10
Mn (mg kg <sup>-1</sup> )	0.07	3.00	0.17
Fe (mg kg <sup>-1</sup> )	6.56	12.90	7.50
Cu (mg kg <sup>-1</sup> )	0.56	0.34	1.32
Zn (mg kg <sup>-1</sup> )	3.91	2.00	0.25

$\mu$  = Population mean;  $T_i$  = Main effects of the water source (A);  $G_j$  = Main effects of the days to harvest (B);  $(TG)_{ij}$  = A x B interaction effect;  $\sum_{ij}$  = Random error

## RESULTS

The pH and mineral composition of the three sources of irrigation water at the beginning of the trial are shown in Table 1. The pH of the water samples ranged from 6.20 to 6.70 while the nitrogen and P contents varied from 0.01 - 0.02%. Nutrient solution (NS) had higher composition of K, Ca, Mn and Fe than the other sources of water.

The effects of sources of water and days to harvesting on water use efficiency (WUE) in producing a unit of a kilogram of fresh maize fodder was highest ( $P < 0.05$ ) from fodder irrigated with NS and harvested at 10 DAS (18.09 kg/lt). Similar WUE values were observed from fodder harvested at 8 and 10 DAS with borehole water (Table 2). Total water used (lt/kg fresh matter) was lowest at 10 DAS with NS. The results showed that total water used to produce 1 kg green fodder and quantity of water used per tray was not affected by the sources of water and day to harvest ( $P > 0.05$ ). The effects of the two factors on WUE in producing a kilogram of green fodder were at the maximum ( $P < 0.05$ ) level 10 DAS using borehole water. This was similar to the value recorded using FHW and harvested 8 DAS (Table 3). In addition, the least total water use (0.89 lt./kg fresh matter) was recorded from treatment with borehole water harvested 10 DAS. Nevertheless, the values were similar for the water treatments as the days to harvest increased.

Irrigating maize with NS and harvesting at 10 DAS had the highest fresh yield (60.42 t ha<sup>-1</sup>), dry matter yield (39.68 t ha<sup>-1</sup>) and green fodder (4.66 kg tray<sup>-1</sup>) (Table 4). The least dry matter yields (32.93 – 34.33 t ha<sup>-1</sup>) were recorded from fodder irrigated with NS (12 DAS), borehole water (12 DAS) and FHW (8, 10 DAS). The highest percentage DM of fresh fodder was recorded from fodder irrigated with NS harvested at 12 DAS and

borehole water harvested at 10 and 12 DAS. The least percentage DM of fresh matter was from fodder irrigated with NS, harvested at 8 DAS (31.11%), borehole water, harvested at 8 DAS (31.74%) and using FHW harvested at 12 DAS (31.67%).

Effects of sources of water and days to harvest on the fresh yields, DMY and proportion of green fodder of wheat are shown in Table 5. The highest ( $P < 0.05$ ) fresh yield was recorded from fodder treated with borehole water and harvested at 10 DAS (58.38 kg/ha). This was not significantly different from yield obtained using FHW and harvested 8 DAS (58.33 kg/ha). The least fresh yield (44.57 kg/ha) was recorded 12 DAS using NS as the source of water. The highest dry matter yields were from fodders treated with FHW and harvested 8 and 12 DAS, and using borehole water but harvested 10 DAS. The least yield was from fodder treated with NS and harvested at 12 DAS.

## DISCUSSION

The pH of the three sources of water used for producing fodder from maize and wheat seeds indicated that they were close to neutral with a range of 6.20 – 6.70. The higher proportions of Ca, K, Mg, Mn and Fe in nutrient solution (NS) than in borehole water and fish hatchery wastewater (FHW) was a clear indication that NS was synonymous to a liquid fertilizer, hence it contained minerals for plant growth and development. Marschner (1995) proposed that in hydroponic systems, plant productivity was closely related to nutrient uptake and the pH regulation. The pH of the nutrient solution and borehole water used in this study were within the range of 5.5 and 6.5 recommended by Resh (2004) for the development of crops.

Water is very important for seed germination and seedling growth as it is essential for enzyme activation, reserve storage breakdown and translocation (Copeland and McDonald, 1995). Water use efficiency (WUE) was highest 10 DAS for the production of maize fodder with

**Table 2.** Effects of sources of water and day to harvest on water utilization of maize fodder.

Parameter	Nutrient solution			Borehole water			Fish Hatchery wastewater			SEM
	8	10	12	8	10	12	8	10	12	
Water use efficiency (kg fresh matter/lt.)	14.19 <sup>b</sup>	18.09 <sup>a</sup>	14.51 <sup>b</sup>	15.57 <sup>ab</sup>	16.22 <sup>ab</sup>	14.60 <sup>b</sup>	13.74 <sup>b</sup>	14.91 <sup>b</sup>	14.66 <sup>b</sup>	5.74
Total water use (lt./kg fresh matter)	1.17 <sup>b</sup>	1.07 <sup>c</sup>	1.13 <sup>b</sup>	1.21 <sup>a</sup>	1.26 <sup>a</sup>	1.13 <sup>b</sup>	1.14 <sup>b</sup>	1.16 <sup>b</sup>	1.14 <sup>b</sup>	0.01
Total water use (liter/tray)	3.70	3.34	3.50	3.50	3.40	3.50	3.66	3.45	3.60	0.10

<sup>a,b,c</sup>: means on the same row with different superscripts are significantly varied ( $P < 0.05$ ); SEM = Standard error of mean.

**Table 3.** Effects of sources of water and days to harvest on water utilization of wheat fodder.

Parameter	Nutrient solution			Borehole water			Fish hatchery wastewater			SEM
	8	10	12	8	10	12	8	10	12	
Water use efficiency (kg fresh matter/lt.)	13.48 <sup>bc</sup>	12.54 <sup>cd</sup>	11.43 <sup>d</sup>	12.74 <sup>cd</sup>	15.40 <sup>a</sup>	13.21 <sup>bc</sup>	15.35 <sup>a</sup>	12.88 <sup>cd</sup>	14.43 <sup>ab</sup>	1.06
Total water use (lt./kg fresh matter)	1.05 <sup>bc</sup>	1.19 <sup>a</sup>	1.11 <sup>ab</sup>	0.99 <sup>cd</sup>	0.89 <sup>d</sup>	1.03 <sup>bc</sup>	0.91 <sup>d</sup>	1.00 <sup>cd</sup>	1.12 <sup>ab</sup>	0.01
Total water use (liter/tray)	3.96 <sup>ab</sup>	3.88 <sup>ab</sup>	3.90 <sup>ab</sup>	3.98 <sup>ab</sup>	3.79 <sup>b</sup>	3.88 <sup>ab</sup>	3.80 <sup>b</sup>	3.83 <sup>b</sup>	3.82 <sup>b</sup>	0.02

<sup>a,b,c,d</sup>: means on the same row with different superscripts are significantly varied ( $P < 0.05$ ); SEM = Standard error of mean.

**Table 4.** Effects of sources of water and days to harvest on the fresh and dry matter yields and proportions of green and dead maize fodder.

Parameter	Nutrient solution			Borehole water			Fish hatchery wastewater			SEM
	8	10	12	8	10	12	8	10	12	
Fresh yield (t ha <sup>-1</sup> )	52.55 <sup>b</sup>	60.42 <sup>a</sup>	50.78 <sup>b</sup>	54.49 <sup>b</sup>	55.14 <sup>b</sup>	51.10 <sup>b</sup>	50.28 <sup>b</sup>	51.43 <sup>b</sup>	52.77 <sup>b</sup>	16.51
Dry matter yield (t ha <sup>-1</sup> )	36.20 <sup>b</sup>	39.68 <sup>a</sup>	32.93 <sup>c</sup>	36.93 <sup>b</sup>	35.83 <sup>b</sup>	33.95 <sup>b</sup>	33.22 <sup>b</sup>	34.33 <sup>b</sup>	35.91 <sup>b</sup>	2.20
DM% of fresh fodder	31.11 <sup>b</sup>	33.89 <sup>ab</sup>	35.11 <sup>a</sup>	31.74 <sup>b</sup>	35.21 <sup>a</sup>	34.10 <sup>a</sup>	33.86 <sup>ab</sup>	33.20 <sup>ab</sup>	31.67 <sup>b</sup>	7.17
Green fodder (kg tray <sup>-1</sup> )	4.08 <sup>ab</sup>	4.66 <sup>a</sup>	3.94 <sup>b</sup>	4.20 <sup>b</sup>	4.29 <sup>ab</sup>	4.00 <sup>b</sup>	3.90 <sup>b</sup>	3.99 <sup>b</sup>	4.08 <sup>b</sup>	6.10
Green fodder proportion (%)	100	100	98.7	100	100	99	100	100	99.1	22.01
Dead fodder proportion (%)	0	0	1.3	0	0	.01	0	0	0.9	0.00

<sup>a,b,c</sup>: means on the same row with different superscripts are significantly varied ( $P < 0.05$ ); SEM = Standard error of mean.

**Table 5.** Effects of sources of water and days to harvest on the fresh and dry matter yields and proportions of green and dead wheat fodder.

Parameter	Nutrient solution			Borehole water			Fish hatchery wastewater			SEM
	8	10	12	8	10	12	8	10	12	
Fresh yield (t ha <sup>-1</sup> )	53.38 <sup>bc</sup>	48.66 <sup>cd</sup>	44.57 <sup>d</sup>	50.71 <sup>bc</sup>	58.38 <sup>a</sup>	51.25 <sup>bc</sup>	58.33 <sup>a</sup>	49.33 <sup>cd</sup>	55.12 <sup>ab</sup>	14.11
Dry matter yield (t ha <sup>-1</sup> )	36.70 <sup>b</sup>	32.25 <sup>c</sup>	28.85 <sup>d</sup>	34.06 <sup>b</sup>	37.06 <sup>a</sup>	33.25 <sup>c</sup>	37.28 <sup>a</sup>	32.89 <sup>c</sup>	37.64 <sup>a</sup>	2.54
DM % of fresh fodder	1.14 <sup>abc</sup>	3.78 <sup>cd</sup>	3.46 <sup>d</sup>	3.92 <sup>bc</sup>	4.51 <sup>a</sup>	3.98 <sup>bc</sup>	4.52 <sup>a</sup>	3.82 <sup>cd</sup>	4.28 <sup>ab</sup>	0.08
Green fodder (kg tray <sup>-1</sup> )	100.00	100.00	98.70	100.00	100.00	99.00	100.00	100.00	99.10	2.12
Proportion of green fodder (%)	0.00	0.00	1.30	0.00	0.00	0.01	0.00	0.00	0.90	0.00

<sup>a,b,c,d</sup>: means on the same row with different superscripts are significantly varied ( $P < 0.05$ ); SEM = Standard error of mean.

NS and at 8 DAS for wheat fodder using borehole water. At these sources of water and days to harvest, maize and wheat used a total of 1.07 and 0.89 lt/kg fresh yield, respectively. Both maize and wheat seeds used 1.0 – 1.2 L of irrigation water to produce one kilogram of fresh fodder which was lower than 1.80, 1.55 and 1.58 L

reported for wheat, barley, and cowpea by Ghazi et al. (2012). The higher quantity of water required by maize than wheat to produce same fresh fodder could be as a result of the bigger size of maize which necessitated the need for more water (solution) for the needed metabolic activities and seed softening during germination and

development. This report agreed with the findings of Al-Karaki and Al-Momani (2011) that producing green fodders under hydroponic conditions is a highly efficient process in terms of water saving compared to field production of green fodders. Thus, this technique will reduce the cost of irrigation of fodder and thereby, increasing profit maximization, as well as promoting fodder production in the dry season and regions where water is scarce. Total water use (lt/kg fresh matter) was lowest on the 10th DAS using NS and borehole water to produce maize and wheat fodder, respectively. This indicated that the peak of water utilization was at 10 DAS. Up till this day, the crops used less water for metabolic activities.

The use of NS for production of fodder was optimal ( $P < 0.05$ ) for maize but not for wheat despite the higher nutrient composition in it than borehole water and FHW. Dry matter yields of wheat and maize when harvested 8 and 10 DAS, respectively were higher than at other period. However, according to Jeton (2016), the maximum fresh yield of 60.02 and 58.22 t ha<sup>-1</sup> recorded from maize and wheat fodders, respectively will be enough to feed 13 -15 cattle daily with an average body weight of 300 – 400 kg and 140 -150 sheep with an average body weight of 25 -35 kg. The fresh yield of 58 - 60 t ha<sup>-1</sup> recorded in this study was similar with the result of Al-Karaki (2011) who recorded fresh yield of 56.0 t ha<sup>-1</sup> from barley grown hydroponically under irrigation with borehole water. A fresh yield of 8-10 kg from one kg of locally grown maize seeds in 7-10 days was reported from farmers producing hydroponics maize fodder under low-cost greenhouses devices in India (Naik et al., 2013). Al-Karaki and Al-Hashimi (2012) recorded average green forage yields of 217, 200, 194, 145 and 131 t ha<sup>-1</sup> for one production cycle (8 days), for cowpea, barley, alfalfa, sorghum and wheat, respectively. Genotypic variations in forage yields have been reported for different cereal and legume crops (Ansar et al., 2010). Factors that can influence the fresh yield and DM content of the hydroponics fodder included the type of crops, days to harvesting, degree of drainage of free water prior to weighing, type and quality of seed, seed rate, seed treatment, water quality, pH, irrigation frequencies, nutrient solution used, light, growing period, temperature, humidity, clean and hygienic condition of the greenhouse. Downward trend in maize and wheat fodder yields was observed after day 10, signifying cessation in growth and development. Day 10 seems to be the best day to harvest maize fodder under hydroponic conditions. This could not be inferred in this study with respect to production of wheat fodder through hydroponics.

## Conclusion

(i) Under hydroponic system, production of green fodder (44-60 t/ha) can be achieved within 8 to 12 days from seeds of maize and wheat using nutrient solution,

borehole water and fish hatchery wastewater as sources of water.

(ii) Less fish hatchery wastewater and nutrient solution was used to produce 1 kg of fresh maize and wheat fodder, respectively. Both crops required less than two liters of water to produce 1 kg of green fodder, hence production of fodder from hydroponic system requires small quantity of water, and will support fodder production where and when there is water scarcity.

(iii) Fodder yields were averagely higher when irrigated with nutrient solution in maize and when irrigated with borehole water and fish hatchery wastewater in wheat at 10 to 12 days after sowing. Hence, 10 DAS is considered the best time to harvest fodder from both crops under hydroponic conditions using NS for maize, and borehole water or FHW for wheat.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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## REFERENCES

- Al-Hashmi C (2008). *Hydroponic green fodder production in the Arabian Gulf Region*, M.S. thesis, Faculty of Graduate Studies, Arabian Gulf University, Manama, Bahrain.
- Al-Karaki GN (2011). Utilization of treated wastewater for green forage production in a hydroponic system. *Emirates Journal of Food and Agriculture* 23:80-94.
- Al-Karaki GN, Al-Momani N (2011). Evaluation of some barley cultivars for green fodder production and water use efficiency under hydroponic conditions. *Jordan Journal of Agricultural Sciences* 7:3.
- Al-Karaki GN, Al-Hashimi M (2012). Green fodder production and water use efficiency of some forage crops under hydroponic condition. *International Scholarly Research Network* P. 3.
- Ansar M, Ahmed ZI, Malik MA, Nadeem M, Majeed A, Rischkowsky BA (2010). Forage yield and quality potential of winter cereal-vetch mixtures under rainfed conditions. *Emirates Journal of Food and Agriculture* 22:25-36.
- Cuddeford D (1989). Hydroponic grass. In *Practice* 11:211-214.
- Copeland OL, McDonald MB (1995). *Seed Science and Technology*, Chapman and Hall, New York, NY, USA, 3rd edition.
- Duncan DB (1955). Multiple Range and F-test. *Biometrics* 11:1-42.
- Dung DD, Godwin IR, Nolan JV (2010). Nutrient content and *in sacco* degradation of hydroponic barley sprouts grown using nutrient solution or borehole water. *Journal of Animal and Veterinary Advance* 9 (18):2432-2436.
- Ghazi N, Al-Karaki I, Al-Hashimi M (2012). Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholar Research Network ISRN. Agronomy* 12 p.
- Jeton S (2016). Hydroponic fodder production. 'Feed the future programme' of US Government global hunger and food security

- initiative in Ethiopia sponsored by USAID. <https://www.prime-ethiopia.org/wp-content/uploads/2016/06/Fast%20Fodder%20Manual%20portrait-fnl.pdf>
- Marschner H (1995). Mineral Nutrition of Higher Plants, Academic Press, ISBN 0-12-473542-8, New York, USA.
- Naik PK, Dhuri RB, Karunakaran M, Swain BK, Singh NP (2013). Hydroponics technology for green fodder production. *Indian Dairyman* 65:54-58.
- Resh HM (2004). Hydroponic Food Production, New concept Press, Inc., ISBN-10: 093123199X, Mahwah, NJ., USA.
- SAS Institute Inc. (2012). SAS/STAT Guide for personal Computer. Version 10<sup>th</sup> ed. Cary, North Carolina, USA.
- Tudor G, Darcy T, Smith P, Shallcross F (2003). The intake and live weight change of drought master steers fed hydroponically grown young sprouted barley fodder (Autograss). Department of Agriculture, Western Australia.