STANDARDIZATION OF HYDROPONICS FODDER PRODUCTION TECHNOLOGY

by

SRUTHI LIZ THOMAS
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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"STANDARDIZATION OF HYDROPONICS FODDER PRODUCTION TECHNOLOGY"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship or other similar title, of any other University or Society.

Vellayani,
Date : 02-09-2019

SRUTHI LIZ THOMAS
(2017-11-054)

CERTIFICATE

Certified that this thesis entitled **"STANDARDIZATION OF HYDROPONICS FODDER PRODUCTION TECHNOLOGY"** is a record of research work done independently by Ms. SRUTHI LIZ THOMAS under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani,
Date: 02-09-2019

Dr. Usha C Thomas
(Major Advisor, Advisory Committee)
Assistant Professor (Agronomy)
AICRP on Forage Crops and Utilization
College of Agriculture
Vellayani, Thiruvananthapuram

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CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. SRUTHI LIZ THOMAS** a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that the thesis entitled **"STANDARDIZATION OF HYDROPONICS FODDER PRODUCTION TECHNOLOGY"** may be submitted by Ms. SRUTHI LIZ THOMAS in partial fulfilment of the requirement for the degree.

Dr. Usha C Thomas
(Chairman, Advisory Committee)
Assistant Professor (Agronomy)
AICRP on Forage Crops and Utilization
College of Agriculture,
Vellayani, Thiruvananthapuram

Dr. O. Kumari Swadija
(Member, Advisory Committee)
Professor (Agronomy) and Head
Department of Agronomy
College of Agriculture,
Vellayani, Thiruvananthapuram

Dr. Mareen Abraham
(Member, Advisory Committee)
Professor (Plant Breeding and Genetics)
College of Agriculture
Vellayani, Thiruvananthapuram

Dr. Jacob John
(Member, Advisory Committee)
Professor and Head
Integrated Farming System Research Station
Karamana, Thiruvananthapuram

Dr. Dhalin D.
(Member, Advisory Committee)
Assistant Professor (Agricultural Engineering)
College of Agriculture,
Vellayani, Thiruvananthapuram

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ADF	Acid detergent fibre
B: C ratio	Benefit cost ratio
CD (0.05)	Critical difference at 5 % level
cm	Centi meter
CRD	Completely randomized block design
DAP	Di ammonium phosphate
DFY	Dry fodder yield
EE	Ether extract
et al.	Co-workers/ Co-authors
Fig.	Figure
g	Gram
g^{-1}	Per gram
g ft^{-2}	Gram per square feet
GFY	Green fodder yield
GDP	Gross domestic product
ha	Hectare
ha^{-1}	Per hectare
K	Potassium
KCl	Potassium chloride
kg	Kilogram
kg^{-1}	Per kilogram
kg kg^{-1}	Kilogram per kilogram
kg m^{-2}	Kilogram per square meter
L	Litre
m^{2}	Square metre
mg	Milligram
mm	Millimetre

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mL	Millilitre
mt	Million tonne
N	Nitrogen
$NH_4H_2PO_4$	Ammonium dihydrogen phosphate
NS	Not significant
No.	Number
NDF	Neutral detergent fibre
SEm	Standard error of mean
viz.,	Namely

LIST OF SYMBOLS

%	Per cent
@	at the rate of
°C	Degree Celsius
₹	Rupee

Introduction

1. INTRODUCTION

India is basically an agricultural country with 2/3rd of rural population depending on it for their livelihood. Livestock is the sub-sector of agriculture which contributes about 4.5 per cent to total Gross Domestic Product (GDP) and 25.8 per cent to the agriculture GDP (GOI, 2017). Livestock plays an imperative role in nutritional security, particularly of small and marginal farmers. But productivity of our animals is 20 to 60 per cent lower than the global average due to improper nutrition, inadequate health-care and management. Among the responsible factors for the low productivity, feed and fodder deficiency is the major factor contributing 50 per cent to this cause. Being the leader in cattle and buffalo population and livestock population increasing every year, current fodder production in our country is not able to meet the requirement of fodder. At present the country faces a deficit of 63.5 per cent green fodder and 23.5 per cent dry crop residues. If the present situation continues deficit will increase to 65.45 per cent in 2030 (IGFRI, 2013). The cultivated area under fodder in Kerala is only 5570 ha. The fodder requirement in the state is 232 m t whereas the availability is only 94.5 m t and deficit of nearly 60 per cent (137.5 m t) (GOK, 2018).

For sustainable dairy farming, quality green fodder which is an essential component of ration for dairy cattle should be fed regularly. Unfortunately, scope for further expansion of fodder cultivation area is low because of pressure on agriculture land for food and cash crops. Other constraints like more labour requirement, more growth time (approximately 45 to 60 days), non-availability of same quality fodder round the year, uncertain rainfall, requirement of manure and fertiliser, scarcity of water etc. in conventional fodder production system would further aggravate the gap in requirement and availability of quality fodder.

As the gap between the demand and supply of green fodder is becoming wide, researchers and farmers are in search of an alternative fodder or fodder production method. In this juncture, hydroponics is an emerging technology that has revolutionized the green fodder production in the 21st century (Tudor *et al.*, 2003). Fodder produced by growing plants in water or nutrient rich solution but without using any soil is known as hydroponics fodder or sprouted grains or sprouted fodder. (Dung *et al.,* 2010a). Hydroponics techniques have proven useful and efficient for producing food for livestock. Fodder is grown year round under controlled climatic condition and it is rich in minerals, proteins, amino acids and vital nutrients. Fodder is free of diseases, residues of pesticides or chemicals and organic in nature. It improves the health, productivity, fertility and longevity of all livestock, and saves land, water and labour (Khanna, 2014).

There are many types of grain that can be grown hydroponically. Grain such as oats, barley, wheat, sorghum and corn have all been tried. According to Jemimah *et al.* (2015), crops *viz.*, maize, barley, oats, finger millet, bajra, sorghum, foxtail millet, rye, triticale, alfalfa, cowpea, horsegram and sun hemp can be grown successfully under hydroponics as fodder. Fodder maize and grain maize among the cereals and also grain cowpea and horsegram among the legumes were identified as better performing crops under hydroponic fodder production system for getting higher green fodder yield (GFY) and quality with reasonable cost (Jolad, 2018).

Optimum seed rate and period of harvest are primary aspects in the agro-techniques of hydroponic fodder production, as the productivity, profitability and quality are associated with it. It is necessitated to select suitable fodder crops for hydroponics system as well as to standardise seed rate and period of harvest for good quality fodder production.

Hydroponics fodder can be produced with the use of fresh water and the use of nutrient rich solution is not obligatory. The added expenses of the nutrient solution also do not justify its use, unless there is significant improvement in the feeding value of the hydroponics fodder due to the use of the nutrient solution. In hydroponic systems, nutrients are provided in the form of nutrient solution at regular interval. This nutrient solution is an aqueous solution containing mainly inorganics ions from soluble salts of essential elements which are required for the growth and development.

Although, the hydroponic technology is practised by some progressive farmers, the scientific data base on standard agro-techniques is meagre. With this background, the study was undertaken with the following objectives:

- To identify suitable fodder crops for hydroponics system
- To standardize nutrient solution, seed rate and period for harvest.

Review of Literature

2. REVIEW OF LITERATURE

India is basically an agricultural country and livestock plays an important role for nutritional and livelihood security of small and marginal farmers. In Indian livestock farming, scarcity of feed and fodder has been the main restrictive factor in improving the livestock production and reproduction efficiencies (Birthal and Jha, 2005).It has become very difficult to get year round supply of quality green fodder considering urbanisation, unavailability of land and labour, climatic changes, scarcity of water etc.(Naik *et al*., 2014).

In these circumstances, alternative methods of fodder production will pave the way for achieving an increase in fodder production in a sustained manner. One such alternative is hydroponic fodder production which provides the year round supply of fresh green fodder with minimal use of land, labour, water and space (Naik and Singh, 2013).It has been reported that to produce the same amount of fodder, hydroponic fodder production requires only about 2 to 3 per cent of that water used under field conditions. Fodder produced hydroponically is of a short growth period of 7 to 10 days and does not require high quality arable land for production to take place, but only a small piece of land. It is of a high feed quality, rich with proteins, fibre, vitamins, and minerals (Khanna, 2014).

Tudor *et al*. (2003) stated that hydroponics fodder production is a well known technique for high fodder yield, year round production and least water consumption. Jemimah *et al.* (2015) also stated that hydroponic fodder production is a boon for farmers whose soil is rocky and infertile and it is found to be a viable farmer friendly alternative technology for landless farmers for fodder production.

Hydroponic fodder is produced in greenhouses under controlled environment within a short period (Sneath and McIntosh, 2003). The greenhouse for the production of hydroponics fodder can be of hi-tech greenhouse type or low cost greenhouse type as per the financial status of the farmer and availability of building material. The Indian Institute of Technology, Kharagpur developed a low cost hydroponic system in a room of which two walls were made up of bricks, while the other two sides (north-south) had double glazed glass windows, which permitted sunlight to get through, but prevented a rise in temperature inside the hydroponic system (Sinsinwar *et al.,* 2012). According to Reddy (2014), any type of shelter, garage, basement, room or low density plastic sheets, greenhouse or poly hut with solid floor of compacted earth, concrete, cobblestone etc. where the temperature, humidity and light can be controlled are used for hydroponic fodder production.

As studies on fodder production through hydroponic technology were very scanty in India, an attempt was made to identify the suitable crops, seed rate, period of harvest and nutrient management strategy for enhancing the fodder yield under hydroponics. The few available already published research works relevant to the topic are reviewed in this chapter.

2.1 SUITABLE CROPS FOR HYDROPONIC FODDER PRODUCTION

Different types of fodder crops *viz*., barley, oats, wheat, sorghum, alfalfa, cowpea and maize can be produced by hydroponics technology. Peer and Leeson (1985) stated that barley can be established as a superior crop under protective condition as it produce higher green fodder and dry matter yield when compared to other crops. Rule *et al.* (1986) recommended wheat crop for hydroponic fodder production due to its high vigour and higher GFY. Reddy *et al.* (1988) confirmed that barley can be grown successfully under hydroponics as a fodder crop. Al-Karaki and Al-Hashimi (2012) studied the green fodder production and water use efficiency of some forage crops under hydroponics condition. They observed that among different crops, cowpea recorded highest green fresh yield and it was followed by barley, alfalfa, sorghum and wheat. Naik *et al.* (2012) conducted a detailed study in hydroponic fodder cultivation under the scheme Rashtriya Krishi Vikas Yojana (RKVY), Govt. of India. Based on the experimental findings, they concluded that fodder maize was found to be well suited crop under hydroponics due to its adaptability and higher GFY.

Heins *et al.* (2015) tested the suitability of temperate seeds viz., barley, oats, rye, triticale and wheat for hydroponic fodder production system and they concluded that barley has recorded strikingly higher green forage yield and found to be superior among temperate seeds. According to Naik *et al.* (2015), maize was found to be the grain of choice for production of hydroponic fodder due to its easy availability, lower cost of seeds, good biomass production and quick growing habit. High digestibility and fermentability of mung bean indicated it could be utilized as dairy feed (Zahera *et al.,* 2015). Ansari (2016) concluded maize followed by barely were economical for hydroponic fodder production based on cost of seed and yield of fodder.

2.2 GROWTH OF DIFFERENT CROPS UNDER HYDROPONIC FODDER PRODUCTION SYSTEM

Clarkson and Lane (1991) evaluated the feasibility of using hydroponically grown barley and the results revealed that barley produced good plant stand with a height of 20 to 22 cm in six to ten days. According to Bill (2002) hydroponic fodder plants attained the plant height of 25 to 30 cm within seven days and ready for harvest. A study conducted by Sneath and McIntosh (2003) revealed that starting of germination and visibility of roots varied with the type of seeds used under hydroponics. They observed that germination started one or two days after seeding and the roots were clearly visible after two and three days after seeding in maize and cowpea seeds, respectively. Hydroponically grown wheat, barley and oats grew rapidly and fairly uniformly and showed no symptom of mineral deficiency although fungal growth was evident (Snow *et al*., 2008). Based on the study, they further stated that average crop heights for wheat, barley and oats at harvest were 19.0, 25.5 and 25.2 cm, respectively. Similarly, Naik and Singh (2013) also reported that the hydroponic maize crop looked like a mat of 20 to 30 cm height consisting of germinated seeds embedded in their white roots and green shoots.

According to Al-Saadi and Al-Zubiadi (2013), barley seeds under hydroponics reached the crop height of about 16 to 18 cm height within the growth period of seven days. They also observed that it had a carpet like appearance with dark green colour shoots and thick white roots. Jolad (2018) found out that among the cereal crops, fodder maize and grain maize were recorded with significantly higher shoot and root length and in the case of legumes, higher shoot and root length were registered in grain cowpea and horsegram. All these four crops were found to be on par with each other and this was followed by fodder cowpea in recording shoot and root length.

2.3 YIELD OF DIFFERENT CROPS UNDER HYDROPONIC FODDER PRODUCTION SYSTEM

Sneath and Mcintosh (2003) observed that a higher GFY of eight to ten kg per kg of barley seed was obtained within seven to eight days under hydroponic system. Al-Ajmi *et al.* (2009) recorded a GFY of about seven to nine kg and dry matter yield of 0.9 to 1.1 kg per kg of seed with a crop height 15 to 30 cm in barley. Dung *et al.* (2010a) recorded 3.7 times increase in fresh weight of barley fodder with dry matter content of 19.7 per cent within seven days under hydroponics. Al-Karaki and Al-Hashimi (2012) found that the highest values for GFYs were recorded in cowpea followed by barley, alfalfa, sorghum, and wheat. Barley and cowpea had produced significantly higher dry fodder yield than other tested crops. However, no significant differences between cowpea and barley in dry fodder yields were noted. Fazaeli *et al.* (2012) conducted a study on yield and feed value of barley grain under hydroponics and reported that average GFY of 4.93 kg per kg of barley seed at day six and 7.21 kg per kg of barley seed at day eight. They also stated that conversion ratio based on the amount of fresh fodder produced per unit of seed used could be approximately four to eight times.

Green fodder yield of maize under hydroponics was found to be five to six folds higher on fresh basis with dry matter content of 11 to 14 per cent (Naik *et al.*, 2014). Naik *et al.* (2015) evaluated the green fodder production ability of different crops under hydroponic fodder production system. Experimental results showed that fresh yield of barley was 2.8 to 8 folds with dry matter content of 8.0 to 19.7 per cent in six to eight days and fresh yield of maize was 3.5 to 6.0 folds with dry matter content of 10.3 to 18.5 per cent in seven to eight days. An elaborative study was conducted by Naik *et al.* (2016) to assess the yield and nutrient content of hydroponic cowpea sprouts at various stages of growth. They found that GFY of hydroponically sprouted cowpea was highest at day nine (6.63 kg kg^{-1} of seed). In a study conducted by Jolad (2018), it was concluded that among the cereal crops, fodder maize recorded higher GFY of 5.48 kg kg^{-1} of seed and dry mater yield of 720.77 g kg^{-1} of seed which was on par with grain maize. Whereas, higher green fodder and dry matter yield were recorded in grain cowpea (5.29 kg kg^{-1} of seed and 692.53 g kg^{-1} of seed, respectively) and horsegram (5.24 kg kg^{-1} of seed and 689.89 g kg^{-1} of seed, respectively) among legume crops.

2.4 QUALITY OF DIFFERENT CROPS PRODUCED UNDER HYDROPONICS FODDER PRODUCTION SYSTEM

Sprouting has been used to improve the nutritional value of the grains. The nutritional value of sprouted grains is improved due to the conversion of complex compounds into relatively simpler compounds that are nutritionally more valuable. Sprouting of grains has resulted in increased protein quantity and quality. Sprouting also increases the concentration of certain nutrients including sugars, minerals and vitamin contents. However, sprouting has resulted in decreased starch content and dry matter content of grains. It also increases the plant enzyme contents (Chavan and Kadam, 1989). Sneath and McIntosh (2003) analysed the composition of sprouted barley and reported that crude protein content ranged from 11.38 to 24.9 per cent at the time of harvest. Naik *et al.* (2014) investigated the nutritional composition of conventionally grown bajra napier hybrid and hydroponics maize fodder. They obtained the conclusion that hydroponics maize fodder is highly nutritious because it contains more crude protein (13.57 %), less crude fibre (14.07 %) and less total ash (8.34 %) as against the conventional bajra napier hybrid. Concentrations of crude protein averaged 15.6 per cent and 17.9 per cent for sprouted barley and wheat, respectively. The NDF was greater for sprouted barley (34.4%) while for wheat it was 26.7 per cent

(Heins *et al.,* 2015). Mung bean sprout grows fast and contains high protein and crude fibre which are frequently deficient in dairy cow diets (Zahera *et al.,* 2015).

Gebremedhin (2015) reported that hydroponic horsegram was found to have higher crude protein content of 30.26 per cent on dry matter basis. This was followed by hydroponic maize fodder with the crude protein content of 16.5 per cent and hydroponics barley fodder with the crude protein content of 14.44 per cent. According to Naik *et al.* (2016), dry matter content of cowpea sprouts under hydroponics was the lowest (6.49 per cent) and crude protein content was highest (31.23 per cent) on ninth day of growing period. Among all the crops tested by Jolad (2018), grain cowpea and horsegram were recorded with significantly higher crude protein content. Among the cereals, considerably higher crude fibre content was recorded in fodder maize and grain maize, and in the case of legumes, fodder cowpea, grain cowpea and horsegram were registered with higher crude fibre content. Regarding ash content, significantly higher values were recorded in fodder cowpea, grain cowpea and horsegram.

2.5 EFFECT OF SEED RATE AND TIME OF HARVEST ON GROWTH OF CROPS UNDER HYDROPONIC FODDER PRODUCTION SYSTEM

Plant height was not influenced by seed density and moreover plant competition could inhibit sprout growth that was germinated in green house because of the low nutrient availability (Knochel *et al.*, 2010). Naik *et al.* (2012) realized seven to nine kg GFY with 20 to 25 cm height with 1.5 kg seed under hydroponic maize production. While El-Morsy *et al.* (2013) stated that increase in the seed density of barley would increase the shoot length and root length. Higher shoot length and root length was observed at a seed density of 1.5 cm (10 kg m^{-2}) as compared to 0.5 cm (5 kg m^{-2}). Ningoji (2018) reported that, at harvest of hydroponically grown maize, significantly higher root and shoot length was documented with 2.50 kg m^{-2} seed rate as compared to 1.50 kg m^{-2} seed rate and it was on par with 2.25 kg m^{-2}.

The growth characters like shoot and root length in sprouts grown under hydroponic system increases with advancement of growing period. Emam (2016) reported that from the first to the eighth day, the main visible change is the increase in root length and thickness.

2.6 EFFECT OF SEED RATE AND TIME OF HARVEST ON YIELD OF CROPS UNDER HYDROPONIC FODDER PRODUCTION SYSTEM

Massantini and Magnani, (1980) reported an increased total dry weight with increasing seeding rate up to 5 kg m^{-2}, but they showed that leaf to root ratio was constant with seeding upto 4 kg m^{-2} and declined rapidly with further increase in seeding rate. On the basis of total dry weight to grain weight ratio, they concluded that a seeding rate of 4 kg m^{-2} is most efficient for seedling growth and higher productivity. Morgan *et al.* (1992) studied the effect of grain rate on hydroponic fodder production. Trays sown with 2.5, 5 and 7.5 kg m^{-2} of grain was assessed for dry matter at seven days and he observed a reduction in dry matter recovery with increased grain density. Fazaeli *et al.* (2012) studied the productivity and nutritive value of barley green fodder under hydroponic system and suggested a seed rate of 4.5 kg m^{-2} as ideal to get higher fresh GFY and dry matter. El-Morsy *et al.* (2013) stated that increase in barley seed density from 0.5 cm (5 kg m^{-2}) to 1.5 cm (10 kg m^{-2}) led to significant increase in total sprouts, shoot and root fresh weight. Islam *et al.* (2016) reported that forage yield of fodder maize was significantly higher at 6.22 kg kg^{-1} seed) compared to 4.42 kg kg^{-1} seed. While, significantly higher forage yield of fodder wheat was noticed at 6.73 kg kg^{-1} seed compared to 4.3 kg kg^{-1} seed. Naik *et al.* (2017) reported that hydroponically grown maize with seed rate 5.1 kg m^{-2} recorded significantly higher total fresh yield (5.14 kg kg^{-1} seed) and leaves fresh yield (1.67 kg kg^{-1} seed) as compared to seed rate of 10.2 kg m^{-2}. But the root yield (6.86 kg kg^{-1} seed) was significantly higher with 10.2 kg m^{-2} seed rate as compared to 3.8 kg m^{-2} (2.55 kg kg^{-1} seed). Significantly higher total dry matter yield (0.68 kg kg^{-1} seed) was observed with 5.1 kg m^{-2} seed rate as compared to 10.2 kg m^{-2} seed rate. Gunasekaran *et al.* (2018) opined that hydroponically grown fodder maize has recorded significantly higher biomass yield with seed rate of 250 g sq. ft^{-1} (4.50 kg kg^{-1} seed) as compared to 100 g sq. ft^{-1} (3.60 kg kg^{-1} seed).

Sneath and McIntosh (2003) stated that 1 kilogram of seed produces six to ten kilograms of fodder and most of this gain comes from water. They saw a reduction in dry matter weight of fodder when compared to grain seed as during soaking and germination, seeds lose dry matter as they use their own energy reserves for growth. Fazeli *et al.* (2012) reported that as the growing period extended from day six to day eight, crude protein, ash, Ether Extract (EE), Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) increased in barley. The fresh yield of hydroponically sprouted cowpea increased and dry matter content (%) decreased with the advancement of growing period (Naik *et al.*, 2013). Akbag *et al.* (2014) reported that seventh day is the best harvest day, in terms of green fodder production. Naik *et al.* (2016) also observed that the fresh yield of hydroponically sprouted cowpea increased with the advancement of growing period and remained similar and highest from sixth day to ninth day growing period. Productivity of mungbean is influenced by seed conversion to fodder that is influenced by seed density (Zahera *et al.,* 2015).

2.7 EFFECT OF SEED RATE AND TIME OF HARVEST ON NUTRITIVE QUALITY OF CROPS UNDER HYDROPONIC FODDER PRODUCTION SYSTEM

Knochel *et al.* (2010) observed that enhanced seed density caused decreased nutrient conversion that could be caused by plant competition to uptake nutrient and water and this competition caused the low nutrient availability in high seed density. While, Zahera *et al.* (2015) concluded that nutrient composition of mung bean green fodder was not influenced by seed density. The seed rate had no effect on the proximate constituents of different portions i.e. roots with germinated seeds, leaves and plants of hydroponic maize fodder. The seed rate of 7.6 kgm^{-2} can be recommended for the production of hydroponics maize fodder for optimal output and all parts of the hydroponics maize fodder are nutritious (Naik *et al.,* 2017).

It is indicated that the ash content of the seeds increased during sprouting. This relatively increases due to the decrease of dry matter, in other terms the alterations are based on changing of proportion of the nutrients (Chavan and Kadam, 1989). Cell wall cellulose accumulation such NDF and ADF per cent was raised due to increasing growth stage (Hoffman *et al.*, 2003). Naik *et al*. (2012) indicated that the corn crude protein content raise following increasing harvest days. Fazeli *et al*. (2012) and Naik *et al*. (2012) in their studies reported that with the progress of harvest period, the plants cell wall components are increased. The ash content of barley was increased by the maturation. This result was in accordance with Naik *et al.* (2012). Dung *et al.* (2012) explains that the fibre content is mostly derived from root and seed husk due to the maturation process and endosperm formation with time. Total biomass and nutrient content were increased in longer harvest time. Chemical composition of hydroponically germinated fodders is changed in relation with harvest days. The fodder dry matter contents were decreased significantly by maturation of sprouts. It was determined that the dry matter content was decreased, the crude protein content was not changed significantly, cell wall contents (NDF, ADF) and ash content were increased by the maturation of the sprouts (Akbag *et al*., 2014).The crude protein (%) of the hydroponically sprouted cowpea fodder was lowest on first day, then increased and remained similar during seventh to ninth day of sprouting period. The EE content increased and remained similar during day fifth to eighth day of sprouting, however, it was highest on ninth day of growth (Naik *et al.*, 2016). Chrisdiana (2018) observed that with increase in time of harvest, NDF and ADF value increase occurs because of the synthesis and accumulation of lignin which usually occurs during the formation and thickening of secondary cell walls.

2.8 NUTRIENT MANAGEMENT FOR HYDROPONIC FODDER PRODUCTION

According to Epstein and Bloom (2005), half strength Hoagland solution is considered as a complete formulation of all required nutrients and is recommended for general use in hydroponic systems. Azevedo *et al.* (2006)

strongly believed that green fodder production under hydroponic has been directly correlated with nitrogen (N) content of the applied water. Lamnganbi and Surve (2017) tested six crops sprayed with two different water soluble fertilizers urea (0.5 %) and 19-19-19 (0.5 %) and found out that plants which were foliar sprayed had a much healthier growth with more plant growth and larger diameter as compared to no foliar sprayed treatments. Ningoji (2018) observed that fodder yield of the hydroponically grown fodder maize differed significantly with foliar nutrition and time of spray. From the study conducted by Jolad (2018), it could be concluded that cultivation of grain maize with foliar application of 19:19:19 @ 1 per cent found to be the best option for attaining maximum GFY and nutritional quality with minimal cost under hydroponic fodder production system. Anil (2018) recommended to use GA3 at 10 mg L^{-1} with African tall to obtain maximum forage yield under hydroponic condition.

2.8.1 Effect of Different Nutrients on Growth of Crops Under Hydroponic Fodder Production System

Study conducted by Massantini and Magnani (1980) showed a positive response to added nutrient solution. They found that leaf growth rate was increased by 31.5 per cent in cereal fodders under hydroponics through the addition of nutrient solution when compared to water alone. (Al-Karaki and Al-Hashimi, 2012) found that crop height of hydroponic barley was increased by 1.5 times when it was irrigated with treated sewage water when compared to tap water. They concluded that this significant increase in growth might be due to nutrient concentration of treated sewage water. Al-Karaki (2011) also reported that the height of barley seedlings was significantly higher when irrigated with waste water containing nutrients than irrigated with normal water. Adrover *et al.* (2013) observed that the treatment with Hoagland nutrient solution had the maximum above ground and below ground productions. Lamnganbi (2017) reported that plants which were foliar sprayed had a much healthier growth with more plant growth and larger diameter as compared to no foliar sprayed treatments. Jolad (2018) observed that among the nutrient foliar spray, application of 19: 19: 19 (1%) recorded significantly higher shoot and root length, while foliar spray of panchagavya (3%), vermivash (1%) and control (without any spray) produced relatively smaller roots and shoots. Ningoji (2018) reported that higher values of growth parameters in fodder maize at harvest *viz.*, shoot length (33.74 cm) and root length (30.16 cm) were noticed with application of two sprays of urea and MOP each @ one per cent at third and tenth day of seeding.

2.8.2 Effect of Different Nutrients on Yield of Crops Under Hydroponic Fodder Production System

Massantini and Magnani (1980) stated that GFY of cereals under hydroponics was found to be superior with application of nutrient solution and this might be due to accelerated growth of seedlings with enhanced nitrogen (N) supply. According to Sneath and McIntosh (2003), fodder production in hydroponic barley can be accelerated by 25 per cent through bringing the nutrients directly to the plants without developing large root systems to seek out food. Al-Ajmi *et al*. (2009) while studying yield and water use efficiency of barley fodder produced under hydroponic system in Gulf Cooperation Council countries using tertiary treated sewage effluents used a seed rate of 4.65 kg m^{-2}, realized GFY of 18.1 kg with an efficiency of 2.76 kg kg^{-1} seed. Dung *et al.* (2010b) also reported the higher GFY of barley with hydroponic nutrient solution.

Al-Karaki (2011) obtained the GFY of 224 t ha^{-1} with use of tap water alone, 276 t ha^{-1} with equal mix of tap water with tertiary sewage treated waste water and 320 t ha^{-1} with tertiary sewage treated waste water alone, respectively in hydroponically grown barley crops. He concluded that higher GFY obtained with tertiary sewage treated waste water might be due to the higher nutrient content of treated waste water especially nitrogen. Ningoji (2018) observed that combined application of urea and MOP each @ 1 per cent recorded significantly higher fodder maize yield (13.25 kg m^{-2}) as compared to individual spray viz., MOP (1%) spray (11.87 kg m^{-2}), 19:19:19 (1%) spray (12.27 kg m^{-2}) and urea (1%) spray (12.24 kg m^{-2}). Jolad (2018) found out that among the nutrient foliar spray tested on hydroponically grown maize, higher GFY of 6.00 kg kg^{-1} of seed and dry matter yield of 780.70 g kg^{-1} of seed were recorded in foliar spray of 19: 19: 19 (1%). Anil (2018) reported that higher forage yield was obtained with spray of 10 mg L^{-1} GA3 in African tall variety.

2.8.3 Effect of Different Nutrients on Nutritive Quality of Crops under Hydroponic Fodder Production System

Provision of nutrients in the hydroponic solution had no effect on dry matter yield as corroborated by Morgan *et al.* (1992). Following the dry matter loss there was no difference in barley fodder with water *vs* nutrient solution. Dung *et al.* (2010a) studied the effect of nutrient solution on yield and quality of barley sprouts under hydroponic condition. They found that the dry matter losses after seven days of sprouting were 16.4 and 13.3 per cent in tap water irrigation and hydroponic nutrient solution, respectively. Higher protein concentration of 17.3 per cent was recorded in sprouts grown with hydroponic nutrient solution than those grown with tap water irrigation (15.9 %). Al-Karaki and Al-Hashimi (2012) reported that the protein content in hydroponically produced fodder reached about 27.4 per cent in crops irrigated with tertiary sewage treated waste water which was considerably higher when compared to barley fodder grown in equal mix of tap water with tertiary sewage treated waste water (24.9 %) and tap water (25.2 %). However, no significant difference was noticed in crude fibre and crude fat content of fodder irrigated with three types of water. Crude protein composition of mung bean could be increased by increased N supplementation from nutrient solution during germination (Naik *et al.*, 2012).

Gunashekaran *et al.* (2018) opined that the crude protein content was higher with spray of 0.1 per cent urea and total ash was higher with 10 per cent vermiwash spray, while crude fibre and ether extract were higher with water spray, in hydroponically grown maize fodder. According to Lamnganbi (2017), dry matter content showed a gradual decline but was improved by foliar application compared to no foliar sprayed treatments and the nutrient content or crop quality was improved by applying foliar spray. Jolad (2018) observed that foliar spray of 19: 19: 19 (1%) recorded significantly higher total protein while, panchagavya (3%), vermivash (1%) and control (without any spray) were recorded with significantly lower protein yield. However, different nutrient foliar spray did not show any significant difference in crude fibre, crude fat and ash contents. Nanavare (2018) studied the effect of nutrient solution (19:19:19) on chemical composition of different varieties of maize and concluded that spraying of 0.75 per cent of 19:19:19 recorded significantly higher nutrient per centage at 7^{th} day and 14^{th} day of hydroponic study.

2.9 ECONOMICS OF HYDROPONIC FODDER PRODUCTION

Naik *et al.* (2013) pointed out that hydroponic fodder can be grown in low cost green houses with locally available grains to cut down the cost of production. They calculated that if seed was home grown, the cost of production was about ₹ 2 to 3 per kg of fresh fodder and if seed was purchased from market, the cost of production was bit higher as ₹ 3 to 3.50 per kg of fresh fodder. The cost of hydroponic systems depends upon the type of construction materials used (Bakshi *et al.,* 2017). Kaouche *et al.* (2016) did the cost benefit analysis of cultivating hydroponic fodder to conventional fodder considering labour, land and water, and concluded that conventional fodder production requires ten times more labour, 200 times more land and eight times more water than hydroponic system. Lamnganbi (2017) opined that foliar sprayed yellow maize both urea treated and 19-19-19 (0.5 %) treated were most economical of all the crops taken and it had high potential in India. Grain maize with foliar spray of 19:19:19 NPK (1%) recorded higher B:C ratio of 1.16 which was closely followed by grain maize along with foliar application of DAP (0.5%) + KCl (0.5%) which registered the B:C ratio of 1.15 (Jolad, 2018). Ningoji (2018) observed that application of two sprays of urea and MOP each @ 1 per cent at 3^{rd} and 10^{th}day of seeding recorded higher gross returns, net returns and benefit cost ratio (B:C ratio) (2.41) as compared to control.

Materials and Methods

3. MATERIALS AND METHODS

The experiment was conducted at Integrated Farming System Research Station, Karamana during November 2018 to June 2019 to identify suitable fodder crops for hydroponics system and to standardize seed rate, period for harvest and nutrient solution. The details of materials used and methods adopted during the course of study are presented in this chapter.

3.1. EXPERIMENTAL MATERIALS

3.1.1. Location

The study was conducted at IFSRS, Karamana, Thiruvananthapuram, Kerala, located at $8^0 28^{'} 25^{''}$ North latitude and $76^0 57^{'} 41^{''}$ east longitude at an altitude of 3.3 m above mean sea level.

3.1.2. Crops

3.1.2.1. Experiment I

This experiment was conducted to find out the best performing crops among the ten crops based on yield, quality and economics by adopting standard hydroponic techniques. The crops taken were rice, barley, maize, wheat, sorghum, pearl millet, finger millet, cowpea, horsegram and greengram.

3.1.2.2. Experiment II:

This experiment was conducted to standardise the seed rate and days of harvest for best performing two crops selected from Experiment I. The crops selected for this experiment were maize and greengram.

3.1.2.3. Experiment III

This experiment was conducted to know the effect of foliar spray of nutrients under hydroponics in maize and greengram, each sown at the seed rate and harvested on the period of harvest standardised from experiment II.

3.1.3 Hydroponic Structure

Low cost hydroponic chamber having the size of 2 m length x 1.3 m width x 1.8 m height was established with GI pipes with four shelves and automatic sprinkler irrigation system (Plate 1). The frame was housed inside a small chamber made of iron mesh to avoid entry of rats and squirrels. It was covered with shade net. Plastic trays of size 500 cm^{-2} were used with drainage holes at the bottom of trays to facilitate drainage of excess water. Motor was used to deliver the water from water tank through laterals fitted with low cost foggers.

3.1.4 Preparation of Nutrient Solutions

3.1.4.1. Hoagland Solution

Chemicals used for Hoagland solution	Stock solution (g to make 1 L)	Final solution (ml to make 1 L)
KNO_3	101.1	5
$Ca(NO_3)_2.4H_2O$	236.2	5
KH_2PO_4	136.1	1
$MgSO_4.7H_2O$	246.5	2

To make 1 L of solution, add 5 ml $Ca(NO_3)_2.4H_2O$ stock solution, 5 ml KNO_3, 1 ml KH_2PO_4, 2 ml $MgSO_4.7H_2O$, 1 ml micronutrient solution and 1 ml iron solution to 800 ml distilled water and make up to 1 L (Maynard and Hochmuth, 2007).

3.1.4.2. Groundnut Cake (Supernatant Solution)

One kg groundnut cake was immersed in water necessary to soak it and kept for four to five days. The supernatant solution was filtered and taken.

3.1.4.3 Starter Solution

A solution of N, P_2O_5 and K_2O in the ratio of 1:2:1 was made by mixing water soluble fertilisers urea, DAP (Diammonium phosphate) and KCl (Potassium chloride).

Plate 1. Low cost hydroponic fodder production system

3.2. EXPERIMENTAL METHODS

3.2.1. Experimental Design and Details

3.2.1.1. Experiment I: To Evaluate the Suitability of Fodder Crops for Hydroponics

The experiment started on November 2018 and two trials were conducted. The experiment was completed by end of November. The experiment to identify suitable crops for hydroponic fodder production was laid out in Completely Randomized Design (CRD) comprised of ten crops (Table 2a and 2b). The treatments were replicated thrice.

Treatments

c_1 - Rice

c_2 - Barley

c_3 - Maize

c_4 - Wheat

c_5 - Sorghum

c_6 - Bajra

c_7 - Ragi

c_8 - Cowpea

c_9 - Horsegram

c_{10} – Greengram

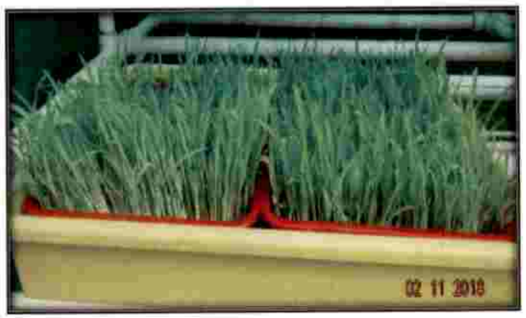
3.2.1.2. Experiment II: Standardization of Seed Rate and Period for Harvest of Fodder in Hydroponics Fodder Production Unit

The experiment started on April 2019 and was completed by end of May 2019. The experiment to standardise the seed rate and period of harvest of the selected crops from experiment I under hydroponics was laid out in factorial CRD. In maize, the experiment was laid out in factorial CRD with three seed rates and four periods for harvest. Considering greengram, it was laid out in factorial CRD with three seed rates and two periods for harvest as it was observed that the crop did not survive beyond nine days in hydroponic fodder production system (Plate3).

Rice

Barley

Wheat



Sorghum

Maize

Bajra

Ragi

Plate 2a. Crops grown under hydroponics system

Cowpea

Greengram

Horsegram

Plate 2b. Crops grown under hydroponics system (continued…)

Plate 3. Failure of greengram after nine days in hydroponic fodder production system

The treatment combinations were replicated thrice. The treatment details are given in Table 1.

Table 1: Treatment details of experiment II

Greengram	Maize
Factor A: Seed rate (s) s_1: 150 g ft $^{-2}$ (1.61 kg m^{-2}) s_2: 175 g ft $^{-2}$ (1.88 kg m^{-2}) s_3: 200 g ft $^{-2}$ (2.15 kg m^{-2})	Factor A: Seed rate (s) s_1: 150 g ft $^{-2}$ (1.61 kg m^{-2}) s_2: 175 g ft $^{-2}$ (1.88 kg m^{-2}) s_3: 200 g ft $^{-2}$ (2.15 kg m^{-2})
Factor B: Period for harvest (t) t_1: 7 days t_2: 9 days	Factor B: Period for harvest (t) t_1: 7 days t_2: 9 days t_3: 11 days t_4: 13 days
s_1t_1: Seed rate of 150 g ft $^{-2}$ and harvested on 7th day s_1t_2: Seed rate of 150 g ft $^{-2}$ and harvested on 9th day s_2t_1: Seed rate of 175 g ft $^{-2}$ and harvested on 7th day s_2t_2: Seed rate of 175 g ft $^{-2}$ and harvested on 9th day s_3t_1: Seed rate of 200 g ft $^{-2}$ and harvested on 7th day s_3t_2: Seed rate of 200 g ft $^{-2}$ and harvested on 9th day	s_1t_1: Seed rate of 150 g ft $^{-2}$ and harvested on 7th day s_1t_2: Seed rate of 150 g ft $^{-2}$ and harvested on 9th day s_1t_3: Seed rate of 150 g ft $^{-2}$ and harvested on11th day s_1t_4: Seed rate of 150 g ft $^{-2}$ and harvested on 13th day s_2t_1: Seed rate of 175 g ft $^{-2}$ and harvested on 7th day s_2t_2: Seed rate of 175 g ft $^{-2}$ and harvested on 9th day s_2t_3: Seed rate of 175 g ft $^{-2}$ and harvested on 11th day s_2t_4: Seed rate of 175 g ft $^{-2}$ and harvested on 13th day s_3t_1: Seed rate of 200 g ft $^{-2}$ and harvested on 7th day s_3t_2: Seed rate of 200 g ft $^{-2}$ and harvested on 9th day s_3t_3: Seed rate of 200 g ft $^{-2}$ and harvested on 11th day s_3t_4: Seed rate of 200 g ft $^{-2}$ and harvested on 13^{h} day

3.2.1.3. Experiment III: Standardization of Nutrient Solution for Hydroponics Fodder Production

The experiment started on June 15th 2019 and was completed by June 27th 2019. The experiment was laid out in CRD, comprised of eight sources of foliar nutrition on the two selected crops with selected seed rate and selected period of harvest. The treatment combinations were replicated thrice.

Treatments - Nutrient solutions

n_1 - Hoagland solution (0.25%)

n_2 - Hoagland solution (0.5%)

n_3 - 19:19:19 (0.5%)

n_4 - DAP (0.5%)+ KCl (0.5%)

n_5 - Starter solution (1:2:1)

n_6 - Vermiwash (10 times dilution)

n_7 - Groundnut cake (supernatant solution- 10 times dilution)

n_8 – Water

3.2.2. Hydroponic Protocols

The different steps followed in hydroponic fodder production are (Plate 4):

3.2.2.1. Selection of Seeds

Seeds of ten crops were obtained from the respective Departments of Tamil Nadu Agricultural University, Coimbatore. Seeds of all crops were cleaned from debris and other foreign materials. Seeds were subjected to a germination test to check for their viability before being used.

3.2.2.2. Seed Treatment

The cleaned seeds were soaked in tap water with 0.1 percent sodium hypochlorite solution (household bleach) overnight for about 12 hours.

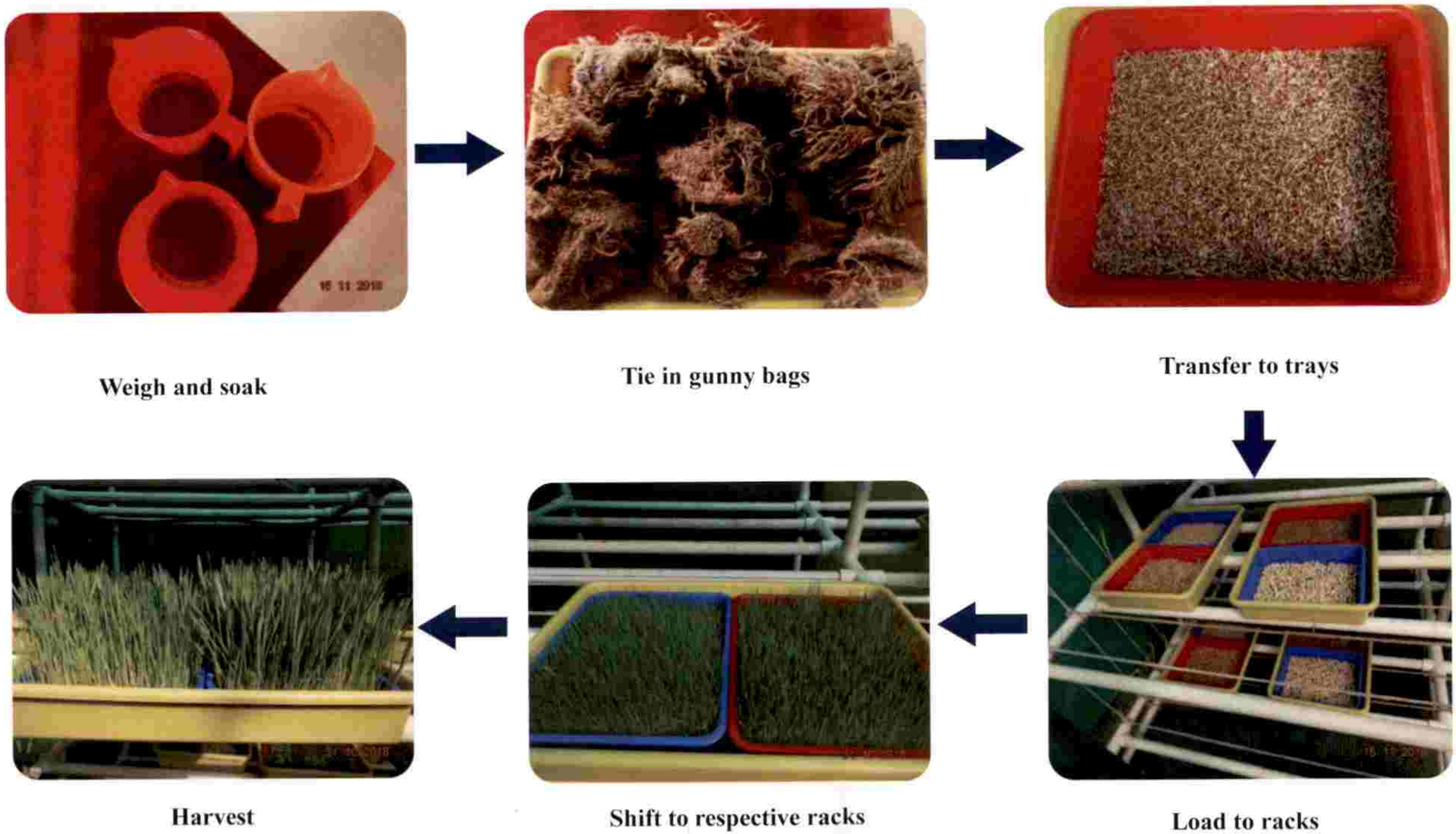


Plate 4. Steps in hydroponics fodder

3.2.2.3. Seed Incubation

Soaked seeds were allowed to germinate in air tight gunny bags kept in dark condition for 24 hours before being loaded into plastic trays for fodder production in the hydroponic unit.

3.2.2.4. Seeding of Sprouted Seeds

The sprouted seeds were uniformly spread over hydroponic plastic trays. In experiment I, the seed rate of 200 g ft^{-2} (2.15 kg m^{-2}) was adopted and in experiment II seed rate as per treatments were adopted. While in experiment III seed rate of 200 g ft^{-2} (2.15 kg m^{-2}) was adopted for both the crops. The trays were stacked on the shelves.

3.2.2.5. Irrigation

Irrigation to the hydroponic fodder was done by automatic spraying of water through foggers at one hour interval during day time at a fixed rate which was enough to keep the seeds or seedlings moist.

3.2.2.6. Harvesting

The experiment was terminated after nine days from seeding in experiment I, as per treatments in experiment II and, seven days for greengram and eleven days for maize in experiment III.

3.2.2.7. Application of Nutrient Solution

Eight different sources of nutrients were tested on greengram and maize in experiment III. The time and source of nutrient foliar spray were given in Table 2.

Table 2. Time and source of nutrient foliar spray

S.No.	Time of spray	Source and concentration of nutrition
1	Morning 08.30 AM on consecutive days from third day of seeding	Hoagland solution (0.25%)
2		Hoagland solution (0.5%)
3		19:19:19 (0.5%)
4		DAP (0.5%)+ KCl (0.5%)
5		Starter solution (1:2:1)
6		Vermiwash (10 times dilution)
7		Groundnut cake (supernatant solution- 10 times dilution)
8		Water

3.3. OBSERVATIONS

3.3.1. Growth Parameters

3.3.1.1. Number of Leaves

Visual counting was followed to count number of leaves.

3.3.1.2. Shoot Length

The length of the seedling was measured from base of the stem to the tip on the day of harvest from five selected plants and mean value was expressed in centimetres.

3.3.1.3. Shoot Weight

Weight of shoot separated from root of the hydroponic mat was weighed and the value was expressed in kg kg^{-1} seed.

3.3.1.4. Root Length

Root length was determined by measuring the length of root from the base of the stem to the tip of the longest root on the day of harvest from five selected plants and mean value was expressed in centimetres

3.3.1.5. Root Weight

Weight of the root separated from the shoot of the hydroponic mat was weighed and the value was expressed in kg kg^{-1} seed.

3.3.2. Yield Parameters

3.3.2.1. Seed to Green Fodder Yield Multiplication Ratio

Weight of seeds sown was divided by the fresh weight of hydroponic green fodder obtained.

3.3.2.2. Green Fodder Yield

The entire plants including roots in the tray were removed and the fresh weight was recorded. The yield of green fodder was expressed in kg of green fodder $kg^{-1}$of seeds.

3.3.2.3. Dry Fodder Yield.

Samples (of green fodder) collected from each tray were air dried and then oven dried at 80° ±5° C for 72 hours. From the dry weight of sample, total dry matter yield was calculated and expressed in kg of dry matter per kg of seeds.

3.3.3. Quality Characteristics

3.3.3.1. Dry Matter Per Cent

Weight of sample before and after oven drying is taken and dry matter per cent is calculated using the formula,

$$DM\ (\%) = \frac{\text{Weight of sample after drying (g)}}{\text{Weight of sample before drying (g)}} \times 100$$

3.3.3.2. Crude Protein

Nitrogen content was estimated by Micro kjeldahl's method and it was multiplied by the factor 6.25 to obtain the total protein content. It was expressed in percentage (Crompton and Harris, 1969).

3.3.3.3. Acid Detergent Fibre

An acidified quaternary detergent solution is used to dissolve cell solubles, hemicellulose and soluble minerals leaving a residue of cellulose, lignin, and heat damaged protein and a portion of cell wall protein and minerals (ash). ADF is determined gravimetrically as the residue remaining after extraction (van Soest, 1965).

3.3.3.4. Neutral Detergent Fibre

The process of determining NDF content involves a neutral detergent that involves a neutral detergent that dissolves plant pectins, proteins, sugars and lipids. This leaves behind the fibrous parts such as cellulose, lignin and hemicellulose. These parts are not easily digestible and so are often not desired within a feedstuff (van Soest, 1965).

3.3.3.5. Ether Extract

The crude fat in the feed sample was extracted with organic solvents such as diethyl ether in a soxhlet fat extraction assembly for several hours. Afterwards the ether in the extraction flask was separated and the flask with the ether extract was dried and weighed. The ether extract was expressed in percentage (AOAC, 1990).

3.3.3.6. Ash Content

Total ash is the non-combustible fraction of the feed, represents the total mineral content in the feed. A weighed quantity of the sample was incinerated and ash left as residue was weighed and percentage was calculated (AOAC, 1990).

3.3.4. Pest and Disease Incidence

No incidence of pest and disease.

3.3.5. Economic Analysis

The economic analysis of the hydroponic fodder production was done in terms of net income and B:C ratio based on cost of cultivation and prevailing price of produce.

3.3.5.1. Net Income

The net income was calculated by deducting cost of cultivation from the gross income and expressed in ₹ kg^{-1} seed.

3.3.5.2. B:C Ratio

Benefit cost ratio was worked out as follows

$$\text{B:C ratio} = \frac{\text{Gross returns (₹ kg}^{-1}\text{ seed)}}{\text{Cost of cultivation (₹ kg}^{-1}\text{ seed)}}$$

3.4. STATISTICAL ANALYSIS

The data related to each parameter was analysed statistically by using Analysis of Variance Technique (ANOVA) like CRD and factorial CRD (Panse and Sukhatme, 1985) and significance was tested by 'F' test (Snedecor and Cocharan, 1967). In the cases were the treatment differences were found significant, critical difference was worked out at five per cent probability level and the values are furnished. The treatment difference that were not significant were denoted as "NS".

Results

4. RESULTS

The experiment was conducted in a low cost hydroponics fodder machine at Integrated Farming System Research Station, Karamana to identify suitable fodder crops for hydroponics system and to standardise seed rate, period of harvest, and nutrient solution. The experimental data collected were statistically analysed and the results obtained are presented below.

4.1. EXPERIMENT 1: TO EVALUATE THE SUITABILITY OF FODDER CROPS FOR HYDROPONICS

4.1.1. Performance Based on Growth Parameters

4.1.1.1. Number of Leaves

Number of leaves recorded at the time of harvest is presented in Table 3. There was no significant variation in number of leaves among the ten different crops grown under hydroponics.

4.1.1.2. Shoot Length

The data pertaining to shoot length recorded at the time of harvest is presented in Table 3. Significant variations were seen in shoot length of different crops tested.

Among the crops, maize (c_3) recorded significantly higher shoot length of 23.23 cm which was on par with greengram (c_{10}) measuring 22.83 cm. The lowest shoot length of 3.76 cm was observed in ragi (c_7).

4.1.1.3. Shoot Weight

Shoot weight recorded at the time of harvest is presented in Table 3. Among the crops, greengram (c_{10}) recorded significantly higher shoot weight of 7.93 kg kg^{-1} seed and the lowest shoot weight of 0.78 kg kg^{-1} seed was observed in sorghum (c_5).

Table 3. Performance of different crops under hydroponics based on growth parameters

Treatments	Number of leaves	Shoot length (cm)	Shoot weight (kg kg^{-1} seed)	Root length (cm)	Root weight (kg kg^{-1} seed)
c_1 - Rice	2.33	8.00	1.09	7.60	3.15
c_2 - Barley	2.33	21.03	1.65	9.47	3.24
c_3 - Maize	2.33	23.23	2.90	13.27	3.15
c_4 - Wheat	2.67	18.98	1.79	8.83	3.47
c_5 - Sorghum	2.33	11.71	0.78	5.94	1.23
c_6 - Bajra	2.33	9.81	1.28	4.75	1.38
c_7 - Ragi	2.67	3.76	2.10	4.61	3.97
c_8 - Cowpea	2.33	21.03	4.04	9.23	1.53
c_9 - Horsegram	2.33	11.74	6.25	12.57	2.38
c_{10} - Greengram	2.33	22.83	7.93	13.51	2.07
SE m(±)	0.33	0.39	0.16	0.25	0.13
CD (0.05)	NS	1.175	0.484	0.739	0.384

4.1.1.4. Root Length

Root length recorded at the time of harvest is presented in Table 3. Among the crops, greengram (c_{10}) recorded the highest root length of 13.51 cm which was on par with maize (13.27 cm). The lowest root length of 4.75 cm was observed in ragi (4.61 cm).

4.1.1.5. Root weight

Root weight recorded at the time of harvest is presented in Table 3. Considering root weight, ragi (c_7) had a significantly higher value for root weight (3.97 kg kg^{-1} seed) compared to other crops.

4.1.2. Performance Based on Yield Attributes

4.1.2.1. Seed to Green Fodder Yield Multiplication Ratio

Data pertaining to seed to GFY multiplication ratio is presented in Table 4. The least amount of seeds required to produce kg^{-1} green fodder was found to be for greengram (c_{10}).

4.1.2.2. Green Fodder Yield

Results revealed that there is significant difference on the green fodder potential of different crops under hydroponics fodder production system (Table 4).

Among the crops, greengram (c_{10}) recorded the highest GFY of 10.17 kg kg^{-1} of seeds. Sorghum recorded the lowest GFY of 2.01 kg kg^{-1} seed.

4.1.2.3. Dry Fodder Yield

DFY recorded is presented in Table 4. Among the ten different crops, DFY was highest for greengram (0.91 kg kg^{-1} seed). Bajra and sorghum recorded the lowest values for DFY (0.33 kg kg^{-1} seed).

Table 4. Performance of different crops under hydroponics based on yield attributes.

Treatments	Seed to green fodder yield multiplication ratio	GFY (kg kg^{-1} seed)	DFY (kg kg^{-1} seed)
c_1 - Rice	0.24	4.23	0.85
c_2 - Barley	0.21	4.82	0.70
c_3 - Maize	0.17	6.04	0.82
c_4 - Wheat	0.19	5.26	0.66
c_5 - Sorghum	0.51	2.01	0.33
c_6 - Bajra	0.39	2.61	0.34
c_7 - Ragi	0.17	5.98	0.55
c_8 - Cowpea	0.19	5.45	0.60
c_9 - Horsegram	0.11	8.62	0.71
c_{10} - Greengram	0.10	10.17	0.91
SE m(±)	0.02	0.25	0.015
CD (0.05)	0.069	0.754	0.043

4.1.3. Performance Based on Quality Characteristics

4.1.3.1. Dry Matter Per Cent

Dry matter content was analysed and presented in Table 5. Among the crops, dry matter per cent was the highest for rice (20.25 %). Legumes recorded low dry matter per cent and the lowest value was for horsegram (c_9).

4.1.3.2. Crude Protein

Crude protein content varied significantly for different crops under hydroponics fodder production system (Table 5).

Among the crops, all legumes had high crude protein content. Greengram (c_{10}) recorded the highest crude protein content of 20.97% which was on par with horsegram (c_9) and cowpea (c_8). The lowest crude protein content was estimated in ragi (c_7).

4.1.3.3. Acid Detergent Fibre

Higher values of fibre is an undesirable character for animal feed. ADF values were analysed and results are presented in Table 5. The lowest ADF value was recorded for maize (c_3) and highest value for rice (c_1).

4.1.3.4. Neutral Detergent Fibre

NDF values was analysed and results are presented in Table 5. The lowest NDF value was recorded for cowpea (c_8) which was on par with horsegram and the highest value for rice (c_1).

4.1.3.5. Ether Extract

Ether extract (fat content) was analysed and presented in Table 5. Greengram (c_{10}) which recorded a value of 3.50 was the highest among different crops which was on par with bajra (c_6) and the lowest value was recorded by ragi (c_7).

Table 5. Effect of different crops under hydroponics on quality parameters, per cent

Treatments	Dry matter	Crude protein	ADF	NDF	Ether extract	Ash content
c_1 - Rice	20.25	14.56	39.41	68.71	2.85	13.01
c_2 - Barley	14.58	13.97	31.34	50.28	2.05	7.87
c_3 - Maize	13.59	15.97	18.86	47.37	2.61	8.66
c_4 - Wheat	12.48	13.72	30.21	52.65	1.97	10.74
c_5 - Sorghum	16.64	14.25	22.40	51.12	2.58	9.40
c_6 - Bajra	13.13	13.33	22.70	54.32	3.16	11.06
c_7 - Ragi	9.19	9.08	34.49	60.50	1.22	11.73
c_8 - Cowpea	11.17	18.29	27.89	32.27	1.61	12.11
c_9 - Horsegram	8.20	19.63	38.12	50.39	2.52	7.18
c_{10} - Greengram	8.98	20.97	25.60	33.57	3.50	8.01
SE m(±)	0.75	1.04	0.77	0.89	0.21	0.51
CD (0.05)	2.216	3.075	2.281	2.645	0.629	1.503

4.1.3.6. Ash content

Ash content was analysed and data is presented in Table 5. Lower values of this parameter are desirable. Among different crops, horsegram (c_9) recorded the lowest value of 7.18 which was on par with greengram, barley and maize, and highest value for rice (c_{10}).

4.1.4. Economics of Different Crops Under Hydroponics Fodder Production System

The data presented in Table 6 depicts net income and B:C ratio of different crops grown under hydroponics fodder production system. Maize crop grown under hydroponics system recorded the highest net income of ₹ 36.30 kg^{-1} seed and B:C ratio of 2.51. B:C ratio of more than one was recorded for rice, barley, wheat, ragi, horsegram and greengram.

Seed to green fodder multiplication was very poor (<3 kg) in sorghum and pearl millet. Hence, these crops were not suitable for hydroponics fodder production. Considering the yield, quality and economics, maize and greengram was selected for the second and third experiment.

4.2. EXPERIMENT II: STANDARDISATION OF SEED RATE AND PERIOD OF HARVEST OF FODDER IN HYDROPONICS FODDER PRODUCTION UNIT

4.2.1. Effect of Seed Rate and Period of Harvest on Growth Parameters of Greengram Under Hydroponics

4.2.1.1. Number of Leaves

The data on effect of seed rate and period of harvest on biometric parameters of greengram on number of leaves is presented in Table 7.

The results revealed that the main effects and the interaction effects did not have any significant influence on number of leaves.

Table 6. Economics of different crops under hydroponics fodder production system

Treatments	Net Income (₹ kg^{-1} seed)	B:C ratio
c_1 - Rice	15.23	1.56
c_2 - Barley	22.13	1.85
c_3 - Maize	36.30	2.51
c_4 - Wheat	2.53	1.05
c_5 - Sorghum	-29.03	0.41
c_6 - Bajra	-22.97	0.53
c_7 - Ragi	15.73	1.35
c_8 - Cowpea	-24.60	0.69
c_9 - Horsegram	11.80	1.14
c_{10} - Greengram	12.67	1.16
SE m(±)	2.54	0.06
CD (0.05)	7.538	0.162

4.2.1.2. Shoot Length

The variation in shoot length of greengram at different seed rates and period of harvest is given in Table 7.

Different seed rates and period of harvest had no significant impact on shoot length. With respect to the interaction effects, s_3t_2 (seed rate of 200 g ft^{-2} and harvested on 9th day) recorded the highest shoot length which was on par with s_1t_2 and s_2t_2.

4.2.1.3. Shoot Weight

The variation in shoot weight of greengram at different seed rates and time for harvest is given in Table 7.

Comparing the different seed rates, s_3 (200 g ft^{-2}) recorded the highest shoot weight which was on par with s_2 (175 g ft^{-2}), while different period of harvest had no significant effect on shoot weight. Among the interaction effects, s_3t_1 (seed rate of 200 g ft^{-2} and harvested on 7th day) recorded the highest shoot weight which was on par with s_2t_1, s_2t_2 and s_3t_2.

4.2.1.4. Root Length

The data on root length of greengram at different seed rates and period of harvest is given in Table 7. Different seed rates and period of harvest had no significant impact on root length. Among the interactions, s_3t_1 showed significantly higher root length which was on par with s_1t_1, s_1t_2, s_2t_1 and s_3t_2.

4.2.1.5 Root Weight

The data on root weight of greengram at different seed rates and period of harvest is given in Table 7.

Among the three seed rates, s_3 (200 g ft^{-2}) recorded the highest root weight, while the different period of harvest had no significant effect on root weight. Among the interactions, s_3t_2 recorded significantly higher root weight which was on par with s_3t_1.

Table 7. Effect of seed rate and period of harvest on growth parameters of greengram under hydroponics

Treatments	Number of leaves	Shoot length (cm)	Shoot weight (kg kg^{-1} seed)	Root length (cm)	Root weight (kg kg^{-1} seed)
Seed rate (S)					
s_1 - 150 g ft^{-2}	2	23.06	5.29	9.65	3.41
s_2 - 175g ft^{-2}	2	23.07	6.28	9.32	3.37
s_3 - 200g ft^{-2}	2	23.35	6.44	9.69	3.74
SE m (±)	-	0.21	0.08	0.29	0.05
CD (0.05)	NS	NS	0.268	NS	0.145
Period of harvest (T)					
t_1 – 7 days	2	22.41	6.05	9.88	3.49
t_2 – 9 days	2	23.91	5.95	9.22	3.52
SE m (±)	-	0.18	0.07	0.23	0.04
CD (0.05)	NS	NS	NS	NS	NS
Interaction (S x T)					
s_1t_1	2	22.18	5.28	9.87	3.39
s_1t_2	2	23.95	5.29	9.43	3.43
s_2t_1	2	22.40	6.40	9.66	3.35
s_2t_2	2	23.74	6.15	8.98	3.39
s_3t_1	2	22.66	6.47	10.12	3.72
s_3t_2	2	24.04	6.41	9.26	3.75
SE m (±)	-	0.31	0.11	0.41	0.12
CD (0.05)	NS	0.983	0.378	0.983	0.369

4.2.2. Effect of Seed Rate and Period of Harvest on Yield Attributes of Greengram under Hydroponics

4.2.2.1. Seed to Green Fodder Multiplication Ratio

The data on seed to green fodder multiplication ratio of greengram at different seed rates and period of harvest is given in Table 8.

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the lowest seed to green fodder multiplication ratio, while the different period of harvest showed no significant difference in the seed to green fodder multiplication ratio.

Among the interactions, s_2t_1, s_2t_2, s_3t_1 and s_3t_2 recorded the same seed to green fodder multiplication ratio.

4.2.2.2. Green Fodder Yield

The data on GFY of greengram at different seed rates and time for harvest is given in Table 8.

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest GFY, while the different period of harvest showed no significant difference in the GFY. Among the interactions, s_3t_1 (seed rate of 200 g ft^{-2} and harvested on 7^{th} day) recorded the highest GFY which was on par with s_3t_2 and s_2t_1.

4.2.2.3. Dry Fodder Yield

The data on DFY of greengram at different seed rates and time for harvest is given in Table 8.

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest DFY and among the different period of harvest greengram harvested at 7^{th} day (t_1) recorded highest DFY. Among the interactions, s_3t_1 (seed rate of 200 g ft^{-2} and harvested on 7^{th} day) recorded highest DFY.

Table 8. Effect of seed rate and period of harvest on yield attributes of greengram under hydroponics

Treatments	Seed to green fodder yield multiplication ratio	GFY (kg kg^{-1} seed)	DFY (kg kg^{-1} seed)
Seed rate (S)			
s_1 –150 g ft^{-2}	0.12	8.79	0.75
s_2 -175g ft^{-2}	0.11	9.64	0.85
s_3 - 200g ft^{-2}	0.10	10.17	0.87
SE m (±)	0.002	0.08	0.015
CD (0.05)	0.005	0.262	0.005
Period of harvest (T)			
t_1 – 7 days	0.11	9.54	0.85
t_2 – 9 days	0.12	9.47	0.80
SE m (±)	0.01	0.07	0.004
CD (0.05)	NS	NS	0.012
Interaction (S x T)			
s_1t_1	0.12	8.67	0.77
s_1t_2	0.11	8.72	0.72
s_2t_1	0.10	9.78	0.87
s_2t_2	0.10	9.54	0.83
s_3t_1	0.10	10.18	0.90
s_3t_2	0.10	10.16	0.84
SE m (±)	0.003	0.12	0.007
CD (0.05)	0.009	0.409	0.021

4.2.3. Effect of Seed Rate and Period of Harvest on Quality Characteristics of Greengram under Hydroponics

4.2.3.1. Dry Matter Per Cent

Dry matter content was analysed and presented in Table 9. Different seed rates had no effect on dry matter per cent of greengram, while among different period of harvest t_1 (7 days) recorded significantly higher dry matter per cent. Among the interactions, s_2t_1 (seed rate of 175 g ft^{-2} and harvested on 7^{th} day) recorded the highest dry matter per cent which was on par with s_1t_1, s_2t_2 and s_3t_1.

4.2.3.2. Crude Protein

Crude protein varied significantly with different seed rates and interaction effects. The results are presented in Table 9.

Different seed rates and period of harvest had no significant effect on crude protein. Among the interactions, s_3t_2 (seed rate of 200 g ft^{-2} and harvested on 9^{th} day) was found to be significantly higher which was on par with s_1t_2, s_2t_2 and s_3t_1.

4.2.3.3. Acid Detergent Fibre

Low fibre content is desirable for cattle feed. The variation in ADF of greengram at different seed rates and period of harvest is given in Table 9.

Different seed rates had no effect on ADF while among the different period of harvest, t_1 (7 days) recorded significantly lower value for ADF. Considering the interactions, s_1t_1 (seed rate of 150 g ft^{-2} and harvested on 7^{th} day) recorded lowest ADF which was on par with s_2t_1 and s_3t_1.

4.2.3.4. Neutral Detergent Fibre

The data on NDF recorded for greengram at different seed rates and period of harvest is given in Table 9.

Different seed rates had no effect on NDF, while among the different period of harvest t_1 (7 days) recorded significantly lower value for NDF.

Table 9. Effect of seed rate and period of harvest on quality characteristics of greengram under hydroponics, per cent

Treatments	Dry matter	Crude Protein	ADF	NDF	Ether extract	Ash content
Seed rate (S)						
s_1 – 150 g ft^{-2}	8.57	21.23	24.31	35.21	2.12	11.27
s_2 -175g ft^{-2}	8.77	21.29	25.20	35.81	2.19	10.89
s_3 -200g ft^{-2}	8.56	21.76	24.58	35.56	2.11	10.66
SE m (±)	0.10	0.81	0.88	0.97	0.10	0.27
CD (0.05)	NS	NS	NS	NS	NS	NS
Period of harvest (T)						
t_1 – 7 days	8.85	21.43	21.82	32.38	2.35	9.86
t_2 – 9 days	8.42	21.428	27.57	38.67	1.93	12.03
SE m (±)	0.08	0.68	0.72	0.79	0.08	0.22
CD (0.05)	0.28	NS	2.232	2.455	0.259	0.687
Interaction (S x T)						
s_1t_1	8.87	21.00	21.79	32.35	2.35	9.90
s_1t_2	8.27	21.47	26.83	38.07	1.89	12.63
s_2t_1	8.88	22.17	21.79	32.35	2.42	9.80
s_2t_2	8.66	20.42	28.62	39.27	1.95	11.99
s_3t_1	8.81	22.12	21.89	32.45	2.28	9.87
s_3t_2	8.31	22.40	27.26	38.67	1.94	11.46
SE m (±)	0.15	0.36	1.21	1.37	0.14	0.38
CD (0.05)	0.481	1.172	4.069	4.659	0.463	1.299

Considering the interactions, s_1t_1 (seed rate of 150 g ft^{-2} and harvested on 7^{th} day) recorded the lowest NDF which was on par with s_2t_1 and s_3t_1.

4.2.3.5. Ether Extract

Ether extract (fat content) was analysed and presented in Table 9. No significant effect was noted on fat content at different seed rates. Among the different period of harvest, t_1 (7 days) recorded the highest fat content.

Considering the interaction effects, s_2t_1 (seed rate of 175 g ft^{-2} and harvested on 7^{th} day) recorded the highest fat content which was on par with s_1t_1 and s_3t_1.

4.2.3.6. Ash content

Ash content was analysed and data is presented in Table 9. Lower values of this parameter is desirable. No significant effect was noted on ash content at different seed rates. Among the different period of harvest, t_1 (7 days) recorded the lowest ash content.

Considering the interaction effect, s_2t_1 (seed rate of 175 g ft^{-2} and harvested on 7^{th} day) recorded the lowest ash content which was on par with s_1t_1 and s_3t_1.

4.2.4. Effect of Seed Rate and Period of harvest on Economics of Greengram Under Hydroponics

The data presented in Table 10 depicts net income and B:C ratio of greengram grown at different seed rates and period of harvest under hydroponics fodder production system.

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest net income and B:C ratio, while the different period of harvest showed no significant difference in the economics of the system.

Among the interactions, s_3t_1 (seed rate of 200 g ft^{-2} and harvested on 7^{th} day) recorded the highest net income and benefit cost ratio which was on par with s_3t_2 and s_2t_1

Table 10. Effect of seed rate and period of harvest on economics of greengram under hydroponics

Treatments	Net income (₹ kg^{-1} seed)	B:C Ratio
Seed rate (S)		
s_1 – 150 g ft^{-2}	1.95	1.03
s_2 -175g ft^{-2}	11.63	1.14
s_3 - 200g ft^{-2}	16.72	1.20
SE m (±)	0.84	0.01
CD (0.05)	2.616	0.03
Period of harvest (T)		
t_1 – 7 days	10.50	1.13
t_2 – 9 days	9.70	1.11
SE m (±)	0.69	0.01
CD (0.05)	NS	NS
Interaction (S x T)		
s_1t_1	1.74	1.02
s_1t_2	2.15	1.03
s_2t_1	12.87	1.15
s_2t_2	10.39	1.12
s_3t_1	16.87	1.20
s_3t_2	16.56	1.19
SE m (±)	0.187	0.013
CD (0.05)	4.113	0.046

4.2.5. Effect of Seed Rate and Period of Harvest on Growth Parameters of Maize Under Hydroponics.

4.2.5.1. Number of Leaves

The data on number of leaves is presented in Table 11. The results revealed that the main effects and the interaction effects did not have any influence on the number of leaves.

4.2.5.2. Shoot Length

The variation in shoot length of maize at different seed rates and time for harvest is given in Table 11.

Among the different seed rates, s_3 (200 g ft^{-2}) recorded the highest shoot length which was on par with s_2, while among the different period of harvest t_4 (13 days) recorded the highest shoot length which was on par with t_3. With respect to the interaction effects, s_3t_4 (seed rate of 200 g ft^{-2} and harvested on 13[th] day) recorded the highest shoot length which was on par with s_1t_3, s_1t_4, s_2t_3, s_2t_4 and s_3t_3.

4.2.5.3. Shoot Weight

The variation in shoot weight of maize at different seed rates and period of harvest is given in Table 11.

Comparing the different seed rates, s_3 (200 g ft^{-2}) recorded the highest shoot weight, while among different period of harvest, t_3 (11 days) recorded the highest shoot weight. Among the interaction effect, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11[th] day) recorded significantly higher shoot weight which was on par with s_3t_4.

4.2.5.4. Root Length

The data on root length of maize at different seed rates and period of harvest is given in Table 11.

Table 11. Effect of seed rate and period of harvest on growth parameters of maize under hydroponics.

Treatments	Number of leaves	Shoot length (cm)	Shoot weight (kg kg^{-1} seed)	Root length (cm)	Root weight (kg kg^{-1} seed)
Seed rate (S)					
s_1 – 150 g ft^{-2}	3	26.58	1.98	21.49	2.87
s_2 -175g ft^{-2}	3	27.00	2.16	21.50	3.02
s_3 - 200g ft^{-2}	3	27.40	2.32	21.49	2.97
SE m (±)	-	0.16	0.03	0.13	0.05
CD (0.05)	NS	0.465	0.085	NS	0.168
Period of harvest (T)					
t_1 – 7 days	3	24.10	1.74	20.47	2.75
t_2 – 9 days	3	25.52	2.01	21.63	2.78
t_3 – 11 days	3	29.04	2.48	21.88	3.22
t_4 –13 days	3	29.31	2.38	21.99	3.14
SE m (±)	-	0.18	0.03	0.15	0.06
CD (0.05)	NS	0.537	0.098	0.441	0.87
Interaction (S x T)					
s_1t_1	3	25.05	1.67	20.5	2.46
s_1t_2	3	25.99	1.8	21.75	2.4
s_1t_3	3	28.9	2.25	21.65	3.37
s_1t_4	3	29.64	2.19	22.05	3.27
s_2t_1	3	24.03	1.89	20.9	3
s_2t_2	3	25.65	2.2	21.29	3.03
s_2t_3	3	28.91	2.31	21.93	3.16
s_2t_4	3	29.42	2.23	21.87	3.14
s_3t_1	3	23.23	1.65	20	2.8
s_3t_2	3	24.92	2.03	21.85	2.91
s_3t_3	3	29.31	2.88	22.05	3.15
s_3t_4	3	28.87	2.71	22.06	3.02
SE m (±)	-	0.32	0.06	0.26	0.11
CD (0.05)	NS	0.869	0.17	0.763	0.324

Different seed rates had no significant impact on root length, while among the different period of harvest t_4 (13 days) recorded the highest root length which was on par with t_2 and t_3. Among the interactions, s_3t_4 (seed rate of 200 g ft^{-2} and harvested on 13th day) showed significantly higher root length which was on par with s_1t_2, s_1t_3, s_1t_4, s_2t_2, s_2t_3, s_2t_4, s_3t_2 and s_3t_3.

4.2.5.5. Root Weight

The data on root weight of maize at different seed rates and period of harvest is given in Table 11.

Among the three seed rates, s_2 (175 g ft^{-2}) recorded the highest root weight which was on par with s_3, while among different period of harvest highest root weight was recorded for t_3 (11 days) which was on par with t_4. Among the interactions, s_1t_3 (seed rate of 150 g ft^{-2} and harvested on 11th day) recorded significantly higher root weight which was on par with s_1t_4, s_2t_3, s_2t_4 and s_3t_3.

4.2.6. Effect of Seed Rate and Period of Harvest on Growth and Yield Attributes of Maize Under Hydroponics

4.2.6.1. Seed to Green Fodder Multiplication Ratio

The data on seed to green fodder multiplication ratio of maize at different seed rates and period of harvest of maize is given in Table 12.

Among the three different seed rates, s_3 (200 g ft^{-2}) and s_2 (175 g ft^{-2}) recorded the lowest seed to green fodder multiplication ratio, while among the different period of harvest at t_3 (11 days) and t_4 (13 days) recorded the lowest seed to green fodder multiplication ratio.

Among the interactions, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11th day) recorded the lowest seed to green fodder multiplication ratio which was on par with s_1t_3, s_2t_3 and s_3t_4.

Table 12. Effect of seed rate and period of harvest on yield attributes of maize under hydroponics

Treatments	Seed to green fodder yield multiplication ratio	GFY (kg kg^{-1} seed)	DFY (kg kg^{-1} seed)
Seed rate (S)			
s_1 – 150 g ft^{-2}	0.22	4.77	0.62
s_2 -175g ft^{-2}	0.2	5.24	0.68
s_3 - 200g ft^{-2}	0.2	5.29	0.67
SE m (±)	0.003	0.06	0.005
CD (0.05)	0.009	0.172	0.014
Period of harvest (T)			
t_1 – 7 days	0.23	4.39	0.62
t_2 – 9 days	0.21	4.79	0.63
t_3 – 11 days	0.18	5.70	0.71
t_4 –13 days	0.18	5.52	0.65
SE m (±)	0.002	0.07	0.006
CD (0.05)	0.007	0.205	0.017
Interaction (S x T)			
s_1t_1	0.26	3.82	0.55
s_1t_2	0.24	4.19	0.57
s_1t_3	0.18	5.62	0.70
s_1t_4	0.19	5.45	0.65
s_2t_1	0.2	4.89	0.68
s_2t_2	0.19	5.23	0.69
s_2t_3	0.18	5.46	0.69
s_2t_4	0.19	5.37	0.64
s_3t_1	0.22	4.46	0.63
s_3t_2	0.2	4.94	0.63
s_3t_3	0.17	6.03	0.74
s_3t_4	0.18	5.73	0.67
SE m (±)	0.003	0.12	0.01
CD (0.05)	0.008	0.355	0.029

4.2.6.2. Green Fodder Yield

The data on GFY of maize at different seed rates and period of harvest is given in Table 12.

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest GFY which was on par with s_2 and among the different period of harvest t_3 (11 days) recorded significantly high GFY which was on par with t_4.

Among the interactions, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11^{th} day) recorded highest GFY which was on par with s_3t_4.

4.2.6.3. Dry Fodder Yield

The data on DFY of maize at different seed rates and period of harvest is given in Table 12.

Among the three different seed rates, s_2 (175 g ft^{-2}) recorded the highest DFY which was on par with s_3 and among the different period of harvest t_3 (11 days) recorded significantly high DFY. Among the interactions, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11^{th} day) recorded the highest DFY.

4.2.7. Effect of Seed Rate and Period of Harvest on Quality Parameters of Maize Under Hydroponics

4.2.7.1. Dry Matter Per Cent

Dry matter content was analysed and presented in Table 13. Different seed rates had no effect on dry matter per cent of maize, while t_1 (7 days) among different period of harvest recorded significantly higher dry matter per cent.

Among the interactions, s_1t_1 (seed rate of 150 g ft^{-2} and harvested on 7^{th} day) recorded the highest dry matter per cent which was on par with s_2t_1 and s_3t_1.

4.2.7.2. Crude Protein

Crude protein varied significantly with different seed rates and interaction effects. The results are presented in Table 13.

Different seed rates had no effect on crude protein, while t_4 (13 days) among different period of harvest recorded significantly high crude protein which was on par with t_3. Among the interactions, s_2t_4 (seed rate of 175 g ft^{-2} and harvested on 13[th] day) was found to be significantly higher crude protein content, which was on par with s_1t_3, s_1t_4, s_2t_3, s_3t_3 and s_3t_4.

4.2.7.3. Acid Detergent Fibre

Low fibre content is desirable for cattle feed. The variation in ADF of maize at different seed rates and period of harvest is given in Table 13.

Different seed rates had no effect on ADF, while among the different period of harvest t_1 (7 days) recorded significantly lower value for ADF. Considering the interactions, there was no significant variations among the treatment combinations and s_1t_1 recorded the lowest ADF.

4.2.7.4. Neutral Detergent Fibre

The data on NDF recorded for maize at different seed rates and period of harvest is given in Table 13.

Different seed rates had no effect on NDF, while among the different period of harvest t_1 (7 days) recorded significantly lower value for NDF. Considering the interaction, s_2t_1 (seed rate of 175 g ft^{-2} and harvested on 7[th] day) recorded the lowest NDF which was on par with s_1t_1 and s_3t_1.

4.2.7.5. Ether Extract

Fat content was analysed and presented in Table 13. No significant effect was noted on fat content at different seed rates. Among the different period of harvest, t_4 (13 days) recorded the highest fat content which was on par with t_2 and t_3.

Considering the interaction effects, s_3t_4 (seed rate of 200 g ft^{-2} and harvested on 13[th] day) recorded the highest fat content which was on par with all treatment combinations except s_1t_1, s_2t_1 and s_3t_1.

Table 13. Effect of seed rate and period of harvest on quality parameters of maize under hydroponics, per cent

Treatments	Dry matter	Crude protein	ADF	NDF	Ether extract	Ash content
Seed rate (S)						
s_1 – 150 g ft^{-2}	13.09	14.64	16.92	44.61	2.33	7.99
s_2 -175g ft^{-2}	12.94	14.73	17.01	44.62	2.45	8.02
s_3 - 200g ft^{-2}	12.74	14.67	17.03	44.79	2.43	8.03
SE m (±)	0.12	0.16	0.06	0.48	0.09	0.14
CD (0.05)	NS	NS	NS	NS	NS	NS
Period of harvest (T)						
t_1 – 7 days	14.17	13.38	16.87	38.52	2.03	7.90
t_2 – 9 days	13.19	14.39	16.90	44.60	2.50	8.05
t_3 – 11 days	12.47	15.28	17.11	46.36	2.51	8.00
t_4 –13 days	11.87	15.67	17.06	49.21	2.57	8.09
SE m (±)	0.14	0.18	0.06	0.55	0.10	0.16
CD (0.05)	0.399	0.563	0.171	1.663	0.295	NS
Interaction (S x T)						
s_1t_1	14.45	13.42	16.82	38.42	1.93	7.64
s_1t_2	13.46	14.35	16.84	44.52	2.43	8.01
s_1t_3	12.54	15.28	17.05	46.54	2.42	8.07
s_1t_4	11.93	15.52	16.97	48.95	2.54	8.23
s_2t_1	13.99	13.42	16.91	38.15	2.10	8.02
s_2t_2	13.29	14.35	16.93	44.92	2.55	8.09
s_2t_3	12.60	15.28	17.12	45.89	2.64	7.89
s_2t_4	11.88	15.87	17.07	49.52	2.52	8.06
s_3t_1	14.06	13.30	16.90	38.99	2.06	8.05
s_3t_2	12.82	14.47	16.92	44.37	2.53	8.06
s_3t_3	12.27	15.28	17.16	46.64	2.47	8.03
s_3t_4	11.79	15.63	17.14	49.15	2.66	7.99
SE m (±)	0.24	0.32	0.11	0.95	0.18	0.27
CD (0.05)	0.607	0.976	NS	2.880	0.511	NS

4.2.7.6. Ash Content

Ash content was analysed and data is presented in Table 13. Lower values of this parameter is desirable. No significant effect was noted on ash content with different seed rates, period of harvest and their interactions.

4.2.8. Effect of Seed Rate and Period of harvest on Economics of Maize Under Hydroponics

The data presented in Table 14 depicts net income and B:C ratio of maize grown at different seed rates and periods for harvest under hydroponics fodder production system.

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest net income and B:C ratio which was on par with s_2 and among the different period of harvest, t_3 (11 days) recorded the highest net income and B:C ratio which was on par with t_4.

Among the interaction, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11^{th} day) recorded highest net income and B:C ratio which was on par with s_3t_4.

4.3. EXPERIMENT III: STANDARDIZATION OF NUTRIENT SOLUTION FOR HYDROPONICS FODDER PRODUCTION

4.3.1. Effect of Different Nutrient Solutions on Growth Parameters of Greengram Under Hydroponics

4.3.1.1. Number of Leaves

Number of leaves recorded at the time of harvest is presented in Table 15. The results revealed that nutrient spray did not have any influence on the number of leaves.

Table 14. Effect of different seed rates and period of harvest on economics of maize under hydroponics

Treatments	Net Income (₹ kg^{-1} seed)	B:C Ratio
Seed rate (S)		
s_1 – 150 g ft^{-2}	23.71	1.99
s_2 -175g ft^{-2}	28.39	2.18
s_3 - 200g ft^{-2}	28.88	2.20
SE m (±)	0.60	0.025
CD (0.05)	1.313	0.073
Period of harvest (T)		
t_1 – 7 days	19.90	1.83
t_2 – 9 days	23.87	1.99
t_3 – 11 days	33.02	2.38
t_4 –13 days	31.19	2.30
SE m (±)	0.69	0.03
CD (0.05)	1.516	0.084
Interaction (S x T)		
s_1t_1	14.20	1.59
s_1t_2	17.92	1.75
s_1t_3	32.17	2.34
s_1t_4	30.52	2.27
s_2t_1	24.94	2.04
s_2t_2	28.30	2.18
s_2t_3	30.61	2.28
s_2t_4	29.72	2.24
s_3t_1	20.55	1.86
s_3t_2	25.38	2.06
s_3t_3	36.28	2.51
s_3t_4	33.32	2.39
SE m (±)	1.20	0.05
CD (0.05)	2.625	0.146

4.3.1.2. Shoot Length

The data pertaining to shoot length recorded at the time of harvest is presented in Table 15.

Shoot length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with spray of 19:19:19 (0.5 %) (n_3), vermiwash (n_6), groundnut cake supernatant solution (n_7) and water (n_8).

4.3.1.3. Shoot Weight

The variation in shoot weight of greengram sprayed with different nutrient solutions is given in Table 15.

The highest shoot weight was recorded for greengram sprayed with hoagland solution (0.25 %) (n_1) which was on par with spray of 19:19:19 (0.5 %) (n_3), combined spray of DAP and KCl at 0.5 per cent each (n_4), and vermiwash (n_6).

4.3.1.4. Root Length

The data pertaining to root length recorded at the time of harvest is presented in Table 15.

Root length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with all other treatments except starter solution (n_5).

4.3.1.5. Root Weight

The variation in root weight of greengram sprayed with different nutrient solutions is given in Table 15.

The highest root weight was recorded for greengram sprayed with hoagland solution (0.25 %) (n_1) which was on par with spray of 19:19:19 (0.5 %) (n_3), combined spray of DAP and KCl at 0.5 per cent each (n_4), and vermiwash (n_6).

Table 15. Effect of different nutrient solutions on growth parameters of greengram under hydroponics

Treatments	Number of leaves	Shoot length (cm)	Shoot weight (kg kg^{-1} seed)	Root length (cm)	Root weight (kg kg^{-1} seed)
n_1 - Hoagland solution (0.25%)	2	22.77	8.14	9.82	2.96
n_2 - Hoagland solution (0.5%)	2	19.63	6.77	9.14	2.45
n_3 - 19:19:19 (0.5%)	2	21.45	7.96	9.81	2.87
n_4 - DAP (0.5%)+ KCl (0.5%)	2	21.74	7.80	9.67	2.84
n_5 - Starter solution (1:2:1)	2	18.43	4.45	7.61	1.60
n_6 - Vermiwash (10 times dilution)	2	22.45	7.59	9.53	2.75
n_7 - Groundnut cake (supernatant solution - 10 times dilution)	2	22.01	7.39	9.24	2.69
n_8 - Water	2	22.40	7.43	9.66	2.66
SE m (±)	-	0.51	0.21	0.28	0.08
CD (0.05)	NS	1.521	0.642	0.844	0.242

4.3.2. Effect of Different Nutrient Solutions on Yield Attributes of Greengram

4.3.2.1. Seed to Green Fodder Multiplication Ratio

The data on seed to green fodder multiplication ratio of greengram sprayed with different nutrient solutions is given in Table 16.

The least amount of seeds required to produce per kg green fodder was found to be for greengram sprayed with hoagland solution (0.25 %) (n_1), 19:19:19 (0.5 %) (n_3), and combined spray of DAP and KCl at 0.5 per cent each (n_4) which was on par with all treatments except n_5.

4.3.2.2. Green Fodder Yield

Data pertaining to GFY is presented in Table 16. Results revealed that spray of nutrient solutions had a marked impact on GFY.

Among the treatments, greengram sprayed with hoagland solution (0.25 %) (n_1) gave the highest GFY which was on par with spray of 19:19:19 (0.5 %) (n_3), combined spray of DAP and KCl at 0.5 per cent each (n_4), and vermiwash (n_6).

4.3.2.3. Dry Fodder Yield

DFY recorded is presented in Table 16. Among the treatments, greengram sprayed with hoagland solution (0.25 %) (n_1) gave the highest DFY which was on par with spray of 19:19:19 (0.5 %) (n_3) and combined spray of DAP and KCl at 0.5 per cent each (n_4).

4.3.3. Effect of Different Nutrient Solutions on Quality Characteristics of Greengram Under Hydroponics

4.3.3.1. Dry Matter Per Cent

Dry matter content is analysed and presented in Table 17. Among different treatments, starter solution (1:2:1) (n_5) recorded the highest dry matter per cent which was on par with hoagland solution (0.5 %) (n_2).

Table 16. Effect of different nutrient solutions on yield attributes of greengram

Treatments	Seed to green fodder yield multiplication ratio	GFY (kg kg^{-1} seed)	DFY (kg kg^{-1} seed)
n_1 - Hoagland solution (0.25%)	0.09	11.10	0.92
n_2 - Hoagland solution (0.5%)	0.11	9.22	0.79
n_3 - 19:19:19 (0.5%)	0.09	10.83	0.88
n_4 - DAP (0.5%)+ KCl (0.5%)	0.09	10.64	0.87
n_5 - Starter solution (1:2:1)	0.16	6.04	0.60
n_6 - Vermiwash (10 times dilution)	0.10	10.34	0.85
n_7 - Groundnut cake (supernatant solution – 10 times dilution)	0.10	10.09	0.83
n_8 - Water	0.10	10.01	0.81
SE m (±)	0.004	0.29	0.08
CD (0.05)	0.016	0.881	0.052

4.3.3.2. Crude Protein

The data on crude protein content is presented in Table 17. Different treatments were found to have no significant effect on the crude protein content of the crop.

4.3.3.3. Acid Detergent Fibre

ADF values were analysed and the results are presented in Table 17. There was no significant variation in the ADF values with the spray of different nutrient solutions.

4.3.3.4. Neutral Detergent Fibre

NDF values was analysed and results are presented in Table 17. There was no significant variation in the NDF values with the spray of different nutrient solutions

4.3.3.5. Ether Extract

Ether extract (fat content) was analysed and presented in Table 17. No significant effect was noted on fat content with application of different treatments.

4.3.3.6. Ash content

Ash content was analysed and data is presented in Table 17. No significant variation was noted on ash content at the application of different treatments.

4.3.4. Effect of Different Nutrient Solutions on Economics of Greengram

The data presented in Table 18 depicts net income and benefit cost ratio of greengram grown with different nutrient solutions.

Greengram sprayed with 19:19:19 (0.5 %) (n_3) recorded the highest net income and B:C ratio which was on par with combined spray of DAP and KCl at 0.5 per cent each (n_4), vermiwash (n_6) and groundnut cake supernatant solution (n_7).

Table 17. Effect of different nutrient solutions on quality characteristics of greengram under hydroponics, per cent

Treatments	Dry matter	Crude Protein	ADF	NDF	Ether extract	Ash content
n_1 - Hoagland solution (0.25%)	8.31	26.02	21.11	32.00	2.47	9.81
n_2 - Hoagland solution (0.5%)	8.58	25.20	20.99	32.55	2.36	9.76
n_3 - 19:19:19 (0.5%)	8.14	25.50	20.99	32.30	2.32	9.80
n_4 - DAP (0.5%)+ KCl (0.5%)	8.20	26.60	20.37	33.00	2.48	9.91
n_5 - Starter solution (1:2:1)	9.03	25.90	21.08	32.49	2.44	9.84
n_6 - Vermiwash (10 times dilution)	8.21	23.80	20.89	31.34	2.45	9.89
n_7 - Groundnut cake (supernatant solution - 10 times dilution)	8.24	26.37	20.87	31.47	2.41	9.89
n_8 - Water	8.53	25.20	20.79	32.35	2.42	9.80
SE m (±)	0.17	0.78	0.86	1.25	0.22	0.23
CD (0.05)	0.527	NS	NS	NS	NS	NS

Table 18. Effect of different nutrient solutions on economics of greengram

Treatments	Net income (₹ kg^{-1} seed)	B:C Ratio
n_1 - Hoagland solution (0.25%)	-55.89	0.66
n_2 - Hoagland solution (0.5%)	-152.56	0.38
n_3 - 19:19:19 (0.5%)	16.77	1.19
n_4 - DAP (0.5%)+ KCl (0.5%)	16.40	1.18
n_5 - Starter solution (1:2:1)	-29.09	0.67
n_6 - Vermiwash (10 times dilution)	10.63	1.11
n_7 - Groundnut cake (supernatant solution – 10 times dilution)	10.89	1.12
n_8 - Water	4.33	1.05
SE m (±)	2.92	0.03
CD (0.05)	8.817	0.089

4.3.5. Effect of Different Nutrient Solutions on Growth Parameters of Maize Under Hydroponics

4.3.5.1. Number of Leaves

Number of leaves recorded at the time of harvest is presented in Table 19. The results revealed that nutrient spray did not have any influence on the number of leaves.

4.3.5.2. Shoot Length

The data pertaining to shoot length recorded at the time of harvest is presented in Table 19.

Shoot length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2), 19:19:19 (0.5 %) (n_3), combined spray of DAP and KCl at 0.5 per cent each (n_4), groundnut cake supernatant solution (n_7) and water (n_8).

4.3.5.3. Shoot Weight

The variation in shoot weight of maize sprayed with different nutrient solutions is given in Table 19.

The highest shoot weight was recorded for maize sprayed with hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2) and combined spray of DAP and KCl at 0.5 per cent each (n_4).

4.3.5.4. Root Length

The data pertaining to root length recorded at the time of harvest is presented in Table 19.

Root length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2) and groundnut cake supernatant solution (n_7).

Table 19. Effect of different nutrient solutions on growth parameters of maize under hydroponics

Treatments	Number of leaves	Shoot length (cm)	Shoot weight (kg kg^{-1} seed)	Root length (cm)	Root weight (kg kg^{-1} seed)
n_1 - Hoagland solution (0.25%)	3	27.58	2.34	24.29	4.15
n_2 - Hoagland solution (0.5%)	3	27.19	2.34	23.68	4.04
n_3 - 19:19:19 (0.5%)	3	26.87	2.09	20.52	3.58
n_4 - DAP (0.5%)+ KCl (0.5%)	3	26.68	2.21	20.11	3.82
n_5 - Starter solution (1:2:1)	3	23.45	1.82	18.31	3.11
n_6 - Vermiwash (10 times dilution)	3	25.36	1.87	22.86	3.19
n_7 - Groundnut cake (supernatant solution - 10 times dilution)	3	26.59	1.98	23.67	3.38
n_8 - Water	3	26.65	2.09	22.05	3.57
SE m (±)	-	0.60	0.06	0.39	0.09
CD (0.05)	NS	1.801	0.19	1.161	0.264

4.3.5.5. Root Weight

The variation in root weight of maize sprayed with different nutrient solutions is given in Table 19.

The highest root weight was recorded for maize sprayed with hoagland solution at 0.25 % (n_1) which was on par with spray of hoagland solution at 0.5 % (n_2).

4.3.6. Effect of Different Nutrient Solutions on Yield Attributes of Maize Under Hydroponics

4.3.6.1. Seed to Green Fodder Multiplication Ratio

The data on seed to green fodder multiplication ratio of maize sprayed with different nutrient solutions is given in Table 20.

The least amount of seeds required to produce per kg green fodder was found to be for maize sprayed with hoagland solution (0.25 %) (n_1) which was on par with hoagland solution (0.5 %) (n_2) and combined spray of DAP and KCl at 0.5 per cent each (n_4).

4.3.2.2. Green Fodder Yield

Data pertaining to GFY is presented in Table 20. Results revealed that spray of nutrient solutions had a marked impact on GFY.

Among the treatments, maize sprayed with hoagland solution (0.25 %) (n_1) gave the highest GFY which was on par with spray of hoagland solution (0.5 %) (n_2).

4.3.2.3. Dry Fodder Yield

DFY recorded is presented in Table 20. Among the treatments, maize sprayed with hoagland solution (0.25 %) (n_1) gave the highest DFY which was on par with spray of hoagland solution (0.5 %) (n_2).

Table 20. Effect of different nutrient solutions on yield attributes of maize under hydroponics

Treatments	Seed to green fodder yield multiplication ratio	GFY (kg kg^{-1} seed)	DFY (kg kg^{-1} seed)
n_1 - Hoagland solution (0.25%)	0.16	6.48	0.87
n_2 - Hoagland solution (0.5%)	0.16	6.37	0.86
n_3 - 19:19:19 (0.5%)	0.18	5.67	0.77
n_4 - DAP (0.5%)+ KCl (0.5%)	0.17	5.64	0.81
n_5 - Starter solution (1:2:1)	0.20	4.94	0.71
n_6 - Vermiwash (10 times dilution)	0.20	5.06	0.71
n_7 - Groundnut cake (supernatant solution - 10 times dilution)	0.18	5.36	0.73
n_8 - Water	0.18	5.65	0.77
SE m (±)	0.004	0.15	0.014
CD (0.05)	0.012	0.44	0.042

4.3.7. Effect of Different Nutrient Solutions on Quality Characteristics of Maize Under Hydroponics

4.3.7.1. Dry Matter Per Cent

Dry matter content is analysed and presented in Table 21. Different treatments were found to have no significant effect on the dry matter content.

4.3.7.2. Crude Protein

The data on crude protein content is presented in Table 21. Among the different treatments, spray of 19:19:19 (0.5 %) (n_3) recorded the highest crude protein content which was on par with starter solution (n_5).

4.3.7.3. Acid Detergent Fibre

ADF values was analysed and the results are presented in Table 21. There was no significant variation in the ADF values with the spray of different nutrient solutions.

4.3.7.4. Neutral Detergent Fibre

NDF values was analysed and results are presented in Table 21. There was no significant variation in the NDF values with the spray of different nutrient solutions

4.3.7.5. Ether Extract

Ether extract (fat content) was analysed and presented in Table 21. No significant effect was noted on fat content with application of different treatments.

4.3.7.6. Ash Content

Ash content was analysed and data is presented in Table 21. No significant variation was noted on ash content at the application of different treatments.

Table 21. Effect of different nutrient solutions on quality characteristics of maize under hydroponics, per cent

Treatments	Dry matter	Crude Protein	ADF	NDF	Ether extract	Ash content
n_1 - Hoagland solution (0.25%)	13.28	15.05	16.85	45.28	2.53	8.13
n_2 - Hoagland solution (0.5%)	13.51	16.08	17.02	45.29	2.66	8.08
n_3 - 19:19:19 (0.5%)	13.53	16.87	17.08	45.55	2.58	8.00
n_4 - DAP (0.5%)+ KCl (0.5%)	14.42	15.85	17.37	45.45	2.59	7.99
n_5 - Starter solution (1:2:1)	14.34	16.67	17.09	45.33	2.74	8.06
n_6 - Vermiwash (10 times dilution)	14.05	15.42	17.29	45.42	2.55	8.06
n_7 - Groundnut cake (supernatant solution - 10 times dilution)	13.68	15.53	17.27	45.35	2.60	7.94
n_8 - Water	13.63	15.40	17.16	45.30	2.60	8.03
SE m (±)	0.39	0.25	0.36	0.40	0.23	0.21
CD (0.05)	NS	0.771	NS	NS	NS	NS

4.3.8. Effect of Different Nutrient Solutions on Economics of Maize Under Hydroponics

The data presented in Table 22 depicts net income and B:C ratio of maize grown with different nutrient solutions.

Maize grown with water (control-n_8) recorded the highest net income and B:C ratio. Combined spray of DAP and KCl at 0.5 per cent each (n_4) was found to have on par value with water for net income.

Table 22. Effect of different nutrient solutions on economics of maize under hydroponics

Treatments	Net income (₹ kg^{-1} seed)	B:C Ratio
n_1 - Hoagland solution (0.25%)	-37.08	0.63
n_2 - Hoagland solution (0.5%)	-193.93	0.25
n_3 - 19:19:19 (0.5%)	27.25	1.93
n_4 - DAP (0.5%)+ KCl (0.5%)	31.17	2.24
n_5 - Starter solution (1:2:1)	24.26	1.97
n_6 - Vermiwash (10 times dilution)	19.14	1.61
n_7 - Groundnut cake (supernatant solution – 10 times dilution)	27.58	2.06
n_8 - Water	32.54	2.36
SE m (±)	1.33	0.04
CD (0.05)	4.023	0.113

Discussion

5. DISCUSSION

5.1. EXPERIMENT I: TO EVALUATE THE SUITABILITY OF FODDER CROPS FOR HYDROPONICS

5.1.1 Performance of Different Crops in Hydroponic Fodder Production System

The performance of cereals like rice, barley, maize and wheat; millets like sorghum, bajra and ragi; legumes like cowpea, horsegram and greengram was studied to find out suitable crops for hydroponic fodder production system.

5.1.1.1. Growth Parameters

The growth parameters viz., number of leaves, shoot and root length of crops were recorded and marked variations in shoot and root length of crops were observed due to different crops under hydroponics. But there was no significant variation in number of leaves among the ten different crops grown under hydroponics.

The shoot length is an index to measure the growth and vigour of plants which contributes to yield in crops. Among the crops, maize (c_3) recorded significantly higher shoot length of 23.23 cm which was on par with greengram (c_{10}) measuring 22.83 cm. Mooney (2005) also reported the variation in shoot length of different crops under hydroponics. This might be due to the presence of higher amount of reserve material in these seeds which would have been helpful for continuous supply of energy to establish better shoot system. Similar results have been observed by Jolad *et al.* (2018). The lowest shoot length of 3.76 cm was observed in ragi (c_7). The probable reason for this might be the limited reserves in the tiny seeds.

As root plays a vital role in water and nutrient absorption, an increase or decrease in root length has direct effect on yield of the crop. Based on the results obtained from the present experiment, it is inferred that significantly higher root length was recorded in greengram (13.51 cm) which was on par with maize (13.27).

Similar results were obtained by Jolad *et al.* (2018). The higher root length of greengram could be attributed to the availability of adequate internal constituents and production of growth promoting substances which initiate the rooting process (Dukare *et al.*, 2017). Higher availability of reducing and non reducing sugars in maize seeds might have favoured the cell development process and in turn increased the root growth. The lowest root length of 4.75 cm was observed in ragi. This might be due to insufficient availability of internal constituents and the poor ability of the seeds to withstand continuous saturation.

5.1.1.2. Yield Attributes

The total yield of the green fodder is resultant of the fresh weight and dry matter accumulation at different parts of plant at different growth stages. Results of the present investigation showed that there is significant difference among different crops with respect to shoot weight, root weight and GFY.

Among the crops, greengram (c_{10}) recorded significantly higher shoot weight and GFY (Fig.1). This is in agreement with findings of Al-Karaki and Al-Hashimi (2011) and Jolad *et al*. (2018). It might be due to improved persistence of shoot and root of these crops which facilitate greater absorption of moisture and nutrients, hence greater accumulation of assimilates which induce profuse vegetative growth and achieve potential yield. The lowest shoot weight and GFY was observed in sorghum (c_5). Loss of crop stand due to metabolic and enzymatic depletion of essential reserves resulted by continuous saturation might be the reason for this lower yield.

Considering root weight, ragi (c_7) had a significantly higher value for root weight compared to other crops. This might be due to the large number of tiny seeds of ragi present as a thick mat.

Among the ten different crops, DFY was higher for greengram (c_{10}) and this can be attributed to the significantly higher GFY. Bajra and sorghum recorded the lowest values for DFY. This could be attributed to the loss of crop stand and high moisture content in these crops in comparison to other tested crops.

5.1.1.3. Quality Characteristics

The observation related to quality parameters *viz.* dry matter per cent, crude protein, ADF, NDF, ether extract and ash content showed significant variations.

Among the crops, all legumes had high crude protein content. Greengram (c_{10}) recorded the highest crude protein content of 20.97 per cent which was on par with horsegram (c_9) and cowpea (c_8). The reason for higher protein content might be due to high protein content of legume seeds, higher nitrogen (N) uptake, rapid synthesize of carbohydrates which was converted and stored as protein. This is in agreement with the findings of Sneath and Mcintosh (2003) and Jolad *et al.* (2018). Ghavidel and Prakash (2007) reported that germination of legume seed is able to improve protein composition.

The digestibility of the fodder crops is indirectly indicated by the fibre content and it occupies prime position in the elevation of fodder crops. It consists of cellulose, hemicelluloses and lignin and hence reduces the digestibility of forages. ADF and NDF below 35 per cent and 50 per cent respectively are considered as good fodder. The NDF value is the total cell wall which is comprised of the ADF fraction plus hemicellulose. NDF values are important because they reflect the amount of fodder or dry matter the animal can consume. As NDF percent increases, the dry matter intake generally decreases. The ADF value refers to the cell wall portions of the fodder that are made up of cellulose and lignin. These values are important because they relate to the ability of an animal to digest the forage. As ADF increases the ability to digest or the digestibility of the forage decreases. From the results it is observed that the lowest ADF value was recorded for maize (c_3) and the lowest NDF value for cowpea (c_8) which was on par with horsegram.

Greengram (c_{10}) recorded the highest ether extract value among different crops which was on par with bajra (c_6). Increased ether extract could be due to the production of chlorophyll associated with plant growth (Fazaeli *et al.,* 2012).

The present investigation showed that among different crops, horsegram recorded the lowest ash per cent which was on par with greengram, barley and maize. Similar findings were also reported by Naik *et al.* (2014) in hydroponic maize.

5.1.1.4. Economics of Cultivation

Higher crop productivity with lesser cost of cultivation could result in better economic parameters like higher net income and B:C ratio. Among all the crops investigated, maize showed maximum net income and B:C ratio (Fig.2). This could probably due to lesser seed cost of maize coupled with comparably higher GFY. Naik *et al.* (2015) also reported the same results and they stated that grain maize is the best choice among different crops for hydroponic fodder production due to its easy availability, quick growing habit, good biomass production and low cost of seeds.

5.1.2. Suitability of Different Crops in Hydroponic Fodder Production System

Among the crops maize recorded the highest shoot length, and greengram recorded the highest root length, shoot weight, GFY and DFY. Maize recorded the highest net income and B:C ratio. B:C ratio of more than one was recorded for rice, barley, wheat, ragi, horsegram and greengram. But in sorghum and pearl millet, seed to green fodder multiplication was very poor (<3 kg) and finger millet had undesirable characters for hydroponics green fodder like lower values for shoot length, shoot weight, protein content, EE and higher values for fibre and ash. Hence these crops were not recommended for hydroponic fodder production system. Considering the yield, quality and economics, maize and greengram was selected for the second and third experiment.

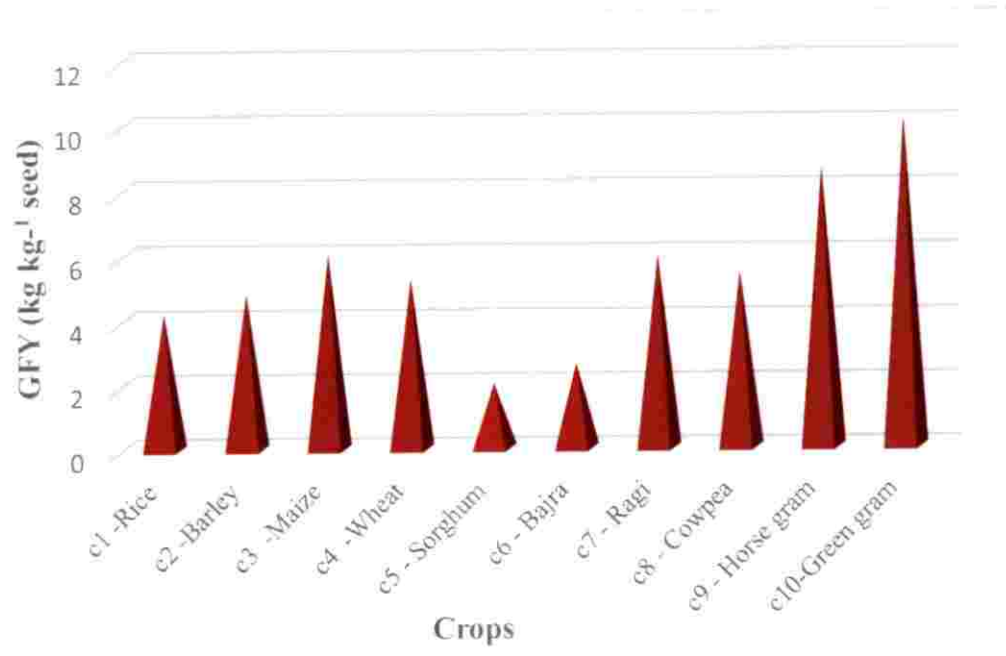


Fig. 1. GFY of different crops in hydroponics fodder production system

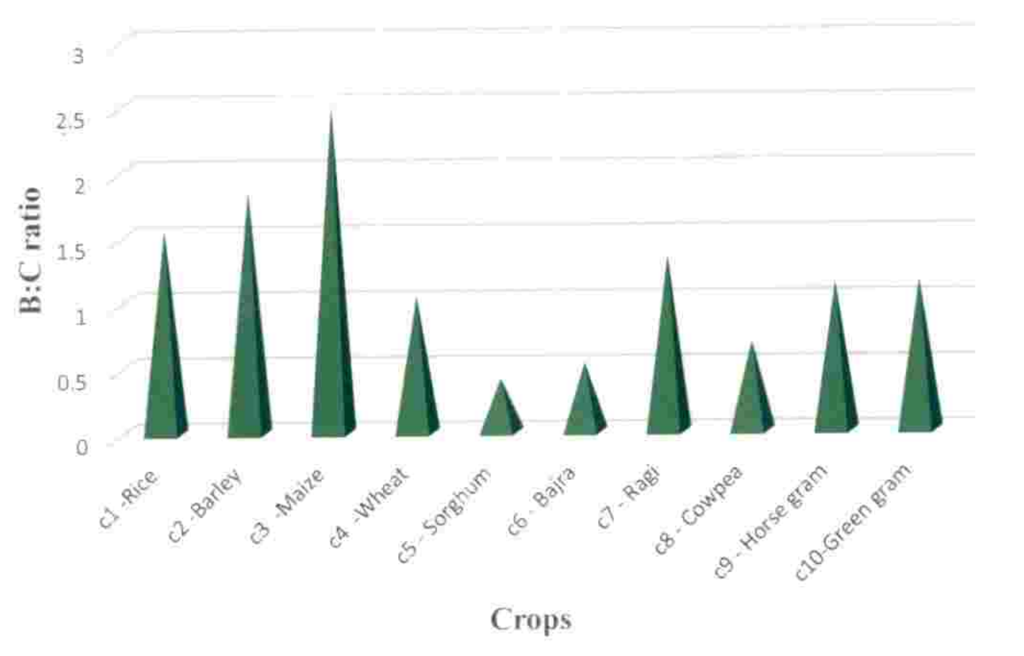


Fig. 2. B:C ratio of different crops in hydroponics fodder production system

5.2. EXPERIMENT II: STANDARDISATION OF SEED RATE AND PERIOD FOR HARVEST OF FODDER IN HYDROPONICS FODDER PRODUCTION UNIT

5.2.1 Effect of Seed Rate and Period of Harvest on Growth Parameters of Greengram Under Hydroponic Fodder Production System

5.2.1.1. Effect on Growth Parameters

Growth parameters are important from the perspective of economical yield. Crop growth is influenced by several internal and external factors, among which, seed rate and period of harvest plays a major role.

The results of present study revealed that the main effects and the interaction effect did not have any significant influence on the number of leaves of greengram. Different seed rates and time for harvest had no significant impact on shoot length. With respect to the interaction effects, s_3t_2 (seed rate of 200 g ft^{-2} and harvested on 9^{th} day) recorded the highest shoot length which was on par with s_1t_2 and s_2t_2. As density increased, plant height and first internode length increased and so at higher density, intense intraspecific competition might have decreased the amount of light available for coexisting plants, leading to taller plants. El-Morsy *et al.* (2013) also stated increase in the seed density of barley will increase its shoot length. As the length of growing period was extended from seven to nine days there was increase in shoot length.

Different seed rates and period of harvest had no significant impact on root length. Among the interactions, s_3t_1 showed significantly higher root length which was on par with s_1t_1, s_1t_2, s_2t_1 and s_3t_2. Increased seed density increased intra plant competition for light and other resources. The light transmission was lower under higher seed density which might have led to increased main root length and number of roots.

5.2.1.2. Effect on Yield Attributes

The total yield of the green fodder is resultant of the fresh weight and dry matter accumulation at different parts of plant at different growth stages. The fresh weight and dry weight are significantly influenced by different seed rates.

Comparing the different seed rates, s_3 (200 g ft $^{-2}$) recorded the highest shoot weight which was on par with s_2 (175 g ft^{-2}), while different period of harvest had no significant effect on shoot weight. In the case of interaction effect, s_3t_1 recorded the highest shoot weight which was on par with s_2t_1, s_2t_2 and s_3t_2.

Among the three seed rates, s_3 (200 g ft $^{-2}$) recorded the highest root weight, while the different period of harvest had no significant effect on root weight. Among the interactions, s_3t_2 recorded significantly higher root weight which was on par with s_3t_1.

Among the three different seed rates, s_3 recorded the highest GFY and DFY, Among the interactions, s_3t_1 recorded highest GFY which was on par with s_3t_2 and s_2t_1 (Fig.3) while s_3t_1 recorded highest DFY which was on par with s_3t_2. Among the different period of harvest, greengram harvested at 7th day (t_1) recorded highest DFY.

The fresh weight of fodder at harvest is sum of fresh weight of individual seedlings, so higher fresh weight of the fodder recorded at higher seed rate might be due to higher plant population compared to lower seed rates. The increased plant population would have increased shoot, root and total fresh weight at the period of harvest. The lower seed rate might result in underutilization of available resources like space and water, which in turn resulted in lesser fodder production. This is in conformity with results of Naik *et al.* (2017). The higher fodder yield of greengram was directly related to total dry matter production.

Results of GFY was as per the findings of Sneath and McIntosh (2003) that the fresh yield of the hydroponically sprouted cowpea increased with the advancement of growing period and remained similar, and the highest from 6th day to 9th day growing period. According to Lorenz (1980), during sprouting, the situation of dry matter decrease is related with degradation of the large part of seed content like carbohydrate (such as starch) which is used for energy source. Dry matter loss was due to the increased water uptake during germination process. (Al-Karaki and Al-Hashimi, 2011). Sprouts can regain some dry matter with the uptake of minerals and effective photosynthesis however in the short growing cycle there is most commonly a dry matter loss ranging from 7 per cent to 47 per cent (Sneath and McIntosh, 2003).

5.2.1.3. Effect on Quality Characteristics

There were no significant differences found in any of quality parameters of hydroponically grown greengram among different seed rates.

Among the interactions, s_3t_2 (seed rate of 200 g ft^{-2} and harvested on 9th day) was found to be significantly higher, which was on par with s_1t_2, s_2t_2 and s_3t_1. Since crude protein content is expressed on dry matter basis and there was an increase in dry matter per cent as period of harvest extended in greengram, greengram harvested on 9th day recorded higher value for crude protein.

Among the different time for harvest, t_1 (7 days) recorded significantly lower value for NDF and NDF. Considering the interactions, s_1t_1 recorded the lowest ADF and NDF values which was on par with s_2t_1 and s_3t_1.

Among the different period of harvest, t_1 recorded the highest fat content, EE and the lowest ash content. Considering the interaction effects, s_2t_1 recorded highest fat content and lowest ash content which was on par with s_1t_1 and s_3t_1. This may be probably due to the loss of dry matter as the time for harvest increase (Trubey *et. al.*, 1969).

5.2.1.4. Effect on economics

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest net income and B:C ratio, while the different period of harvest showed no significant difference in the economics of the system. Among the interactions, s_3t_1 (seed rate

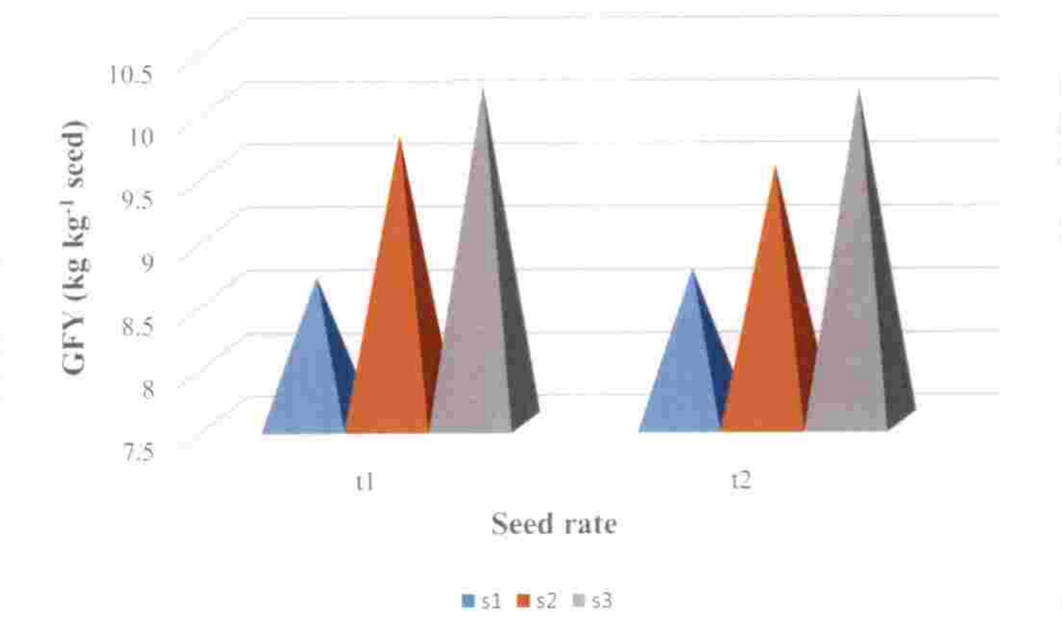


Fig. 3. Effect of different seed rates and period of harvest on GFY of greengram under hydroponics

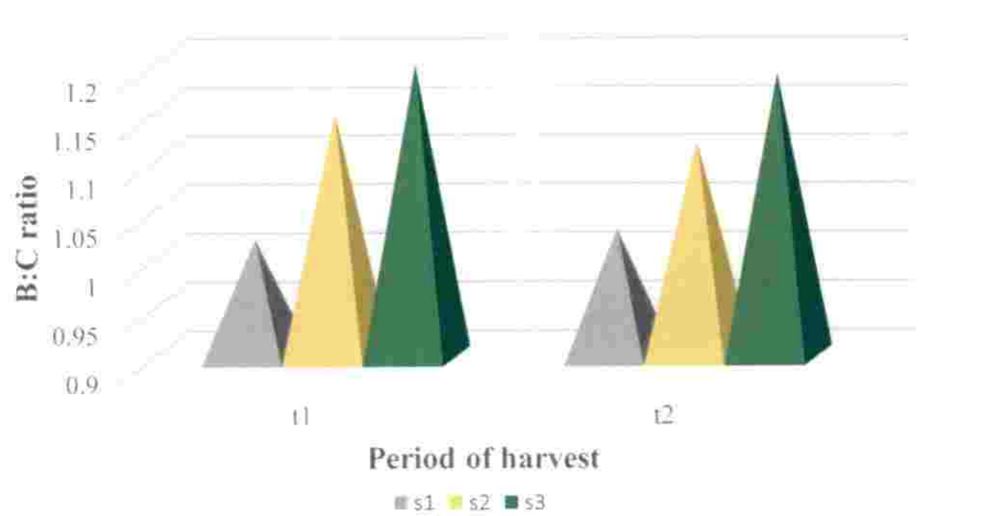


Fig. 4. Effect of different seed rates and period of harvest on B:C ratio of greengram under hydroponics

of 200 g ft^{-2} and harvested on 7^{th} day) recorded highest net income and B:C ratio (Fig.4) which was on par with s_3t_2 and s_2t_1. The increased seed rate increased the total fodder yield of greengram which in turn increased net return and B:C ratio. These results are in consonance with Naik *et al.* (2017).

5.2.2. Effect of Seed Rate and Period of Harvest on Growth Parameters of Maize Under Hydroponic Fodder Production System

5.2.2.1 Effect on Growth Parameters

The results revealed that the main effects and the interaction effects did not have any influence on the number of leaves of maize.

Among the different seed rates, s_3 (200 g ft^{-2}) recorded the highest shoot length which was on par with s_2, while among the different period of harvest t_4 (13 days) recorded highest shoot length which was on par with t_3. With respect to the interaction effects, s_3t_4 recorded the highest shoot length which was on par with s_1t_3, s_1t_4, s_2t_3, s_2t_4 and s_3t_3. As seed density increased crops were shaded, thus light transmittance was lower which leads to increased shoot length. Similar results were observed by Ningoji (2018).

Different seed rates had no significant impact on root length, while among the different period of harvest t_4 (13 days) recorded the highest root length which was on par with t_2 and t_3. Among the interactions, s_3t_4 (seed rate of 200 g ft^{-2} and harvested on 13^{th} day) showed significantly higher root length which was on par with s_1t_2, s_1t_3, s_1t_4, s_2t_2, s_2t_3, s_2t_4, s_3t_2 and s_3t_3. With the increase of seed density and time for harvest root proliferation increased. Similar results were observed by Ningoji (2018).

5.2.2.2. Effect on Yield Attributes of Maize

Comparing the different seed rates, s_3 (200 g ft^{-2}) recorded the highest shoot weight and s_2 (175 g ft^{-2}) recorded the highest root weight, while among different period of harvest, t_3 (11 days) recorded highest shoot and root weight. With respect to interaction effect, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11^{th} day) recorded significantly higher shoot weight which was on par with s_3t_4 and s_1t_3 recorded significantly higher root weight which was on par with s_1t_4, s_2t_3, s_2t_4 and s_3t_3.

Among the three different seed rates, s_3 (200 g ft $^{-2}$) recorded the highest GFY which was on par with s_2 and among the different period of harvest t_3 (11 days) recorded significantly high GFY which was on par with t_4. Among the interactions, s_3t_3 recorded highest GFY (Fig.5) which was on par with s_3t_4 and, s_3t_3 recorded highest DFY which was on par with s_3t_4, s_1t_3, s_1t_4, s_2t_3 and s_2t_4.

Here the higher fresh yield of the plant at 200 g ft $^{-2}$ (s_3) seed rate and harvested at 11th day (t_3) is mainly due to higher dry matter accumulation per kg seeds in different parts of the plant at harvest. The dry matter accumulation increased due to increased growth parameters like shoot length, root length, shoot weight and root weight. This is in conformity with results of Ningoji (2018) who also reported that the fresh yield of shoot, root and total yield per kg seeds sown increased with increased seed rate up to 2.5 kg m^{-2} and thereafter it decreased with 2.75 kg m^{-2}.

Higher dry matter accumulation is mainly ascribed to increased photosynthetic ability and by the higher plant population per unit area in 2.15 kg m^{-2} as compared to 1.88 kg m^{-2} and 1.61 kg m^{-2}, where in lower plant population per unit area, lower growth and yield attributing parameters reduced the dry matter accumulation significantly.

Among the different period of harvest t_3 (11 days) recorded significantly high DFY. This increase in DFY, even though dry matter per cent decreased with growth of cowpea sprouts, is due to the significant increase of GFY.

5.2.2.3. Effect on Quality Characteristics

There were no significant differences found in any of quality parameters of hydroponically grown fodder maize due to different seed rates. Naik *et al*. (2017) also did not observe significant differences in quality parameters of hydroponically grown fodder maize under different seed rate.

Among different period of harvest, t_4 (13 days) recorded significantly high crude protein which was on par with t_3. Among the interactions, s_2t_4 was found to be significantly higher crude protein content, which was on par with s_1t_3, s_1t_4, s_2t_3, s_3t_3 and s_3t_4. Since crude protein content is expressed on a dry matter basis and there was an increase in dry matter from t_1 to t_4 as there was an increase in crude protein content (Trubey *et al.*,1969).

Lowest ADF and NDF values were recorded when harvested on the 7th day (t_1). Considering the interactions, there was no significant variation in ADF values among the treatment combinations and s_2t_1 recorded lowest NDF which was on par with s_1t_1 and s_3t_1. This is similar to the observation by Chrisdiana (2018) that the increase in NDF and ADF value occurs because of the synthesis and accumulation of lignin which usually occurs during the formation and thickening of secondary cell walls.

Among the different period of harvest, t_4 (13 days) recorded highest ether extract value which was on par with t_2 and t_3. Considering the interaction effect, s_3t_4 recorded highest fat content which was on par with all treatments except those harvested at time t_1 (s_1t_1, s_2t_1 and s_3t_1). Increased ether extract could be due to the production of chlorophyll associated with plant growth (Fazaeli *et al.*, 2012). No significant effect was noted on ash content due to different seed rates, period of harvest and their interactions.

5.2.2.4. Effect on Economics

Among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest net income and B:C ratio which was on par with s_2 and among the different period of harvest, t_3 recorded the highest net income and B:C ratio which was on par with t_4. Among the interactions, s_3t_3 recorded highest net income and B:C ratio which was on par with s_3t_4 (Fig.6). The increased seed rate increase the total fodder yield of maize that in turn increased net return and B:C ratio. Higher growth and yield parameters helped to achieve higher fodder yield which finally resulted in higher net return and B:C ratio compared to other treatments (Ningoji, 2018).

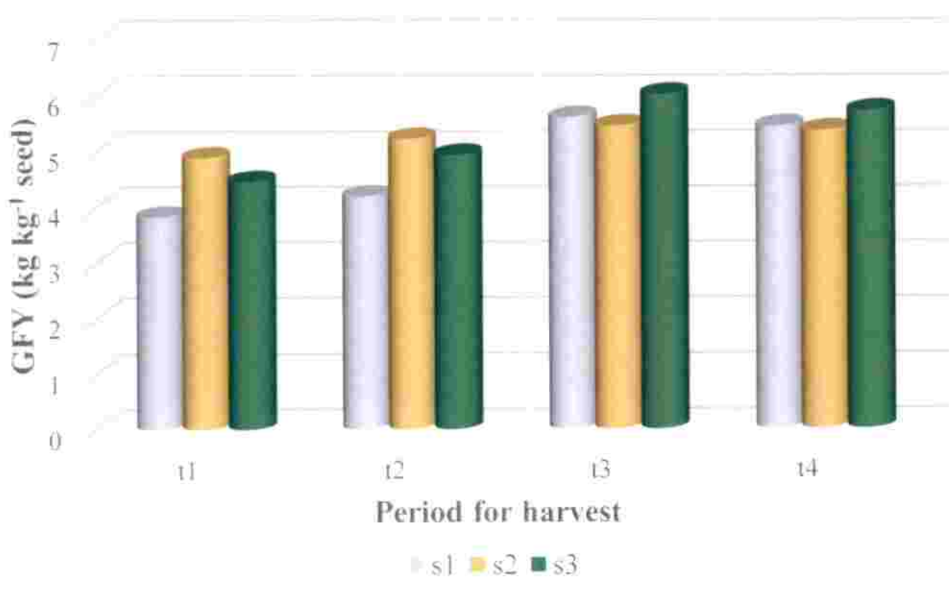


Fig. 5. Effect of different seed rates and period of harvest on GFY of maize under hydroponics

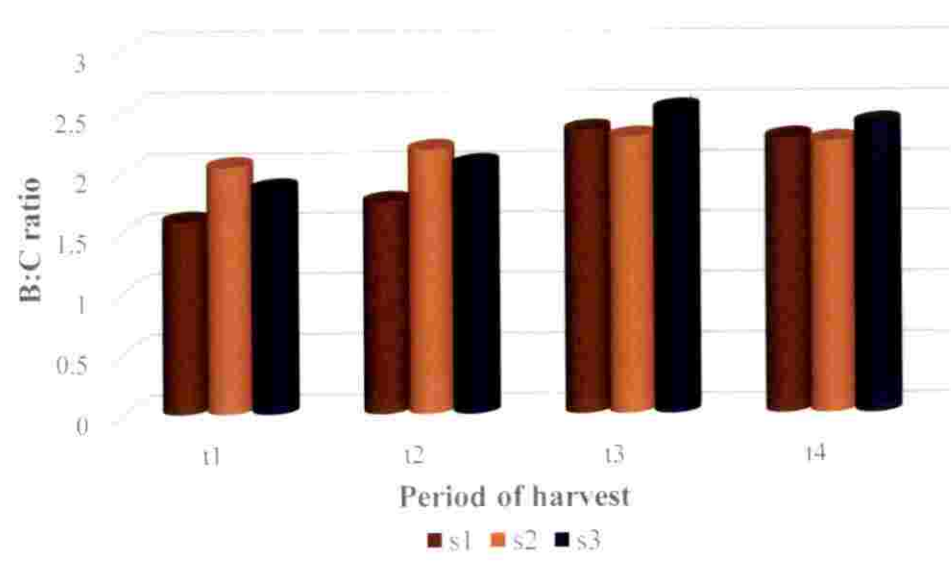


Fig. 6. Effect of different seed rates and period of harvest on B:C ratio of maize under hydroponics

5.3. EXPERIMENT III: STANDARDIZATION OF NUTRIENT SOLUTION FOR HYDROPONICS FODDER PRODUCTION

5.3.1 Effect of Nutrient Solutions on Greengram under Hydroponics Fodder Production System

5.3.1.1 Effect on Growth Parameters

Foliar spray seemed not to play any role in increasing number of leaves as it remained same in all the foliar spray treatment in hydroponically grown greengram.

Better growth was recorded in foliar applied treatments than the control in all the crops taken for the experiment. The plant height and root length growth were steady (Lamnganbi and Surve, 2017).

Shoot length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with spray of 19:19:19 (0.5 %) (n_3), vermiwash (n_6), groundnut cake supernatant solution (n_7) and water (n_8). According to Mehta *et al.* (2017), enhancement of shoot length might be attributed to the increased supply of nutrients in general and N in particular. Higher photosynthetic activity with greater N supply had led to taller shoots.

Root length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with all other treatments except starter solution (n_5). Increased availability of N and phosphorous with above nutrient foliar spray might have enhanced the cell differentiation and multiplication which might be the reason for higher root length.

The findings of the study is in conformity with the studies of Epstein and Bloom (2005) who reported that half strength hoagland solution is considered a complete formulation of all required nutrients and is recommended for general use in hydroponic systems. In this way, the treatment with hoagland solution had the maximum above ground and below ground productions (Androver *et al.*,2013).

5.3.1.2 Effect on Yield Attributes

Yield of a plant largely depend on interactions of various physiological, biochemical and morphological changes that takes place during growth and development of crops and it also depends on optimum availability of resources like nutrients, space, light and water. Nutrients plays an important role in physiological and biochemical processes in plant influencing growth, development and finally the yield.

Nutrient foliar spray imparted a significant effect on GFY of greengram under hydroponics (Fig.7). Among the treatments, greengram sprayed with hoagland solution at 0.25 % (n_1) gave the highest shoot weight, root weight, GFY and DFY which was on par with spray of 19:19:19 at 0.5 % (n_3), combined spray of DAP and KCl at 0.5 % each (n_4), and vermiwash (n_6). This increase could be attributed to the fact that N plays a dominant role in the meristematic activity and cell division which in turn increase the number of cells leading to improved vegetative growth and dry matter accumulation. Potassium (K) activates enzymes which are involved in protein synthesis and carbohydrate translocation which might help for vigorous root development, growth and development of plant leading to increased fodder yield (Ningoji,2018). Adequate availability of nutrients and the presence of larger photosynthesizing surface, production and accumulation of photosynthates proceeded at a rapid rate leading to greater dry matter accumulation. It might be the reason for significantly higher dry matter yield in these treatments (Jolad, 2018).

5.3.1.3 Effect on Quality Characteristics

Different treatments were found to have no significant effect on the quality characteristics of the crop. This might be due to the result as reported by Dung *et al.* (2010) that the short life cycle of seven days does not seem likely to be adequate to bring about the desired changes that would encourage the use of a nutrient solution.

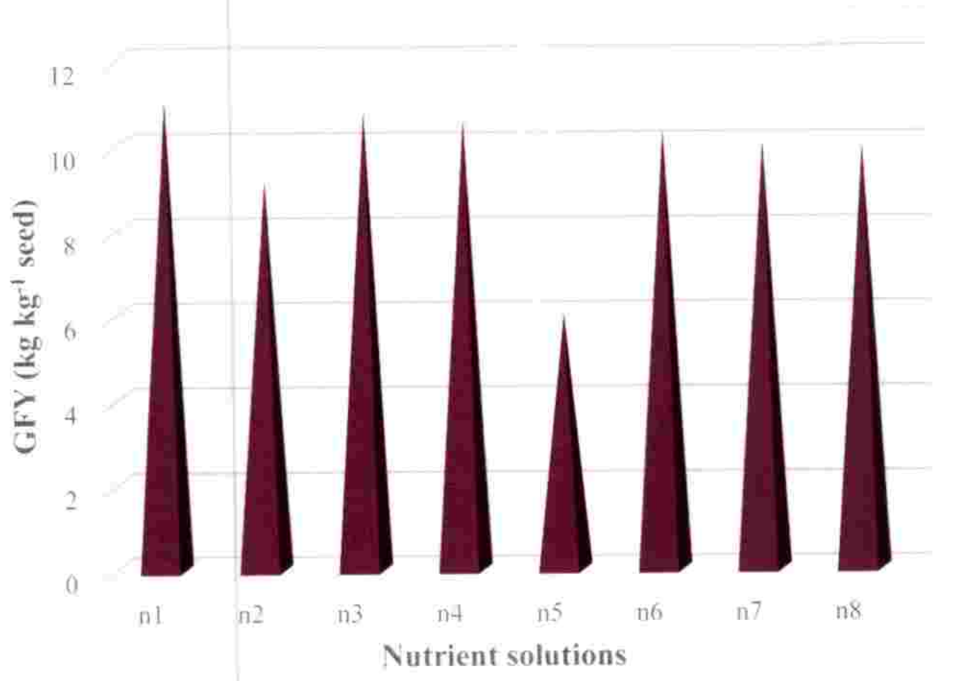


Fig. 7. Effect of different nutrient solutions on GFY of greengram under hydroponics

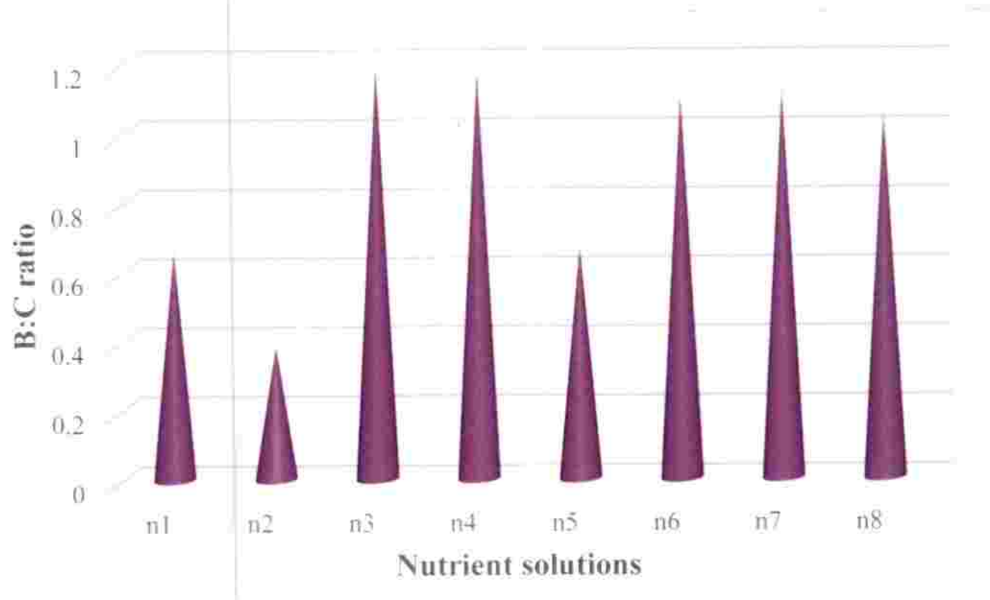


Fig. 8. Effect of different nutrient solutions on B:C ratio of greengram under hydroponics

5.3.1.4. Effect on Economics

Greengram sprayed with 19:19:19 (0.5 %) (n_3) recorded highest net income and B:C ratio which was on par with combined spray of DAP and KCl at 0.5 per cent each (n_4), vermiwash (n_6) and groundnut cake supernatant solution (n_7) (Fig.8). All the solutions were sprayed twice, at 3rd and 5th day. Even though higher GFY was obtained with spray of Hoagland solution at (0.25) (n_1), high cost of the chemical made its use in hydroponic fodder production uneconomical. Considering the forage yield and chemical price, greengram sprayed with 19:19:19 (0.5 %) (n_3) was found to be the best treatment.

5.3.2. Effect of Nutrient Solutions on Maize under Hydroponics Fodder Production System

5.3.2.1 Effect on Growth Parameters

Foliar spray seemed not to play any role in increasing number of leaves as it remained same in all the foliar spray treatment in hydroponically grown maize.

Shoot length was the highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2), 19:19:19 (0.5 %) (n_3), combined spray of DAP and KCl at 0.5 per cent each (n_4), groundnut cake supernatant solution (n_7) and water (n_8). Application of N and K would have increased the shoot length due to improved meristematic activity in terms of increased cell division and elongation. Greater cell elongation might have resulted in increased shoot length (Ningoji, 2018).

Root length was highest with the spray of hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2) and groundnut cake supernatant solution (n_7). Application of N and K would have increased root length attributing the role of N and K in activation of many enzymes which are responsible for vigorous long roots (Ningoji, 2018). Better growth was recorded in foliar applied treatments than the control in all the crops taken. The plant height and root length growth were steady (Lamnganbi and Surve, 2017).

5.3.2.2 Effect on Yield Attributes

Fodder yield of the hydroponically grown maize differed significantly among different foliar sprays.

The highest shoot weight was recorded for maize sprayed with hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2) and combined spray of DAP and KCl at 0.5 per cent each (n_4). The highest root weight was recorded for maize sprayed with hoagland solution (0.25 %) (n_1) which was on par with spray of hoagland solution (0.5 %) (n_2). Androver *et al.* (2013) reported that the treatment with hoagland solution had the maximum above ground and below ground productions.

Among the treatments, maize sprayed with hoagland solution (0.25 %) (n_1) gave the highest GFY (Fig.9) and DFY which was on par with spray of hoagland solution (0.5 %) (n_2). This might be due to proportional supply of primary macro nutrients which in turn allowed the leaves to function photosynthetically and triggered the metabolic activity in seedlings that led to higher growth and finally yield. The higher GFY with foliar application of nutrients was also reported by Al-Karaki and Al-Momani (2011) in hydroponic barley crop. Lamnganbi and Surve (2017) also stated that application of foliar nutrients increased fodder yield of white and yellow maize significantly compared to control.

5.3.2.3 Effect on Quality Characteristics

Regarding the nutrient foliar spray on hydroponically grown maize, application of 19:19:19 (0.5 %) (n_3) recorded the highest crude protein content which was on par with starter solution (n_5). This might be due to accelerated accumulation of protein with adequate supply of primary nutrients. The current observations are in line with the findings of Al-Karaki and Al-Hashimi (2011) and Jolad (2018). ADF and NDF content was not altered with foliar nutrition. It might be because, as it is a genetically controlled attribute, it cannot be modified significantly through agronomic manipulations (Jolad, 2018).

No significant effect was noted on ADF, NDF, EE and ash content with application of different nutrient treatments.

5.3.2.4. Effect on Economics

Considering the yield obtained as well as the price of the chemicals sprayed, maize grown with water (control-n_8) recorded the highest net income and B:C ratio (Fig.10). Spray of 19:19:19 (0.5 %) (n_3) was found to have on par value with water for net income. All the solutions were sprayed at 3rd, 5th, 7th and 9th day. Even though higher GFY was obtained with spray of Hoagland solution (0.25 %) (n_1), high cost of the chemical made its use in hydroponic fodder production uneconomical.

5.4. SEED RATE, PERIOD OF HARVEST AND NUTRIENT SOLUTION FOR HYDROPONIC FODDER PRODUCTION

Analysis of the results of the study indicated that maize and greengram are suitable crops for hydroponic fodder production. Maize grown at a seed rate of 200 g ft^{-2} with water and harvested on 11th day and greengram at a seed rate of 200 g ft^{-2} sprayed with 19:19:19 (0.5 %) and harvested on 7th day were found to give best results considering biometric parameters, quality and economics.

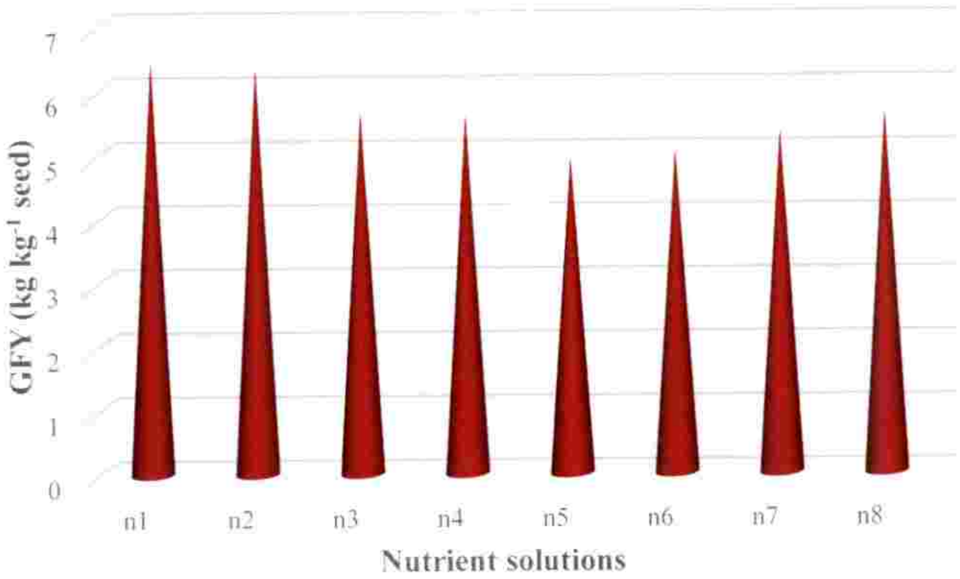


Fig. 9. Effect of different nutrient solutions on GFY of maize under hydroponics

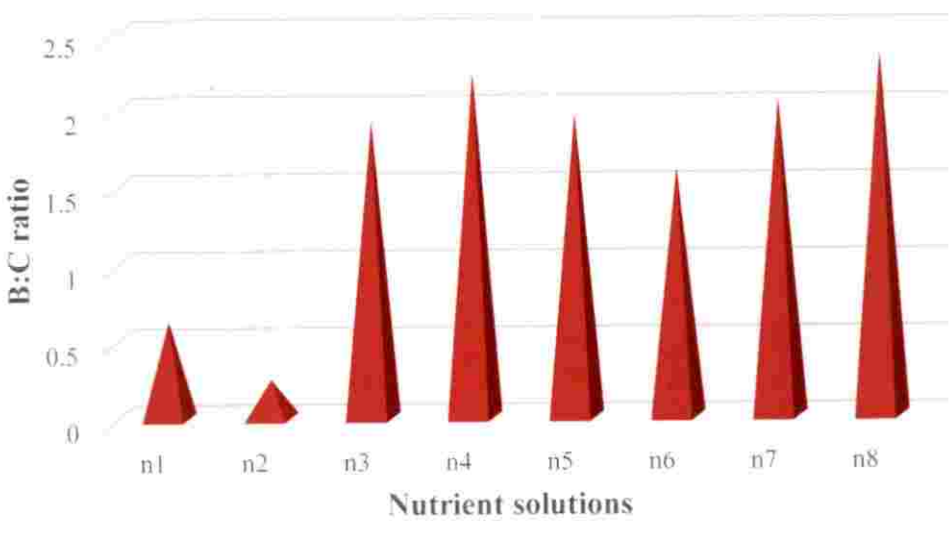


Fig. 10. Effect of different nutrient solutions on B:C ratio of maize under hydroponics

Summary

6. SUMMARY

A study entitled 'Standardization of hydroponics fodder production technology' was undertaken during 2017-2019 at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala with the objectives to identify suitable fodder crops for hydroponics system and to standardize nutrient solution, seed rate and period of harvest. Research work comprised three experiments which was carried out in a low cost hydroponics fodder production system at the Integrated Farming System Research Station, Karamana, Thiruvananthapuram. Summary of the results obtained are presented below under separate heads.

6.1 EXPERIMENT I - TO EVALUATE THE SUITABILITY OF FODDER CROPS FOR HYDROPONICS

The first experiment was aimed to identify suitable fodder crops for hydroponics fodder production system. The experiment was laid out in CRD and the crops included in the trial were rice (c_1), barley (c_2), maize (c_3), wheat (c_4), sorghum (c_5), bajra (c_6), ragi (c_7), cowpea (c_8), horsegram (c_9) and greengram (c_{10}).

Among the crops maize recorded the highest shoot length, and greengram recorded the highest root length, shoot weight, GFY and DFY.

Considering quality parameters, greengram recorded highest crude protein content and EE value. Lower values of fibre and ash is desirable for animal feed. Lowest values for ADF, NDF and ash were reported for maize, cowpea and horsegram respectively.

Maize recorded the highest net income (₹ 36.30) and B:C ratio (2.51). B:C ratio of more than one was recorded for rice, barley, wheat, ragi, horsegram and greengram.

But in sorghum and pearl millet, seed to green fodder multiplication was very poor (<3 kg), which is not recommended for hydroponic fodder production system. Considering the yield, quality and economics, maize and greengram was selected for the second and third experiment.

6.2 EXPERIMENT II: STANDARDISATION OF SEED RATE AND PERIOD FOR HARVEST OF FODDER IN HYDROPONICS FODDER PRODUCTION UNIT

The second experiment was done to standardize seed rate and period of harvest of the selected crops. Three different seed rates *viz*, s_1 : 150 g ft^{-2} (1.61 kg m^{-2}), s_2: 175 gft^{-2} (1.88 kg m^{-2}), s_3 : 200 g ft^{-2} (2.15 kg cm^{-2}) and four different period for harvest *viz,* t_1 : 7 days, t_2 : 9 days, t_3 : 11 days and t_4 : 13 days were adopted. But, in the case of greengram it was observed that the crop did not survive beyond nine days in hydroponic fodder production system and hence only two periods of harvest *viz*, t_1 and t_2 were taken for greengram. Both crops were separately analysed in CRD with two factors.

In greengram, number of leaves, root length and shoot length did not show any significant variation among different seed rates and periods of harvest. Different period of harvest did not have any effect on shoot and root weight, while greengram at 200 g ft^{-2} recorded the highest shoot and root weight. GFY was not affected by period of harvest while greengram harvest on 7th day recorded the highest DFY. The highest seed rate tested i.e, 200 g ft^{-2} recorded the highest GFY and DFY. Hence, greengram sown at 200 g ft^{-2} and harvested on the 7th day resulted in the highest GFY and DFY.

There was no significant difference in any quality parameters of hydroponically grown greengram due to different seed rates. Greengram harvested on 7th day recorded the lowest values for ADF, NDF and ash content, and the highest dry matter per cent and EE value. Net income and B:C ratio did show any significant effect among different period of harvest, while greengram sown at 200 g ft^{-2} (s_3) recorded the highest value for both. Greengram sown at 200 g ft^{-2} and harvested on 7th day (s_3t_1) recorded the highest net income (₹ 16.87) and B:C ratio (1.20).

In maize, among the three different seed rates, s_3 (200 g ft^{-2}) recorded the highest GFY which was on par with s_2 and among the different times of harvest t_3 (11 days) recorded significantly high GFY which was on par with t_4. Among the interactions, s_3t_3 (seed rate of 200 g ft^{-2} and harvested on 11th day) recorded the highest GFY. In maize, no significant difference was found in any of quality parameter due to different seed rates. Among different period of harvest, t_4 (13 days) recorded significantly high crude protein, while t_1 (7 days) recorded the lowest values for ADF and NDF. Among the interactions, s_2t_4 (seed rate of 175 g ft^{-2} and harvested on 13th day) recorded significantly higher crude protein content. It was observed that maize sown at 200 g ft^{-2} and harvested on 11th day (s_3t_3) recorded significantly high value for net income (₹36.28) and B:C ratio (2.51).

Hence, these best combinations of seed rate and period of harvest for both the crops (s_3t_3: seed rate of 200 g ft^{-2} and harvested on 11th day for maize and s_3t_1: seed rate of 200 g ft^{-2} and harvested on 7th day for greengram) were selected for the next experiment.

6.3. EXPERIMENT III: STANDARDIZATION OF NUTRIENT SOLUTION FOR HYDROPONICS FODDER PRODUCTION

The third experiment was done to standardize nutrient solution for hydroponics fodder production. The nutrient solutions tested were n_1: hoagland solution (0.25%), n_2: hoagland solution (0.5%), n_3: 19:19:19 (0.5%), n_4 : DAP (0.5%) + KCl (0.5%), n_5 : starter solution (1:2:1), n_6 : vermiwash (10 times dilution), n_7 : groundnut cake (supernatant solution) and n_8 : water (control), which was sprayed on alternate days from 3rd day. Both crops were separately analysed in CRD.

In greengram, spray of hoagland solution (0.25%) (n_1) resulted in higher shoot weight, root weight, root length, shoot length and GFY, but the B:C ratio was less than one. Spray of 19:19:19 (0.5%) (n_3) recorded on par values with hoagland solution (0.25%) (n_1) for shoot weight, root weight, root length, shoot length, GFY. Different treatments were found to have no significant effect on the quality characteristics of the crop. Significantly higher B:C ratio of 1.19 was recorded for spray of 19:19:19 (0.5%) (n_3).

In maize, spray of hoagland solution (0.25%) (n_1) resulted in higher shoot weight, root weight, root length, shoot length and GFY, but a B:C ratio of less than one. Application of 19:19:19 (0.5 %) (n_3) recorded the highest crude protein content which was on par with starter solution (n_5), while the other quality characteristics were not affected by the application of nutrient solutions. The highest B:C ratio of 2.36 was recorded in the treatment n_8 i.e, water (control).

From the results, it can be concluded that both maize and greengram are suited for hydroponics fodder production. Maize grown at a seed rate of 200 g ft^{-2}, with water and harvested on 11th day, and greengram at a seed rate of 200 g ft^{-2} sprayed with 19:19:19 (0.5%) and harvested on 7th day was found to give the best results considering growth parameters, yield, quality and economics.

Future line of work

- Need to standardize the agro techniques for hydroponic fodder production of other forages *viz*., barley, horsegram and cowpea.
- Need to study the combinations and proportion of cereals and pulses under hydroponic production for balanced animal diet.
- Need to study the influence of light on growth, quality and yield of hydroponics fodder.

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STANDARDIZATION OF HYDROPONICS FODDER PRODUCTION TECHNOLOGY

by

SRUTHI LIZ THOMAS

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ABSTRACT

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COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM- 695 522
KERALA, INDIA

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ABSTRACT

The study entitled "Standardization of hydroponics fodder production technology" was undertaken during 2017-2019, at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, with the objectives to identify suitable fodder crops for hydroponics system and to standardize nutrient solution, seed rate and period for harvest.

Research work comprised three experiments which was carried out in a low cost hydroponics fodder production system at the Integrated Farming System Research Station, Karamana, Thiruvananthapuram. The crops were grown in a hydroponics machine made of PVC pipes with 2m x 1.3m x 1.8m length, breadth and height with four shelves and automatic sprinkler irrigation system. The first experiment was aimed to evaluate the suitability of fodder crops for hydroponics. The experiment was laid out in completely randomised design and the crops included in the trial were rice (c_1), barley (c_2), maize (c_3), wheat (c_4), sorghum (c_5), bajra (c_6), ragi (c_7), cowpea (c_8), horse gram (c_9) and greengram (c_{10}). The seeds were soaked in 0.1 per cent sodium hypochlorite solution for 12 hours, tied in gunny bag and kept for germination for 24 hours. The seeds were then transferred to trays following a seed rate of 200 g ft^{-2} (0.22 g cm^{-2}). Among the crops, maize recorded the highest net income and B:C ratio. Considering yield and quality, greengram recorded significantly superior GFY (10.17 kg kg^{-1}seed), protein content (20.97 %), the lowest values for fibre and ash, and a B:C ratio more than one. In sorghum and pearl millet, seed to green fodder yield multiplication was very poor (<3 kg). Finger millet had undesirable characters for hydroponics green fodder like lower values for shoot length, shoot weight, protein content, EE and higher values for fibre and ash. Hence, maize and greengram were identified and selected for the next experiment.

The second experiment was done to standardize seed rate and period of harvest of the selected crops. Three different seed rates *viz*, s_1 : 150 g ft^{-2} (1.61 kg m^{-2}), s_2: 175 gft^{-2} (1.88 kg m^{-2}), s_3 : 200 g ft^{-2} (2.15 kg cm^{-2}) and four different period for harvest *viz,* t_1 : 7 days, t_2 : 9 days, t_3 : 11 days and t_4 : 13 days

were adopted. But, in the case of green gram, it was observed that the crop did not survive beyond nine days in hydroponic fodder production system and hence only two periods of harvest *viz*, t_1 and t_2 were taken for green gram. Both crops were separately analysed in completely randomised design with two factors. It was observed that maize sown at 200 g ft^{-2} (s_3) and harvested on 11th day (t_3) recorded significantly higher values for GFY (6.03 kg kg^{-1}seed) and B:C ratio. While, greengram sown at 200 g ft^{-2} (s_3) and harvested on 7th day (t_1) recorded significantly higher values for GFY (10.18 kg kg^{-1}seed) and B:C ratio. Hence, these best combinations of seed rate and period of harvest for both the crops were selected for the next experiment.

The third experiment was done to standardize nutrient solution for hydroponics fodder production. The nutrient solutions tested were n_1: hoagland solution (0.25%), n_2: hoagland solution (0.5%), n_3: 19:19:19 (0.5%), n_4 : DAP (0.5%) + KCl (0.5%), n_5 : starter solution (1:2:1), n_6 : vermiwash (10 times dilution), n_7 : groundnut cake (supernatant solution) and n_8 : water (control), which was sprayed on alternate days from 3rd day. Both crops were separately analysed in completely randomised design. In green gram, spray of hoagland solution (0.25%) (n_1) resulted in higher shoot weight, root weight, root length, shoot length and GFY, but the B:C ratio was less than one. Spray of 19:19:19 (0.5%) (n_3) recorded on par values with hoagland solution (0.25%) (n_1) for shoot weight, root weight, root length, shoot length, GFY and a significantly higher B:C ratio. In maize, spray of hoagland solution (0.25%) (n_1) resulted in higher shoot weight, root weight, root length, shoot length and GFY, but a B:C ratio of less than one. The highest B:C ratio was recorded in treatment n_8 i.e, water (control).

From the results, it can be concluded that both maize and greengram are suited for hydroponics fodder production. Maize grown at a seed rate of 200 g ft^{-2} with water and harvested on 11th day, and greengram at a seed rate of 200 g ft^{-2}, sprayed with 19:19:19 (0.5%) and harvested on 7th day were found to give the best results considering growth parameters, yield attributes, quality and economics.

സംഗ്രഹണം

"ഹൈഡ്രോപോണിക്സിൽ തീറ്റപ്പുൽ കൃഷിയുടെ സാങ്കേതിക ക്രമീകരണം" എന്ന വിഷയത്തെക്കുറിച്ച് വെള്ളായണി കാർഷിക കോളേജിലെ വിളപരിപാലന വിഭാഗത്തിൽ 2017 മുതൽ 2019 വരെ ഒരു പഠനം നടത്തുകയുണ്ടായി. ഹൈഡ്രോപോണിക്സിലെ തീറ്റപ്പുൽകൃഷിയ്ക്ക് അനുയോജ്യമായ വിളകൾ ഏതൊക്കെയാണെന്ന് കണ്ടെത്തുക, അവയുടെ വിത്ത് നിരക്ക്, അനുയോജ്യമായ പോഷകലായനി, വിളവെടുപ്പിനുള്ള സമയം എന്നിവ ക്രമീകരിക്കുക തുടങ്ങിയവയായിരുന്നു പഠനത്തിന്റെ പ്രധാന ലക്ഷ്യങ്ങൾ.

ഗവേഷണ പഠനം മൂന്ന് പരീക്ഷണങ്ങളായിട്ടാണ് നടപ്പാക്കിയത്. ചെലവ് കുറഞ്ഞ ഹൈഡ്രോപോണിക്സ് തീറ്റപ്പുൽകൃഷി ഉൽപാദന യന്ത്രം ഉപയോഗിച്ച് കരമനയിലുള്ള സംയോജിത കൃഷി ഗവേഷണ കേന്ദ്രത്തിലാണ് ഗവേഷണം നടത്തിയത്. ഹൈഡ്രോപോണിക്സ് യന്ത്രം പി.വി.സി പൈപ്പുകൾ (2 മീ x 1.3 മീ x 1.8 മീ നീളം, വീതി, ഉയരം യഥാക്രമം) ഉപയോഗിച്ച് നിർമിച്ചിരിക്കുന്നു. ഇതിൽ നാല് അറകളും സ്വയം പ്രവർത്തിക്കുന്ന തുള്ളിനന ജലസേചനവും അടങ്ങിയിരിക്കുന്നു.

ഒന്നാമത്തെ പരീക്ഷണം കംപ്ലീറ്റ്ലി റാൻഡമൈസ്ഡ് ഡിസൈൻ എന്ന രീതിയിൽ മൂന്ന് പ്രാവശ്യം ആവർത്തിച്ചു. ഈ പരീക്ഷണത്തിൽ നെല്ല്, യവം, ചോളം, ഗോതമ്പ്, മണിചോളം, ചാമ, കൂവരക്, പയർ, കാണം, ചെറുപയർ തുടങ്ങിയവ ഉപയോഗിച്ചു. ഇതിൽ ചോളത്തിന് കൂടുതൽ ആദായം ലഭിച്ചു. കൂടുതൽ തീറ്റപ്പുല്ല് ലഭിച്ചത് ചെറുപയറിനാണ്. അതിനാൽ ചോളത്തിനെയും ചെറുപയറിനെയും അടുത്ത പരീക്ഷണത്തിനായി തിരഞ്ഞെടുത്തു.

രണ്ടാമത്തെ പരീക്ഷണത്തിൽ വിത്ത്നിരക്കും വിളവെടുപ്പ് കാലാവധിയുമാണ് ക്രമീകരിച്ചത്. ഒരു ചതുരശ്ര അടിയ്ക്ക് 200 ഗ്രാം ചോളം വിത്തുകൾ ഉപയോഗിച്ച് 11ാമത്തെ ദിവസം വിളവെടുപ്പ് നടത്തിയപ്പോഴാണ് ഏറ്റവും കൂടുതൽ തീറ്റപ്പുല്ലും വരവ് ചെലവ് അനുപാതവും ലഭിച്ചത്. എന്നാൽ

ചെറുപയറിന് ഏറ്റവും ലാഭം കിട്ടിയത് ഒരു ചതുരശ്ര അടിക്ക് 200 ഗ്രാം വിത്ത് ഉപയോഗിച്ച് 7ാം ദിവസം വിളവെടുത്തപ്പോഴാണ്.

മുന്നാമത്തെ പരീക്ഷണത്തിൽ അനുയോജ്യമായ പോഷക ലായനി കണ്ടെത്തുകയായിരുന്നു ലക്ഷ്യം. 0.25% ഹോഗ്ലാന്റ് ലായനി ഉപയോഗിച്ച് ചോളത്തിലും ചെറുപയറിലും കൂടുതൽ തൈകളുടെ നീളവും, വേരിന്റെ നീളവും, തീറ്റപ്പുൽ ഉൽപാദനവും കണ്ടെത്തി. എന്നാൽ വരവ് ചെലവ് അനുപാതം കുറവായിരുന്നു. ഏറ്റവും കൂടുതൽ വരവ് ചെലവ് അനുപാതം രേഖപ്പെടുത്തിയത് ചെറുപയറിൽ 19:19:19 (0.5%) ലായനിക്കും , ചോളത്തിൽ ജലത്തിനുമാണ്.

ചോളം ഒരു ചതുരശ്ര അടിയ്ക്ക് 200 ഗ്രാം വിത്തുപയോഗിച്ച് 11ാം ദിവസം വിളവെടുപ്പ് നടത്തിയതും, ചെറുപയർ ഒരു ചതുരശ്ര അടിയ്ക്ക് 200 ഗ്രാം വിത്തുപയോഗിച്ച് 7ാം ദിവസം വിളവെടുപ്പ് നടത്തി 19:19:19 ലായനി (0.5%) തളിച്ച് നൽകുന്നതും ആണ് ഹൈഡ്രോപോണിക്സിലെ ഏറ്റവും മികച്ച തീറ്റപ്പുൽകൃഷി രീതികൾ എന്ന് കണ്ടെത്തി.