Wick Material and Media for Capillary Wick Based Irrigation System in Kenya

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Abstract: ***With 640m^3 annual water recharge, Kenya is classified as a water deficit country hence the need to identify and adopt water saving irrigation and water management strategies. Capillary wick is an innovative technique of irrigation that uses minimal amount of water. Five wick materials namely: Blanket material (BM), Cotton Woven (CW), Cotton Non-woven (CNW), 100% Polyester Cloth Material (CL) and Imported Wick Material (IWM) were tested for suitability as wick material for the irrigation system. Wick materials were selected based on their water holding capacity (WHC), water absorption pattern (WAP) and maximum capillary height (MCH). In addition, four media types namely: Soil + Sand + Manure (SSM), Soil + Cocopeat + Manure + Sand (SCMS), Soil + Cocopeat + manure + Pumice (SCMP) and Cocopeat + manure + Pumice (CMP) were tested for use in the Capillary Wick Irrigation System (CWS). The media were tested for water holding capacity, water absorption pattern, bulk density and moisture release characteristics (MRC). Of the five wick materials tested, cloth material had the best performance in terms of WAP and MCH but had slightly lower WHC. Therefore cloth material was selected as the best locally available wick material for use in CWS. Of the four media types tested, media SCMP and SSM had the highest performance in terms of WAP and MRC. Evaluation of the materials and media with crops need to be carried out and suitable crops identified for growing in the system.***

Keywords: Substrate, water saving, capillary irrigation system, sustainability

1. Introduction

Agriculture continues to play a predominant role in the economy of Kenya but growth in the agricultural sector has been declining. In 2008, the sector contracted by 5.1 % compared to a growth rate of 2.3 % in 2007. This decline was attributed to adverse weather conditions resulting in inadequate moisture for crop production. Under vision 2030, Kenya's GDP is projected to grow at the rate of 10% annually in the next 20 years and agricultural sector has been identified as a key area to spur this growth (GOK, 2007). New frontiers expected to be opened to spearhead this growth are efficient use of irrigation and exploitation of under-utilized lands [1]. Kenya is classified as a water scarce nation and Agriculture consumes 70% of the available water limiting access to water for domestic, industrial, environmental, recreational and energy production uses [2]. Thus water saving irrigation strategies could substantially increase the water available for other uses.

The use of drip irrigation system is one effort of making use of water as efficiently as possible under protected cultivation. However, most of the small scale farmers lack capital to install drip irrigation system and hence apply water manually using buckets and hosepipes, methods that are laborious and not efficient in water utilization. There is need to develop irrigation systems which are simple, affordable and also with capacity for improved crop water productivity.

Capillary Wick Irrigation System (CWS) is a sub-irrigation system that involves the use of a device that delivers water by capillary movement from a reservoir to the plant growing medium. Sub-irrigation systems save on labour, time and water costs compared to conventional watering systems when plants are grown in pots (Dole et al., 1994) and are thus more economical and efficient than overhead irrigation systems [3, 4]. Capillary Wick Irrigation System is suitable for greenhouse production to increase efficiency of water and nutrient use in production of crop plants [5]. The system results in higher quality produce, there is reduced water loss as there is no runoff, reduced labour costs, reduced incidences of diseases among other advantages such as saving on time and operational costs. This innovative method is also easy and cheap to install and operate [6] and thus suitable for small scale farmers in Kenya. This system is not currently used in Kenya and is therefore necessary to evaluate its performance in order to determine its suitability in greenhouse vegetable production. Use of locally available material can ensure that the system is affordable to the resource poor farmers. This study therefore sought to identify suitable locally available wick material and media for use with capillary wick based irrigation system.

2. Materials and Methods

2.1 Selection of wick material

Identification of the best wick material for use in the capillary wick irrigation system was determined through laboratory experiments. Five wick materials were evaluated (Table 1) were evaluated. Parameters measured included water holding capacity (WHC), water absorption pattern (WAP) and maximum capillary height (MCH). The experiments were carried out in a completely randomized design and the treatments were replicated three times. The dimensions of the wick material were 4 cm wide by 45 cm long.

Table 1: Wick materials tested

Material type	*Description*
BM	Blanket material used as floor dusters
CW	Cotton woven material used as floor dusters
CNW	Cotton Non-woven material used as floor dusters
CL	100% Polyester cloth material
IWM	Imported wick material used for irrigation in Japan and served as the control.

To determine water holding capacity (WHC), the materials were first oven dried at 50 °C to constant weight. Weight of the wick materials was measured using an electronic balance (LIBROR EB-3200D-A, Shimadzu Corporation, Japan). The materials were then immersed in a shallow basin of water and allowed to saturate from the bottom to top. After saturation the materials were placed in a humid enclosure to drain excess water and their saturated weights were measured using an electronic balance (LIBROR EB-3200D-A, Shimadzu Corporation, Japan). Water holding capacity of each material was calculated as follows:

$$\text{WHC (\%)} = \left(\frac{M_S\text{-}M_D}{M_S}\right) * 100 \text{ Eqn 1}$$

where WHC is water holding capacity, M_S is mass of saturated wick material and M_D is dry mass of wick material.

For capillary rise, the materials were oven dried and thereafter pegged on a string clamped on two ring stands as shown in Figure 1. The bottom end of each material was placed into a beaker filled with water. Water rise was measured in centimeters using a meter rule at 30 minutes interval over a time course of 180 minutes. Maximum capillary height was measured when there was no further water rise.

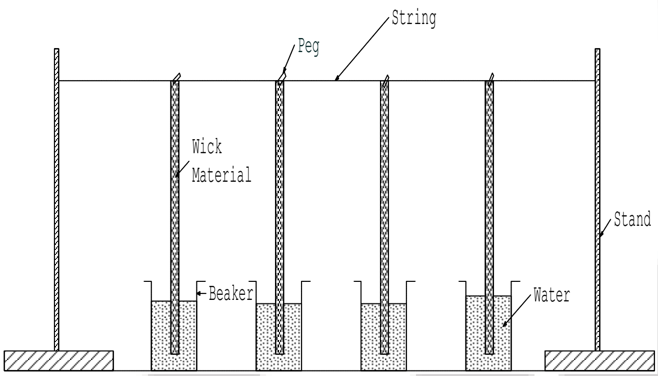

Figure 1: Set up for determination of wick material water absorption pattern and maximum capillary height.

Media selection: Identification of best media for use in the capillary wick irrigation system was also determined through laboratory experiments. Parameters determined included water holding capacity, water absorption rate, bulk density and moisture release characteristics for each media. Four types of media were evaluated (Table 2). The experiments were carried out in a completely randomized design (CRD) with three replications.

Table 2: Types of media tested

Media type	*Description*
SSM	3 parts forest soil, 2 parts sand and 1 part manure.
SCMS	2 parts forest soil, 4 parts cocopeat, 1 part manure and 1 part sand.
SCMP	2 parts forest soil, 4 parts cocopeat, 1 part manure and 1 part pumice.
CMP	4 parts cocopeat, 1 part manure and 2 parts pumice

Determination of media water holding capacity (WHC) was done for each media by oven-drying the sample in screened Hilgard soil cup (5 cm in diameter and 5 cm in height) fitted with a whatman filter paper No. 2 and weighed to get the dry weight. The cup was then placed in a shallow basin of water and the sample was allowed to saturate from the bottom to the surface. After saturation the cup was placed in a humid enclosure to drain excess water. The mass of dry media (M_D) and saturated media (M_S) were estimated using an electronic balance (LIBROR EB-3200D-A, Shimadzu Corporation, Japan).Water holding capacity was calculated as follows:

$$\text{WHC (\%)} = \left(\frac{M_S\text{-}M_D}{M_S}\right) * 100 \text{ Eqn 2}$$

where WHC is water holding capacity, M_S corresponds to mass of saturated media and M_D to dry mass of media.

Water absorption pattern (WAP) of media was determined by oven-drying samples in a clear plastic tube (2 cm in diameter and 50 cm in length) clamped on a ring stand (Figure 2). One end of the glass tube was covered with a whatman filter paper No. 2 secured using a rubber band and was placed into a 250 ml beaker. Water was added up to 250 ml mark. Water absorbed was measured in mls at 5 minutes interval over a time course of 30 minutes. This was done by marking the level of water in the beaker after every 5 minutes. The amount of water in mls required to top up to the marked point was recorded as water absorbed. For determination of Bulk density, media sample was filled into a core ring (5 cm in diameter and 5 cm in height) and oven dried at 105 °C for 48 hours. The dry mass of the sample was determined and bulk density calculated as follows:

$$\rho b = \frac{M_D}{M_V} \text{ Eqn 3}$$

where ρb is bulk density (g/cm^3), M_D is dry mass of media and M_V is total volume of media.

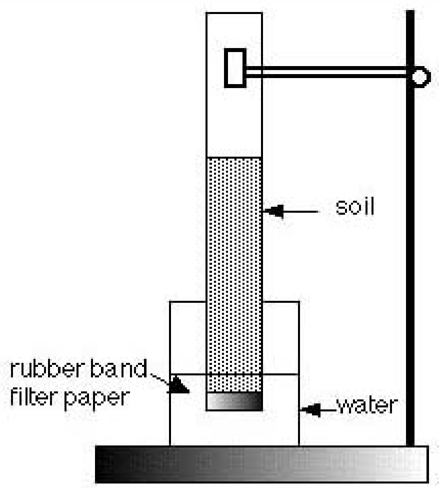

Figure 2: Schematic representation of set up for determining water absorption pattern of the media.

Determination of particle density was done by measuring the volume of water displaced by the media particles (volume of solids only). Particle density was calculated similarly to bulk density but only volume of solids was used. Total porosity was calculated using the formula:

$$\text{TPS}\ (\%) = \left(\frac{1-\rho b}{\text{Particle density}}\right) * 100 \text{ Eqn 4}$$

Where TPS is total porosity (%) and ρb is bulk density of media.

Moisture release characteristics of each media were determined using a Moisture Equivalent Centrifuge (Model H-1400pF, Kokusan Corporation, Japan). Samples were prepared by filling media into core rings (5 cm in diameter and 5 cm in height) whilst compacting. The samples were saturated for 24 hours in a laboratory and thereafter allowed to drain excess water. Weights of the saturated samples were recorded before loading into the centrifuge. The machine was run at different tensions ranging from 0.05 to 15.85 for one hour at each tension level. Weights of samples were recorded at each tension level. Samples were then oven dried at 110 °C for 24 hours to obtain the dry weights. Volumetric moisture content (θv) was computed as follows for all the tension levels and the results were used to obtain the available water.

$$\theta v = \left(\frac{M_S\text{-}MT}{MD}\right) * \rho b \text{ Eqn 1}$$

where MS corresponds to mass of saturated media, MT to mass of media at each tension level, MD to dry mass of media and ρb to bulk density of media.

Data analysis: The data were analyzed using GLM procedure in the Statistical Analysis System [7] software version 9.1 (SAS Institute, Cary, NC, USA). Data were subjected to Analysis of Variance (ANOVA) to determine if the different wick materials or media differed significantly When ANOVA was significant, treatment means were separated by Least Significant Difference (LSD) test at P=0.05.

3. Results

3.1 Selection of Wick Material

Five wick materials were compared (Table 3) for water absorption pattern (capillarity action), maximum capillary height (MCH) and water holding capacity (WHC). The wick materials were significantly different in water absorption (P <0.01) over the entire time course. The cloth material (CL) had the highest water absorption pattern with 10.9 cm at 180 minutes while lowest capillarity action was recorded in cotton woven material (CW) with 4.4 cm at 180 minutes (Table 3). Capillarity action was in the order CL > IWM > CNW > BM > CW over the entire time course. This cloth material commonly used as a shoulder shawl and composed of 100% polyester performed even better (Table 3) than the control (IWM) used for wick irrigation in Japan which had a water rise of 8.1 cm at 180 minutes. Significant differences also existed (P <0.01) in MCH and WHC (Table 3). MCH was measured at 48 hrs when there was no further water rise. The MCH followed the order CL>IWM>CNW>BM>CW with 19.4 cm, 14.4 cm, 10.9 cm, 6.4 cm and 5.2 cm respectively. CW, CNW and IWM were not significantly different in WHC with 86.9%, 86.7% and 86.3% respectively. The cloth material however had a significantly lower water holding capacity of 79.7%.

3.2 Selection of Media

The media types were significantly different in water absorption pattern and water holding capacity. Water absorption rate was high in SSM with 132.7 ml at 30 minutes and lowest in CMP with 61.3 ml at 30 minutes (Table 4). The water absorption rate followed the order SSM>SCMP>SCMS>CMP with 132.7 ml, 114 ml, 84.7 ml and 61.3 ml respectively (Table 4). The bulk densities of the media were: SSM (1.07 g/cm^3), SCMP (0.35 g/cm^3), SCMS (0.42 g/cm^3) and CMP (0.32 g/cm^3). Water holding capacity was high in SCMP with 72% while SSM had the lowest water holding capacity of 38%. Significant differences were also observed in moisture release characteristics (MRC) of the media types (Figure 3). Of importance are two characteristic points; pF 2.48 (equivalent to field capacity) and pF 4.2 (equivalent to permanent wilting point) of which the difference in soil water content between these two points is the available water (AW). SSM had significantly higher amount of available water (7.4%) compared to 5.3%, 4.9% and 3.2% under SCMP, SCMS and CMP respectively (Figure 3). Based on these results SCMP and SSM were selected and further evaluated in a greenhouse study.

Table 3: Capillarity action of different wick materials over a time course study of 180 minutes and their water holding capacity (WHC)

Type of wick	*Water rise/ capillarity action in cm*							
	Time in minutes						*MCH*	*WHC*
	30	60	90	120	150	180		(%)
BM	0d	3.5c	4.5c	5.2e	5.4d	5.4d	6.4d	84.6b
CW	0d	2.8d	3.2d	3.7d	4.2e	4.4e	5.2e	86.9a
CNW	2.6c	3.7c	4.4c	5.7c	6.1c	6.3c	10.9c	86.7a
CL	6.1a	7.5a	8.9a	10.2a	10.6a	10.9a	19.4a	79.7c
IWM	4.8b	6.4b	7.1b	7.7b	8b	8.1b	14.4b	86.3a
LSD	0.30	0.30	0.45	0.27	0.28	0.37	0.83	0.01
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Means followed by the same letter within the column are not significantly different (P<0.01).

Table 4: Amount of water absorbed by different types of media contained in a 2 cm diameter plastic tube over a time course of 30 minutes and their water holding capacity (WHC)

Type of media	*Water absorption in mls*							
	Time in minutes						*AW*	*WHC*
	5	10	15	20	25	30	(%)	(%)
SSM	28.0a	60.7a	95.7a	121.7a	130.7a	132.7a	7.4a	84.6b
SCMS	19.0b	33.3c	47.3c	71.0c	79.3c	84.7c	4.9c	86.9a
SCMP	18.3d	46.0b	70.3b	92.7b	101.0b	114.0b	5.3b	86.7a
CMP	7.3c	14.0d	30.0d	37.7d	56.0d	61.3d	3.2d	79.7c
LSD	4.48	3.35	2.98	3.39	3.07	2.98	0.02	0.02
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Means followed by the same letter within the column are not significantly different (P<0.05).

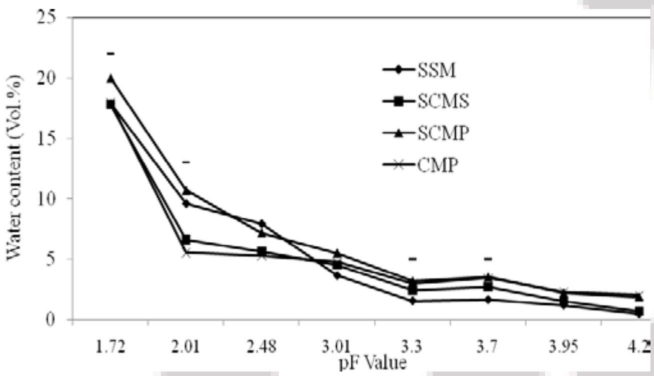

Figure 3: Moisture release curves of the different media types. Horizontal bars show LSD0.05.

4. Discussion

Selection of wick material and media were the most important factors for the establishment of capillary wick irrigation system (CWS) in Kenya. Five wick materials and four media types were compared. For all the wick materials tested, significant differences were observed in their water absorption pattern (WAP) or capillarity action, maximum capillary height (MCH) and water holding capacity (WHC). Cloth material performed better than all other materials in WAP and MCH while poor performance was recorded in cotton woven material. This cloth material however had a slightly lower water holding capacity compared to other materials.

Capillarity action of the wick is an important factor in wick culture systems since they are self watering sub-irrigation systems using wick to absorb water [4, 5]. Capillarity action was in the order CL>IWM>CNW>BM>CW over the entire time course. This cloth material is commonly used as a shoulder shawl and is composed of cotton. There is limited literature currently on local wick materials for use in Capillary Wick System. Materials which have been tested and used in wick culture systems elsewhere include bonded non-woven fabric [5], polyester capillary mat [8] and rolled polyester clothes [9]. In this current study, cloth material demonstrates the best attributes for capillary wick irrigation system and is therefore recommended as best suitable wick material (see results in Table 3).

It is very clear from the current study results that not all materials can be used with Capillary Wick Irrigation System as shown by poor performance by several materials tested. The cloth material had good water absorption characteristics and was later found not susceptible to rotting thus can be reused in production provided care is taken to avoid spread of diseases. Capillarity action and durability of the wick material are attributes for success of Capillary Wick Irrigation System.

Media types were compared for their water absorption pattern (WAP), water holding capacity (WHC) and moisture release characteristics (MRC). Water absorption characteristics of the growth media is an important factor in Capillary Wick irrigation System [10]. The media types were significantly different in water absorption pattern, water holding capacity and moisture release characteristics. Media SSM had the highest water absorption pattern while lowest was in CMP. The water absorption pattern revealed significant differences in the following order SSM>SCMP>SCMS>CMP. SCMP had the highest water holding capacity of 72% while SSM had the lowest water holding capacity of 38%.

The media types significantly differed in moisture release characteristics (MRC). The moisture release characteristics are used to plot a soil water characteristic curve or pF curve. Field capacity (pF 2.48) and permanent wilting point (pF 4.2) are two characteristics points of the pF curve which are of importance in crop production. The difference in soil water content between these two points is the available water which is defined as amount of water readily available for plant uptake and utilization [11]. For optimal growth conditions, 30 – 45% of water held in a root media should be easily available water [12]. SSM had the highest amount of available water followed by SCMP, SCMS and CMP respectively. SCMP and SSM were selected based on these results and the two media were compared in production of tomato under capillary wick irrigation system.

5. Conclusion and Recommendations

From the study we conclude that cloth material composed of polyester is the most suitable local wick material for use in capillary wick based irrigation system. The Soil + Sand + Manure combination and the Soil + Cocopeat + Manure + Pumice combinations are suitable media for use in the system. These findings pave way for further evaluation of the system with growing crops. Such evaluation should compare the capillary wick irrigation system to existing irrigation systems such as drip irrigation. Crops suitable for growing using the system should also be determined.

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References

[1] KNBS, Economic Survey. 2008, Nairobi, Kenya: Ministry of Planning, National Development and Vision 2030. 44.
[2] MoWID, Kenya national water development report. 2005, Nairobi, Kenya: Ministry of Water and Irrigation Development.
[3] Klock-Moore, K.A. and T.K. Broschat, Irrigation systems and fertilizer affect petunia growth. HortTechnology, 2001. 11: p. 416-418.
[4] Son, J.E., et al., Nutrient-flow wick culture system for potted plant production: System characteristics and plant growth. Scientia Horticulturae, 2006. 107: p. 392-398.
[5] So, I.S., et al., Production of Cyclamen Using Capillary Wick System: I. Influence of Wick Material and Root Substrate Composition. Journal of Korean Flower Research Society, 2003. 11(2): p. 199-206.
[6] Bainbridge, D.A., Alternative irrigation systems for arid land restoration. Ecological Restoration, 2002. 20: p. 23-30.
[7] SAS-Institute, SAS statistical software. Version 9.1. 2002, SAS Institute, Cary, NC: USA.
[8] Chanseetis, C., et al., Application of capillary hydroponic system to the lettuce growing under tropical climate conditions. Acta Horticulturae, 2001. 548: p. 401-408.
[9] Kang, B.K. and S.H. Han, Production of seed potato (Solanum tuberosum L.) under the recycling capillary culture system using controlled release fertilizers. Journal of Japanese Society of Horticultural Science, 2005. 74(4): p. 295-299.
[10] Klock-Moore, K.A. and T.K. Broschat, Effect of four growing substrates on growth of ornamental plants in two irrigation systems. HortTechnology, 2001. 11: p. 456-460.
[11] Cornelis, W., et al., Soil-Water Management: Practical Exercises Manual. 2007, Belgium: International Centre for Eremology, Ghent University. 124.
[12] Verdonck, O.V., R. Penninck, and M. De-Boodt, The physical properties of different horticultural substrates. Acta Horticulturae, 1983. 150: p. 155-160.

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