Computers and Electronics in Agriculture 112 (2015) 200–208

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Wetting patterns and water distributions in cultivation media under drip irrigation

Zhigang Liu [a,c], Pingping Li [a,b,*], Yongguang Hu [a], Jizhang Wang [a]

[a] Institute of Agricultural Engineering, Jiangsu University, Zhenjiang 212013, China
[b] College of Forest Resources and Environment, Nanjing Forestry University, Nanjing 210037, China
[c] College of Engineering, Huazhong Agricultural University, Wuhan 430070, China

ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form 24 December 2014
Accepted 2 January 2015
Available online 17 January 2015

Keywords:
Wetting pattern
Water distribution
Drip irrigation
Cultivation media

ABSTRACT

The infiltration and distribution of water in two kinds of cultivation media are examined under different conditions of drip irrigation in terms of flow, volume, and initial medium water content and the models were used to express the horizontal migration distance and the vertical migration distance, and express the size of the wetting body indirectly. The results show that in different media, the wetting body is shaped like a rotating projectile, whose maximum horizontal infiltration radius occurs at 3–6 cm below the medium surface. Under drip irrigation of the same volume, the volume of the medium wetting body declines while the horizontal and vertical migration rates of the medium wetting front both rise with increasing irrigation flow; additionally, there are declines in medium water content, and water content increment at the same position. Under drip irrigation of the same duration, increasing irrigation flow leads to increases in the volume of the medium wetting body, horizontal and vertical migration rates of the medium wetting front, surface medium water content, and the medium wetting range. Under drip irrigation at the same flow, there are increases in the width and depth of the medium wetting body, declines in the migration rate of the medium wetting front, and horizontal rises in the progressively decreasing rate of medium water content as the irrigation volume increases. Under drip irrigation of the same duration, the horizontal migration rate of the medium wetting front rises while the vertical migration rate of the medium wetting front declines with increasing initial medium water content; correspondingly, medium wetting body tends to flatten gradually as a whole, and the increment of medium water content at the same position is diminished.

1. Introduction

Drip irrigation technology is often preferred over sprinkler and other irrigation methods (Mmolawa and Or, 2000), because it can conserve water, increase crop production, and improve crop quality (Skaggs, 2001). The number of studies on drip irrigation have increased in recent years, because agricultural irrigation has become an increasingly serious challenge. Singh et al. (2006) simulated the soil wetting pattern with subsurface drip irrigation from a line source, Li et al. (2006) analyzed the relationships between dripper discharge and soil wetting pattern for drip irrigation, Assouline (2002) studied the effects of microdrip and conventional drip irrigation on water distribution and uptake, and Patel and Rajput (2008) simulated the dynamics of soil water under onion irrigated by a subsurface drip.

However, most of these studies were conducted on soil (Huang and Han, 2011; Shen and Hao, 2006; Assouline, 2002). In fact, global agriculture has changed dramatically over the last few decades, and the use of soilless cultures has expanded enormously (Raviv and Lieth, 2008). Currently, many soilless crops are cultivated on different substrates such as peat, perlite, rockwool, coconut coir, and scoria (De Rijck and Schrevens, 1998; Naddaf et al., 2011; Bougoul and Boulard, 2006). Rockwool and peat are the most widely used growing medium throughout the world. However, peat is non-renewable and its extraction is environmentally damaging, and farmers are worried about the harmful effects of rockwool fiber on human health and the problems of disposal after use (Marfa et al., 2002; Yu and Komada, 1999; Heiskanen, 1995).

Waste vinegar residue is a by-product in vinegar production, with two million tons produced annually in china (Song et al., 2012), and is available at little cost for use as a growing medium

* Corresponding author at: Institute of Agricultural Engineering, Jiangsu University, Zhenjiang 212013, China.
E-mail address: liuz.g@163.com (P. Li).

http://dx.doi.org/10.1016/j.compag.2015.01.003
0168-1699/

after fermentation. It not only releases available nutrients, but has solved the problem of reusing solid waste, and does not damage the environment. Waste vinegar residue has its own specific physical and chemical properties, which have a major influence on water balance. However, to our knowledge, no studies have yet investigated wetting pattern and water distribution in substrates under drip irrigation. Moreover, little is known about the effects of variability in the water application rate and initial water content. We studied wetting pattern and water distribution in two kinds of vinegar residue-based substrates under drip irrigation, and the effect of drip irrigation flow, irrigation volume and initial water content.

2. Materials and methods

2.1. Vinegar residue

Vinegar residue is the solid waste product from vinegar production. It contains large amounts of fiber and is acidic. By artificially adjusting the pH, adding effective microorganism groups, and combining with environmental regulation and control technology in the fermentation process, vinegar residue is transformed into an organic substrate.

2.2. The test substrates

Two kinds of vinegar residue substrates were used as growth media, T_1, grind vinegar residue (100%); T_2, grind vinegar residue (50%) and peat (50%). The physical properties are shown in Table 1.

2.3. Experimental setup

The experiments were conducted using plexiglass containers, 40 cm long × 40 cm wide × 30 cm height. The substrates were packed in the container with 5 cm increments to obtain a constant bulk density. Water was added to the substrates through a dripper, connected to a flexible hose. The outlet was insert about 3 cm into the substrate at the corner of the container to reduce evaporation.

The positions of the moving wetting front on the surface and in the vertical plane of the substrate were recorded visually. Probes were used to measure water content in the substrates. A calibration curve for the probe was obtained by taking into account the change in temperature, bulk density and electronical conductivity with water content (Nemali et al., 2007). The container was vertical rotated 90 degrees to avoid water redistribution in the substrate, and opened after irrigation, then the probes were inserted into the substrate. Probes had radial and vertical intervals of 3 cm and 4 cm respectively, starting 3 cm from the point of application and moving outward.

Three variables affecting substrate wetting pattern and water distribution, drip irrigation flow, irrigation volume and initial water content were investigated. The water was applied at a rate of 0.15 L h^{-1}, 0.35 L h^{-1}, and 0.5 L h^{-1} through a dripper and the different irrigation flows were obtained by changing the irrigation pressure. The irrigation volume could obtain by multiplying irrigation flow and irrigation duration. Three treatments of initial water content were 0.16 cm^3 cm^{-3}, 0.23 cm^3 cm^{-3}, 0.28 cm^3 cm^{-3} for T_1 and T_2 respectively. Three replications were used for each experiment.

2.4. Data analysis

The data was analyzed by multiple straight lines & scatter and contour of the professional scientific drawing software sigmaplot 10.

3. Results and discussion

3.1. Variation patterns of medium wetting body under drip irrigation conditions

The water migration occurs in the horizontal (*X*-axis) and vertical directions (*Y*-axis) during drip irrigation. In this process, changes in the medium wetting body are examined in the plane of XOY (point O is the position of drip the arrow). Fig. 1 shows the shape of wetting bodies in two kinds of growth media (initial medium water content, $\theta = 0.23$ cm^3 cm^{-3}) under drip irrigation (irrigation flow, $q = 0.15$ and 0.5 L/h) at different infiltration times. The shape of wetting bodies in different growth media resembles a rotating projectile, whose horizontal infiltration radius occurs at 3–6 cm below the surface rather than at the surface. This phenomenon is mainly related to medium uniformity and infiltrability.

3.1.1. Effects of drip irrigation flow and volume on the wetting body

Under the same volume at different drip flows were analyzed with a volume of 0.15 L at a flow of 0.15 L/h (stop at 60 min) and 0.5 L/h (stop at 20 min) (Fig. 1). The volume of medium wetting bodies formed at the irrigation flow of 0.15 L/h is larger than that at the flow of 0.5 L/h, the horizontal infiltration distance and vertical infiltration depth at 0.15 L/h were at least 23.3% and at most 5.5% greater than 0.5 L/h in different media respectively. These results demonstrate that under the same irrigation volume, irrigation flow exerts a stronger effect on the horizontal infiltration distance than the vertical infiltration depth of the medium wetting body, and it needs for a longer period of time to reach the same irrigation volume under a low drip irrigation flow, thus forming a larger medium wetting body that is mainly reflected in the horizontal infiltration distance.

Under the same drip irrigation duration, the volume of medium wetting bodies formed in different media is larger at an irrigation flow of 0.5 L/h than at a flow of 0.15 L/h, the horizontal and vertical infiltration distances at a flow of 0.5 L/h in different media are at least 1.04- and 1.34-times those at a flow of 0.15 L/h respectively under drip irrigation for 60 min, it is mainly because the higher the irrigation flow used, the larger the irrigation volume accumulated at the same duration of drip irrigation, and the greater the volume of the medium wetting body formed.

Under the same drip flow with different irrigation volumes, the horizontal and vertical infiltration distances of medium wetting bodies are enlarged correspondingly as the irrigation volume increase, and the vertical infiltration distance of medium wetting bodies is constantly greater than their horizontal infiltration distance throughout the irrigation process, it indicates that the irrigation volume has a greater effect on the vertical infiltration distance of medium wetting bodies than on their horizontal infiltration

Table 1
Physical properties of vinegar residue substrates.

Substrates	Bulk density (g/cm^3)	Total porosity (%)	Air-filled porosity (%)	Hold water porosity (%)	Saturated hydraulic conductivity (cm/s)
T_1	0.120	71.5	41.0	30.5	0.084
T_2	0.159	74.1	28.2	45.9	0.051