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Full Length Research Paper

Crop coefficients and yield response factors for onion (*Allium Cepa.* L) under deficit irrigation and mulch practices in Samaru, Nigeria

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This report presents a study of crop coefficient (Kc) and yield response factors (Ky) for onion crop cultivated under deficit irrigation and different mulch covers in Samaru, Northern Nigeria. The field experiments were conducted at the irrigation fields of the Institute for Agricultural Research (IAR) irrigation field in 2008/2009 and 2009/2010 irrigation seasons using surface irrigation method. The experiments consisted of 16 treatments in each season. They comprised of four levels of water application depths (25, 50, 75, and 100% of weekly reference evapotranspiration (WRET)) and four levels of mulching (no-mulch, using rice straws, black and transparent polyethylene materials). Water applied per irrigation and soil moisture contents before and after irrigation was monitored throughout the seasons, while onion bulbs were harvested at the end of season and weighed. Average daily crop water use (crop consumptive use) were estimated from the soil moisture content using the soil moisture depletion method, while daily reference evapotranspiration (ETo) were computed from weather data using the FAO-Penman Montieth method. Crop coefficient values (Kc) were computed as the ratio of crop water use to ETo. The water stress coefficients (Ks) were computed by relating crop coefficient of the fully irrigated treatments to the deficit irrigated treatments. The yield response factor (Ky) were obtained by relating relative yield decreases to relative crop water use deficits. The study showed that crop water use of the onion crop decreased with increase in irrigation deficit. Applying water at 50% WRET reduced peak consumptive use of the onion crop by about 20%, while applying water at 25% WRET reduced crop water use by about 40%. Kc values of fully irrigated treatments ranged from 0.39 to 1.15, while Kc values of the deficit irrigated treatments varied from 0.24 to 1.13. Mulch materials did not significantly influence crop coefficient, but deficit irrigation did. Kc decreased with increase in water deficit with resultant water stress coefficients (Ks) ranging from 0.59 to 0.96. The relative yield decreases of the onion crop were proportionally greater with increase in evapotranspiration deficit for both mulched and no-mulch conditions. However, the proportional decrease in yield under the no-mulch condition was much higher than the mulched condition. Among the mulch materials, the proportional decrease in yield in the polyethylene materials were over 10% lower than the rice straw mulch. The Ky of the onion crop under no-mulch condition was 1.15, while Ky values for the mulched treatments were 1.13, 1.00 and 1.05 for rice straw-, white polyethylene-, and black polyethylene- mulch, respectively. The crop coefficients and yield response factors developed in this study are reliable as they had similar trends in two seasons, and could be used in irrigation design and scheduling for onion in the study area.

Key words: Onion, deficit irrigation, mulching, crop coefficient (Kc), yield response factor (Ky), crop water use.

INTRODUCTION

Onion (*Allium cepa* L.) is one of the major bulbous crop among vegetables and of high economic importance globally. According to Pathak (2000), out of 15 vegetables listed by Food and Agricultural Organization

(FAO), onion stands second to tomato in terms of total annual production. World annual production stands at 46.7 million tonnes from 2.7 million ha (FAOSTAT, 2011). Onion is known and reported to be medicinal (Gomez, 2003) and is used as condiment in the preparation of curry, chutney, and prickle (Anisuzzaman et al., 2009).

In Nigeria, onion is also next to tomato among the horticultural crops of high economic values. It is one of the major ingredient for making stews and soups which are eaten in virtually every home in Nigeria once or twice a day. The average annual production in the last five years based on FAOSTAT data is about 640,000 tonnes. The crop is largely cultivated in the northern part of the country because of the favourable climate. During the dry season, onion is cultivated under total irrigation mostly by surface (wild flooding, furrow and check basin) irrigation method. Seasonal water applied to the crop by farmers range from 400 to 700 mm depending on water availability and frequency of irrigation (NAERLS, 2009). The farmers' irrigation intervals range from 3 to 7 days, depending on soil type and access to water. The average yield at farmers' fields is about 6 to 15 t ha^{-1} depending on the level of input available to the farmers.

As the search for methods of producing more crops with limited water supply while minimizing water used for irrigation at field levels in order to release more water for other users beside agriculture in the river basins intensifies, deficit irrigation with mulching is seen as one options of achieving the aforementioned goal. Deficit irrigation is the practice of irrigating crops deliberately below their water requirements. Such practice is aimed at minimizing water applied to the crop so as to maximize crop yield per water applied, even though there might be the attended consequences of yield reduction. Many research works have been carried out to study the consequences of deficit irrigation on onion crop (Olalla et al., 1994; Pelter et al., 2004; Mermoud et al., 2005; Bekele and Tilahum, 2007; Ouda et al., 2010; Pejić et al., 2011). The onion crop, being shallow rooted, extracts water from the top 30 cm depth of soil; thus the upper soil area must be kept moist to simulate root growth and provide adequate water for the plant (Anisuzzaman et al., 2009). Mulching is well known to be one means of conserving soil moisture and reducing evaporation from the top soil area. Mulching can be done with organic or inorganic materials like polyethylene sheets. According to Rhu et al. (1990) and Kashi et al. (2004), besides conserving soil moisture, polyethylene mulch also increases soil temperature and moisture in early spring, reduce weed problems and certain insect pest and also simulate higher crop yields by more efficient utilization of soil moisture. A research gap in the region where onion is produced in Nigeria is the knowledge of water requirement of the onion crop under deficit irrigation with mulch practices. Moreover, the consequences of deficit irrigation regimes are yet to be fully understood. Two key parameters commonly required in determining crop water requirement and prediction of yield - water response to deficit irrigation are crop coefficienc (Kc) and yield response factor (Ky). Crop coefficiency is the ratio of crop actual evapotranspiration (ETc) to a reference evapotranspiration (ETo) which can be calculated using the FAO-Penman-Monteith method (Allen et al., 1998).

The Kc integrates the crop and soil conditions that make a given crop's evapotranspiration more or less than the reference evapotranspiration. On the other hand, the yield response factor (Ky) is ratio of relative yield reduction to relative evapotranspiration deficit. It is that factor that integrates the weather, crop and soil conditions that make crop yield less than its potential yield in the face of deficit evapotranspiration. The Kc and Ky parameters are commonly required as input data in some empirical water production functions like (Jensen, 1968; Stewart et al., 1977) to predict crop yield response to water. They are also required in process-based crop-soil simulation models like CROPWAT (Smith, 1992); CROPSYST (Stockle and Nelson, 1996); SWAP (van Dam et al., 1997) which uses them to link the crop growth modules to the soil water dynamics modules for effective prediction of crop yield and soil water balance.

The objectives of this study were: (1) to develop crop coefficients for field-grown onion under deficit irrigation and mulch practices for the study location; (2) to determine the yield response factors of the onion crop under the mulch materials used. It is anticipated that the information generated in this study will be useful for developing crop water requirements for irrigated onion under deficit irrigation regimes and for the overall improvement of irrigation water management in the study area.

MATERIALS AND METHODS

Study location

The field trials were conducted during the dry seasons of 2008/2009 and 2009/2010 at the Institute for Agricultural Research (I.A.R) irrigation fields in Samaru - Zaria, Northern Nigeria. Samaru - Zaria lies on Latitude 11°11' N, Longitude 7°35'E, and altitude 686 m above mean sea level, and is located in the Northern Guinea Savannah ecological zone of Nigeria with a semi-arid climate. It has three distinct seasons which consist of a hot dry season which spans from March to May; warm rainy season which spans from June to early October, and the cool dry (harmattan) season which spans from November to February. The average relative humidity is about 36.0% during the dry season and 78.5% during the wet season, and the average minimum and maximum temperatures are 15.6 and 38.5°C, respectively. The on-set of rains in the area is in May, but effective rainfall begins in late June and falls till early October, with a peak in August. The mean annual rainfall depth is 1150 mm, with an average peak of 650 mm in August, as obtained from the Meteorological Office of the Institute for Agricultural Research (I.A.R). The cool-dry (harmattan) and hot dry seasons are

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Table 1. Weather data for the 2008/2009 irrigation cropping season.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Wind speed (km/day)	Sunshine hours	ETo (mm/day)
December	29.7	12.0	21.0	229.0	9.7	4.4
January	28.7	11.0	33.0	235.5	8.9	5.0
February	31.6	14.7	27.0	229.3	9.6	5.7
March	33.2	17.3	33.0	183.0	9.0	6.9
April	35.7	24.6	55.5	197.4	8.5	7.2

Table 2. Weather data for the 2009 /2010 irrigation cropping season.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Wind speed (km/day)	Sunshine hours	ETo (mm/day)
December	30.7	12.7	16.0	199.0	9.8	5.4
January	34.3	13.0	11.0	156.5	8.9	6.0
February	37.6	17.8	19.0	167.3	9.4	6.7
March	37.2	21.3	38.0	133.0	9.0	6.6
April	39.7	22.6	63.5	177.4	8.0	6.2

Table 3. Physical properties of the soil of the experimental site.

Depth (mm)	FC %dwb* @ 33 kPa	PWP % dwb @ 1500 kPa	Bulk density (kg/m^3)	Clay (%)	Silt (%)	Sand (%)	Textural class
0 - 150	13.5	6.1	1.58	29	40	31	Loam
150 - 300	15.7	6.5	1.60	39	36	25	Clay Loam
300 - 450	18.8	8.7	1.45	41	30	29	Clay loam

* dwb = Dry weight basis.

the months for irrigation. The weather favours the growth of crops like wheat, tomato, onion, carrot, lettuce cucumber, green maize, and sunflower, under total irrigation. Tables 1 and 2 show the weather conditions for the two seasons the experiments reported herein were carried out.

Soil of the experimental site

The soils of Samaru - Zaria are mantle of residues overlain by aeolian deposits, classified as alfisols, based on the USDA (1975) classification (Aremu, 1980). The soil of the site where the experiments were carried out for the two seasons had the top soil (0 - 150 mm depth) as loam in texture, with a bulk density of 1.58 kg m^{-3}, while the 150 - 450 mm depth was clay loam with average bulk density of 1.53 kg/m^3. The total available water (TAW) was about 70 mm/450 mm depth. Table 3 shows some physical properties of the soil of the experimental site.

Description of Experimental treatments

The field experiments consisted of 16 treatments in each season. The treatments were composed of four levels of irrigation (water application depths) and four levels of mulch practice, thus constituting a 2^4 factorial experiment. The four levels of irrigation include water application depths of 100, 75, 50, and 25% of weekly reference evapotranspiration (WRET), while the four levels of mulch practice consisted of no mulch (NM); use of rice straw (RSM), black polyethylene (BPM), and transparent polyethylene mulch (TPM) as mulch materials. The 16 treatments were replicated three times, making a total of 48 plots. Table 4 gives further description of the experimental treatments. The experiments were laid on the field with treatments assigned to plots in a randomized complete block design (RCBD), with the blocks lying across the general slope of the field. The blocks were separated by a distance of 1.5 m, while the basins in each block were separated by a distance of 0.5 m which serves as buffer to minimize lateral movement of water from one basin to another. The same field layout was used for the two seasons.

Agronomic operations

A land area of 50 × 25 m was prepared into levelled basins of 2.5 × 2.5 m and transplanted with onion seedling on 4th January, 2009 (2008/2009 season) and 18th December, 2009 (2009/2010 season). The variety of onion planted in 2008/2009 season was Composite IV, while in 2009/2010 season the Red Creole variety was planted. The change in variety was due to due to inability to obtain Composite IV seeds to raise the nursery in 2009/2010 season. The onion seedlings were raised in the nursery and transplanted eight weeks after planting in 2008/2009 season and six weeks after planting 2009/2010 season. Onion seedlings are usually transplanted 6 weeks after planting in the study area. The delay in transplanting in 2008/2009 session was due to logistics and late preparation of experimental plots. The transplanting was done in row at plant spacing of 20 cm between plant and 25 cm between rows giving a plant population of 153,600 stands per hectare. Fertilizer was applied at the rate of 150 kg/ha N, given in

Table 4. Experimental treatments description.

Treatment No.	Treatment label	Description
1.	$I_{100}M_{NM}$	Water application depth of 100 % WRET, no mulch.
2.	$I_{75}M_{NM}$	Water application depth of 75 % WRET, no mulch.
3.	$I_{50}M_{NM}$	Water application depth of 50% WRET, no mulch.
4.	$I_{25}M_{NM}$	Water application depth of 25 % WRET, no mulch.
5.	$I_{100}M_{RSM}$	Water application depth of 100 % WRET, mulched with rice straw.
6.	$I_{75}M_{RSM}$	Water application depth of 75 % WRET, mulched with rice straw.
7.	$I_{50}M_{RSM}$	Water application depth of 50% WRET, mulched with rice straw.
8.	$I_{25}M_{RSM}$	Water application depth of 25% WRET, mulched with rice straw.
9.	$I_{100}M_{CPM}$	Water application depth of 100% WRET, mulched with transparent polyethylene.
10.	$I_{75}M_{CPM}$	Water application depth of 75 % WRET, mulched with transparent polyethylene
11.	$I_{50}M_{CPM}$	Water application depth of 50 % WRET, mulched with transparent polyethylene
12.	$I_{25}M_{CPM}$	Water application depth of 25 % WRET, mulched with transparent polyethylene
13.	$I_{100}M_{BPM}$	Water application depth of 100% WRET, mulched with black polyethylene
14.	$I_{75}M_{BPM}$	Water application depth of 75 % WRET, mulched with black polyethylene
15.	$I_{50}M_{BPM}$	Water application depth of 50 % WRET, mulched with black polyethylene
16.	$I_{25}M_{BPM}$	Water application depth of 25 % WRET, mulched with black polyethylene

two applications. Di-ammonium phosphate fertilizer (NPK 15:15:15) was first applied at the rate of 75 kg/ha N at two weeks after transplanting and Urea fertilizer (NPK 46:0:0) was applied at the rate of 75 kg/ha N at six weeks after transplanting. The fertilizers and the rates of application were as recommended by the Institute for Agricultural Research, Samaru - Zaria. The mulch materials were placed six days after transplanting in both seasons. The polyethylene materials (both black and transparent) were cut to size and placed over the entire basin. Holes were created in accordance with the plant spacing and the onion seedlings were passed through the holes. The thickness of the polyethylene measured with a micrometer screw gauge was about 2 mm. The average weight of rice straw mulch spread in each of the plot with such treatment was 3.5 kg. Weeding was done twice, at three and six week after transplanting, before the addition of fertilizer. However, in the mulched plots, only the first round of weeding was carried out. The mulch materials were carefully removed and placed back after weeding. In the rice straw and black polyethylene mulched plots, weeds were effectively suppressed after the first round of weeding, so that there was no need for a second weeding. However, in the transparent polyethylene mulched plots weeds continued to grow, and unfortunately, weeding could not be carried out because it was no longer possible to remove the mulch material as such attempt may destroy the plant or the mulch materials. The rate of growth of weeds in the transparent polyethylene mulch plots in the 2009/2010 season was high, and did affect the growth and development of the crop. Disease and pest attack were not noticed in the two seasons.

Irrigation water application

Surface irrigation method was used in the two seasons. Water was released from the main canal into a lateral ditch which conveys the water by gravity to the field ditches which service the basins. A pair of 5 cm diameter PVC tube of length 50 cm was installed in each basin to admit water into the basins. The PVC tubes were installed through the embankment of each basin with one end in the field ditch and the other end in the basin. The tubes were installed to give a free orifice flow into the basins. Stage gauges were placed at the water inlet of each basin to measure the depth of water over each tube as water enters the basin. PVC corks were placed at the entrance such that when the corks were removed, water flows into the basins. When the desired depth of water was applied the PVC corks were used to stop the flow of water into the plot. Using the orifice flow equation and the depth of flow recorded from the stage gauge, the flow rates into each basin were quickly determined and related to time of application to give to each plot the desired depth of water application. The time required to apply the depth of water was monitored using a stop watch.

The amount of water applied at every irrigation event (a weekly irrigation interval) was observed throughout the crop growing season) based on the reference evapotranspiration amount for that week of irrigation and the experimental treatment. The average weekly reference evapotranspiration for December, January, February, and March (rounded up to whole number) were 30, 30, 40 and 45 mm, respectively. Thus, for treatment irrigated at 100% WRET, water applied ranged from 30 to 45 mm depth depending on the month. The seasonal water applied for the treatments irrigated at 100, 75, 50, and 25% WRET were 485, 395, 305, and 225 mm, respectively in 2008/2009 season, and 495, 405, 315, 230 mm respectively in 2009/2010 season. The difference in seasonal water applied was due to the number of irrigation carried out in the seasons, from transplanting to crop maturity, being 12 in 2008/2009 season and 14 in 2009/2010 season.

Soil moisture measurement

The soil moisture status of each plot was monitored throughout the crop growing season in both seasons using soil moisture resistance blocks. Three soil moisture resistance block (gypsum blocks) were installed in each plot at 10, 22 and 37 cm depths to monitor the electrical resistance of the soil moisture at 0 - 15, 15 - 30 and 30 - 45 cm depths, respectively. The gypsum blocks were locally fabricated and calibrated on the field to relate electrical resistance measured to gravimetric moisture content for the soil of the experimental site using the methods of Ejieji and Fasasi (2003). The calibration curve was defined by a power function obtained as:

$$GMC = 536.17 * RS^{-0.394} \quad (r^2 = 0.937) \qquad (1)$$

where, GMC is gravimetric soil moisture content (%) and RS is soil moisture resistance in ohms (Ω). Electrical resistance measurements were carried out twice a week, at two days after irrigation and on the seventh day (just before the next irrigation), and the reading converted to gravimetric moisture content (% dry weight basis) using Equation 1. It was assumed that the soil, being largely loamy in texture, will attain field capacity two days after irrigation. This was confirmed as moisture contents measured two days after irrigation were relatively close (± 4%) to field capacity values obtained in the laboratory for the soil profile layers.

Crop maturity and harvest

The crop began to show signs of maturity (over 70% dropping of leave-head) at 12 and 14 weeks after transplanting in the 2008/2009 and 2009/2010 seasons, respectively. Irrigation was withdrawn that same week and soil moisture measurement was stopped two weeks after, particularly on 3rd April, 2009 for the 2008/2009 season and 7th April, 2010 for the 2009/2010 season. Harvesting was carried out about one week after, particularly on 10th April, 2009 for the 2008/2009 season and 13th April, 2010 for the 2009/2010. Harvesting was done by lifting the onion bulbs with the dry matter using a hand hoe. The eight rows in each plot were lifted (without discards), properly labelled and taken to be laboratory to cure for about two weeks. Thereafter, the onion bulbs were separated from the dry matter and weighed.

Determination of crop water use

The crop water use between successive moisture measurements was estimated using the soil moisture depletion method (Michael, 1999), with the expression given as:

$$CWU = \frac{\sum_{i=1}^{n}\left(MC_{1i} - MC_{2i}\right) * A_{si} * D_i}{t} \qquad (2)$$

where, CWU is average daily crop consumptive use between successive soil moisture content sampling periods (mm/day); MC_{1i} is soil moisture content (g/g) at the time of first sampling (2 days after irrigation) in the i^{th} soil layer; MC_{2i} is soil moisture content (g/g) at the time of second sampling (7 days after irrigation) in the i^{th} layer; A_{si} is bulk density (g/cm^3) of the i^{th} layer; D_i is thickness of i^{th} layer (mm); 'n' is number of soil layers sampled in the root zone depth D, and 't' is number of days between successive soil moisture content sampling. The weekly consumptive use was obtained as the product of the daily crop consumptive use between successive soil moisture content sampling and the number of days in the week (7), while the seasonal crop water use was the summation of the weekly CWU. The crop consumptive use of the treatments irrigated at 100% WRET (with or without mulch), were regarded as actual consumptive use while the CWU of the deficit irrigated treatments (I_{75}, I_{50} and I_{25}) were regarded as deficit consumptive use ($CWU_{deficit}$). The evaporation component was still included in the crop water use of the mulched treatments because it could not be ascertained from this study that evaporation was totally screened out by the mulch materials. Although the mulch materials completely covered the basins planted to crop, the embankments of the check basins were not completely covered, which make them potential source of loss of water due to evaporation, howbeit small.

Computation of reference evapotranspiration (ETo)

Reference evapotranspiration (ETo) was computed using the FAO-Penman-Monteith method as given in Allen et al. (1998). The weather data obtained from the meteorological station situated about 400 m away from the experimental site for the seasons when this study was carried out were daily maximum and minimum temperatures, maximum and minimum relative humidity, wind speed at 2 m height and sunshine hours.

Computation of crop coefficients

The crop coefficient (Kc) for the fully irrigated treatments was computed on weekly basis as the ratio of the average daily CWU of the fully irrigated treatments to the average daily ETo (Equation 3). The crop coefficient of the deficit irrigated treatments (referred to as $Kc_{deficit}$) was computed as the ratio of the average daily CWU of the deficit irrigated treatments to the average daily ETo for the week (Equation 4).

$$Kc = \frac{CWU}{ETo} \qquad (3)$$

$$Kc_{deficit} = \frac{CWU_{deficit}}{ETo} \qquad (4)$$

Computation of water stress coefficient (Ks)

The water stress coefficient (Ks) integrates the crop and soil factors that make the actual crop water use of the deficit irrigated condition differ from crop water use under fully irrigated condition. The relationship was expressed as:

$$CWU_{deficit} = Ks * CWU \qquad (5)$$

where, Ks is water stress coefficient; Other parameters were as previously defined.
Substituting Equation 3 in 5,

$$CWU_{deficit} = Ks * Kc * ETo$$ (Allen et al., 1998) (6);

and from Equations 4 and 6

$$Ks = \frac{Kc_{deficit}}{Kc} \qquad (7)$$

The values of Kc, $Kc_{deficit}$ and Ks for the four growth stages of the crop were computed by finding the averages of the weekly coefficients values for the growth stages.

Computation of yield response factor

The yield response factor was computed for each of the mulch practice using the Doorenbos and Kassam (1979) equation re-arranged as

$$Ky = \frac{\left(1 - \frac{Ya}{Ym}\right)}{\left(1 - \frac{SCWU_{deficit}}{SCWU}\right)} \qquad (8)$$

where, Ya is bulb yield of deficit irrigated treatments, Ym is bulb yield of the fully irrigated (I_{100}) treatments, $SCWU_{deficit}$ is seasonal

Table 5. Average daily evapotranspiration of the onion crop in 2008/2009 irrigation season.

Treatment		Growth stage												
		Establishment		Vegetative				Bulb formation				Bulb enlargement- Maturity		
		Days after transplanting												
		2 - 9	10 - 16	17 - 23	24 - 30	31 - 37	38 - 44	45 - 51	52 - 58	59 - 65	66 - 72	73-79	80-87	88-101
NM	I_{100}	1.5	1.8	1.8	3.2	3.7	4.4	4.9	5.5	6.0	6.3	6.3	5.4	2.6
	I_{75}	1.7	1.9	1.8	2.7	3.1	3.8	4.3	5.2	5.9	6.1	5.6	4.9	3.3
	I_{50}	1.5	1.6	1.9	2.3	2.5	3.4	4.1	4.6	4.9	4.4	3.7	3.2	4.4
	I_{25}	1.1	1.3	1.4	1.9	1.8	2.0	2.2	3.3	3.9	3.9	4.1	3.0	2.7
RSM	I_{100}	1.4	1.7	1.7	3.0	3.4	4.0	4.8	5.7	5.8	6.2	6.2	4.9	3.0
	I_{75}	1.5	1.6	1.6	2.5	3.1	3.5	4.6	5.3	5.8	6.1	5.7	4.4	3.0
	I_{50}	1.3	1.4	1.7	2.2	2.2	2.8	3.6	4.2	4.4	5.0	5.1	3.9	2.1
	I_{25}	1.1	1.7	1.5	1.5	2.2	2.1	2.6	2.7	3.0	3.2	3.0	3.1	2.4
TPM	I_{100}	1.2	1.9	2.1	2.1	2.7	3.6	5.0	5.4	5.9	6.1	6.1	4.7	2.5
	I_{75}	1.3	1.7	2.0	2.4	2.6	3.5	4.4	5.4	6.0	6.0	5.5	4.2	2.1
	I_{50}	1.4	1.5	1.6	1.9	2.7	2.6	3.8	3.7	4.2	4.7	4.3	4.2	2.3
	I_{25}	0.9	1.4	1.3	1.2	1.4	1.8	2.8	3.1	3.7	3.4	3.1	2.5	2.8
BPM	I_{100}	1.3	1.6	2.2	2.3	2.5	3.7	4.3	4.8	5.5	6.3	6.2	4.8	2.7
	I_{75}	1.3	1.4	1.6	2.2	2.5	3.6	4.6	4.6	5.1	5.8	6.2	5.1	1.6
	I_{50}	1.4	1.4	0.9	1.5	1.8	3.1	3.8	3.5	4.3	5.5	5.2	4.5	1.8
	I_{25}	1.1	1.1	1.4	1.9	1.8	2.2	2.7	3.4	3.7	3.8	3.4	2.7	2.6
	ETo	3.8	4.4	4.0	4.7	5.1	4.7	5.5	5.8	5.2	6.0	5.5	6.7	6.5

consumptive water use of the deficit irrigated treatments and SWCU is crop water use of the fully irrigated treatment.

RESULTS AND DISCUSSION

Daily crop water use

Tables 5 and 6 show the average daily consumptive use of the onion crop in 2008/2009 and 2009/2010 seasons, respectively. The daily consumptive use ranged from 0.9 to 6.3 mm day^{-1} in 2008/2009 season and 1.3 to 6.3 mm day^{-1} for 2009/2010 season across the treatments. A comparison of the daily crop water use on the bases of irrigation treatment indicated that daily crop water use decreased with increase in deficit irrigation. The average peak consumptive use of the treatments given full irrigation (I_{100}) was 6.2 mm day^{-1} and 6.0 mm day^{-1} in 2008/2009 and 2009/2010 seasons, respectively. The average peak consumptive use of the deficit irrigated treatments (that is, I_{75} (25% deficit), I_{50} (50% deficit), and I_{25} (75% deficit)) were 6.1, 5.1 and 3.6 mm day^{-1}, respectively for 2008/2009 season, and 5.9, 5.0 and 3.5 mm/day, respectively for 2009/2010 season. The decrease in daily consumptive use due to deficit irrigation ranged from 2 to 42% in 2008/2009 season and 3 to 42% in 2009/2010 season, with the highest values in the range occurring at I_{25} treatments. The pattern of decrease in consumptive use as a result of deficit irrigation was expected since deficit

Table 6. Average daily evapotranspiration of the onion crop in 2009/2010 irrigation season.

Treatment		Growth stage												
		Establishment		Vegetative				Bulb formation				Enlargement-Maturity		
		Days after transplanting												
		2 - 9	10 - 16	17 - 23	24 - 30	31 - 37	37 - 44	45 - 51	52 - 58	59 - 65	66 - 72	73 - 79	80 - 87	88 - 94
NM	I_{100}	2.2	2.3	2.7	3.1	3.3	4.5	4.9	5.6	5.7	5.9	5.4	4.2	2.8
	I_{75}	2.1	2.5	2.6	2.7	2.9	3.6	4.3	5.0	5.4	5.7	4.8	4.3	3.7
	I_{50}	1.4	1.6	1.9	1.9	2.2	2.5	3.2	4.6	4.9	4.9	3.7	3.2	3.2
	I_{25}	1.3	1.3	1.4	2.1	2.2	2.3	3.0	3.3	3.3	3.0	2.7	2.7	2.5
RSM	I_{100}	1.7	1.7	2.3	2.7	3.1	4.0	4.8	5.2	5.9	5.7	5.4	4.9	3.0
	I_{75}	1.7	1.7	1.9	2.5	3.3	3.5	4.6	5.0	5.5	5.6	5.1	4.4	3.0
	I_{50}	1.5	1.7	2.1	2.2	2.2	2.5	3.3	3.9	4.3	4.7	4.5	3.9	2.1
	I_{25}	1.2	1.3	1.5	1.9	2.0	2.4	2.6	3.5	3.7	3.4	3.0	2.5	2.4
TPM	I_{100}	1.8	1.9	2.1	2.8	3.0	4.5	5.0	5.7	5.9	5.8	5.5	4.7	2.5
	I_{75}	1.8	1.9	2.0	2.7	2.9	3.5	4.4	5.4	5.7	5.7	5.2	4.2	2.1
	I_{50}	1.4	1.9	1.8	1.9	2.7	2.9	3.2	3.4	4.2	4.7	4.3	4.2	2.3
	I_{25}	1.3	1.7	1.8	2.0	2.3	2.5	2.8	3.0	3.1	3.1	2.5	1.8	1.9
BPM	I_{100}	1.6	1.8	2.2	2.9	3.7	4.2	5.2	5.6	6.3	6.3	5.9	4.8	3.3
	I_{75}	1.6	1.8	1.8	2.6	3.5	3.9	4.9	5.5	6.0	6.4	5.6	4.8	2.8
	I_{50}	1.4	1.4	1.9	2.1	2.1	3.1	3.8	3.5	4.3	5.5	5.2	4.5	1.8
	I_{25}	1.1	1.1	1.4	1.7	1.8	2.4	2.5	2.6	3.0	3.9	3.4	3.0	2.5
	ETo	3.5	3.4	3.9	4.1	4.4	4.6	4.7	4.9	5.4	5.6	5.8	6.2	5.9

irrigation reduces the amount of water available in the soil for plant uptake. The study however reveals that applying water at 50% of atmospheric evaporative demand (reference evapotranspiration) reduces peak consumptive use of the onion crop by about 20%. More so, if water is applied at 25% of evaporative demand, the peak consumptive use of the onion crop will be reduced by about 40%. A comparison of the daily crop water use as influenced by mulching shows that the daily CWU of the NM treatments ranged from 1.1 to 6.3 mm day^{-1} in 2008/2009 and 1.3 to 5.9 mm day^{-1} in 2009/2010 season across irrigation regimes, while the average daily CWU of the mulched treatments ranged from 0.9 to 6.3 mm day^{-1} in 2008/2009 and 1.1 to 6.3 mm day^{-1} in 2009/2010 season across irrigation regimes. However, a careful study of the trend of the daily CWU reveals that in the two seasons, the daily crop water use of the NM treatments, irrespective of irrigation regime, were about 2 to 10% higher than the mulched treatments only at establishment to vegetative growth stages. At bulb formation to enlargement stages, the average CWU of the mulched treatments were found to be about 0 - 15% higher than the no-mulch treatment. Notable among the mulched treatments was the black polyethylene mulch (BPM) treatments, which were found to be higher than both the NM and other mulched treatments. The peak consumptive use of the BPM treatments was noticed to be higher than the NM treatment by 6 - 15%, depending on the irrigation regime, with higher value in the range occurring at higher irrigation deficit. The peak consumptive use of the BPM was also found to be higher than the other mulched treatment by 2 to 16% in 2008/2009, and 5 - 21% in 2009/2010 season. Higher CWU in the NM treatments compared to the mulched treatments at establishment to vegetative growth stages can be attributed to the influence of direct surface evaporation since the crop cover at these growth stages was still less than 75%. But at bulb formation stage where the crop had attained full vegetative cover thereby reducing drastically surface evaporation, the mulch materials may have aided moisture conservation, thus making more water available in the soil for plant uptake thereby leading to higher transpiration rate in the mulched treatment. FAO-56 (Allen et al., 1998) noted that transpiration may increase by 10 - 30% for horticultural crops under plastic mulch relative to no-mulch condition.

Crop coefficients under full irrigation conditions

Tables 7 and 8 shows the crop coefficient values for onion crop for 2008/2009 and 2009/2010 seasons, respectively. The Kc of the fully irrigated treatments ranged from 0.39 to 1.15, 0.37 to 1.13, 0.32 to 1.13, and 0.34 to 1.13 for the NM, RSM, TPM, and BPM treatments, respectively in 2008/2009 season. In 2009/2010 season, the Kc of the fully irrigated treatments ranged from 0.47 to 1.14, 0.49 to 1.09, 0.42 to 1.16, and 0.46 to 1.17 for the NM, RSM, TPM, and BPM treatments, respectively. The least values in the ranges above were either the Kc at the beginning of the season (which may be taken as the $Kc_{initial}$) or the end of the season (which may be taken as Kc_{end}), while the highest values were the peak Kc which may be taken as the Kc_{mid}. The K_{cmid} values were recorded at the latter part of bulb formation to earlier part of bulb enlargement stages in both seasons.

The mean Kc values of the no-mulch treatment for four growth stages of the crop: establishment, vegetative, bulb formation, and bulb enlargement to maturity stages (which may also be classified as: initial, rapid, midseason and late-season) were found to be 0.40, 0.70, 1.01 and 0.79, respectively in 2008/2009 season, and 0.66, 0.80, 1.07 and 0.69, respectively in 2009/2010. The mean Kc values for the four growth stages of the RSM treatment in 2008/2009 season were 0.38, 0.65, 1.00 and 0.77 for the initial, rapid, midseason and late season, respectively, while in 2009/2010 season the values were obtained as 0.50, 0.71, 1.05 and 0.74, respectively.

The mean Kc values for the four growth stages of the TPM and BPM treatments in 2008/2009 season were 0.35, 0.57, 1.00 and 0.73, and 0.35, 0.58, 0.93 and 0.76, respectively. In 2009/2010 seasons however, the values for the four growth stages were found to be 0.54, 0.72, 1.09 and 0.71, respectively for the TPM treatments, and 0.50, 0.76, 1.14 and 0.78, respectively for the BPM treatments. It was noticed that the mean Kc values of the 2009/2010 season were higher than the 2008/2009 season by 8 to 15%. This may not be unconnected with the difference in onion cultivars planted in the two seasons. It may also be as a result of seasonal (weather) variability. Some researchers have recorded variability in Kc values over years, e.g. Martinez-cob (2007) for maize, Ferreira and Carr (2002) for potato, and Amayreh and Al-Abed (2005) for tomato. Despite the differences in the Kc values of the two seasons, the results showed a good degree of similarity which is an indication of an established trend.

The Kc values obtained in this study under the no-mulch condition closely agree with those reported by FAO-56 (Allen et al., 1998) who gave Kc values of 0.7, 1.05 and 0.75 for initial, midseason and late season for the onion crop. The Kc values for the late season was however higher than that obtained by Bossie et al. (2009) who reported values of 0.47, 0.99 and 0.46 for initial, mid- and late- seasons for onion (Red Bombay cultivar) in Awash Melkassa, Ethiopia. Lopez-Urrea et al. (2009) also reported values of 0.65, 1.2 and 0.75 for initial, mid- and late- seasons for onion under sprinkler in Spain. It must be noted that Kc is affected by all the factors that influences soil water status, weather factors, soil characteristics and agronomic techniques that affect crop growth (Doorenbos and Pruitt, 1977; Stanghellini et al., 1990; Annandale and Stockle, 1994). Therefore, Kc values reported in literature for the same crop may vary slightly or significantly if their growing conditions differ.

A comparison of the Kc values of the different management conditions showed that in 2008/2009 season, the Kc values of the NM treatments were higher than the mulched treatments by about 5 - 12.5%, 7 - 19%, 1 - 8% and 3 - 8%, for initial, rapid, midseason and late season stages, respectively. These findings agrees with FAO-56 (Allen et al., 1998) which suggested that Kc values of horticultural crops at mid- and late- seasons under plastic mulch may be less by 10 to 30% compared with no mulch condition, depending on the frequency of irrigation. The decrease, they said, is associated with reduction in soil evaporation. However, in 2009/2010 season, the Kc values of the no-mulch treatment were only higher than the mulch treatments at initial and rapid stages by about 18 - 24 and 5 - 12%, respectively. At mid- and late- seasons, the Kc values of the mulched treatments were found to be higher than no- mulch treatments by about 2 to 13%. The reason for this change in trend could not be traced. A comparison of the Kc values among the mulched treatments showed difference of between 0 to 7% only across the stages; which

Table 7. Crop coefficients for the onion crop in 2008/2009 season.

Treatment		Establishment (2 - 16)		Vegetative (17 - 44)				Bulb formation (45 - 72)				Enlargement to maturity (73 - 101)		
		2 - 9	**10 - 16**	**17 - 23**	**24 - 30**	**31 - 37**	**38 - 44**	**45 - 51**	**52 - 58**	**59 - 65**	**66 - 72**	**73 - 79**	**80 - 87**	**88 - 101**
		Kc of NM treatment												
NM	I_{100}	0.39	0.41	0.45	0.68	0.73	0.94	0.89	0.95	1.15	1.05	1.15	0.81	0.40
		$Kc_{deficit}$ of NM treatments												
	I_{75}	0.45	0.43	0.45	0.57	0.61	0.81	0.78	0.90	1.13	1.02	1.02	0.73	0.51
	I_{50}	0.39	0.36	0.48	0.49	0.49	0.72	0.75	0.79	0.94	0.73	0.67	0.48	0.68
	I_{25}	0.29	0.30	0.35	0.40	0.35	0.43	0.40	0.57	0.75	0.65	0.75	0.45	0.42
		Kc of RSM treatment												
RSM	I_{100}	0.37	0.39	0.43	0.64	0.67	0.85	0.87	0.98	1.12	1.03	1.13	0.73	0.46
		$Kc_{deficit}$ of RSM treatments												
	I_{75}	0.39	0.36	0.40	0.53	0.61	0.74	0.84	0.91	1.12	1.02	1.04	0.66	0.46
	I_{50}	0.34	0.32	0.43	0.47	0.43	0.60	0.65	0.72	0.85	0.83	0.93	0.58	0.32
	I_{25}	0.29	0.39	0.38	0.32	0.43	0.45	0.47	0.47	0.58	0.53	0.55	0.46	0.37
		Kc of TPM treatment												
TPM	I_{100}	0.32	0.43	0.53	0.45	0.53	0.77	0.91	0.93	1.13	1.02	1.11	0.70	0.38
		$Kc_{deficit}$ of TPM treatments												
	I_{75}	0.34	0.39	0.50	0.51	0.51	0.74	0.80	0.93	1.15	1.00	1.00	0.63	0.32
	I_{50}	0.37	0.34	0.40	0.40	0.53	0.55	0.69	0.64	0.81	0.78	0.78	0.63	0.35
	I_{25}	0.24	0.32	0.33	0.26	0.27	0.38	0.51	0.53	0.71	0.57	0.56	0.37	0.43
		Kc of BPM treatment												
BPM	I_{100}	0.34	0.36	0.55	0.49	0.49	0.79	0.78	0.83	1.06	1.05	1.13	0.72	0.42
		$Kc_{deficit}$ of BPM treatments												
	I_{75}	0.34	0.32	0.40	0.47	0.49	0.77	0.84	0.79	0.98	0.97	1.13	0.76	0.25
	I_{50}	0.37	0.32	0.23	0.32	0.35	0.66	0.69	0.60	0.83	0.92	0.95	0.67	0.28
	I_{25}	0.29	0.25	0.35	0.40	0.35	0.47	0.49	0.59	0.71	0.63	0.62	0.40	0.40

Growth stage; Days after transplanting (column groupings above).

Table 8. Crop coefficients for the onion crop in 2009/2010 season.

Treatment		Growth stage												
		Establishment (2 - 16)		Vegetative (17 - 44)				Bulb formation (45 - 72)				Enlargement to maturity (73 - 94)		
		Days after transplanting												
		2 - 9	10 - 16	17 - 23	24 - 30	31 - 37	37 - 44	45 - 51	52 - 58	59 - 65	66 - 72	73 - 79	80 - 87	88 - 94
		Kc of NM treatment												
NM	I_{100}	0.63	0.68	0.69	0.76	0.75	0.98	1.04	1.14	1.06	1.05	0.93	0.68	0.47
		$Kc_{deficit}$ of NM treatments												
	I_{75}	0.60	0.64	0.67	0.66	0.66	0.78	0.91	1.02	1.00	1.02	0.83	0.69	0.63
	I_{50}	0.40	0.47	0.49	0.46	0.50	0.54	0.68	0.94	0.91	0.88	0.64	0.52	0.54
	I_{25}	0.37	0.38	0.36	0.51	0.50	0.50	0.64	0.67	0.61	0.54	0.47	0.44	0.42
		Kc of RSM treatment												
RSM	I_{100}	0.49	0.50	0.59	0.66	0.70	0.87	1.02	1.06	1.09	1.02	0.93	0.79	0.51
		$Kc_{deficit}$ of RSM treatments												
	I_{75}	0.49	0.50	0.49	0.61	0.75	0.76	0.98	1.02	1.02	1.00	0.88	0.71	0.51
	I_{50}	0.43	0.50	0.54	0.54	0.50	0.54	0.70	0.80	0.80	0.84	0.78	0.63	0.36
	I_{25}	0.34	0.38	0.38	0.46	0.45	0.52	0.55	0.71	0.69	0.61	0.52	0.40	0.41
		Kc of TPM treatment												
TPM	I_{100}	0.51	0.56	0.54	0.68	0.68	0.98	1.06	1.16	1.09	1.04	0.95	0.76	0.42
		$Kc_{deficit}$ of TPM treatments												
	I_{75}	0.51	0.56	0.51	0.66	0.66	0.76	0.94	1.10	1.06	1.02	0.90	0.68	0.36
	I_{50}	0.40	0.56	0.46	0.46	0.61	0.63	0.68	0.69	0.78	0.84	0.74	0.68	0.39
	I_{25}	0.37	0.50	0.46	0.49	0.52	0.54	0.60	0.61	0.57	0.55	0.43	0.29	0.32
		Kc of BPM treatment												
BPM	I_{100}	0.46	0.53	0.56	0.71	0.84	0.91	1.11	1.14	1.17	1.13	1.02	0.77	0.56
		$Kc_{deficit}$ of BPM treatments												
	I_{75}	0.46	0.53	0.46	0.63	0.80	0.85	1.04	1.12	1.11	1.14	0.97	0.77	0.47
	I_{50}	0.40	0.41	0.49	0.51	0.48	0.67	0.81	0.71	0.80	0.98	0.90	0.73	0.31
	I_{25}	0.31	0.32	0.36	0.41	0.41	0.52	0.53	0.53	0.56	0.70	0.59	0.48	0.42

suggest that the type of mulch materials did not significantly causea difference in Kc values.

Crop coefficient values under deficit irrigation conditions

Tables 7 and 8 also show the crop coefficient values under deficit irrigation conditions for the different management practices ($Kc_{deficit}$). It can be noticed that crop coefficients were highly significantly affected by irrigation deficits, as the values decreases with increase in deficit irrigation. A comparison of Kc (fully irrigated treatments) and $Kc_{deficit}$ showed that the mean values of Kc were higher than $Kc_{deficit}$ by about 6, 24 and 40% for I_{75}, I_{50} and I_{25} treatments, respectively. The peak Kc values of the respective mulch management conditions were noticed to be higher than the peak $Kc_{deficit}$ values by about 18 - 25% in both seasons, which suggest that under deficit irrigation, peak crop coefficient values may be reduced by up to 25%.

The mean $Kc_{deficit}$ values of the no-mulch treatment for four growth stages of the crop: establishment, vegetative, bulb formation, and bulb enlargement to maturity stages (taken as initial, rapid, midseason and late season, respectively) were found to be 0.37, 0.51, 0.78 and 0.63, respectively in 2008/2009 season, and 0.49, 0.55, 0.82 and 0.58, respectively in 2009/2010. The mean $Kc_{deficit}$ values of the treatment mulched with rice straw mulch were also found to be 0.35, 0.48, 0.75 and 0.60 for the initial, rapid, midseason and late season, respectively in 2008/2009 season, and 0.44, 0.55, 0.81 and 0.58, respectively in 2009/2010 season. The mean $Kc_{deficit}$ values of the four stages for the transparent polythene and black polythene mulch treatments in 2008/2009 season were 0.33, 0.45, 0.76 and 0.56, and 0.32, 0.44, 0.75 and 0.61, respectively. In 2009/2010 seasons however, the values for the four stages were found to be 0.48, 0.56, 0.79 and 0.53, respectively for the transparent polythene, and 0.41, 0.55, 0.84 and 0.63, respectively for black polythene mulch treatments. It was noticed that there was no significantly differences among the mean $Kc_{deficit}$ values of mulched and no-mulch treatments, which implies that mulching did not necessarily influence crop coefficient under deficit irrigation.

Water stress coefficients

Table 9 shows the water stress coefficients (Ks) values computed for the 2008/2009 and 2009/2010 seasons. The seasonal average (SA) values are also indicated in the Table. The Ks values of the four growth stages ranged from 0.51 to 1.00 across the treatments and seasons (Ks > 1.00 should be taken as 1.00), while the seasonal average Ks ranged from 0.59 to 0.97. Ks values generally range from zero (absolute water stress in which there is no evapotranspiration at all and the plant withers) to 1.00 (no water stress in which evapotranspiration is at maximum).

The water stress coefficients can be classified on the basis of its impact on seasonal consumptive use as: critical ($0.1< Ks \leq 0.5$), severe ($0.51< Ks \leq 0.75$), moderate ($0.76 < Ks \leq 0.90$) and minor ($0.91 < Ks \leq 0.99$). Based on this classification, it can be inferred that the water stress coefficient of the I_{75} treatments, irrespective of mulch management practice, were minor except at vegetative stage where it had moderate effect. The seasonal average Ks of the I_{75} treatments were also minor while those of I_{50} and I_{25} treatments were moderate and severe, respectively. The Ks were noticed to have similar trend for the two seasons, which implies that the impacts of the deficit irrigation schedules were consistent, irrespective of cropping season and onion cultivar.

Relative yield decrease, seasonal crop water use deficit and yield response factors

Table 10 shows the relative decreases in seasonal crop water use and bulb yield in 2008/2009 and 2009/2010 seasons.

The actual values of bulb yield and seasonal crop water use and the effects of the experimental treatments have been reported by Igbadun et al. (2012). The relative yield decrease and relative SCWU deficit were noticed to increase with increase in irrigation deficit in the mulched or no-mulch practices, except in the transparent mulched treatments where the bulb yield of the I_{75} treatment was found to be higher than the other treatments in the group.

However, the computation of the relative yield decrease was done with reference to the fully irrigated treatment in order to be consistent. It may be noticed from Table 10 that relative decreases in seasonal crop water use of the I_{75} treatments were only between 2 and 12%, while the relative yield decreases were also between 2 and 12%.

The relative decreases in SCWU of the I_{50} treatments ranged between 17 and 26% and relative yield loss of between 8 and 33%. The relative decreases in SCWU of the I_{25} treatments were found to be between 38 and 47% and relative yield losses of between 42 and 57%. This was the bases of classifying the water stress coefficient of the I_{75}, I_{50} and I_{25} treatments as minor, moderate and severe, respectively.

Figures 1 to 4 show the yield response factors (Ky) for the NM, RSM, TPM and BPM treatments, respectively, obtained by plotting the pooled data of the relative yields and relative seasonal crop water use of the two seasons of each treatment. The seasonal Ky values were obtained as 1.15, 1.13, 1.00 and 1.05 for the NM, RSM, TPM and BPM, respectively.

The coefficient of determination (r^2) for each relationship was good (> 0.75). According to Doorenbos and Kassam (1979), Ky < 1.0 indicates that the decrease in yield is proportionally less with increase in water deficit, while yield decrease in proportionally greater when

Table 9. Water stress coefficients (Ks) of onion crop in 2008/2009 and 2009/2010 seasons in Samaru.

Treatment label		2008/2009 season					2009/2010 season				
		ES*	VG	BF	EM	SA	ES	VG	BF	EM	SA
NM	I_{75}	1.10**	0.87	0.95	0.96	0.97	1.02	0.87	0.92	1.03	0.96
	I_{50}	0.94	0.78	0.79	0.78	0.82	0.66	0.63	0.79	0.82	0.73
	I_{25}	0.74	0.55	0.59	0.69	0.64	0.57	0.59	0.57	0.64	0.59
RSM	I_{75}	0.99	0.88	0.97	0.93	0.94	1.00	0.93	0.96	0.94	0.96
	I_{50}	0.87	0.75	0.76	0.79	0.79	0.94	0.75	0.75	0.79	0.81
	I_{25}	0.89	0.61	0.51	0.59	0.65	0.73	0.64	0.61	0.60	0.65
TPM	I_{75}	0.97	0.99	0.97	0.89	0.96	1.00	0.90	0.95	0.91	0.94
	I_{50}	0.95	0.82	0.73	0.80	0.83	0.90	0.75	0.69	0.85	0.80
	I_{25}	0.75	0.54	0.58	0.62	0.62	0.81	0.70	0.54	0.49	0.64
BPM	I_{75}	0.94	0.92	0.96	0.94	0.94	1.00	0.91	0.97	0.94	0.96
	I_{50}	0.99	0.67	0.82	0.84	0.83	0.82	0.71	0.73	0.83	0.77
	I_{25}	0.77	0.68	0.65	0.63	0.68	0.64	0.56	0.51	0.63	0.59

* ES = Establishment; VG = vegetative; BF = Bulb formation; EM = Bulb enlargement to maturity stages; SA = Seasonal average. ** = Ks > 1.00 should be taken as 1.00.

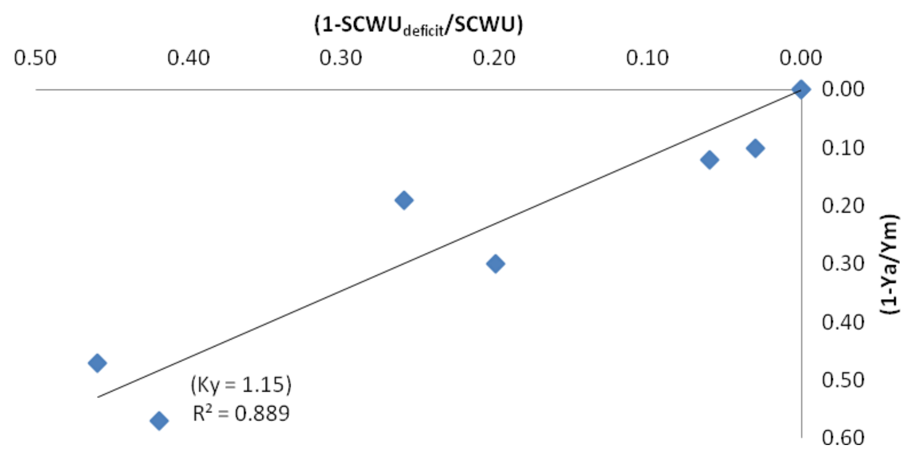

Figure 1. Yield response factor (Ky) of the no-mulch treatment.

Table 10. Relative yield and relative seasonal crop water use of the onion crop for 2008/2009 and 2009/2010 seasons.

Treatment		2008/2009 Season		2009/2010 Season	
		Relative SCWU deficit	Relative decreasing yield	Relative SCWU deficit	Relative decreasing yield
NM	I_{100}	0.00	0.00	0.00	0.00
	I_{75}	0.03	0.10	0.06	0.12
	I_{50}	0.20	0.30	0.26	0.19
	I_{25}	0.46	0.47	0.42	0.57
RSM	I_{100}	0.00	0.00	0.00	0.00
	I_{75}	0.09	0.12	0.05	0.09
	I_{50}	0.24	0.27	0.22	0.18
	I_{25}	0.42	0.45	0.38	0.49
TPM	I_{100}	0.00	0.00	0.00	0.00
	I_{75}	0.02	0.08	0.08	-0.03
	I_{50}	0.17	0.33	0.21	0.08
	I_{25}	0.42	0.44	0.41	0.41
BPM	I_{100}	0.00	0.00	0.00	0.00
	I_{75}	0.03	0.10	0.05	0.02
	I_{50}	0.18	0.27	0.25	0.16
	I_{25}	0.42	0.42	0.43	0.50

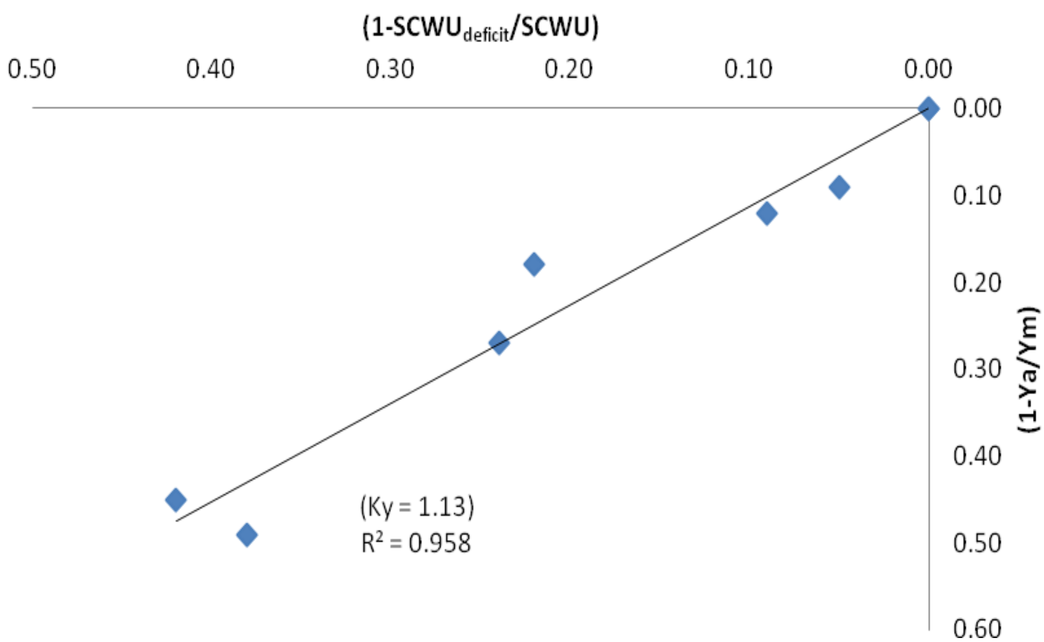

Figure 2. Yield response factor (Ky) of the rice straw mulch treatment.

Ky>1.0. The results of this study show that with or without mulch, the yield decreases of the onion crop were proportionally greater with increase in evapotranspiration deficit. It is however noticed that the Ky values of the no-mulch treatment was higher than the mulched treatment by about 2 to 13%, which implies that the proportional decrease in yield under the no mulch condition was much higher than the mulched condition. It also suggests that mulching helped to cushion the impact of the deficit irrigation on yield.

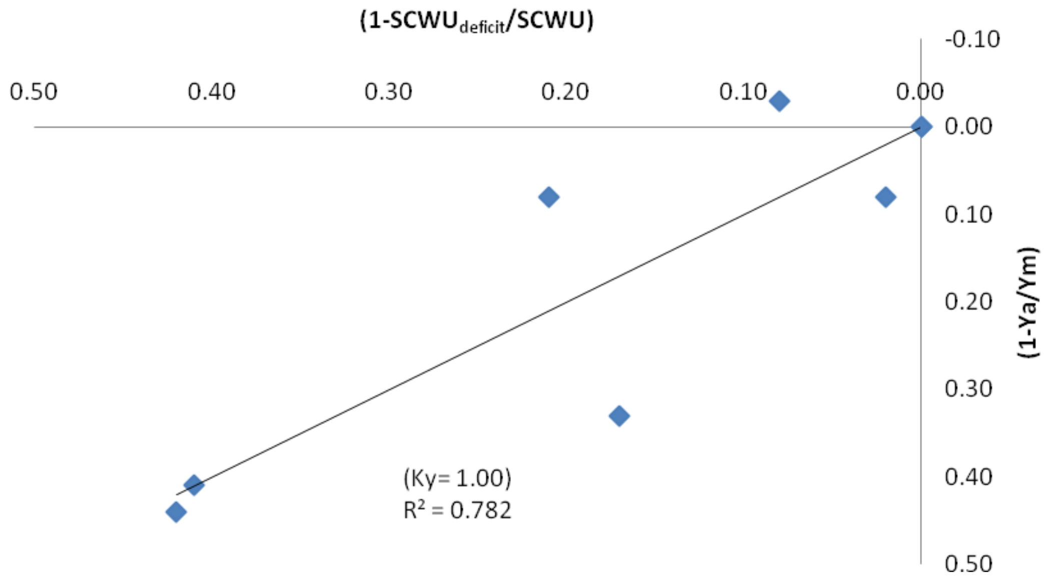

Figure 3. Yield response factor (Ky) of the transparent polyethylene mulch treatment.

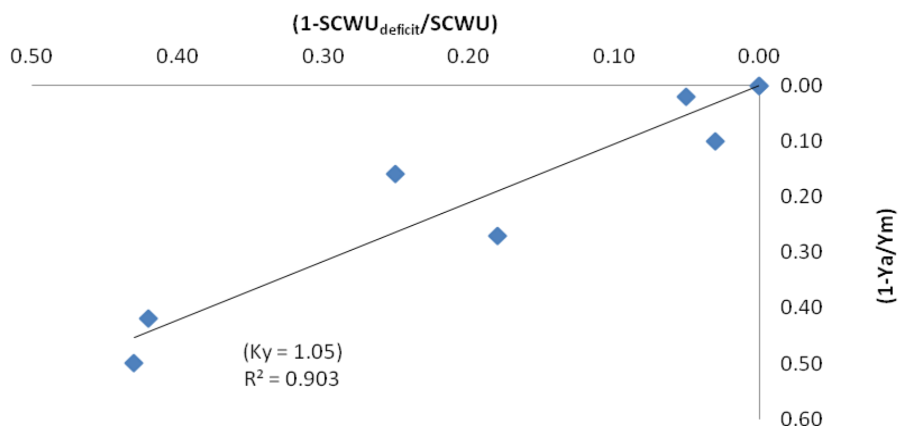

Figure 4. Yield response factor (Ky) of the black polyethylene mulch treatment.

Among the mulch materials, the polyethylene materials helped to cushion the relative decrease in yield as a result of water deficit more than the rice straw mulch. The Ky values obtained in this study closely agrees with Doorenbos and Kassam (1979) which gave seasonal Ky value of onion crop as 1.10. They are however lower compared to those reported by Kipkorir et al. (2002) which gave Ky value of 1.28 for onion in Perkerra, Kenya, and Kadayifci et al. (2005) which reported Ky value of 1.50 for the onion crop in Turkey.

Conclusion

Crop coefficients (Kc) and yield response factors (Ky) for onion crop cultivated under deficit irrigation and different mulch cover were determined in this study. The Kc values of fully irrigated treatments ranged from 0.39 to 1.15, while those of the deficit irrigated treatments varied from 0.24 to 1.13. The yield response factor (Ky) of the onion crop under no-mulch condition was 1.15, while Ky values for the mulched treatments were 1.13, 1.00 and 1.05 for the rice straw-, white polyethylene- and black polyethylene- mulch, respectively. The crop water use of the onion crop decreased with increase in irrigation deficit. Applying water at 50% of atmospheric evaporative demand (reference evapotranspiration) reduced peak consumptive use of the onion crop by about 20%, while applying water at 25% of evaporative demand reduced crop water use by about 40%. Mulch materials did not significantly influence crop coefficient of the onion crop but irrigation deficit. Crop coefficient decreased with increase in water deficit with resultant water stress coefficients classified as minor, moderate and severe for water application depths of 75, 50 and 25% weekly reference evapotranspiration, respectively. Irrespective of mulching or mulch materials, the yield decreases of the onion crop were proportionally greater with increase in evapotranspiration deficit as reflected by the Ky values. However, the proportional decrease in yield under the no mulch condition was much higher than the mulched condition. Among the mulch materials, the polyethylene materials helped to cushion the relative decrease in yield as a result of water deficit more than the rice straw mulch. The crop coefficients and yield response factors developed in this study are reliable as they had similar trends in two seasons, and thus could be used in irrigation design and scheduling for onion in the study area.

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REFERENCES

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop Evapotranspiration: Guideline for Computing Crop Water Requirements. FAO Irrig. Drain. Paper 56:300.

Amayreh J, Al-Abed N (2005). Developing crop coefficients for field-grown tomato (*Lycopersicom esculentum* M.) under drip irrigation with black plastic mulch. Agric. Water Manage. 73:247-254.

Anisuzzaman M, Ashrafuzzaman M, Ismail MR, Uddin MK, Rahim MA, (2009). Planting time and mulching effect on onion development and seed production. Afr. J. Biotech. 8(3):412-416.

Annandale JG, Stockle CO (1994). Fluctuation of crop evapotranspiration coefficients with weather. Sensitivity Anal. Irrig. Sci. 15:1-7.

Aremu JA (1980). Effect of different cultivation techniques on infiltration. Unpublished M.Sc. Thesis of the Department of Soil Science submitted to the Postgraduate School of the Ahmadu Belo University, Zaria, Nigeria.

Bekele S, Tilahum K (2007). Regulated deficit irrigation scheduling of onion in a semi arid region of Ethiopia. Agric. Water Manag. 89:148-152.

Bossie M, Tilahum K, Hordofa T (2009). Crop coefficient and evapotranspiration of onion at Awash Melkasa, Central Rift Valley of Ethiopia. Irrig. Drain. Syst. 23:1-10.

Doorenbos J, Kassam AH, (1979). Yield Response to Water. FAO Irrigation and Drainage Paper No. 33, FAO, Rome, Italy. p. 193.

Doorenbos J, Pruitt WO (1977). Guideline for prediction of crop water requirement. Irrigation and Drainage Paper No.24. FAO, Rome. Italy. Page 144.

Ejieji CJ, Fasasi MB (2003). Development of a soil water sensor using gypsum block and a multi-meter. J. Agric. Res. Dev. 2:89-92.

FAOSTAT (2011). Food and Agriculture Organization (FAO), Rome. Crop-FAOSTAT. faostat.fao.org/site/567/default.aspx. Site visited 09/10/2011.

Ferreira TC, Carr MKV (2002). Responses of potatoes (*Solanum tuberosum* L.) to irrigation and nitrogen in a hot climate I. Water Use. Field Crop Res. 78:51-64.

Gomez RS (2003). Amazing power of healing plants. Inter-American Division Publishing Association 2905 NW. 87th Avenue, Miami Florida 33172, USA.

Igbadun HE, Ramalan AA, Oiganji E (2012). Effects of regulated irrigation deficit and mulch on yield, water use and crop water productivity of onion in Samaru, Nigeria. Agric. Water Manage. 109:162-169.

Jensen ME (1968). Water consumption by agricultural plants. In: Kozlowski TT (ed.), Water Deficits in Plant Growth, vol. 1. Academic Press, New York, pp. 1–22.

Kadayifci A, Tuylu GT, Ucar Y, Cakmak B (2005). Crop water use of Onion (*Allium cepa.* L.) in Turkey. Agric. Water. Manage. 72:59-68.

Kashi A, Hosseinzadeh S, Babalar M, Lessani H (2004). Effect of black polyethylene mulch and calcium nitrate application on growth and yield of watermelon (*Citrullus lanatus*. L). J. Sci. Technol. Nat. Res. 7:1-10.

Kipkorir EC, Raes D, Masaje B (2002). Seasonal water production functions and yield response factors for Maite and onion in Perkerra, Kenya. Agric. Water Manage. 56:229–240.

Lopez-Urrea R, de Santa Olalla FM, Montoro A, Lopez-Fuster P (2009). Single and dual crop coefficients and water requirements for onion (Allium cepa L.) under semiarid conditions, Agric. Water Manage. 96:1031–1036.

Martinez-Cob A (2007). Use of thermal units to estimate corn crop coefficients under semiarid climatic conditions, Irrig. Sci. 26(4):335-345.

Mermoud A, Tamini TD, Yacouba H (2005). Impacts of different irrigation schedules on the water balance components of an onion crop in a semi-arid zone. Agric. Water Manage. 77:282-295.

Michael AM (1999). Irrigation Theory and Practice. Reprint. Vikas Publishing House PVT Ltd. New Delhi.

NAERLS (2009). Dry Season Performance Evaluation Report. National Agricultural Extension and Research Liaison Services. Ahmadu Bello University, Zaria.

Olalla FM, Velero JA, Corles CF (1994). Growth and production on onion crop (*Allium cepa.* L) under different irrigation scheduling. European J. Agron. 3:85-92.

Ouda SA, Elenin RA, Shreif MA (2010). Using yield-stress model to predict the impact of deficit irrigation on onion yield. Fourteen International Water Technology Conference. IWTC 14 2010, Cairo, Egypt. pp. 383-393.

Pathak CS (2000). Hybrid seed production in onion. J. New Seeds 1:89-108.

Pejić B, Gvozdanović-Varga J, Milić S, Ignjatović-Ćupina A, Krstić D, Ćupina B (2011). Effect of irrigation schedules on yield and water use of onion *(Allium cepa* L.). Afr. J. Biotech. 10(14):2644-2652.

Pelter GQ, Mittelstad R, Redulla CA (2004). Effects of water stress at specific growth stage on Onion bulb yield and quality. Agric. Water. Manage. 60(2):107-115.

Rhu AK, Mushi AAA, Khan MAH (1990). Effect of different mulches on the growth of potato (*Solanum tuberosum*. L.). Bangladesh J. Bot. 19:41-46.

Smith M (1992). CROPWAT: A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper 46. FAO, Rome, P. 89.

Stanghellini C, Bosma AH, Gabriels PCJ, Werkoven C (1990). The water consumption of agricultural crops: how crop coefficient are affected by crop geometry and microclimate, Acta Horticult. 278:509–516.

Stewart JL, Danielson RE, Hanks RJ, Jackson EB, Hagon RM, Pruit WO, Franklin WT, Riley JP (1977). Optimizing crop production through control of water and salinity levels in the soil. Utah Water Research Lab. PR. 151-1, Logan, UT, P. 191.

Stockle CO, Nelson R (1996). *Cropping System Simulation Model. User's Manual*. Biological System Engineering Dept., Washington State University, Pullman WA 99164-6120, P. 165.

United States Department of Agriculture (USDA) (1975). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA, Washington D.C.

Van Dam JC, Huygen J, Wesseling JG, Feddes RA, Kabat P, van Waslum P E V, Groenendjik P, van Diepen CA (1997). Theory of SWAP version 2.0: Simulation of Water Flow and Plant Growth in the Soil-Water-Atmosphere-Plant environment. Technical Document 45. The Netherlands: Wageningen Agricultural University and DLO Winand Staring Centre, P. 90.