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INCREASING WATER AND ENERGY UNIT PRODUCTIVITY OF DRIP IRRIGATION SYSTEM WITH RICE STRAW MULCHING.

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ABSTRACT

In this study under clay soil conditions during two seasons 2008 and 2009, built in emitter type was used to irrigate pepper crop with 96 h irrigation interval. In order to increase the benefits of water and energy units using water depletion strategy, three amounts of applied water 80, 90, and 100% of gross irrigation requirements (IR_g) were studied with two different soil coverage cases, 1-rice straw mulching(RM) 2- normal (NM) conditions. Rice straw mulching with abundance (500g/m^2) was used to decrease the effect of water depletion on pepper crop productivity. In general, increasing the amount of applied water led to increase crop productivity. The results showed that rice straw mulching led to increase the pepper crop productivity with all the amounts of applied water. The treatment (RM80) gave the maximum water use efficiency while the maximum water use efficiency under normal conditions was at (NM90) treatment. The two former treatments gave also the maximum productivity of energy unit. The study recommended using rice straw mulching if compared to normal conditions in order to increase crop productivity in addition to the increase of water and energy units' productivity. Using 80% of IR_g with rice straw mulching and 90% of IR_g will give the maximum water use efficiency and energy use efficiency at the two cases under experimental conditions.

INTRODUCTION

The modern production practices including increasing inputs of agrochemicals, irrigation and the growth of more productive cultivars have led to significant increase in crop yields. However, these practices have led to an increase in the input of energy Hülsbergen *et al.* (2001), which has raised many concerns over sustainable use of energy resources. Energy input in agriculture is directly related to the irrigation technology adopted, and the level of production Hatirli *et al.* (2006). The agricultural modernization which requires increasing amounts of energy inputs is, at the same time, essential for providing enough food for growing populations Stout (1990). Crop intensification through high inputs of water, energy and macro nutrients has been articulated as the way forward, especially in land scarce regions, but this has profound implications for global water and energy budget Khan and Hanjra (2009). Water can be saved through better management of its delivery and application Khan *et al.* (2004); Khan *et al.* (2005).The 'balancing act' between crop production and environmental sustainability involves boosting water productivity Molden *et al.* (2007) and energy productivity de Fraiture *et al.* (2007) through a range of measures. Efficient irrigation methods are important means for boosting crop productivity .The energy required for installation and operation of high technology water efficient irrigation systems like drip irrigation is significantly higher than traditional systems. Despite the internal and external environmental and economic benefits increase resulted from improvement in irrigation efficiency, a balanced use of water and energy resources is vital in terms of productivity of agriculture as well as for environmental sustainability Beare and Heaney (2001). Drip irrigation system is suitable for different soil types and has high irrigation efficiency. Mulching is one of the most important ways to preserve water in soil and reduce evaporation losses Olson (1995). Organic mulching moderates the temperature of the root zone. It also provides an insulation effect, keeping the soil warmer during the winter and cooler during the summer Clatterbuck (2003). Drip irrigation is compatible with mulching, because the grower can maintain optimum moisture under the mulching Olson (1995). Deficit (or regulated deficit) irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied Kirda *et al.* (1999). Using mulching may help to avoid the effect of deficit irrigation on crop productivity. This study aimed to the following:

1- Using deficit irrigation strategy in order to increase water and energy unit productivity.
2- Reducing the effect of deficit irrigation on crop productivity by using rice straw mulching.

MATERIALS AND METHODS

Study area

An experiment had been taken place in the field crops research center, Sakha village, Kafrelsheikh governorate, Egypt (longitude 30.95, latitude 31.11, altitude 20 m). The field work taken place in a 40x40m^2 area of clay soil (Table1) during 2008 and 2009 successive seasons. A drip irrigation network was set in a part of the total area acting 36.6x30 m^2. Laterals 30m long, 1.2 m spacing with built- in emitters 30 cm spacing between emitters were used. Fig.1 shows the used drip irrigation network layout.

The emitters' average flow rate was 4.41 l/h at 10m of water operating pressure head. This operating pressure head was used as it was recommended by El-Nemr (2010) for such type of emitters to obtain the best uniformity parameters. Pepper crop (California wonder TMR300) was used as an example for vegetable crops which is highly sensitive for the amount of applied water changes. Seeds transplanted in a plantation area in 10 March 2008 and 17 March 2009 for the two successive growing seasons respectively. Ca $(H_2Po_4)_2.CaCo_3$ was added to the plantation area with a rate of 357 kg/ha. The seedlings were put after 40 days to the permanent study area. The study area was ploughed two times. The first plough was to get the soil rid of weeds and previous crop (Cucumber) residues. 357 kg/ha of Ca $(H_2PO_4)_2$, 238 kg/ha K_2So_4, and 119 kg/ha $(NH_4)_2SO_4$ were added to the soil before second plough operation in addition to 71.4 kg/ha Organic nutrient. 476 kg/ha $(NH_4)_2SO_4$ was added after 30 days of transplanting in permanent soil. 357 kg/ha Ca Po_4 plus 476 kg/ha $(NH_4)_2SO_4$ were added after 60 days of transplanting in permanent soil. During flowering period 476 kg/ha $(NH_4)_2SO_4$ in addition to 119 kg/ha K_2SO_4were added. During harvesting period 476 kg/ha $(NH_4)_2SO_4$ were added every two picks in order to keep the production commercial specification. 96 hours irrigation interval was used for all treatments.

Table 1: Mechanical analysis for the soil of the experiment area.

Depth (cm)	Particle size distribution			Soil texture	F.C,%	Bulk density, g/cm^3
	Sand, %	Silt, %	Clay, %			
0-15	22.56	27.67	49.69	Clay	41.50	1.26
15-30	22.20	24.73	52.27	Clay	39.83	1.31
30-45	20.50	25.90	52.80	Clay	38.40	1.29
45-60	21.30	25.00	53.20	Clay	36.39	1.38

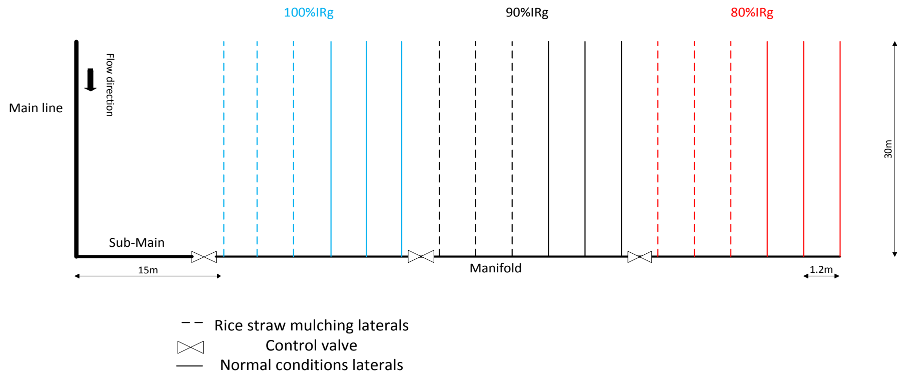

Fig.1: Schematic diagram of the used drip irrigation network

Variables and statistical design

Split plot statistical design was used in the study. Soil surface covering case as main plot, including rice straw mulching (RM) and normal or no-mulching (NM) conditions. Amount of applied water as sub-main plot, including three percentages of gross irrigation requirements (IR_g) 80, 90, and 100%. Rice straw mulching was with abundance of 500 g/m^2 as it was recommended for soil moisture preservation in addition to avoid over-mulching risk El-Nemr (2006).

Amount of applied water

Reference evapotranspiration (ET_o) for pepper crop was calculated using CROPWAT computer program FAO (1992). Gross irrigation requirements (mm/day) were calculated referring to FAO (1980). The amount of applied water of the three percentages 80, 90, and 100% of gross irrigation requirements (IR_g) are listed in table 2. The drip irrigation system efficiency was assumed 85%. A 100 ml sample for both irrigation and drainage water was collected to calculate the leaching requirements (percentage of irrigation water electric conductivity to the drainage water electric conductivity). Leaching requirements was 40% of crop evapotranspiration (ET_c).

Crop productivity

Each treatment was replicated three times as shown in the irrigation network layout (Fig.1). The average of the three replicates for each treatment was used to express the total crop productivity calculations. Pepper was collected after maturity and reaching the acceptable commercial size. Pepper weighed on 2 digits accuracy balance. The total productivity of each lateral act the productivity of 36 m^2, this productivity was factored to calculate the crop productivity per ha.

Water use efficiency

Water use efficiency (WUE), has been used to describe the pepper crop productivity per water unit. It was determined by applying the following equation Jensen (1983):

$$\mathbf{WUE} = \frac{Y}{W_a} \qquad (1)$$

Where:-

WUE = water use efficiency, kg/m^3, Y = total yield kg/ha, and, W_a = total applied water, m^3/ha.

Power and energy calculations

The pump brake power was calculated as follows:-

$$BP = WP/\eta \qquad (2)$$

Where:

BP= brake power, WP= water power, and η = decimal pump efficiency, assumed 0.6.

$$WP = Q \times H_t \times \omega \qquad (3)$$

Where:

Q= required discharge at the network, H_t= total head, ω = water specific weight.

$$H_t = H_f + H_s + H_e \qquad (4)$$

H_f =friction loss, H_s =static head, H_e =emitter operating pressure head.

The suction static head was 10m. The following formula was used to calculate the friction loss for main line, sub-main line, manifold, and laterals. The c value was 150. Hazen and Williams (1920):-

$$S = \frac{10.67xQ^{1.85}}{C^{1.85}Xd^{4.87}} \qquad (5)$$

Where:

S = head loss (in m of water) per m of pipeline length, Q = volumetric flow rate in m^3/s and d = inside pipe diameter in m.

The friction loss in connectors and valves was assumed 10% of the total friction loss El-Gendy *et al.* (2001). The inner diameters of main line, sub-main, and manifolds were 12.7, 7.62, and 5.08 cm respectively. The calculated power was multiplied to the operation time to calculate the total energy consumption. . The operating times during season were 74.33, 53.24, and 59.16 h for the 80, 90, and 100% percentages respectively.

Energy use efficiency (EUE)

The energy use efficiency was calculated to express the crop produced from energy unit. The following equation was used:

$$EUE = \frac{Total\ yield, kg}{Total\ energy\ \text{input, kW.h}} \qquad (6)$$

Where: EUE= Energy use efficiency, kg/kW.h.

RESULTS AND DISCUSSION

Crop productivity

Table.2 shows pepper productivity for all treatments. The results observed during the seasons 2008, and 2009 show that increasing amount of applied water led to increase crop productivity for both rice straw mulching and normal conditions. The largest crop productivity reached 16.1, and 16,0 Mg/ha at RM100 treatment for both years. The minimum productivity was 12 Mg/ha and 11.48 for 2008, and 2009 years respectively at NM80 treatment. At year 2008, reducing the amount of applied water from 100 to 80% gave a decrease of 5.5% of maximum productivity crop productivity under rice straw mulching while the decrease was 20.0% of maximum productivity under no mulching conditions. Year 2009 results showed that, reducing the amount of applied water from 100 to 80% gave a decrease of 12.7% of maximum crop productivity under rice straw mulching while it was 22.0% of maximum productivity under no mulching conditions. This may be due to the ability of rice straw mulching to keep soil moisture content which will lead to reduce the effect of water shortage on crop productivity El-Nemr (2006). The means comparison test was achieved for each year separately. The mean comparison test showed that there was no significant difference in crop productivity with all amounts of applied water under rice straw mulching for both growing seasons. The normal conditions showed no significant difference between 100 and 90% IR_g amounts, while the crop productivity at 80% was significantly different. That may be due to the clay soil water holding capacity, which may helped to keep soil moisture content in a range that may led to keep the crop productivity reduction in non-significantly different range.

Table 2: Crop productivity (Mg/ha) during growing seasons. Values followed by the same single letter for each season are not significantly different at 0.05 level.

Season	Treatment	Amount of applied water (%IR_g)			L.S.D
		80	90	100	
2008	Rice straw mulching	15.20 a	15.62 a	16.1 a	1.912
	Normal	12.00 b	14.73 a	15 a	
2009	Rice straw mulching	13.96 ab	15.02 a	16.00 a	2.514
	Normal	11.48 b	14.39 a	14.72 a	

Water use efficiency

Water use efficiency was used to describe the amount of crop produced from one volumetric unit of water. WUE values listed in table 3 showed that the largest WUE values were at RM80 treatment. They were 3.09, and 2.83 kg/m^3 for the years 2008, and 2009 respectively. The treatment NM80 gave the minimum water use efficiency during the two seasons. Because of the non-significant decrease in crop productivity under rice straw mulching for the different amounts of applied water, the reduction in the amount of applied water led to increase the produced crop of unit of water as the productivity was not significantly affected. Under normal conditions, the non-significant reduction in crop productivity between NM100, and NM90 treatments led to increase the water use efficiency at NM90 treatment (2.66, and 2.59 kg/m^3) compared to (2.44, and 2.39 kg/m^3) at NM100 treatment. For all amounts of applied water, rice straw mulching led to increase the benefit of unit of water if compared to the normal conditions. The averages of WUE values for the years 2008, and 2009 under all treatments were calculated and listed in table 3. The average values of WUE showed that the most beneficial use of unit of water will be at RM80 treatment. The lowest WUE values were at NM80 treatment because of the significant reduction in crop productivity. Comparing the average values of water use efficiency of the two years showed that, decreasing amount of applied water from 100 to 80% IR_g under rice straw mulching, increased the water use efficiency by 11.8% while it gave a decrease of 1.2% under normal conditions.

Table 3: Water use efficiency (kg/m^3) for all treatments.

	Amount of Applied water, m^3/ha		WUE, kg/m^3		
	2008	***2009***	***2008***	***2009***	***Average***
RM80	4917.593	4929.71	3.09	2.83	2.96
RM90	5532.292	5545.93	2.82	2.71	2.77
RM100	6146.992	6162.14	2.62	2.60	2.61
NM80	4917.593	4929.71	2.44	2.33	2.39
NM90	5532.292	5545.93	2.66	2.59	2.63
NM100	6146.992	6162.14	2.44	2.39	2.42

Energy use efficiency

Data listed in table.4 show that the largest value of power productivity for both years was at RM80. The minimum value was NM80 treatment. The average energy use efficiency values of the two years showed that, decreasing the amount of applied water from 100 to 80% IR_g made an increase of 11.65% of the maximum energy unit productivity under rice straw mulching. The normal conditions' decrease in the amount of applied water from 100 to 80% IR_g, showed a decrease of 1.61% of maximum energy use efficiency obtained under this case. Comparing the average maximum energy use efficiency values under rice straw mulching and no- mulching showed that using rice straw mulching will lead to increase the energy use efficiency by 18.19%. The ability of rice straw mulching to reduce the effect of water depletion on crop productivity in addition to keeping the crop productivity reduction in a non-significantly different range, helped to increase the benefits of energy unit.

Table 4: Energy use efficiency (kg/kW.h) for all treatments.

Treatment / Year	RM80	RM90	RM100	NM80	NM90	NM100
2008	88.59	80.93	75.07	69.94	76.32	69.94
2009	78.06	75.00	72.16	64.19	71.86	66.39
Average	83.33	77.97	73.62	67.07	74.09	68.17

CONCLUSION

Over 2008 and 2009 successive seasons, increasing amount of applied water led to increase pepper productivity whether under rice straw mulching or normal conditions. Using rice straw mulching showed productivity increase at all amounts of applied water when compared to normal conditions. The decrease in crop productivity under rice straw mulching was not significant at all amounts of applied water. Reducing the amount of applied water under rice straw mulching from 100 to 80% gave a decrease of 5.5, and 12.7% for the years 2008, and 2009 respectively, while it was 20, and 22% for the same two years under no-mulch conditions respectively. This non-significant decrease led to increase the WUE which got its maximum values for the two years at the RM80 treatment. The NM80 treatment gave the minimum values. . Comparing the average values of water use efficiency of the two years showed that, decreasing amount of applied water from 100 to 80% IR_g under rice straw mulching, increased the water use efficiency by 11.8% while it gave a decrease of 1.2% under normal conditions. RM80 treatment gave also the largest energy unit productivity for the two years 88.59, and 78.06 kg/kW.h. NM80 treatment gave the minimum energy use efficiency 69.94, and 64.19 kg/kW.h for the both two years 2008, and 2009 respectively. The obtained results showed that, under clay soil conditions for pepper crop, it can be recommended to use rice straw mulching (500g/m^2) with 80% IR_g in order to increase the benefits of both water and energy units production. The irrigation interval effect on crop productivity should be studied beside the effect of amount of applied water for clay soil because the short interval may not show a significant effect for water regime because of the high water holding capacity of clay soil.

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زيادة انتاجية وحدة المياه والطاقة لنظام الرى بالتنقيط باستخدام التغطية بقش الأرز

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أجريت دراسة حقلية تحت ظروف التربة الطينية بمركز بحوث المحاصيل الحقلية ، قرية سخا، محافظة كفر الشيخ خلال الموسمين الزراعيين 2008 و 2009. تم استخدام نظام الرى بالتنقيط (نقاطات داخل الخط) بضاغط تشغيل 10م لرى محصول الفلفل بفاصل زمني 96 ساعة تحت ظروف التربة الطينية. وهدفت الدراسة الى محاولة استغلال أسلوب النقص المائي لزيادة الاستفادة من وحدة المياه والطاقة من خلال استخدام التغطية بقش الأرز بغرض استغلال قدرة التغطية على الحفاظ على رطوبة التربة وبالتالي تخفيف الأثر السلبي لنقص مياه الرى على انتاج المحصول. تمت التغطية بقش الأرز بكثافة (500ج/ م^2) .شملت التجارب استخدام ثلاث كميات من مياه الرى 80، 90، 100% من الاحتياجات المائية القصوى، تحت ظروف التغطية بقش الأرز والظروف العادية (عدم التغطية). وقد أظهرت النتائج أن زيادة كمية المياه المضافة من خلال نظام الرى سوف تؤدي الى زيادة انتاج المحصول تحت ظروف التغطية والظروف العادية. كما أن التغطية بقش الأرز قد أدت لزيادة انتاج المحصول لكل كميات مياه الرى المضافة مقارنة بالظروف العادية. أوضحت انتاجية المحصول خلال عامى 2008، 2009 عدم وجود فروق معنوية بين قيم الانتاجية مع استخدام التغطية بقش الأرز لكل كميات المياه المضافة بينما لم يكن هناك اختلافاً معنوياً بين قيم الانتاجية تحت الظروف العادية لكميتى المياه 90،100% من الاحتياجات القصوى وان وجد اختلافاً معنوياً بين الكميتين السابقتين و الكمية 80%. وقد يعزى عدم الانخفاض المعنوي باستخدام قش الأرز لقدرته على الحفاظ على المحتوى الرطوبي للتربة مما يخفف من أثر النقص المائي على الانتاج بالاضافة للظروف الحرارية الجيدة التي يوفرها للتربة مما يساعد في تحسين النمو وبالتالي زيادة الانتاج . وقد ادى هذا الانخفاض غير المعنوي في الانتاجية الى زيادة الاستفادة من وحدة المياه، حيث أظهر متوسط حسابات كفاءة استخدام المياه للعامين 2008، 2009 أن خفض كمية المياه من 100 الى 80% من الاحتياجات المائية القصوى سوف يؤدي إلى زيادة كفاءة استخدام المياه بنسبة 11.8% من قيمة كفاءة استخدام المياه مع استخدام قش الأرز والرى بنسبة 100 % من الاحتياجات المائية القصوى، بينما لوحظ نقص 1.2% تحت الظروف العادية لنفس كميات المياه. كما أظهر متوسط نتائج الموسمين أن تخفيض كمية المياه من 100 الى 80% من الاحتياجات القصوى سوف يؤدي الى زيادة انتاجية وحدة الطاقة بنسبة 11.65% بينما وجد نقص 1.61% تحت الظروف العادية مع نفس التخفيض لكمية المياه. وقد أوصت الدراسة تحت الظروف التجريبية باستخدام التغطية بقش الأرز والرى بنسبة 80% من الاحتياجات المائية القصوى لضمان تحقيق أعلى اتاجية لوحدة الماء والطاقة.كذلك دراسة أثر الفاصل الزمني بين مواعيد الرى على الانتاج نظراً لاحتمال عدم وجود فروق معنوية في الانتاج مع تخفيض كمية مياه الرى عن الاحتياجات المقررة ، خاصة مع الفواصل الزمنية القصيرة نظراً للسعة التخزينية العالية للتربة الطينية .

قام بتحكيم البحث

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