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Mulching Effects on Water use Efficiency of Corn Yield

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A FIELD study was conducted in the summer seasons of 2007 and 2008 at the Agricultural Experimental Station of Faculty of Agriculture, Cairo University, Giza, to evaluate the effect of different mulch materials on water evapotranspiration (ET) and water use efficiency of corn yield. The mulching treatments were no-mulch, plastic mulch and rice straw mulch. Theoretical water evapotranspiration (ETo) was calculated for each treatment using Penman-Monteith (P.M) and Modified Penman (M.P) equations. The actual crop coefficient (Kc) and water use efficiency (WUE) were calculated for mulched and un-mulched treatments. The results revealed that corn yield was generally higher under mulched treatments compared with un-mulched treatments. Plastic and rice straw mulches significantly increased grain yield by 17.0 % and by 10.0 % compared to un-mulched treatment, respectively. The highest values of water use efficiency were obtained under plastic mulch treatment followed by rice straw mulch treatment. The increase in (WUE) was about 24.0 % and 14.0 % under plastic and rice straw mulches as compared to un-mulched treatment, respectively. Plastic mulch was more effective than rice straw in decreasing water evapotranspiration, increasing water use efficiency and grain yield of corn. The theoretical crop coefficient (Kc) values reported by the FAO were higher than the actual (Kc) values obtained for all treatments. Mulching resulted in lower (Kc) values compared to un-mulching. However, the difference between theoretical and actual (Kc) values was not significant when using Penman-Monteith (P.M) equation. The (ETa) values were approximately closed to the crop evapotranspiration (ETc) obtained by Penman-Monteith (P.M) equation compared to those values obtained by Modified Penman (M.P) equation. The study confirmed that mulching has a benefit effect on increasing corn yield.

Keywords: Evapotranspiration, Plastic mulch, Rice straw mulch, Corn, Water use efficiency.

As the demand for irrigation water increases, it becomes essential to use water more efficiently. Improving water use efficiency requires a development of satisfactory means to estimate crop water requirements or evapotranspiration (ETo). In Egypt, great attention has been paid to increase the corn (*Zea mays*) production as one of the main cereal crops. This could be achieved by using high yielding cultivars and improving the agronomic practices such as mulching. Mulch management allows using plant residue and employing it in a benefit way for soil and water conservation. On the other hand, rice straw becomes a big problem to get rid of, so that the farmers oblige to burn the rice straw and this lead to environmental pollution. Sien *et al.* (2008) stated that although many experiments have recently been carried out to investigate the effect of plastic mulch, few studies on ET and Kc of maize with plastic mulch have been done. It is essential to understand maize evapotranspiration and crop coefficient.

Many materials have been used as mulch, such as plastic film, crop residue, straw, gravel, sand, etc. however plastic film and straw materials were used most commonly (Unger, 2001 and Berglund *et al.*, 2006). Mulch is a protective layer of a material that is spread on top of the soil surface. Returning crop residues to the soil improves soil quality and productivity through favorable effects on soil properties (Lal & stewart, 1995).

Mulch management, in general, and straw mulch, in particular, helped in conservation of soil moisture in the root zone, which influenced grain yield, higher moisture status, increased root proliferation and thus enhanced availability of nutrients to crop roots (Sarkar & Rana, 1999 and Sarkar, 2005). It was also indicated that surface-applied mulches provide several benefits to crop production through improving water, heat energy, nutrient status in soil, preventing soil and water loss and controlling weed (Bu *et al.*, 2002; Ji & Unger, 2001 and Xiying *et al.*, 2005).

Vegetative mulching was effective in reducing the loss of evaporation from the soil surface by forming a barrier between the soil surface and the atmosphere and thus reducing the vapour pressure gradient at the soil- atmosphere interface (Gupta & Acharya, 1993). It was also found that an artificial barrier with straw mulch helped for slow and steady entry of water and thus reduced drainage loss (Moitra *et al.*, 1996). Sauer *et al.* (1996) found that the presence of residue on the surface reduced soil water evaporation by 34 to 50%.

Rathore *et al.* (1998) observed that more water was conserved in the soil profile during the early growth period with straw mulch than without it. They also added that subsequent uptake of conserved soil moisture moderated plant water status, soil temperature and soil mechanical resistance, leading to better root growth and higher grain yields. Unger (1986) and Wicks *et al.* (1994) reported that maintain crop residue on the soil surface increased maize yields. The yield increase was correlated with increase in water content in the soil due to reduced evaporation.

The objectives of this study were: (a) determine the actual evapotranspiration for corn under mulch conditions, (b) evaluate the effect of different mulch types on the yield and water use efficiency, (c) calculate crop coefficients (Kc) for corn using two empirical equations, Penman-Monteith (P.M) and modified penman (M.P) in order to identify the best empirical equation for predicting actual evapotranspiration for corn yield.

Material and Methods

This experiment was conducted at the Agricultural Experimental Station, Faculty of Agricultural, Cairo University, Giza, during summer season (2007 and 2008). The experiment was performed in a complete randomized block design with four replicates. Each replicate was 6.0 m length and 4.0 m width. The mulching treatments were, rice straw mulch (RSM), white plastic mulch (WPM) and no mulching (NM). The experimental units were separated from each other by a belt (2.0 m width) to avoid lateral movement of irrigation water. Rice straw mulch was applied by hand at a rate of 2.1 ton/fed. A 0.3 cm thick plastic sheet was used to cover the soil area between crop rows. Mulching treatments were imposed 20 days after sowing (Table 1).

Planting pattern

Corn (variety S.C 10) was planted in 1 and 4 June, 2007 and 2008, respectively. Corn was in furrows, at 30 cm distance between hills and 70 cm distance between furrows and was thinned into one plant per hill (recommended planting method) to get 20.000 plants/fed (Moalr, 2005).

Fertilization regimes

Types, application rates and dates of application for different utilized fertilizers for corn were applied according to the recommendation of (Moalr, 2005).

Soil water content measurement

Soil water content was monitored each irrigation, before and after 48 hr. Soil samples were collected from three soil layers (0-20, 20-40 and 40-60 cm). Moisture contents were determined gravimetrically for each soil sample. The amounts of actual evapotranspiration under each irrigation treatment were determined according to Israelsen & Hansen (1962) using the following equation:

$$ETa = \left(\frac{\theta v2 - \theta v1}{100}\right) d$$

Where:

ETa: Actual evapotranspiration mm / interval.

$\Theta v2$: Soil moisture content after irrigation on volume basis (%).

$\Theta v1$: Soil moisture content before irrigation time on volume basis.

d : Depth of soil layer (mm).

Reference evapotranspiration (ET_o)

The (ET_o) values were calculated using Penman-Monteith (P.M) equation according to Allen & Pereira (1998) and Modified Penman (M.P) equation according to Doorenbos & Pruitt (1984). The meteorological data collected from the nearest Agrometerogical Station, Dokki were used.

TABLE 1. Meteorological data during 2007 and 2008 seasons.

Growing season 2007								
Month	MAX-T C^0	MIN-T C^0	TEM-AV. C^0	MAX-RH %	MIN-RH %	RH-AV. %	WIN-SP m / sec	SUNSHINE hours
June	34.28	22.72	28.50	75.08	26.13	50.61	2.09	12.40
July	34.03	23.60	28.81	79.70	33.14	56.42	1.98	11.90
Aug.	34.22	24.05	29.13	82.71	35.18	58.94	1.99	11.10
Sep.	32.12	21.91	27.02	79.64	34.60	57.12	1.88	10.30
Growing season 2008								
Month	MAX-T C^0	MIN-T C^0	TEM-AV C^0	MAX-RH %	MIN-RH %	RH-AV. %	WIN-SP m / sec	SUNSHINE hours
June	36.3	22.5	29.4	54.0	34.3	44.2	4.07	12.4
July	35.9	23.2	29.6	62.7	41.7	52.2	3.73	11.9
Aug.	36.8	23.6	30.2	61.0	39.0	50.0	3.67	11.1
Sep.	35.7	22.3	29.0	59.7	38.3	49.0	3.03	10.3

Crop coefficient (Kc)

Crop coefficient (Kc) was calculated using the following equation:

$$Kc = ET_a / ET_o$$

Where:

ET_a= Actual evapotranspiration.

ET_o= Reference evapotranspiration.

Kc= Crop coefficient of corn.

Soil sampling and methods of analysis

Undisturbed and disturbed soil samples were collected from three successive soil depths (0-20, 20-40, and 40-60 cm) to determine some physical and chemical characteristics of the investigated soil site, according to the methods described by Page *et al*. (1982) for chemical soil properties and Klute (1986) for physical soil properties.

Water use efficiency (WUE)

Water use efficiency of crop was calculated according to Giriappa (1983) using the following equation:

$$CWUE = \frac{\text{Yield (Kg/fed)}}{\text{ETa (m3/fed)}}$$

Grain and seed yields

Grain yields of maize were obtained from a central area 1.4 m x 1.5 m. of each plot to avoid the borders effect and calculated as kg / fed.

Statistical analysis

The treatment means were compared using Duncan's Multiple Range Test according to (Snedecor & Cochran, 1980). The (L.S.D) and the student t-test (paired) were done at 0.05 level of significance.

Results and Discussion

Data of soil physical and chemical characteristics of the experimental soil site are presented in Table 2.

TABLE 2. Soil physical and chemical characteristics of the experimental site.

Soil characteristics	Soil depths (cm)		
	0-20	20-40	40-60
Particle size distribution %			
C.sand	2.6	0.8	1.8
F.sand	55.2	58.4	56.0
Silt	21.7	18.1	20.3
Clay	20.5	22.7	21.9
Texture class	Sandy clay loam	Sandy clay loam	Sandy clay loam
Chemical properties			
$CaCO_3$ %	4.56	3.22	1.39
Organic matter %	1.94	1.71	1.26
pH (soil paste)	7.95	7.89	7.97
ECe (soil paste extract)	2.53	2.33	1.73
Physical properties			
Bulk density (g/cm^3)	1.17	1.30	1.37
Field capacity (θv%)	43.3	45.9	43.4
Wilting point (θv%)	19.5	23.5	21.6
Available water (θv%)	23.8	22.4	21.8

The results revealed that the soil of the experimental site is sandy clay loam throughout the whole profile layers. All layers of the soil profile are non-saline, slightly alkaline; contain slight percentages of calcium carbonate and organic matter.

Reference evapotranspiration (ETo)

The major parameters required to calculate the (ETo) are the climatological data, length of the growth period of the cultivated crops and surface properties.

Data illustrated in Table 3 shows the values of reference evapotranspiration (ETo) calculated according to Penman-Monteith (P.M) and modified penman (M.P) equations. The (ETo) values calculated by the different equations are maximum in June and gradually decreased to minimum in September in 2007 season. While, in 2008 season the maximum (ETo) values is found in July and decreased to minimum in September. This trend is due to the variation in sowing data and in climate in the two seasons. The (ETo) values calculated by Penman-Monteith (P.M) method were lower than those values obtained by the modified penman (M.P) method during the growing months in both seasons.

Actual evapotranspiration (ETa)

The monthly changes in the actual evapotranspiration (ETa) for corn crop as affected by different mulching treatments during the growing seasons are shown in Table 3. Data illustrate that the monthly values of (ETa) under the studied treatments increased from June to August then decreased from August to September. The (ETa) values under mulching soil are lower than the (ETa) values under un-mulching soil. Plastic mulch treatments recorded the lowest values of (ETa) followed by rice straw mulch treatments as compared to the un-mulched treatments. A significant difference was obtained between un-mulched soil and mulched soil with plastic and rice straw. Plastic and rice straw mulches reduce (ETa) by 5.86 % and 3.51 %, in the first season and by 5.93% and 2.86 % in the second season, respectively as compared with un-mulched soil. These results may be due to the higher water evaporation under rice straw mulch compared with plastic mulch.

TABLE 3. Monthly ETo and ETa (mm/month) for corn under different treatments according to the studied equations.

Growing months	(ETo)		(ETa)		
	P.M	M.P	WPM	RSM	*NM*
	Season 2007				
June	318.00	310.40	104.47	107.72	116.45
July	274.40	292.80	233.15	239.71	243.26
Aug.	240.60	264.10	231.16	235.46	245.47
Sep.(23 days)	153.90	172.50	126.13	129.32	132.95
Total	986.80	1039.70	694.91	712.21	738.13
L.S.D (0.05)	-	-	5.82		
	Season 2008				
June.(26days)	246.74	264.16	83.48	86.51	91.46
July	265.36	295.12	215.56	219.64	224.51
Aug.	261.33	280.55	243.85	252.67	257.56
Sep.(27 days)	191.70	240.30	140.27	146.65	152.71
Total	965.13	1080.13	683.16	705.47	726.24
L.S.D (0.05)	-	-	6.08		

Crop coefficient (Kc)

The actual crop coefficient (Kc) calculated for the different types of mulching and the theoretical (Kc) values given by the FAO are shown in Table 4. The maximum FAO crop coefficient value (1.20) is obtained in August while the minimum value (0.40) is obtained in June with an average of (0.87 and 0.84) over the whole first and second seasons. The actual (Kc) increased from June to August then declined in September in both seasons. The actual minimum (Kc) values are obtained under plastic mulch followed by rice straw mulch as compared to the un-mulching treatment. The significant differences between the theoretical (Kc) values given by the FAO and the actual (Kc) values were tested using t-test, (Table 4). The theoretical (Kc) values given by the FAO is not significantly different than the actual (Kc) values calculated by Penman-Monteith equation under both mulched and un-mulched treatments in the two seasons. However, there is a significant difference between theoretical and (Kc) values calculated with plastic and rice straw mulches by modified-penman equation in both seasons. Actual crop coefficient calculated by Penman-Monteith equation compare well with those reported by FAO.

TABLE 4. Calculated and theoretical crop coefficient (Kc) for corn under mulched and un-mulched conditions.

Growing months	P.M (Equation)			M.P (Equation)			FAO (Kc)
	WPM	RSM	NM	WPM	RSM	NM	
	Season 2007						
June	0.33	0.34	0.37	0.33	0.35	0.38	0.40
July	0.85	0.87	0.89	0.75	0.77	0.79	0.92
Aug.	0.96	0.98	1.02	0.92	0.93	0.95	1.20
Sep.(23days)	0.82	0.84	0.86	0.72	0.75	0.77	0.95
Growing season	0.74	0.76	0.79	0.68	0.70	0.72	0.87
t- test value	3.18	2.83	2.33	4.15*	3.62*	2.99	-
	Season 2008						
June (26days)	0.34	0.35	0.37	0.32	0.33	0.35	0.39
July	0.81	0.83	0.85	0.73	0.74	0.76	0.86
Aug.	0.93	0.96	0.99	0.87	0.90	0.92	1.20
Sep.(27days)	0.73	0.76	0.79	0.58	0.61	0.64	0.90
Growing season	0.71	0.73	0.75	0.63	0.65	0.67	0.84
t-test value	2.54	2.29	1.88	3.21*	3.18*	2.87	-

* Not significantly different.

Crop evapotranspiration (ETc)

Table 5 shows the (ETc) values calculated for the different mulching treatments in both seasons. Crop coefficient (Kc) values given by the FAO and (ETo) values calculated by Penman-Monteith and modified-Penman equations were used to calculate (ETc) values. The calculated (ETc) values are higher than the actual evapotranspiration (ETa); this may be due to the variation in climate of the studied region. It is also observed that (ETc) values obtained by Modefied-Penman are higher than those values obtained by Penman-Monteith method. The Penman-Monteith method is approximately close to the (ETa) values.

TABLE 5. The ETc (mm/month) calculated by the studied equations and FAO (Kc) during the two seasons.

Growing months	(ETc)			
	Season 2007		Season 2008	
	P.M	M.P	P.M	M.P
June	127.20	124.16	96.23	103.02
July	252.42	269.38	228.21	253.80
Aug.	288.72	316.92	313.59	336.66
Sep.(23days)	146.21	163.88	172.53	216.27
Total	814.58	874.38	810.56	909.75

Corn grain yield

Data of corn grain yield (Kg/fed) are presented in Table 6 for all the studied treatments in both growing seasons. The highest grain yield of corn is obtained with plastic mulch treatments followed by rice straw mulch treatments as compared with the un-mulch treatments in both seasons. Plastic and rice straw mulches significantly increased grain yield by 16.65% and 10.38 % in the first season and by 17.24 % and 10.63 % in the second season over the un-mulched treatments, respectively. The increase in the yield of corn under mulching may be rendered to decreasing water evaporation from the soil surface; mulching increase shading and consequently reduces evaporation from soil surface. However, plastic mulch was superior to rice straw mulch in reducing soil evaporation. The superiority of plastic mulch may be due to the higher moisture content % under plastic than under straw mulches which observed from the low (ETa) values recorded under the plastic mulch compared to the rice straw mulch. Plastic mulch resulted in increasing the availability of water to corn plants which increased the corn yield.

TABLE 6. Grain yield of corn (Kg/fed) as affected by mulching and no-mulching treatments.

Mulching treat.	I	II	III	IV	Mean
	Season 2007				
Plastic mulch	4383.2	4290.9	4517.2	4459.5	4412.7
Rice straw mulch	4324.8	4184.5	4075.8	4117.3	4175.6
No-mulch	3924.1	3797.9	3830.4	3579.2	3782.9
L.S.D (0.05)	191.08				
	Season 2008				
Plastic mulch	4376.7	4418.4	4369.7	4085.6	4312.6
Rice straw mulch	3982.7	3967.2	4143.4	4184.3	4069.4
No-mulch	3631.6	3720.5	3678.6	3682.5	3678.3
L.S.D (0.05)	177.41				

A significant difference between plastic and rice straw mulches on corn grain yield of no-mulching is obtained in both growing seasons.

Water use efficiency (WUE)

Water use efficiencies (WUE) calculated for the different studied treatments are shown in Table 7. In general, the values of water use efficiency (WUE) increase with the applying of mulch treatments. The highest increase in (WUE) is obtained under plastic mulch followed by rice straw mulch as compared to un-mulch treatments in both seasons. This may be due to the increase of corn yield under mulching treatments as a result of increasing the availability of water, decreasing of the weed and decreasing of water evapotranspiration. Plastic and rice straw mulch generally increased (WUE) by 24.0 %, 14.0 % over the un-mulched treatment, respectively in both seasons. A significant difference in (WUE) among treatments was obtained.

TABLE 7. Water use efficiency (Kg/m^3) of corn yield as affected by mulching and un-mulching treatments.

Treatments	Season 2007	Season 2008
Plastic mulch	1.51	1.50
Rice straw mulch	1.39	1.37
No-mulch	1.22	1.21
L.S.D (0.05)	0.041	0.039

Conclusion

Mulched treatments were more effective in reducing water evaporation, increasing water use efficiency and corn grain yield compared to un-mulched treatments. Plastic mulch was more effective in reducing evapotranspiration and improving water use efficiency as compared to rice straw mulch. Although, plastic mulch is superior to rice straw mulch, it adds costs to the farmers. Applying rice straw mulch would lower these costs and increases the environment benefit compared to plastic mulch. It is suggested that increasing the applied rate of rice straw can raise its performance in reducing evaporation. The results also concluded that the (Kc) values were lower under mulching compared to un-mulching. It is preferred to use Penman-Monteith (P.M) equation to predict the evapotranspiration of corn under the studied region.

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تأثيرات التغطية على كفاءة استخدام المياة لمحصول الذرة

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أجريت تجربه حقلية في محطة التجارب الزراعية بكلية الزراعة جامعة القاهرة بالجيزة خلال صيف موسمى ٢٠٠٧،٢٠٠٨ وذلك لدراسة :
أ. الاستهلاك المائي للذرة الشامية تحت نظم تغطية مختلفة. ب. دراسة تأثير نوعين مختلفين من الاغطية على المحصول وأيضا تقدير كفاءة استخدام الماء تحت كل نوع. ج. حساب معامل المحصول للذرة باستخدام بعض المعادلات التجريبية (بينمان مونتيث وبينمان المعدلة). كانت معاملات التغطية لسطح التربة كالتالى : المعاملة الأولى تم فيها تغطية التربة ببلاستيك أبيض و المعاملة الثانية بقش الأرز والمعاملة الثالثة ترك فيها سطح التربة بدون تغطية ونفذت التجربة فى نظام البلوكات العشوائية التامة بعدد أربعة مكررات لكل معاملة وأوضحت النتائج فى كل من الموسمين أن:- الاحتياجات المائية الفعلية تحت نظام عدم التغطية أعطت أعلى قيمة يليها الاغطية باستخدام قش الارز ثم اقل الاحتياجات المائية كانت تحت نظام التغطية بالبلاستيك وقد أدت التغطية بالبلاستيك الى خفض قيم الأستهلاك المائى لنباتات الذرة بمقدار ٦,٠٪ بينما أدت معاملة التغطية باستخدام قش الارز الى خفض قيم الأستهلاك المائى بمقدار ٣,٠ ٪ بالمقارنة بنظام عدم التغطية.

وجد أن غلة محصول الذرة كانت اعلى تحت نظام التغطية و ذلك بالمقارنة بالمعاملات غير المغطاة وقد تفوقت معاملة التغطية البلاستيكية على معاملة التغطية باستخدام قش الارز حيث أدت الى زيادة محصول الذرة الشامية بمقدار ١٧,٠٪ بينما أدت معاملة التغطية باستخدام قش الارز الى زيادة المحصول بمقدار ١٠,٦ ٪ بالمقارنة بنظام عدم التغطية.

وجد أن معامل المحصول يقل تحت نظام التغطية و ذلك بالمقارنة بعدم التغطية ولم يكن هناك فرق معنوى بين قيم معامل المحصول المحسوبة بأستخدام معادلة بينمان مونتيث وقيم الـFAO.

وجد أيضا من نتائج التجربة أن معادلة بينمان مونتيث المدروسة فى حساب البخر نتح أعطت نتائج أقرب للواقع من معادلة بينمان المعدلة تحت ظروف التغطية وعدم التغطية للمنطقة المدروسة.

وجد كذلك أن أعلى كفاءة في استخدام المياه كان تحت نظام الاغطية البلاستيكية يليها الاغطية باستخدام قش الارز ثم بدون غطاء وهذا يعنى أن نظام التغطية سواء بالبلاستيك او قش الارز يؤدى الى زيادة كبيرة في إنتاجية وحدة المساحة من الأرض مقارنة بعدم التغطية. وتؤكد الدراسة أن أستعمال نظام تغطية التربة ذو تأثير مفيد على أرتفاع محصول الذرة الشامية.