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Effect of Hydrophobic Polymer Application and Irrigation Rates on Yield of Field Grown Okra

P. Cookson[1*], H. AbdelRahman[1], and P. Hirsbrunner[2]

[1]*Department of Soil and Water Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University,*
P.O. Box 34, Al-Khod 123, Muscat, Sultanate of Oman
[2]*Nestec Research Institute, Chers-le-Blanche, Vevey, Switzerland*

أثر استخدام المركبات الطاردة للمياه ومعدلات الري على إنتاجية البامية

بيتر كوكسن وحيدر عبدالرحمن وبيير هيرسبورنر

خلاصة: لتحسين كفاءة الري أهمية كبيرة في ترشيد استهلاك المئياه في المناطق الجافة. في هذه التجربة تمت دراسة أثر مركب طارد للمياه (جلدسبار) في تحسين كفاءة استخدام المياه وإنتاجية محصول البامية. تمت معالجة التربة برش سطحها بالمادة الطاردة وتركها لكي تجف، ومن ثم تم تقييم إنتاجية البامية التي زرعت في أبريل وحصدت في أكتوبر ورويت بمعدلين للمياه مقارنة مع الأحواض غير المعالجة. زادت إنتاجية المحصول وكفاءة استخدامها للمياه باستخدام المركب كما أمكن جني كميات لكبير من المحصول مبكراً. كما تم الحصول على نفس الإنتاجية باستخدام المعدلات الأقل للمياه في الأحواض المعالجة مقارنة مع المعدلات العليا في الأحواض غير المعالجة بتوفير كميات من المياه بلغت ٢٥ و ٥٠% خلال فصلي الصيف والشتاء على التوالي.

ABSTRACT: Improving irrigation efficiency is of great importance in conserving water resources of arid countries. The effect of a hydrophobic polymer (called Guilspare[#]) to improve yields and water use efficiencies of okra *(Adelmoschus esculentus)* plants was investigated using a 3x3 Latin Square field experiment. Soils were treated with Guilspare by spraying the surface with an aqueous solution and left to dry. Yields of okra, planted in April and October, were assessed from plots receiving two rates of Guilspare application against an untreated control. Each column within the design received irrigation water at separate rates. Yields and water use efficiencies were generally higher, and a higher proportion of the total yield was harvested earlier, from Guilspare treated than untreated plots. Comparisons of yields from treated plots receiving lowest irrigation rates and untreated plots receiving the highest irrigation rate, suggested that similar yields can be obtained by using the polymer with, approximately, 25% and 50% less water in summer and in winter, respectively.

Keywords: dripline irrigation, water use efficiency, water saving potential.

Okra is a warm season crop that can command relatively high prices when supplied fresh to markets during summer months. However, strategies to improve the efficiency of irrigation water use by plants, such as okra, are required in farming systems where irrigation water is scarce (Callaghan *et al.*, 1988; Hoffman and Martin, 1993). Crops need to consume water for transpiration, but the process is accompanied by evaporative losses, especially from wet and unshaded soil surfaces. The efficiency of transpiration in relation

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[*] Corresponding author.

[#] Samples were supplied by Guilford Development, Geneva, Switzerland. Use of trade names or commercial products does not constitute endorsement by Sultan Qaboos University.

to irrigation water application has been defined by Howell (1990) as an increase in marketable yield or per unit of irrigation applied. Many field experiments have been conducted to establish empirical relationships between the yield of a range of crops and irrigation water applied (Shalhevet *et al.,* 1979; Howell, 1990; Hundertmark and Al-Maamari, 1995), especially when deficiencies in soil water are alleviated (FAO, 1986). It should be noted, however, that an increase in the ratio of yield to irrigation applied might not necessarily imply an improvement in the economic efficiency of irrigation water use.

Increasing the efficiency of irrigation water use by crops is an important goal for crop and irrigation scientists (Hillel, 1990). This can be achieved through stimulating yield through plant breeding (Richards *et al.*, 1993), altering the partitioning of carbohydrate to fruit bearing parts (Takami *et al.*, 1990), improving nutrient uptake (Martinez Hernandez *et al.*, 1991), and reducing soil salinity (Letey, 1993) by effective irrigation techniques. In addition, investigators have attempted to reduce evaporation by shading the soil surface (Streak *et al.*, 1995), covering soil surfaces with plastic sheeting (Peters and Russell, 1959; Brady, 1990) and organic mulches (Kemper *et al.*, 1994; Jalota and Prihar, 1998), and adding water absorbing gels (Al-Omran *et al.*, 1987; Al-Omran *et al.*, 1991). Plastic sheeting can be costly, however, in terms of initial purchase, and labor and machinery to apply, and causes disposal problems in landfills (Kemble *et al.*, 1995). The lack of availability of organic materials to produce effective mulches often limits their usefulness in semi-arid and arid countries.

An alternative method of reducing evaporation is to produce a hydrophobic barrier in the surface layer of soil (Hillel 1980a and b; Sojka and Lentz, 1994). Soils can development a degree of hydrophobicity under natural conditions (Wallis *et al.*, 1990; Wallis and Horne, 1992), but the effect is localized to areas where waxy plant residues are incorporated into the soil. The present paper is an evaluation of a hydrophobic soil treatment, using a recently synthesized polymer, in a field experiment growing okra plants subject to different irrigation application rates. Preliminary laboratory studies (personal communication, P. Hirsbrunner) indicate that a solution of the potassium salt of methylsiliconate (called 'Guilspare') polymerizes in soil to form a permanently dry, thin soil layer that can act as a barrier to evaporation (Weyenberg, 1988). The effects of a reduction in evaporation, through applications of Guilspare, on crop yield are difficult to predict, however, since the amounts of water lost through evaporation and transpiration vary, depending on soil water content, and the evaporative demand of the atmosphere.

The objective of the trials in the present study were to determine the effects of treating soil with Guilspare on yield and water use efficiencies of field grown okra plants supplied with different rates of irrigation, during spring and autumn growing seasons in Oman. Water use efficiencies of plants were estimated from the ratio of yield to water applied. Differences between the amounts of water supplied to plants in Guilspare treated soil and those in natural soil, while achieving similar yields, were used as estimates of the water saving potential of Guilspare application.

Materials and Methods

EXPERIMENTAL SITE AND LAYOUT OF PLOTS: A nearly level 33 by 16 m area, at the Agricultural Experiment Station of Sultan Qaboos University was used for this study. The soil (classified as coarse-loamy over sandy, mixed, hyperthermic, Typic Torriarents) has a loam layer, approximately 50 cm deep, overlying coarse sandy material. The texture of the top 25 cm layer, as determined by a hydrometer method, was loam (12% clay, 46% silt, and 42% sand). The pH ranged from 8.2 to 8.6, and the area was naturally low in organic matter, but had received regular, annual applications of animal manure and compound fertilizer. Soil salinity was highly variable, varying from low (less than 4 dSm^{-1} in saturated paste extracts) to moderately high (i.e. 20 dSm^{-1}). Due to low rainfall, all crop production at the site depends entirely on irrigation. Irrigation water quality, supplied from on-farm wells diluted by potable water, was non-saline and non-sodic.

The experimental area was chisel ploughed, rotovated, and hand raked to remove stones prior to Guilspare application and planting. The same area was used for the successive crops of okra.

The experiment consisted of three Guilspare treatments assigned at random to nine plots, arranged as 3 rows and 3 columns of a Latin Square. Each column, consisting of four 34 m lengths of 13 mm diameter pressure regulated driplines arranged one meter apart, and was divided into three 10 m long plots, surrounded by 1 m wide walkways. Columns were separated from each other by 2 m wide walkways. Water emitters along the driplines were 50 cm apart. Irrigation for each column was independently controlled and metered through an inlet valve.

GUILSPARE APPPLICATION: Solutions of Guilspare were prepared by dilution with tap water to the following concentrations: 0, 7.5, and 15 mL L^{-1}. Diluted solutions were applied to separate treatments at the uniform rate of 4 L m^{-2}. Solutions were evenly applied to dry soil surfaces using a handheld plastic four-meter long spray-bar, attached to a tractor mounted agro-chemical spray pump. The volume of Guilspare solution applied was adjusted by accurately timing the speed at which the spray-bar passed over a unit area of soil. The process of application was found to be rather time consuming and, consequently, the use high capacity (more than 10,000 L) water tanks is recommended. After application, Guilspare solutions were allowed to dry for six days prior to planting.

METEOROLOGICAL DATA: Maximum, minimum air temperature and relative humidity and solar radiation data were recorded by an automatic weather station on site. Reference potential evapotranspiration (ETo) rates (Penman Method) were calculated using a Soil Conservation Service, version 3.1, software package.

CULTIVATION AND IRRIGATION RATES: Three-week-old seedlings of a heat tolerant okra variety (Pusa Sawani) supplied by Pocha Seeds PVT. Ltd. of Pune, India, raised in a plastic shade house were transplanted on 12 April (spring planting), into pre-irrigated plots at an average density of two plants per emitter. Rice *et al.*, (1987) recommended seeding okra in rows 50-70 cm apart with 30-40 cm between plants, whereas, in the present experiment they were transplanted into rows 100 cm apart with the equivalent of 25 cm between plants. Harvesting (by hand) commenced on 16 May and was complete by 22 July.

After the last harvest, plants were allowed to dry in the field, and stubble and roots removed by hand. The site was, replanted after pre-irrigation, on 6 October (autumn planting), with three-week-old seedlings of okra variety, Clemson Spineless, supplied by Royal Sluis of Holland. The planting density was the same as in spring. Harvesting commenced on 21 November and was completed by 3 January. Since okra is priced, in Oman, on the basis of fresh weight, all harvest data were calculated in terms of Tonnes (green pod) per ha. After the final harvest of each growing season, the heights of 20 plants per plot were measured, using a meter ruler.

No fertilizer was applied to the spring planted crop, but three weeks prior to the autumn planting 50 kg ha^{-1} of 20-10-10 fertilizer was injected through the irrigation system to all plots. At regular intervals during the autumn growth period, plants were sprayed with insecticide to suppress white fly infection. White flies did not appear on spring planted okra.

Spring and autumn planted seedlings received three rates of irrigation application. Individual irrigation rates are referred to as a percentage of ETo experienced during the period of growth. Irrigation commenced daily, at approximately 8 a.m. The amounts applied were adjusted so the same column received water in a fixed proportion to the amount received by the highest rate of application.

STATISTICAL ANALYSIS: Analysis of Variance (ANOVA) for a Latin Square design was used to detect significance differences in cumulative yields between Guilspare treatments and irrigation rates for cumulative yield data and from individual harvests, from each planting season. Mean separation was achieved using Duncan' s Multiple Range Test (DMRT) at the 5% and 10% levels of probability. ANOVA was performed on okra height data using the two-way option in Michigan State University (M-STAT) statistical software package, treating 20 heights from each plot as replicates from 9 treatments.

Results and Discussion

METEOROLOGICAL DATA, ETO ESTIMATES AND IRRIGATION RATES: During the spring growth period, highest mean maximum and lowest mean minimum air temperatures were 46.5 and 24.2 °C, respectively. Relative humidity varied from 9.4 to 98.7%, and wind speed from 1.19 to 4.51 m s^{-1}. Cumulative reference evapotranspiration ETo was 827.8 mm for the growth period. The amounts of water applied to each irrigation treatment were 1002, 852, and 721 mm, i.e. in ratios of 1.21, 1.03 and 0.87 to cumulative ETo, respectively.

During the autumn growth period, highest mean maximum and lowest mean minimum air temperatures were 38.0 and 14.6 °C, respectively. Relative humidity varied from 7.6 to 99.3%, and wind speed from 0.85 to 2.28 m s^{-1}. Cumulative reference evapotranspiration (ETo) for the growth period was 390.04 mm. The amounts of water applied to each irrigation treatment were 397.8, 258.6, and 190.9 mm, i.e. in ratios of 1.02, 0.66, and 0.49 to cumulative Eto, respectively.

In spring, average daily irrigation rate received by the 1.21 ETo treatment was, for the whole growth period, 10.3 mm d^{-1} (Table 1). However, until 39 days after transplanting the rate was 15.02 mm d^{-1}. Thereafter, water application was reduced to a rate of 7.02 mm d^{-1}. The relative amounts of water applied to other treatments were similarly, initially higher and then lower in approximately the same proportion. The reason for the higher rate of application was to avoid the possibility of premature seedling mortality due to heat stress.

TABLE 1

Total and daily rates irrigation water applied.

A. Spring growth period

Days from Transplanting	Irrigation Water Applied (mm)		
	0.87 ETo	1.03 ETo	1.21 ETo
1 to 39	426.4 (10.93)	522.8 (13.41)	586.0 (15.02)
40 to 99	296.7 (5.03)	327.4 (5.55)	413.9 (7.02)
Total	723.2 (7.31)	850.3 (8.59)	1000.3 (10.10)

Average daily application rates are given in parentheses.

B. Autumn growth period

Days from Transplanting	Irrigation Water Applied (mm)		
	0.49 ETo	0.66 ETo	1.02 ETo
Total	193.2 (2.17)	249.9 (2.81)	397.8 (4.47)

Daily application rates are given in parentheses.

During the autumn growth period, the rate of water application was more constant than in spring, and the 1.02 ETo application treatment received on average 4.47 mm d^{-1}.

Peirce (1987) reported that okra is a predominantly tropical crop and should be preferably grown in the temperature range of 18 to 35°C. Yields are reported (Splittstoesser, 1990) to respond to irrigation applications of between 3.6 and 5.4 mm d^{-1} during dry weather.

In the present study, plants usually wilted each afternoon from May onwards. As a result plants, especially those receiving the lowest irrigation rate shed older leaves prematurely. Leaf shed was most marked from plants in treatment combination of highest Guilspare application and lowest irrigation rate. These plants tended to be larger than plants growing in corresponding control plots and, hence, appeared to suffer more from wilting. Plants growing with higher irrigation rates did not begin to shed leaves until after the seventh harvest. During the autumn growth period little or no leaf shedding was observed.

The differences in the degree of shading of soil surfaces experienced by experimental plots during the growth seasons were not determined. However, by following the common cultivation practice in Oman of separating driplines by 1 m and planting at 50 cm spacing the result was for plant canopies to be relatively open and similar between treatments.

INFLUENCE OF GUILSPARE APPLICATION AND IRRIGATION RATES ON OKRA YIELDS

Spring Growth Period: ANOVA (Table 2) revealed that yield differences between Guilspare treatments and irrigation rates were not significant at the 5% level of probability. However, the increase in cumulative yields in Guilspare treatment at the higher application concentration, averaged over all irrigation rates, relative to controls was high i.e. 40.3% (Table 3). The highest cumulative yield, i.e. 4.09 T ha^{-1}, was obtained using the higher concentration of Guilspare and irrigated at the rate of 1.21 ETo. In comparison, okra yields (green pods) from tropical countries have been reported to vary between 2 and 3 T ha^{-1} (Tindall, 1992), but in California yields of up to 25.7 T ha^{-1} were achieved in 1994, (Aguiar and Mayberry, 1998).

TABLE 2

Analysis of variance for total okra yields.

A. Spring planting

Source of Variation	DF	Sum of Squares	Mean Squares	*F* Value	Significance
Between GT	2	2.5654222	1.2827111	3.739	NS
Between IR	2	0.1708222	0.0854111	<1	NS
Between Rows	2	0.2544888	0.127444	<1	NS
Error	2	0.6859557	0.3429778		
Total	8	3.6766889			

B. Autumn planting

Source of Variation	DF	Sum of Squares	Mean Squares	*F* Value	Significance
Between GT	2	8.3622600	4.1811300	44.17	0
Between IR	2	2.6053627	1.3026814	13.76	NS
Between Rows	2	0.7232187	0.3616094	3.820	NS
Error	2	0.1893146	0.0946273		
Total	8	11.880156			

Note: IR refers to Irrigation Rate and GT to Guilspare Treatment.
*NS - refers to levels of probability of 5% and not significant, respectively.

ANOVA of data from individual harvests (Figure 1) revealed that yields from Guilspare treatments, were significantly higher at the third and fourth harvests, than from controls ($F_{2,\ 2}$ = 28.3 and 25.6, respectively). Yields for the third harvest from the higher Guilspare concentration treatment, averaged over all irrigation rates, were almost double those from controls (i.e. 0.79 compared to 0.39 T ha^{-1}, respectively). Cumulative yield from harvest numbers 1 to 3, when averaged over all irrigation rates, from the higher Guilspare concentration treatment was 1.36 T ha^{-1} as compared with 0.58 T ha^{-1} from controls. These yield increases are within the range, as reported by Kemble *et al.* (1995), of 'two to three times' higher yield from okra plants grown under black plastic than on bare ground.

The causes of the low degree of statistical significance found for relatively large differences in yields between Guilspare treatments and controls were due, in part, to a high degree of error arising from the design of the experiment. Yields of okra plants appeared to be affected by both the relatively high irrigation rates applied early in the season, and the layout of the

TABLE 3

Effect of Guilspare treatment and irrigation water applied on cumulative okra yields (in T ha^{-1}).

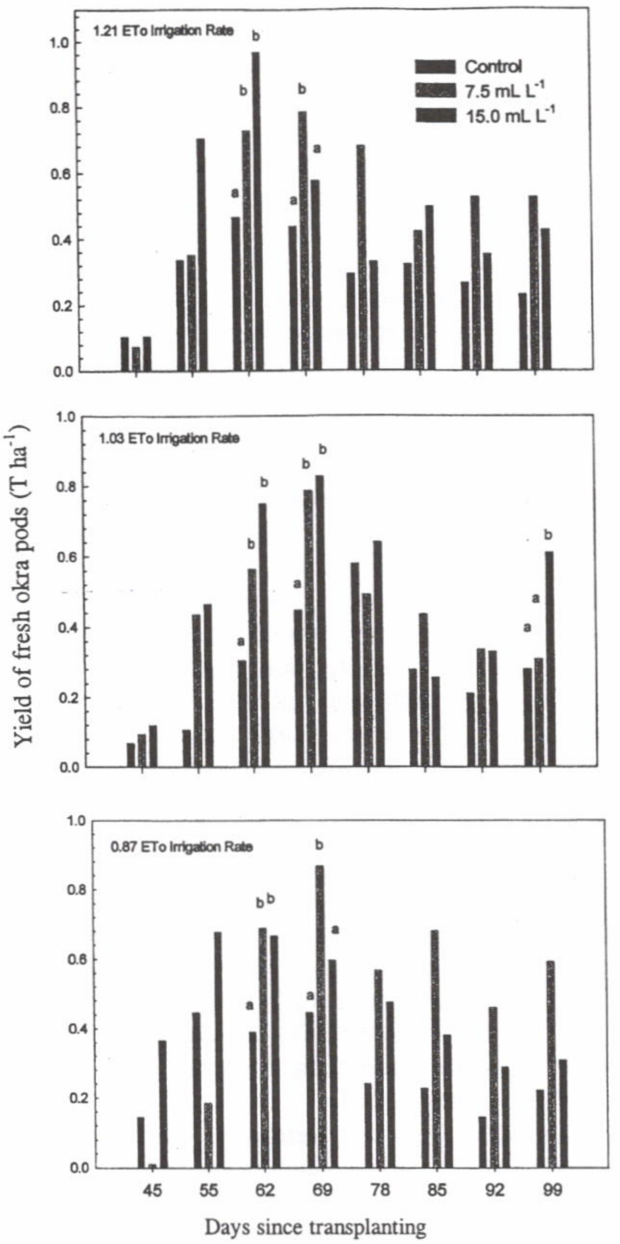
A. Spring planting

Guilspare Treatment	Irrigation Water Application		
	0.87 ETo	1.03 ETo	1.21 Eto
Control	2.26	2.27	2.45
G1	4.06	3.45	4.09
G2	3.76	3.99	3.95
Mean	3.36	3.24	3.50

B. Autumn planting

Guilspare Treatment	Irrigation Water Application		
	0.49 ETo	0.66 ETo	1.02 ETo
Control	2.90a	2.74b	3.14b
G1	3.35a	3.65ab	5.04a
G2	4.35a	5.26a	6.25a
Mean	3.54A	3.88AB	4.81AB

Figures in each row followed by the same lower case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 0.308. Figures followed by the same upper case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 0.178.



Columns with similar letters are not significantly different at the 5% level of probability.

Figure 1. Effects of Guilspare application and rate of irrigation on yields of fresh okra, at individual harvests, during the spring growth period.

TABLE 4

Effect of Guilspare treatment and irrigation water applied on water use efficiency (in kg $ha^{-1}mm^{-1}$).

A. Spring planting

Guilspare Treatment	Irrigation Water Application		
	0.87 ETo	1.03 ETo	1.21 ETo
Control	3.13b	2.67b	2.45a
G1	5.61a	4.06ab	4.09a
G2	5.20a	4.69a	3.95aA
Mean	4.65A	3.81AB	3.50B

Figures in each row followed by the same lower case letter are not significantly different at the 10% level of probability, according to DMRT, with SEM of 0.465. Figures followed by the same upper case letter are not significantly different at the 10% level of probability, according to DMRT, with SEM of 0.269.

B. Autumn planting

Guilspare Treatment	Irrigation Water Application		
	0.49 ETo	0.66 ETo	1.02 ETo
Control	15.01b	10.96b	7.89b
G1	17.39ab	14.61ab	12.66ab
G2	22.52a	21.05a	15.71a
Mean	18.31A	15.54AB	12.09B

Figures in each row followed by the same lower case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 1.090. Figures followed by the same upper case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 0.629.

irrigation system used. Firstly, water application rates were substantially higher during the first 39 days of the experiment before being reduced, on average, by 53%. Since flowering commenced 36 days after transplanting and the first harvest was taken after 45 days, then plants, growing with even the lower irrigation rate, had probably not experienced excessive water stress prior to initial flowering. Secondly, as a result of the layout of the irrigation driplines each irrigation event for Guilspare treatments and controls occurred simultaneously. However, since plants under Guilspare treatments tended to be larger than control plants, then after the second harvest, these plants appeared to suffer higher relative degrees of heat and water stress than control plants. The experimental design appeared to allow heat and water stresses to be confounded. For example, larger leaves developing on plants in Guilspare treated plots appeared to wilt sooner than those of control plants, and shed prematurely which probably reduced yields at later harvests.

Plants from Guilspare treated plots produced relatively higher proportions of fruit earlier in the season than control plants. Averaged over all irrigation rates, yields for harvest numbers 1 to 3 amounted to 41.1% of total cumulative yield from the higher Guilspare concentration treatment, whereas yields from controls were only 33.1% of total yield in the same period.

Water use efficiencies by plants growing under the higher Guilspare concentration treatment were significantly higher than controls, except when the highest rate of irrigation was applied (Table 4). Averaged over all irrigation rates, water use efficiencies for Guilspare treatments were 4.60 compared to 2.75 kg ha^{-1} mm^{-1} for controls. Average water use efficiencies increased significantly, from 3.50 to 4.65 kg ha^{-1} mm^{-1}, as the rate of irrigation was decreased from 1.21 to 0.87 ETo, respectively. Highest water use efficiencies recorded, from Guilspare treatments with the lowest rate of irrigation (i.e. 0.87 ETo), were more than double those found from controls with the highest rate

TABLE 5

Effect of planting date, irrigation water application, and Guilspare treatment on okra plant heights (cm).

A. Spring planting

Guilspare Treatment	Irrigation Water Application		
	0.87 ETo	1.03 ETo	1.21 ETo
Control	54.4d	58.7cd	57.1cd
G1	54.3d	63.2bc	73.0a
G2	61.0bc	67.1ab	61.2bc
Mean	56.5A	63.0B	63.7B

Figures in each row followed by the same lower case letter are not significantly different at the 10% level of probability, according to DMRT, with SEM of 2.249. Figures followed by the same upper case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 1.587.

B. Autumn planting

Guilspare Treatment	Irrigation Water Application		
	0.49 ETo	0.66 ETo	1.02 ETo
Control	22.5a	42.3a	48.6a
G1	34.5b	48.6ab	53.4ab
G2	36.1b	52.3b	58.6b
Mean	31.0A	47.7B	53.5C

Figures in each row followed by the same lower case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 2.357. Figures followed by the same upper case letter are not significantly different at the 5% level of probability, according to DMRT, with SEM of 1.361.

of irrigation (i.e. 1.21 ETo). It should be noted that the increases in water use efficiencies, as defined above by the ratio yield to water applied, following Guilspare application do not necessarily reflect an improvement in the economics of water use.

Heights of okra plant heights after final harvest are given in Table 5. Average plants heights increased significantly as the rate of irrigation was increased from 0.87 to 1.03 ETo. Guilspare treatment at the higher rate of application resulted in significantly taller plants than controls, with the lower rates of irrigation. At the highest rate of irrigation, Guilspare application did not appear to significantly increase plant height as compared to controls. Since okra flowers are borne singly in leaf axils, then as the stem elongates more flowers are produced and increased pod development occurs. Hence, the height of an okra plant is related to its cumulative yield. In addition, the number of pods an okra plant produces, often increases the more frequently mature pods are harvested. To obtain highest quality produce, farmers harvest pods every 4 to 5 days. In the current experiment, plants from all plots were harvested on the same day, irrespective of pod quality.

Autumn growth period: The amount of water applied by irrigation treatments, both in absolute and relative terms, were lower during the autumn than the spring growth period, since ETo rates were, as expected, also lower, in line with reduced air temperatures.

Cumulative yields from plots receiving the higher Guilspare concentration treatment were significantly higher than controls, at the 0.66 and 1.02 ETo rates of irrigation (Table 3). The highest cumulative yield was obtained from the higher Guilspare concentration treatments with the higher irrigation rate of 1.02 ETo, i.e. 6.25 T ha^{-1}, and was almost double the yield from the corresponding control plot. With the lowest irrigation rate (i.e. 0.49 ETo) the ratio of yield from the higher Guilspare concentration treatment to control was reduced to 1.50. This suggests that increased yields by Guilspare application may be best achieved by plants in a hot and arid climate, with relatively high irrigation rates, rather than attempting to reduce irrigation, provided sufficient water is available.

ANOVA of yield data for individual harvests (Figure 2), revealed that okra yields at the third harvest were significantly higher, at the 5% level of probability, than at other harvests. In addition, yields from the higher Guilspare concentration treatment were significantly greater, at the 5% level of probability ($F_{2,2} = 44.2$), than from controls, for all irrigation rates. However, yields from the lower Guilspare concentration treatment were significantly higher than controls, only for the irrigation rate of 1.21 ETo. The high yields at the third harvest were probably due to the relatively lengthy growth period of 29 days prior to harvest.

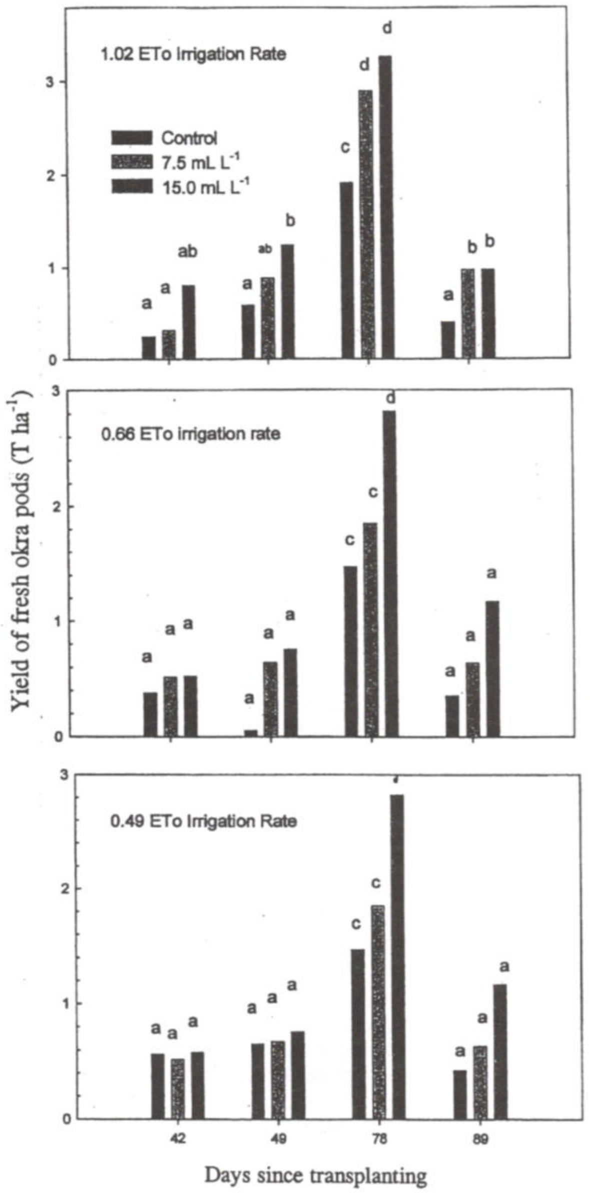
As shown in table 4, water use efficiencies were higher, on average, by plants growing under the higher Guilspare application than controls, (i.e. 19.7 and 11.3 kg ha^{-1} mm^{-1}, respectively). The highest water use efficiency recorded, 22.5 kg ha^{-1} mm^{-1}, was associated with the lower (i.e. 0.49 ETo) rate of irrigation and the higher Guilspare concentration treatment.

Okra plants growing with the higher rate of application of Guilspare were significantly taller than control plants during the autumn growth period at each level of irrigation (Table 5). Reducing the rate of irrigation tended to reduce, on average, the height of okra plants.

It is interesting to note the large differences, averaged over all irrigation rates, found in crop water efficiencies by control plants between spring and autumn (i.e. 2.8 and 11.3 kg ha^{-1} mm^{-1}, respectively). These results would suggest that late planting dates in spring should be avoided if irrigation water consumption is to be minimized.

The difference between the lowest water use efficiency recorded in spring of 2.45 kg ha^{-1} mm^{-1}, and the highest recorded in autumn of 22.5 kg ha^{-1} mm^{-1}, suggests that combining Guilspare application with an appropriate planting date time, can increase water use efficiency of okra by a factor of 9.18.

The potential to save irrigation water by applying Guilspare appears to be dependent on the date of planting. For spring planting, statistically similar yields were obtained with 730 mm of irrigation water



Columns with similar letters are not significantly different at the 5% level of probability.

Figure 2. Effects of Guilspare application and rate of irrigation on yields of fresh okra, at individual harvests, during the autumn growth period.

in the presence of Guilspare, at either concentration of application, as compared to untreated soils with 1000.3 mm, suggesting that the water saving potential of Guilspare application was 27%. For autumn planting, yields were statistically similar from plots treated with Guilspare at 7.5 mL L^{-1} with 193.2 mm of irrigation as compared to untreated soils with 397.8 mm, suggesting a water saving potential of 51.4%.

Several serious concerns need to be addressed regarding application cost and environmental acceptability of Guilspare before the widespread use can be recommended. According to the manufacturers, Guilspare costs about 3 US dollars per liter to produce, i.e. sufficient to treat an area of 33.3 m^2 when applied at the rate of 4 L m^{-2} after dilution to 7.5 mL L^{-1}. The autumn okra yield improvement relative to untreated soil of 1.9 T ha^{-1} (equivalent to 6.32 kg per 33.3 m^2) may be unlikely to recover the costs of application, if sold locally at the market price of about 1 dollar per kg. In the present study, however, successive vegetable crops were taken from soils treated with a single application of Guilspare thus prolonging the period of production between applications. An alternative strategy to reduce cost may be to apply Guilspare around irrigated perennial fruit trees or date palms thus extending the period between applications to between 8 and 10 years. A full economic study of introducing Guilspare application into farming systems for a range of crops is needed.

Some of the environmental concerns regarding Guilspare application are, increased risk of erosion due to reduced infiltration rates through the treated soil layer, a reduction in volume of the rooting zone and the potential for salt accumulation in soil due to reduced irrigation. Naturally occurring soil hydrophobicity can induce erosion through increased run off as a result of lower infiltration rates, and reduce the volume of soil available for roots to explore. These problems may be less severe in Guilspare treated soils where hydrophobicity is generated in a limited volume of surface soil and if applied, as in the present study, to level sites. The adverse effects of reduced infiltration rate may possibly be avoided by, either employing subsurface dripline irrigation, or adding wetting agents to irrigation water. The potential risks of increased salinization in soil due to reducing irrigation rates in arid areas need to be assessed, especially in relation to the general soil water conditions in cultivated land.

The full reasons for the observed yield improvements under Guilspare treated soils relative to controls plots are not fully understood. By reducing evaporative water losses from soil below the treated surface layer, Guilspare application probably allowed more soil water to be available for crop uptake. However, a general improvement in soil water conditions could also have resulted in lower soil salinities in the rooting zone, more efficient water uptake per length of root, avoidance by plants of heat stress, and a more uniform soil water content between driplines. Guilspare applications, from visual observation alone, also appeared effective in reducing the incidence of weed infestation in irrigated but unplanted companion plots. Guilspare application at the higher concentration, appeared to almost entirely prevent germination of weed seedlings in the spring growth period following application. This effect may be commercially important since, at present, few herbicides are registered for weed control in okra fields (Kemble, *et al.*, 1995). Applications of trifluralin preplant, or diphenamid pre-emergence are usually recommended (Peirce, 1987) and more recently bromoxynil (Prostko, *et al.*, 1998). Hillel (1980b) also observed suppression of weed germination when using siliconate polymers as a hydrophobic soil treatment. He suggested that germination was inhibited because of the permanently dry surface layers generated in the soil by the hydrophobic polymer. Further studies into the effect of Guilspare application on weed growth are needed.

Conclusions

In the field trials reported, Guilspare applications with a concentration of 15 mL L^{-1} and rate of 4 L m^{-2} significantly increased autumn grown okra yields, averaged over the irrigation rates used, by 44.6% compared to controls, and by a statistically non-significant increase of 40.2% in spring. It was also shown that the amount of irrigation water needed by okra plants growing under Guilspare could be reduced by as much as 25% in spring and 50% in autumn, while still giving comparable yields to plants growing without Guilspare. The application of Guilspare significantly increased the water use efficiency of plants during both growing periods. Further investigation of the effect of Guilspare applications, as regards economic viability and environmental acceptability, are required before any recommendation to use Guilspare can be offered. However, Guilspare did not cause any visible harm to the plants, which grew and fruited normally, if not earlier, than plants on untreated plots.

The hydrophobic effect of a single application of Guilspare persisted for two growing periods (i.e. from April to the following January). However, the long-term consequences of the movement and accumulation of soluble salts beneath the polymer layer needed to be assessed. In addition, the combined effects of climate, irrigation, root penetration, machinery and human activity, which may affect the stability of the layer, require further investigation.

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