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Optimization of Modern Irrigation for Biosaline Agriculture

تحسين نظم الري الحديثة للزراعة الملحية

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ABSTRACT: Supplemental irrigation water is a must to offset the water requirement to produce profitable crops in most arid and semiarid zones, where fresh water resources are insufficient to meet the pressure of irrigated agriculture. This necessitates the use of poor quality water resources. These waters if not properly managed and used can cause serious soil related problems (salinity, sodicity, destruction of soil structure), in addition to decline in crop yields. Biosaline agriculture (using saline water on saline soils to grow salt-tolerant crops) becomes the only option for the farmer when both soil and water resources are saline and the water resource is scarce. In this regards key design considerations must be taken into account when irrigating with salty waters to optimize water uses and to reduce subsequent soil salinity development. Sprinkler irrigation systems are commonly used in irrigation of large-scale agricultural production systems. However, they tend to concentrate salts on the leaves of plants. For this reason discharge and degree of overlap between consecutive sprinkler heads, are key design parameters when applying salty waters. Trickle irrigation is the most efficient system and is gaining importance in the GCC countries in agriculture and landscape irrigation. The objective of this study was to optimize modern irrigation systems through development of design standards for drip (emitters spacing) and sprinkler irrigation systems (single head jet and overlapping) by applying saline water. The effect of emitter spacing (drip) and overlapping (sprinkler) were tested for the formation of salt contours in soil. The leaching ratio (LR) is the overall soil salinity within the rhizosphere divided by the average irrigation water salinity. In this study LR is used to evaluate the effectiveness of irrigation systems in developing soil salinity. From the present investigations it is concluded that when using saline water for irrigation, the soil salinity development can be significantly reduced by decreasing emitter spacing i.e. an ECe of 26, 90 and 126 dS/m was developed with 25, 50 and 75 cm emitter spacing respectively. Microsprinklers are more effective in terms of leaching capability as compared to impact sprinklers. Overlapping in sprinkler irrigation reduced the evaporation compared with single jet where no overlapping was made. This has a direct effect on soil salinity development. Wind has a significant effect on the water distribution (sprinkler experiment) and subsequent salinity development and can cause long-term salinity problems. Windbreak can offer solutions to this effect.

Keywords: *Optimization; biosaline agriculture; trickle; sprinkler; leaching ratio.*

المستخلص: عتبر مياه الري التكميلي ضرورية لمواجهة الاحتياجات المائية لإنتاج المحاصيل المربحه في معظم المناطق القاحله وشبه القاحلة بسبب عدم كفاية موارد المياه العذبة لتلبية ضغوط الزراعة المروية. ويتطلب ذلك في الكثير من الاحيان الاعتماد على موارد مياه ذات نوعية متدنية، وإذا لم يتم استخدامها وإدارتها بشكل سليم يمكن ان تتسبب في مشاكل خطيرة للتربة (الملوحة، الصودية، وتدمير بنية التربة)، بالإضافة إلى انخفاض إنتاجية المحاصيل. وفي هذه الحالة تصبح الزراعة الملحية (أي استخدام مياه مالحة في ترب مالحة لإنتاج محاصيل مقاومة للملوحة) الخيار الوحيد المتاح للمزارعين عندما

يكون كلا من التربة وموارد المياه مالحة والموارد المائية شحيحة. وتحت هذه الظروف الملحية هناك ضرورة للأخذ في الاعتبار تصميم معاملات أنظمة الري لتعظيم استخدام المياه ولتقليل مخاطر تراكم الاملاح في التربة. وتعتبر انظمة الري بالرش من الانظمة الاكثر استخداماً في ري أنظمة الإنتاج الزراعي كبيرة الحجم، إلا ان هذه الانظمة تميل إلى تركيز الاملاح على اوراق النباتات. ولهذا السبب، فإن كمية التصريف ودرجة التداخل بين رؤوس الرشاشات المتتالية تعتبر من الاعتبارات الهامة في التصميم عند استخدام المياه المالحة. ومن جهة اخرى تعتبر انظمة الري بالتنقيط من اكثر الانظمة كفاءة وتلقى اهتماما متزايدا في دول مجلس التعاون الخليجي سواء في الزراعة الإنتاجية او التجميلية. وهدفت هذه الدراسة إلى الحصول على التصميم الامثل لنظم الري الحديثة هذه عند استخدام المياه المالحة من خلال تطوير معايير تصميمية لنظام الري بالتنقيط (المسافات بين المنقطات) ونظام الري بالرش (قوة تدفق المرشة ودرجة التداخل بين الرشاشات). وتم اختبار تاثير المسافة بين المنقطات (في حالة الري بالتنقيط) ودرجة التداخل بين الرشاشات (في حالة الري بالرش) من خلال ملاحظة التركيز الملحي الكنتوري المتكونة في التربة، وتم استخدام نسبة الغسيل (LR)، وهي معدل ملوحة التربة في منطقة الجذور مقسومة على متوسط ملوحة مياه الري المستخدمة، لتقييم فعالية نظام الري في تفاقم ملوحة التربة. ولقد خلصت الدراسة إلى انه عند استخدام المياه المالحة في الري بالتنقيط فانه يمكن الحد من تراكم الاملاح بدرجة كبيرة عن طريق تقليل المسافات بين المنقطات، حيث كانت درجة التوصيل الكهربائي (ECe)26، 90، و 126ديسيسيمنز/متر للمسافات بين المنقطات 25، 50، و 75 سم، على التوالي، كما تبين ان الرشاشات الصغيرة اكثر فعالية من حيث القدرة على الترشيح مقارنة بالرشاشات ذات التدفق العالي. ولقد دلت نتائج الدراسة على ان التداخل في الري بالرش عمل على تخفيض البخر مقارنة برشاش واحد بدون تداخل، ولهذا تاثير مباشر على تراكم الملوحة في التربة. وفي تجربة الرشاشات تبين ان الرياح لها تاثير كبير على توزيع المياه وبالتالي تراكم الاملاح، ويمكن ان يتسبب في مشاكل التملح على المدى البعيد. ويمكن استخدام مصدات للرياح كحل لهذه المشكلة.

كلمات مدخلية : *تحسين، الزراعة الملحية، التنقيط، الرش، نسبة الغسيل.*

INTRODUCTION

World wide concerted efforts are being made to improve irrigation water-use efficiencies to enhance crop production in irrigated agriculture, where supplemental irrigation water is a must to offset the water requirement of crops and to produce profitable crops in most arid and semiarid regions. The general shortage of the good quality water in most of the semi-arid and arid zone countries necessitates the use of saline water. However, the injudicious use of saline water is often associated with the development of soil salinity.

It is generally recognized that saline water affects soil properties and plant growth. The misuse of this saline water ultimately converts the good soils in to saline soils. Saline soils are significant as formations of ecosystem on the earth affected by high concentrations of soluble salts, and as means of crop production with little economic value due to salinity. Many plants either fail to grow in saline soils or their growth is retarded significantly. However, few plants grow well on saline soils; therefore, soil salinity often restricts options for cropping in a given area. Under extreme saline conditions (soil and water) the only choice is the adoption of biosaline agriculture, which is gaining importance in countries where soil and water resources are degraded.

The success of irrigated agriculture lies both with the quality (fresh, brackish, and saline) and quantity of irrigation water (irrigation budgeting). These waters if not properly managed and used can cause serious soil related problems (salinity, sodicity, destruction of soil structure) in addition to decline in crop yields. In this regards key design considerations must be taken into account when irrigating with salty waters. Sprinkler irrigation systems are commonly used in irrigation of large-scale agricultural production systems. However, they tend to concentrate salts on the leaves of plants. For this reason discharge and degree of overlap between consecutive sprinkler heads, are key design parameters when applying salty waters. Trickle irrigation is the most efficient system and is gaining importance in the Gulf Cooperation Council (GCC) countries in agriculture and landscape irrigation. The leaching ratio (LR) is the overall soil salinity within the rhizosphere divided by average irrigation water salinity. In this study LR is used to evaluate the effectiveness of irrigation systems in developing soil salinity. A sustainable production system is achieved when the LR approaches unity.

The objective of this study is to optimize modern irrigation systems through development of design standards for drip (emitters spacing) and sprinkler irrigation systems (single head jet and overlapping) applying saline water. The effect of emitter spacing (drip), overlapping (sprinkler) were tested for the formation of salt contours in soil. The results were used in models to validate and calibrate the salts distribution.

RESOURCE INFORMATION

The International Center for Biosaline Agriculture (ICBA) Dubai United Arab Emirates, occupies an area 100 ha, of which 37 ha area is allocated for experimental purposes. The soils of ICBA are generally level, loose sandy surface, very deep and calcareous. Due to the sandy nature, the soils have very high drainage capacity (well to somewhat excessively drained), and are moderate to rapidly permeable. The soils are developed from wind blown sandy calcareous material and are highly prone to wind erosion, the windbreakers at the ICBA station offset the wind effects to a certain extent. Organic matter is very low (<0.5%) and the Munsell Soil Color-dry (GretagMacbeth. 2000) is 10YR 6/4 pale brown, which is a composite reflection from the dominance of carbonates and sand, with insignificant contribution of organic matter to color composition.

There is one water source (flow rate 45 m^{3}/hr) at the ICBA station that is saline (Electric conductivity (EC) 30 dS/m) and the quality fluctuates slightly with aquifer recharge after heavy rain. Water composition is shown in Table 1. Fresh water (EC = 3 dS/m) is brought from Dubai-Al-Ain area at Habab, which flows from Dubai Municipality water line at a rate of 40 m^3 per hour. There are two water pumps, which extract water from these two sources. From these sources two water lines run parallel to each other and enter into mixing chambers where two waters are mixed in different ratios to achieve desired salinity levels before entering into experimental plots.

Soil Taxonomic Class of the Experimental Site

The experimental site was assessed for taxonomic class using the norms and standards of the United States Department of Agriculture "Soil Taxonomy" (Soil Survey Division Staff, 1993; USDA-NRCS, 1999 & 2003). The soil is classified as ***carbonatic, hyperthermic Typic Torripsamment***. Where carbonatic is the mineralogy class i.e., more than 40% $CaCO_3$ in fine earth fraction , hyperthermic is the soil temperature regime (the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperature is more than 6°C at a depth of 50 cm from the soil surface). Typic torripsamment indicates typical desert sandy soil at soil subgroup level of USDA Soil Taxonomy.

Table 1. Water quality at ICBA.

Parameter	Value
Water salinity	EC = 30 dS/m
Water Conductivity Class	C4 (very high salinity water)
Residual Sodium Carbonates	Nil
Sodium adsorption Ratio	31 $(mmoles/l)^{0.5}$
Water Sodicity Class	S4 (very high sodium water)
Water Class (Richards, 1954)	C4S4

Physical and Chemical Characteristics of Surface Soil

The methods used are from USDA-NRCS (1996), except where otherwise stated. Complete Particle Size Distribution Analysis (PSDA) was made by using the modified hydrometer method (Day, 1965; Shahid, 1992) supplemented with wet sieving (that allows quantification of sub fractions of sand) suitable for soils with low organic matter contents. The data (sand, silt, clay) presented is on less than 2 mm basis. Textural class is reported by plotting the sand (2-0.05 mm), silt (0.05 to 0.002 mm) and clay (<0.002 mm) values on the textural triangle (Soil Survey Division Staff, 1993). The saturation percentage (SP) is determined by the volume of water added to a known amount of soil to prepare saturated soil paste; the SP value is plotted into the model suggested by USDA (USDA-NRCS, 1995) to determine water retention at 15 bars (W15) and available water capacity (AWC) of soils. The pH was measured on a saturated soil paste (pHs) and the EC in the saturation extract collected from the saturated soil paste under vacuum. The calcium carbonates equivalents were determined by the Back Titration procedure, where a known amount of soil was reacted with a known amount of 1N HCl, and the unused acid was back titrated against 1N NaOH solution in the presence of phenolphthalein indicator to a pink color end point. The soil results are presented in Table 2, which clearly reveals that soil is fine sand in texture, saline, moderately alkaline and strongly calcareous.

Table 2. Physical and Chemical Characteristics of Soil (0-30 cm).

Physical Characteristics	
Gravels (2-5 mm)	<0.5%
Very coarse sand (2-1 mm)	3%
Coarse sand (1 – 0.5 mm)	3%
Medium sand (0.5 - 0.25 mm)	4%
Fine sand (0.25 – 0.1 mm)	51%
Very fine sand (0.1-0.05 mm)	37%
Coarse silt (0.05 – 0.02 mm)	0.5%
Fine silt (0.02 – 0.002 mm)	0.5%
Clay (<0.002 mm)	1.0%
Total Sand (2-0.05 mm)	98%
Total silt (0.05-0.002 mm)	1.0%
Total clay (<0.002 mm)	1.0%
Textural Class	Fine sand
Saturation Percentage	26%
Water retention at 15 bar (W15)	6.5%
Available Water Capacity (AWC)	4.13%
Chemical Characteristics	
Electrical conductivity of saturation extract (ECe)	12.3 dS/m
pHs	8.22-moderately alkaline
CaCO3 (equivalents)	53%

Water Quality

Irrigation water was analyzed for standard water quality parameters (water salinity, residual sodium carbonates-RSC, and sodium adsorption ratio-SAR). The importance of these parameters in relation to water quality for irrigated agriculture is discussed in detail by Shahid (2004). Water salinity refers to the total concentration of dissolved salts-salinity hazard. Sodicity-relative proportion of sodium cations to other cations particularly Ca and Mg i.e., SAR ($SAR = Na/[(Ca+Mg)/2]^{0.5}$) expressed as $(mmoles/l)^{0.5}$, where all concentrations are in meq/l. The high SAR deteriorates soil structure and reduces water penetration into and through soil. Similar to drought and salinity, excess proportion of sodium, in comparison to calcium and magnesium, reduce water availability to the crops. Residual Sodium Carbonates (RSC) – bicarbonate anion and carbonate anion concentration as related with calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations [$RSC = (CO3^{2-} + HCO3^{-}) - (Ca^{2+} + Mg^{2+})$] where all concentrations are in meq/l.

Water Salinity and Sodicity Class – C4S4

C4 water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and highly salt-tolerant crops should be selected. S4 class is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

EXPERIMENTAL SETUP

Two field experiments were conducted at the ICBA station; 1) effect of emitter spacing on the formation of salt contours; 2) sprinkler overlapping and distribution to maximize leaching.

Experiment 1

Three emitter spacings (25 cm, 50 cm and 50 cm) were tested in this experiment. Each drip line was 2 meters apart (Fig. 1) and triplicated. To avoid the effects of replications, each replication was 3 meter apart.

The initial soil salinity level was 12.3 dS/m. By mixing saline and fresh water a salinity level of 19 dS/m was achieved, and irrigation was applied through these driplines twice a day, 30 minutes in the morning and 30 minutes in the evening over a period of 90 consecutive days. Soil samples were collected at 0-20 cm depth for salinity measurement. The LR was used to determine salinity development with the effect of different emitter spacing. The LR was determined by this (ECe/ECw) relationship, where ECe is the electrical conductivity of the soil saturation extract and ECw the electrical conductivity of the irrigation water. The LR in relation to emitter spacing is presented in the form of salt contours around the emitters.

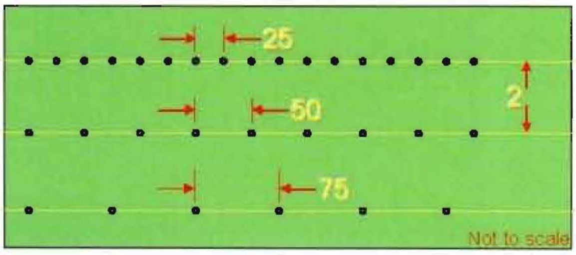

Fig. 1. Experimental set up and emitter spacing.

Experiment 2

In this experiment the performance of micro and impact sprinklers was tested by single jet and through overlapping. The objective was to maximize uniformity and to minimize evaporation. The water was collected in catch cans (placed at a distance of 0.5 m) and evaporation along the jet line was calculated based on salinity variations in the collected waters (Fig. 2).

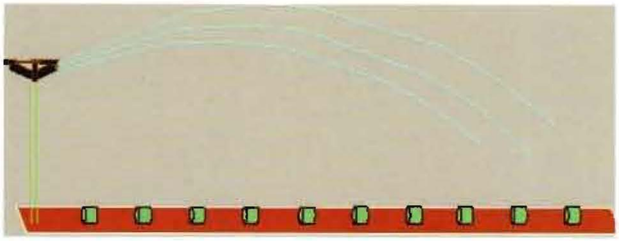

Fig. 2. Setup for measurement of water evaporation by correlation with collected water salinity.

The overlapping in micro and impact sprinkler was maintained at 90% during the course of the experiment. Soil salinity developed through sprinkler irrigation was evaluated by analyzing soil samples.

RESULTS

Effect of Emitter spacing on soil salinity development – trickle irrigation

In this experiment the performance of emitter spacing was tested in terms of LR of the soil. Soil salinity values obtained from the saturated soil pastes were used to prepare the salinity contour lines. The results are presented in Figures 3-5. These figures clearly show that the higher LR and salinity is recorded almost in the center of the emitters (Chhabra, 1986). In drip irrigation the salts accumulation occurs in two processes: in the first process, the soil becomes saturated and water and solutes spread in various directions saturating the neighboring voids and moving further (Fig. 5); in the second process which occurs between consecutive irrigation cycles, evaporation of water and uptake of water and nutrients by plants occur and the solutes are redistributed in the soil, the final buildup of salts in the soil results from the interaction of these two processes throughout the crop season.

Figures 4-6 clearly illustrate that the minimum LR/salinity is developed near the emitters and increases towards the center of two emitters. It is very evident from the Figures 4-6 that by

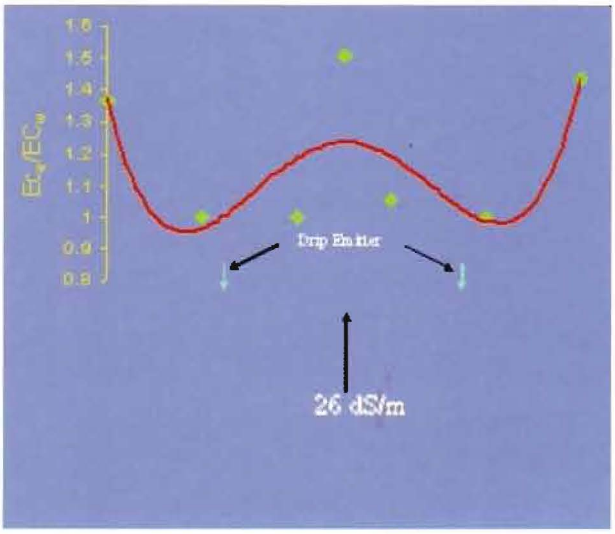

Fig. 3. Initial stage of soil saturation with drip irrigation.

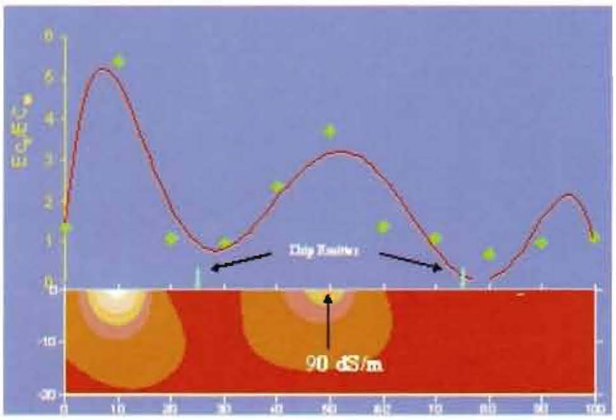

Fig. 4. Soil salinity contours (leaching ratio) with respect to 25 cm spacing.

decreasing the emitter spacing from 75 to 25 cm, the LR as well as soil salinity is reduced significantly. The soil salinity with 75 cm emitter spacing was recorded as 102 dS/m compared with 25 cm emitter spacing where a relatively lower ECe (29 dS/m) was recorded. There was only a slight difference in LR and ECe with 50 and 75 cm emitter spacing. The effects of emitters spacing on soil salinity contours (top view) can be seen at a glance in Fig. 7.

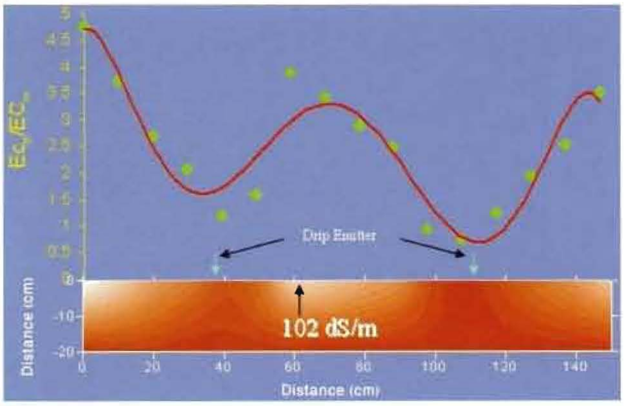

Fig. 5. Soil salinity contours (leaching ratio) at a drip spacing of 75 cm.

Fig. 6. Initial stage of soil saturation with drip irrigation.

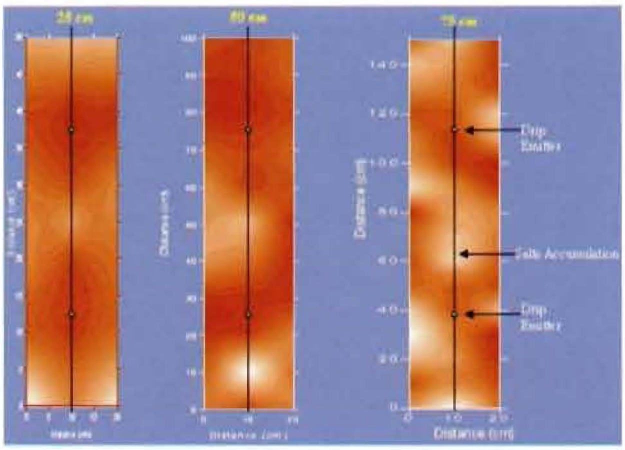

Fig. 7. Comparative salinity contours in three emitter spacing – top view.

Micro and impact sprinkler– single jet

In this experiment the performance of micro and impact sprinkler was evaluated in terms of water evaporation, which was calculated from the volume of water collected in catch cans and their salinity levels. The catch cans were placed in the experimental sites at a uniform distance of 0.5 m meter (Fig. 8 and 9). The results of water evaporation and water salinity development are presented in Figs (10-11).

Fig. 8. A view of experimental layout.

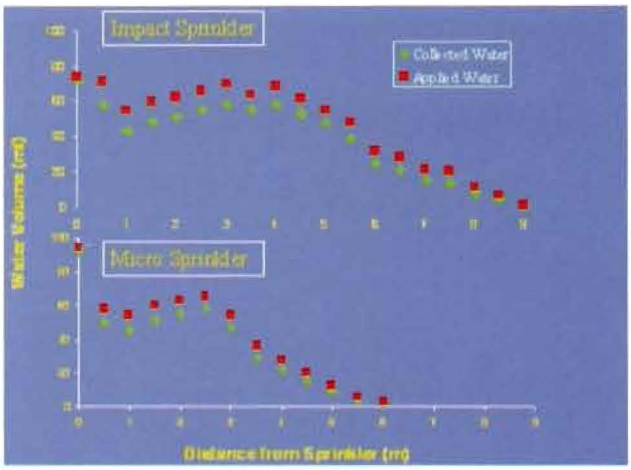

Fig. 9. A view of experimental layout.

Fig. 10 shows that the impact sprinkler performed better than the microsprinkler in reducing water evaporation. Similarly lower water salinity was recorded in the water collected in the impact sprinker compared to the water collected in the micro sprinkler. This experiment was conducted only for two hours, prolonged irrigation

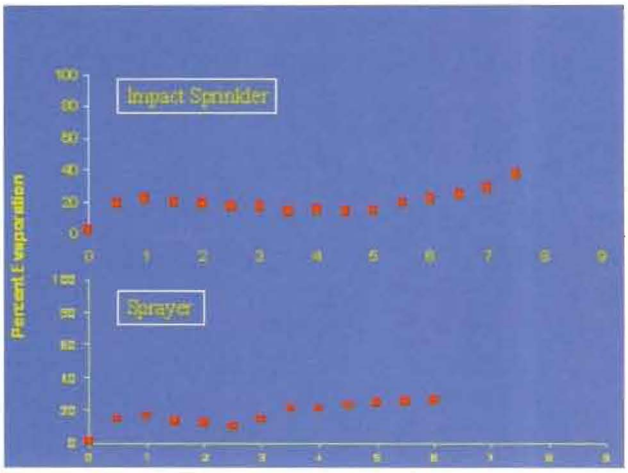

Fig. 10. Comparison of impact ad micro sprinkler on water evaporation.

may cause significant salinity consequences in the soil. Therefore, a very careful irrigation management using saline water is needed.

Overlapping in Micro Sprinkler

The performance of a micro sprinkler as a single jet, and with an overlapping of 90% was tested in terms of water salinity development. The results are presented in Fig. 11. The comparison clearly shows higher water salinity development with a single jet at a distance of 6 meters; whereas an EC of 24 dS/m was recorded with 90% overlapping. This development is related to water evaporation, the distance the water particle travels, mixing through overlapping in addition to other factors.

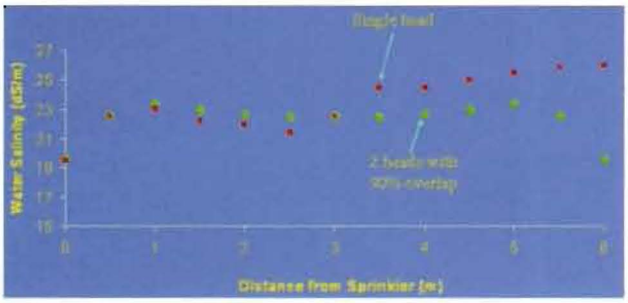

Fig. 11. Salinity reduction through overlap of two consecutive sprinkler heads at 90 %.

In another experiment water and soil salinity was tested in sprinkler irrigation. In this experiment wind has significantly affected the water distribution and the subsequent salinity development. The trend of salinity development is shown in Fig. 12. Since there was no control over the wind, it is concluded that in areas where wind can play an important role, windbreakers can offer a solution to the improvement in water distribution and salinity development. The blue area shows higher salinity due to uneven distribution of water through wind effect.

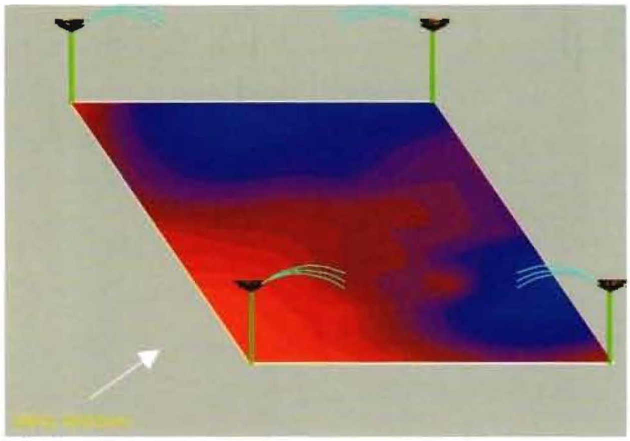

Fig. 12. Salinity development through sprinkler irrigation.

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