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A NEW REVOLUTIONARY TECHNOLOGY TO FEED BILLIONS BY ESTABLISHING SUSTAINABLE AGRICULTURE ON SMALL AND LARGE LANDSCAPES INCLUDING URBAN REGIONS GLOBALLY

[*1]Smucker, A.J.M., [2]Yang, Z. [1]Guber, A. K., [3]He, X.C. [3]Lai, F.H. and [1]Berhanu, S.

[1]Michigan State University, East Lansing, MI, USA 48824
[2]Chang'an University, Xi'an, China
[3]Private Business, Beijing, China

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ABSTRACT

More food needs to be produced on soils located near consumer markets globally. This mandate requires innovative hydropedologic technology that produces more food with less water. Since most of the farmland is currently under production or has been badly eroded, more of the 26% land area occupied by highly permeable sand soils needs to be converted to sustainable agricultural production. Opportunities for reducing groundwater pollution in sands require additional exploration of innovative hydropedological mechanisms improving the retention of gravitational water in the root zone. Following model testing of a revolutionary innovative technology, a greenhouse lysimeter was constructed and the sand soil equipped with spatially distributed impermeable subsurface soil water retaining membranes. The entire lysimeter volume of sand was equipped with multiple soil water probes, soil solution vacuum extraction probes and minirhizotrons to best quantify soil water, nutrient, and root distributions within the plant rhizosphere. This report identifies improvements in soil water holding capacities in plant root zones and water bypass rates of membranes during excess irrigation. At the onset, HYDRUS-2D modeling identified optimally configured aspect ratios for soil water retention membranes, spatially distributed to retain uniform maximum volumetric soil water contents for establishing higher field capacity of water coupled with optimal soil aeration in the root zones of plants. Furthermore, these membrane configurations needed to be engineered to optimal drainage during excess rainfall or supplemental irrigation rates greater than 9.4 cm per day, avoiding saturation within and above these water retention membranes. This lysimeter design enabled us to quantify accelerated water conductivity within the soil and plant root zone located above these membranes installed at multiple depths. Lower soil water matric potential in the capillary fringe above these membranes doubled the water holding capacity, increased maize production by 240%, increasing water use efficiency by 77% while increasing shoot to root ratios 30%. This new soil water retention technology (SWRT) can be installed manually in very small gardens and equipment is being developed for installing up to 5 hectares daily at reasonable prices with return on investment of one year for vegetable crops and up to 5 years for maize and soybean crop rotations. We believe this new SWRT conversion of sand soils will develop sustainable agricultural production of maize that approaches 20 metric tons of grain per hectare for each of one to three crops annually.

INTRODUCTION

There is an increasing global imperative to produce more food with less water during the next several decades. Since most of the best farm land is currently cultivated, new and innovative technologies are needed to convert some of the more permeable sand soils into sustainable agricultural production. Highly permeable Spodisols, Torroxic and UstoxicOxisols are too often abandoned to deep rooted annual plants thatfrequently shift regions into deserts orthey areexcessively irrigatedleaching agricultural nutrients into groundwater (Sanchez *et al*. 2009).

Corresponding author: Smucker, A.J.M.,
Michigan State University, East Lansing, MI, USA 48824

Most designs to enhance soil water retention in sands have concluded commercial methods are needed toeconomically install highly functionalsoil water retainersthat optimize soil water and nutrient contents within plant root zoneswithout increasing the risk of soil flooding during excess rainfall (Erickson *et al*, 1968; Mualem, 1976;Garrity and Vejpa, 1992;Tilman *et al*., 2002; Passioura, 2006). Water is increasingly becoming scarce and agriculture represents the main consumptive use of this natural resource, accounting for 70% of freshwater withdrawals in the world. Irrigated agriculture accounts for 16% of the world's cultivated land, contributing 40% of global crop production (OECD, 1993). Changing climates require more frequent and site-specific applications of uniform soil water and nutrient retention by highly permeable soil. Harvesting water where it falls or where it is added by supplemental irrigation remains the greatest opportunity for increasing sustainable crop production during the next many decades. Plant water deficits have beenranked as the greatest, up to 90%, abiotic restrictionto sustainable plant production (Boyer and Westgate, 2004). Local surface water shortage in areas receiving rainfall greater than 300mm annually, continue to limit plant productivity and contribute to human malnutrition and related diseases (Passioura, 2006; Barrett, 2010). Currently, excessive irrigation is the best, on farm, approach to avoid drought. However, precision irrigation management requires additional experience, time and energy. Therefore, a novel, self-regulating and long-term soil water retaining technology that uniformly retains and redistributes optimal plant available soil water and nutrients within plant root zones of more than 2.3 billion hectares of sands (FAO, website, 2010) before large quantities of food can be sustainably produced by household gardens, community farmlands and large fields globally.

Projections of 68% and 183% increased production of non-irrigated wheat and maize in Brisbane sands (Smucker and Basso, 2013), by theSystem Approach for Land Use Sustainability (SALUS) model (Basso *et al*., 2007) encouraged the development of engineered subsurface water retention membranes. Attempts to avoid the early promotion of plant growth and later crop losses growing on water retention membranes, reported by Garrity *et al*., (1992), we continued to test new more precise designs of U-shaped membranes having different aspect ratios. These laboratory tests lead to the establishment of a larger lysimeter containing different soil water retention membranes configurations of aspect ratios located at different soil depths. This report summarizes soil-plant-water optimizations that led to the identification of optimal water retention membranes which doubles soil water retention while self-regulating optimal water, nutrient and oxygen contents in plant root zones.

MATERIALS AND METHODS

Bouma and Denning (1972) reported unsaturated hydraulic conductivity in profiles of Plainfield sand increased from 0.04 to 11.5 cm per dayassoil water matric potentials dropped from -60 to -20 hPa. More recent measurements by Yang *et al*., (2011) reported saturated hydraulic conductivity (Ks) was reduced to 15.6% in acid washed white medium textured sand columns containing membranes with graduated reductions in permeability, compared to the 13.37 m/d rates through the same sand without membranes. Combininga trilogy of capillary rise above newly retained soil water regions within sand columns (Yang *et al*., 2011) and soil water retention graphs of sands, Figure 1, we developed troughs of 3 mil polyethylene film, having different width to depth ratios designed toretain and redistribute uniform soil water contents within a medium fine sand having a bulk density of 1.55 Kg/m with a calculated total porosity of 42%.Six water retention membranes were manually installed during the filling of 3.069 MTof medium fine sand in a greenhouse lysimeter with dimensions of 120cm x 150cm by 110cm deep and confined by a water tight 8 mil polyethylene film. Fifty-seven 5TE dielectric permittivity soil water, temperature and salinity probes (Decagon, Pullman, Washington),twenty-seven Teflon soil solution samplers (Van Walt Limited, Haslemere, UK) and clear plastic horizontal minirhizotron tubes, diameters of 5 cm, all uniformly installed, in triplicate, along uniform spaces to the membranes and across the length of the lysimeter during the sand filling, Figure 2. Individual depth and horizontal positioning to the nearest neighbor of each membrane was based upon the capillary rise rates and maximum heights of water flux above a free water surfaceintercepted and retained maximum quantities vertical water flow, Figure 2.

Horizontal and vertical gaps between,above and below each water impermeable membrane, having different aspect ratio and soil depth, were designed to permit drainage of completely saturated soil from within each membrane, at different rates to establish their individually improved field capacity ranging betweenvolumetric water content (VWC) of15and 19%. Gaps between lysimeter walls and the 42 and 75 cm membranes were large enough to permit significantly more water to drain from these sands, enabling us to quantify uniquely different plant growth in sand without membranes below their root systems in this area.All reported soil water and plant data in this report contrast soil areas and plants growing in sands above soil water retaining membranes and plants grown in sands with no membranes below their root systems. Soil VWC was recorded at 15 minute intervalsby Em50 data loggers (Decagon, Pullman, Washington) atuniformly spaced triplicate regions above, within and below all subsoil water retention membranes, Figure 2.

A 110 day maize crop (DeKalb DKC 46-61 Roundup Ready/Liberty Link/ BT) was planted insix rows spaced at18 cm, each with 11 plants, spaced at 14 cm. Each plant occupied 252 $cm^2$of sand surface areas located above water retention membranes, designated as SWRT membranes, or without membranes by plants growing near the lysimeter wall. Daily photoperiod of 16 hourlight intensity similar to mid-day solar photosynthetic radiation received in July, in East Lansing, MI, 84^o 28’57” West. Sixteen-hour photoperiod was achievedby 4 uniformly spaced model PL 2000, 400Watts HPShalide lamps for the duration of the maize crop. A Hoagland’s solution modified for maize was the source of daily irrigation/fertigation delivered to the entire surface of the lysimeter withequally spaced and uniformly distributed surface drip tapes by 5 evenly spaced emitters along six low pressure surface drip tapes uniformly spaced across the lysimeter sand surface (Netafim, Tel Aviv, Israel) at rates of 10 L per 6 minutes from plant emergence to the 3 leaf stage. Thenfertigation was increased to 20 L during 12 minutes through the 8 leaf stage and increased to 30 L during 18 minutes until plant maturity. Gravitational drainage of excess solution was collected below 6 evenly spaced 10 cm openings across the underside of the lysimeter, Figure 2. Maize root development was observed at the 9, 12 and 3 o’clock position surfaces of the transparent MR tubeby the Bartz minirhizotron digital camera equipped with a “Smucker multiple position index handle” for repeated recording of roots at exact soil positions of previous measurements (Bartz Technology, Carpenteria, California). Aboveground plant parameters measured included plant height from soil surface to tips of tallest leaf. Data in this report will be limited to water capacities and plant production influenced by the upper three water retention membranes. As the three deeper membranes, 67 and 75 cm, contributed little to the maize plant growth and development. We calculated unsaturated soil water supply capacity (C) among the soil volumes adjacent to the upper three membranes within the plant root zone of the lysimeter. C values in equation (1), from (Hillel, 2004)were calculated using changes in the matric potential, from the soil water retention graph, Figure 1, for different VWC values recorded along, above and below both membranes located at the 65 to 5 cm depth.

$$C(\theta) = \frac{d\theta}{d\psi} \quad (1)$$

Where C(θ) is the specific water capacity at the volume soil water content (θ) and the negative matric potential (-Ψ) of the soil water moving between adjacent soil water resistivity probes and verified by destructively sampled cores. This value was estimated using the slope of the range of soil water retention graphic values, Figure 1, collected in this study corresponding to the most linear portion of the soil water retention curve as described by Hillel (2004). When K(θ) and C(θ) values for each volumetric soil water content were identified then the diffusivity D(θ), within the soil at each of these locations and time was calculated by equation (2):

$$D(\theta) = \frac{K(\theta)}{C(\theta)} \quad (2)$$

Where D(θ) is the soil water diffusivity at volumetric water contents(VWC)θand the hydraulic conductivity K(θ) is divided by specific water capacity C(θ) in equation (1). Unsaturated hydraulic conductivity K(θ) was calculated by Darcy's law for each soil region of each water probe.

Comparisons of water diffusivity focused on the water retention membranes labeled as 27 and 42. The shallower V-shaped 27 membrane trough was 30 cm wide and 20 cm deep displayed an aspect ratio of 1.5 to 1 with a base at 42 cm below the soil surface. The two deeper U-shaped 42 membrane troughs were 30 cm wide x 15cm deep displaying an aspect ratio of2 to 1 with their bases at 49 cm below the soil surface (Figure 2). Observations of water flux rates between membrane positions, at their respective specific water holding capacities, contributed to our understanding of the separate and combined contributions of position and aspect ratio contributed to their respective diffusivities of stored water within the soil profile.

HYDRUS-1D software (Šimùnek *et al*., 1999) was implemented in this study to evaluate soil water membrane retention efficiencies to redistribute irrigation water. Established simulation domains were established to reproduce experimental conditions. We considered homogeneous soil profiles containing different aspect ratios among the single V-shaped membrane, 27cm, having an aspect ratio of 1.5:1 and two; 42cm U-shapedsoil water retention membranes having aspect ratios of 2:1,and all three 67cm and 72cm membranes havingaspect ratios of 3:1.Upper boundary conditions were assigned forspecific time variables based upon water flux consistent with rates of irrigation, evaporation (EV) and transpiration (TR). The irrigation time and rates were set based on the irrigation schedule used in the lysimeter experiment, while EV and TR values were estimated based on air temperature and humidity conditions, at zero wind, maintained in the greenhouse during the experiment (Guber *et al*., 2015). The vertical root spatial distribution in HYDRUS-2Dwas modeled using Vrugt *et al*. approaches published (2001a, 2001b). The maximum root depth, depth of maximum intensity and parameter *Pz* were set to 100 cm, 50 cm and 2.5 cm, respectively. A water stress function as suggested by van Genuchten (1987) described the decrease in root water uptake with *P50*, *P3* and *PW* parameters set to -100 cm, -330 and -10^4 cm, respectively. Example of soil water profiles maintained inside the 27 and 42 membranes and outside the 42 soil water retention membranes are shown in Figure 3. An example of the volumetric soil water contents maintained here were limited to soil water measurements and modeling at 1 hour intervals beginning immediately before planting of maize seeds until physiological black layer of maize maturity.

The HYDRUS-2D model was calibrated and validated on data in the sand lysimeter experiment. Measured water content dynamics in 13 locations were split into calibration and validation datasets. The first dataset consisted of soil water contents obtained during first 6 days of the experiment, when large irrigation rates resulted in high oscillations in soil water contents. The second dataset included data for the remaining 110 days, when lower irrigation rates were used to provide optimal conditions for maize growth. The calibrated and validated HYDRUS-2D model used to identify optimal irrigation of these different soil water retention membranes focused our practices toward maximum conservation of irrigation water, while providing optimal moisture condition for maize growth. Optimal growth conditions were assessed as deviations from potential root uptake. Three water application scenarios were considered: 10, 20 and 30 L day^{-1}, applied every 24, 12 and 8 hours, respectively. The first irrigation rate was set to 120 L day^{-1} similar to that in the sand lysimeter experiment. To evaluate water conservation efficiency of the soil water retention membranes, HYDRUS-1D simulations were performed with and without water retaining membranes below the majority of plant roots. Drainage efficiency was estimated using the ratio between cumulative drained volume (Vdr) and total volume of water applied to the surface of the sand lysimeter (Virr).Small ratio values indicated larger water conserving capacity. Large ratio values indicated smaller water conserving capacity. Plant water uptake efficiency was estimated using the ratio between values of cumulative (Vup) and potential root uptake (Vp). Lower ratios lead to plant water deficit stresses.

RESULTS

Calculations of water diffusivity within this highly instrumented lysimeter coupled with HYDRUS-1D modeling of retained supplemental irrigation above impermeable water retention membranes, permitted us to confirm calculated hydropedologic theory that volumetric soil water contents in sand soil can be doubled in maize root zones, maintained by prescriptive irrigation scheduling and our hypothesis that crop production would be doubled relative to naturally drained water contents of sands without water retaining membranes, Figure 3. Prescriptive irrigation rates and frequencies are compulsory to provide sufficient moisture for maximum maize growth in sands when quantifiable retention rates are constant. HYDRUS-1D computed ratios between cumulative real root uptake (Vup) and potential water available for root uptake (Vp) values for the majority of the vegetative and all the reproductive phonological stages of the maize crop in lysimeter sands was 0.986 in root zone regions above membranes compared to 0.271 for sands without membranes (Table 1). These modeled estimates indicated hospitable growing conditions can be established and maintained for maximize maize yields with less water when water retaining membranes, below the root zone, are present at appropriate depths below the soil surface. During our first irrigation study with these soil water retaining membranes, our irrigation rates were somewhat excessive in terms of water conservation. Although 65% of irrigation/fertigation solutions were lost by drainage in sands with water retaining membranes, VWC doubled in the maize root zone above water retaining membranes, Figure 3. In addition to doubling soil water contents, these membranes retained at lower matric potentials, Figures 1 and 3,enabling greater root uptake ratesof more water retained in the root zone, Table 1.

Table 1. Percentage of irrigated water drained from the sand lysimeter (Vdr/Virr) and the ratio between values of cumulative and potential root uptake (Vup/Vp) measured for 3 irrigation rates with and without soil water retention technology (SWRT) membranes.

Irrigation rate	SWRT Membrane		No SWRT Membrane	
L day^{-1}	Vdr/Virr	Vup/Vp	Vdr/Virr	Vup/Vp
10	52.7%	0.965	95.0%	0.097
20	58.2%	0.983	95.8%	0.248
30	71.5%	0.988	97.8%	0.294

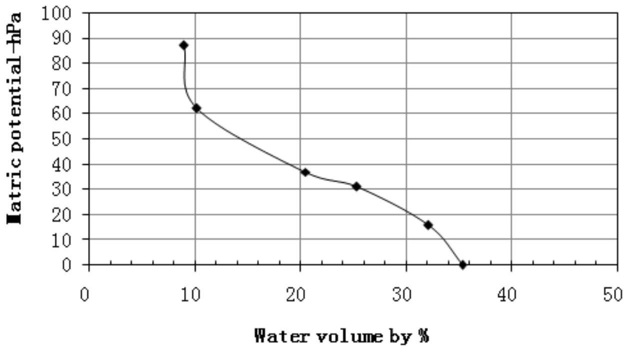

Figure 1. Soil water retention graph for medium fine sand containing water saving membranes in the lysimeter. This graph was the average of three evaluations used for identifying soil water supply capacities across three soil regions.Moisture sensors above, within and below each water saving membrane doubled volumetric water content (VWC) providing at least two-fold more plant available water for prolonged time periods.

Although calculated unsaturated soil water diffusivity, equation (2), above the deeper 42 U-shaped membrane was twice ($1.75x10^{-3}$) the diffusivity of the shallower 27 V-shaped barrier ($0.85x10^{-3}$) similar maximum volumetric soil water contents could be maintained within water retention membranes 27 and 42, with frequent irrigations, Figure 3. The more rapid accumulation of surface irrigation solution within the shallower membrane, compared to the deeper membrane, is obvious, yet, the much earlier and more rapid removal of water from the shallower in contrast to the more gradual water loss rate by the deeper membranes suggest additional interactions between membrane configuration, soil depth and root density remain to be determined. These water data combined with modeled retention and uptake accurately identified interactive relationships among geometric configurations of membranes at different depths. Contrasting permeability and capillary rise parameters generally depend upon a myriad of soil textures, irrigation rates across soil depth and unsaturated diffusivity. However, more uniform VWC can be established in root zones of sands lined with geometrically shaped water-impermeable membranes.

The VWC retained in the root zone sands at soil water metric potentials of -20 hPa, by soil water retaining membranes increased maize plant height 70%, Figure 5, at 77% greater the water use efficiency rates, Figure 7. Water conserving soil water retaining membranes enabled roots to uptake at least 2-fold greater quantities of plant available water than plant roots growing in sands without membranes in their root zone, Table 1. Excessive drainage losses, 96%, of irrigated sands without membranes, dramatically reduced root water uptake to Vup/Vp to 27% when naturally drained sands approached10% VWC, Figure 3. Accumulating hysteresis of frequent droughts continued to mountin maize plants growing on naturally drained sands during the entire vegetative and reproductive periods from the 3rdleaf to black layer (Table 1). In contrast, the absence of drought conditions by maize plants growing on membrane- enhanced water holding capacities retained at lower soil water matric potentials, Figure 1,increased shoot to root ratios to levels of 3.5 exceeding shoot to root ratios of plant roots growing in naturally drained sands without membranes by 48% (Table 2). Above ground plant growth, photo assimilate retention in the form of whole plant biomass aboveground, is essential for obtaining the highest harvest index. This accelerated above ground plant growth rate doubled plant biomass per square meter well beyond controls, regardless of retaining membrane depth, Figure 6. These water saving membrane-enhanced benefits to plants offer exciting potential for sustainably increasing agricultural production on marginal sands. Whether these newly identified additional soil water retention technologies promote luxury water consumption, is unknown.

Table 2. Above and belowground of maize plant growth in sand containingsoil water retention technology (SWRT) membranes. Membranes below theroot zone increased biomass by 136% with concomitant 48% increase in shoot to root ratio. N = 14 plants.

Treatments	Plant Biomass g. (Std.dev.)	Roots /100 cm^2(Std.dev.)	Shoot: Root
No SWRT membrane	104(46)	44 (6.0)	2.36
SWRT membranes	245(71)	70 (12)	3.50

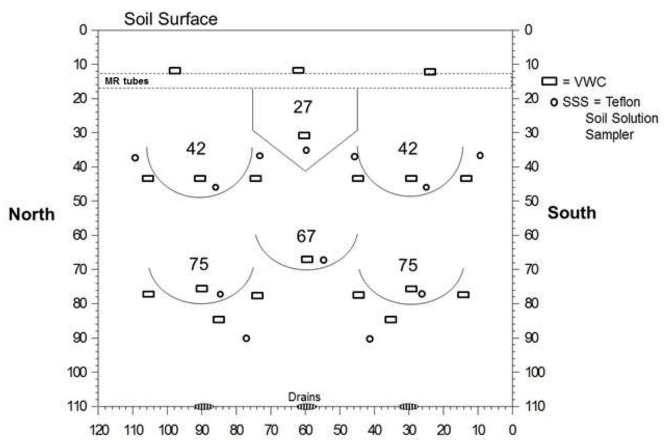

Figure 2. Greenhouse lysimeter 110 cm deep x 120 cm wide x 150 cm long containing medium fine sand with spatially distributed subsurface water retaining membrane troughs at multiple depths throughout the length of the lysimeter. V-shaped (27) with aspect ratio of 1.5:1, and U-shaped(42) membranes installed with aspect ratios of 2:1(42). Both were designed to double soil water contents in plant root zones compared to surrounding sand with no membranes. Nineteen soil water, temperature and salinity probes and 12 Teflon suction lysimeters (SSS) were distributed in triplicate at equal distances inside and along each side of the soil water retention membrane.

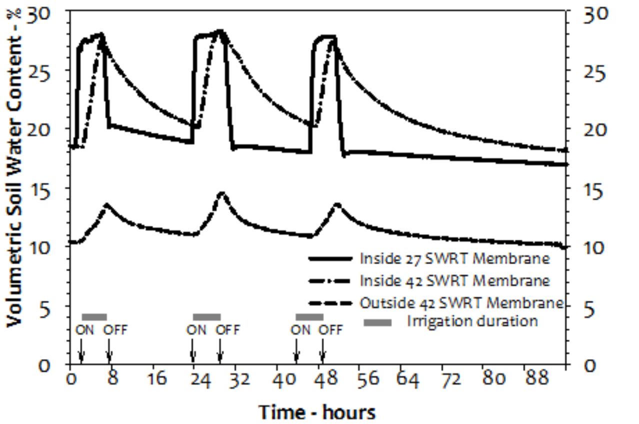

Figure 3. Average volumetric soil water contents above, recorded four times hourly, within and outside the middle 27 framed below and on each side by 2 U-shaped membranes at42cm. Each data point represents the averages of 3 soil water probe replications evenly distributed within the length of the 27cm membrane, 6 soil water probe replications evenly distributed within the two 42cm membranes and 12 soil water probes replications evenly distributes outside the two 42cm membranes.

Figure 4. Photo of maize growth at grain filling stage in lysimeter, Figure 2. Plant populations were 2.885 times greater than current field populations planted at 45 cm row spacings. Irrigation/fertigation was uniformly distributed across the lysimeter surface by six equally spaced surface drip tape, not shown. (A) shows open ends of three minirhizotrons evenly distributed at depths shown in Figure 2. (B) shows vacuum flasks used to extract soil solutions from 36 multiple locations diagrammed in Figure 2. No soil nutrient data are reported here.

Therefore, we are continuously modeling to better identify improved prescription levels of irrigation rates and associated fertigation regimes for maximum plant growth and grain production. Plant parameter responses to these varied water retention membranes in the lysimeters with and without water saving membranes, located below their root zone area, are essential for identifying specific depths and spatial distributions of field installed membranes. Above ground plant growth, photoassimilate distribution in the form of whole plant biomass between above and belowground plant structures across time are important.

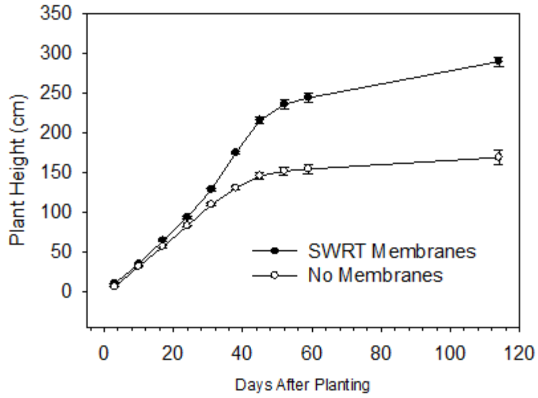

Figure 5. Accelerated maize shoot growth by increased soil water contents within and above SWRT membranes below the root zones of irrigated maize planted at narrow row and in-row spacing. Errors for each bar identify standard errors of 10 and 30 plants for each DAP.

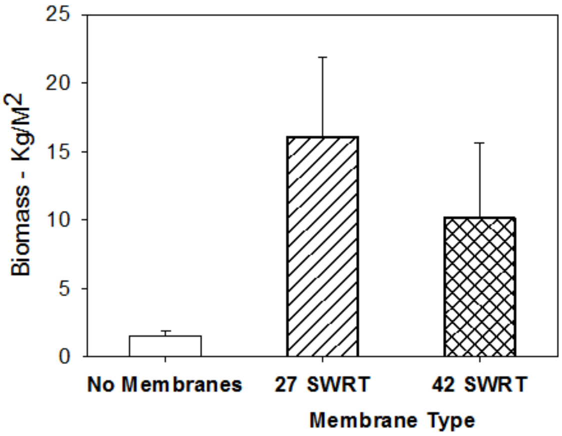

Figure 6. Final biomass for 20 maize plants grown in sand with SWRT membranes having their midways located at 27 and 42 cm directly below plant root zones and for 10 plants grown in sand without water retaining membranes. Errors for each bar are standard errors of 10 plants.

These identified soil water improvements appear to be verified in first and second year field trials reported by Kavdir *et al*., (2014). We believethese soil water retentionmembrane improvements in sand water contents can match or exceed water use efficiencies by maize plant hybrids reported by Ritchie and Basso (2008). Recent reports by Kavdir *et al*, (2012) identified soil water conservation of 60%in semi-arid regions of Turkey while producing the highest quality turfgrass with 33% greater biomass.

Conclusions

Searching for the best soil and plant management practices on highly permeable soils often omit the possibility of optimizinglow matric potential gravitational water in the plant root zone. Soil depth, aspect ratios and spatial placement of soil water retention membranes were tested in a highly monitored lysimeter filled with sand and equipped with high populations of soil water probes to quantify our hypothesis that improved soil water retention enhances uniform flux rates instigating enhancedplant-available water in the root zone for longer periods of time. Measured VWC, drainage, water uptake by roots and calculated soil water conductivity in this lysimeter containing enhanced maize productionwere combined with HYDRUS modeling ofwater distribution potentials above, within, and around spatially distributed impermeable polyethylene troughs at multiple depths. These data clearly confirm and identify the mechanisms controllingwater retaining membranes as they double water holding capacity of sands, reducing water losses by natural gravitational drainage through sand profiles by 95% and 98% of all surface applied water, Table 1. Sands equipped with subsurface water retention membranes retained 25 to 65% of the surface irrigation rates. Extremely high water losses through unconstrained sand profiles drastically reduced plant water uptake ranging from 9% to 29% of all surface applied water while maize roots located above water retaining membranes absorbed 51 to 72 % of irrigation water applied to the soil surface, Table 1.

This is the first report certification of how aspect ratio, soil depth, and relative location of strategically spaced U-shaped polyethylene membranes can double water holding capacities that diminish plant exposures to drought in sands even during higher plant populations of maize. Soil water retention graph in Figure 1 identifies how greater water holding capacities reduce the soil water matric potential from -60 to -40 hPa. Improved and more homogenous unsaturated water flux within the plant root zone by membranes coupled with precision irrigation scheduling, boosts the efficient uptake of plant-available water 77%, Figure 7, eliminating plant water deficits with ensuing 30% greater shoot to root ratios, Table 2. Improved sand water retention by impermeable membranes leads to a 7.5-fold increase in aboveground maize biomass, Figure 6.Depths, aspect ratios and spacing of soil water retention networks are necessary before installing subsoil water retention membranes in field test sites. Currently, patented commercial soil water retention membrane installation chisels are being manufactured for fail-safe precision installation of similar polyethylene membranes into field soils, Soil water retaining membranes in lysimeters and field sites are being used to evaluate similar modifications and yield increases for maize, peppers, cotton, cucumbers, soybeans and tomatoes in four states and three countries.

Greater water and nutrient retention in plant root zones will dramatically increase both food and biomass productivity per unit of land. A key to this challenge is to better understand the intricacies of soil biological, chemical and physical processes and precisely improved water holding capacities in plant root zones. No other natural resource improvement in plant root zones will lead to economic, environmental, political and social stability more than when water is prescriptively applied in a manner that improves plant resilience to drought and the full range of changing climates. Expanded field investigations are needed before the full potential of water retention systems can be established to maximize water conservation while reducing operator time and irrigation energy costs. As commercial installers become certified and licensed to install fail-safe water retaining membranes, farmer adaptation of water retention in sands could soon match current rates of installing drainage systems on finer textured soils. Then the need for expanding expensive networks of irrigation canals and long distance transport of foodstuff will be replaced by household and urban gardens, small and large holder farming operations. As this new soil water retention technology (SWRT) becomes adopted across even small portions of the 2.3 billion hectares of sands, we predict major portions of today's current food shortages will be replaced by SWRT enhanced sustainable agricultural production across both humid and arid regions bringing a blue revolution to food production for the projected 9 to 10 billion people on planet Earth.

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