Final Project Report for three-year CIG grant with one year no-cost extension

Project Title: Drought Reduction and Water Conservation by Increasing Water Retention in the Root Zone
Agreement No. 69-3A75-13-093
Principal Investigator: Dr. Alvin J.M. Smucker, Professor, Michigan State University
Time frame covered by this final report: May 2013 through April 2017
Date of submission: July 28, 2017
Abbreviations: SWRT (Soil water retention technology), VWC (volumetric water content), WUE (water use efficiency), ROI (return on investment of SWRT membrane installation only)

1. Deliverables identified on the grant agreement:

- The revolutionary SWRT increased soil water holding capacity 25% to 40% and maintained optimal soil water, nutrient and oxygen contents in crop root zone increasing multiple year average of maize grain by 47% and vegetables by 24%
- SWRT increased WUE by 19% to 41% depending on crop and type of irrigation
- SWRT membranes reduced N leaching by 40% in narrow row maize
- SWRT optimized soil water content eliminated drought-induced root death
- ROI for SWRT membrane installations are 2 years of SWRT enhanced green pepper yield and 5 to 6 years of SWRT enhanced grain row crop yield
- SWRT contributes to 10 ecosystem deliverables on p. 22

2. Table of Contents

3. Executive Summary

This SWRT membrane technology has impacted farmers, commercial membrane installers, local, state and national commodity organization across multiple agricultural and manufacturing industries. Field proven SWRT has the potential to change lives and regional landscapes domestically and internationally where highly permeable sandy soils have prohibited sustainable agricultural production of nutritious food and fiber for energy.

The following goals and objectives for this project were met and exceeded:

1) Improved water retention in root zones of sandy soils
2) Quantify water use efficiency of drought tolerant and susceptible cultivars
3) ROI of SWRT improved sands
4) Develop WUE best management practices for models and CCA training

This project demonstrated field installations of SWRT membranes on fields in Arizona, California, Michigan, Texas increased yields when irrigated and not irrigated.

All goals were met and exceeded during this four-year project. Sixteen crops were tested at six field sites. We learned to not rely on the accuracy of commercial GPS guidance systems which may work well for shallow near surface installations of seed and fertilizer. However, greater drag forces of 3 to 4 SWRT MIC (membrane installation chisel) installing PE film at depths of one and two feet required more accurate X, Y and Z control for the most uniform membrane installation depths and spatial distribution. Current four chisel SWRT MIC implement accurately installs membranes in all three dimensions. A more accurate AGPS XMC 3D guidance system available through Cook Soil Water Systems and other drainage tile installers has been retrofitted to SWRT MIC implements, is now available to all future SWRT MIC, for the most accurate depth and aspect ratio configuration of SWRT membranes.

Our desire for the no-cost one-year extension was to identify 2 and three years of SWRT enhanced crop improvement across different years of production for drought tolerant and none tolerant cultivars of maize. Data yielded by those trials has attracted plant genetic scientists to use the three soil water supply capacities of SWRT field sites containing membrane retained, control drained irrigation scheduling providing drought free, irrigated control, periodic drought, and a none irrigated rainfed control which generally provides periodic drought, sometimes optimal soil water content for a few days following rainfall events at the same location for years of field testing the full degree of drought tolerance among multiple crop rotations. This additional no-cost extension also provided an additional year of testing the range of SWRT provision of drought avoidance across crop and cover crop seasons in Michigan. Once plant water deficits are eliminated, maize grain production achieved 20.8 Mt/ha (338 bu/a) plus 9.5 MT/ha (8.5 t/a), an unbelievable accomplishment for irrigated maize production on marginal sands transformed into sustainable agriculture while benefiting the environment, p. 22.

Primary customers benefiting from this grant include:

- Farmer's highly permeable sand fields and hill top areas, sandy loam, and loamy sand are the immediate benefactors of SWRT membranes with complete ROI of SWRT membrane installation within 2 to 6 years. Water and nutrient savings are also being incorporated into SWRT cost-benefits websites that include biomass sales for liquid fuel production, total equipment cost, fuel, labor, land rental and debt interest, taxes, crop insurance, water and nutrient costs, and other value chain components from storage and drying to transport from farm gate.
- If 20% of the maize and soybean produced on irrigated sand soils were converted to SWRT improved production systems, USA grain exports would increase by at least $10 billion.
- Commercial soil drainage line installers are very interested in becoming certified and licensed installers of SWRT membranes as farmer contracts for installing drainage systems diminish. Training workshops are prepared and beta tested.
- Irrigation drip tape manufacturers and installers are among the expanding industries interested in SWRT improved sustainable agriculture.
- Manufacturing of SWRT membrane installation machines will soon be hiring dozens to hundreds of new employees as the SWRT agricultural industry expands onto millions and billions of sand soils in the USA and internationally.
- Economies of low income communities located on highly permeable soils benefit significantly as more farms are transformed into sustainable agriculture.
- SWRT provided drought avoidance will liberate most crops to produce at their highest genetic potential.
- SWRT has matured. Statistically significant improvements in soil water and nutrient retention across a single drought year, 1 wet year and 2 normal years in Michigan, production increased and multiple stages of peer reviewed publications, note list in Appendix A, pp. 15-17. This new phenomenal long-term technology should be included in the NRCS Conservation Practice Standards. Please note expanded rationale listed on p. 22.

All funds were spent as projected within the no-cost extension of the original three-year project. This additional time also attracted matching support by agricultural industries, the State of Michigan, and Michigan State University. This NRCS/CIG project has attracted interest and parallel support by the Linden Irrigation Corporation, Midland Value Chain, John Deere, and literally dozens of current installers of drainage lines. These efforts have extended goal no. 4, outlined above, to combine DSSAT and HYDRUS 2D models which model additional advantages of SWRT beyond sandy and loamy sand soils. Additional information is published by Guber, et al and Tutum, et al., (2015) cited in Appendix A, page 15.

Additional methods employed to demonstrate alternative technology in this project include surface polymer mulch with vegetables. Combinations of SWRT water retention membranes and polymer mulch resulted in the greatest IWUE. Chisel numbers on the original prototype were increased from 2 to 3 and now to 4 as each chisel was more streamlined reducing drag forces during SWRT membrane installation. Doubling the chisels combined with improved 3D AGPS XMC guidance system establishes fail-safe installations that attract additional commercial installers.

Quantifiable physical results from this project include highest production levels of maize, soybean, potatoes and some vegetables. Installation fees for installing long-term SWRT membranes can be recovered by SWRT induced yield increases during the first 2 years for commercial vegetables and 5 to 7 years for most agricultural row crops. Significantly higher HI values and shoot to root ratios for maize will alter plant breeding programs for maximum yields on drought free sand soils. Phenomenal promotion of plant growth and production contributes additional sales of up to 8 - 10 MT/ha (~7 - 9 tons/a) of stover for ethanol production.

SWRT conversion of sands to sustainable agriculture offers a total ROI in 2 to 6 years while increasing annual income 20% to 40% greater for decades through generations without maintenance costs to the SWRT membrane. Greater farmer income will improve the economy of current low income rural regions. Short ROI, continuous profit gains by farmers, another tier of income by commercial installers, and value of sandy guaranteed farm lands are projected to increase from $1,800 to $5,800 per acre (conversational estimates by local realtors). Fewer payments to SWRT land owners, for drought reduced production will ultimately reduce insurance premiums (Personal conversation with Mr. David Armstrong, President and CEO Greenstone Farm Credit Services). Federal, State and local programs needed to implement this project include expansion of EQUIP and state CIG funding for improving sand soil production while preserving the environment. Note 10 ecosystem services by SWRT in topic f. p. 22. Adding SWRT enhancement of production and agro-ecosytems services to the national list of new technologies will further promote national support of water retention by the 2018 Farm Bill.

Major recommendations resulting from this project include the urgent need to subsidize farmer investments for installing SWRT membranes on sandy soils of low income rural areas. SWRT contributions to increased WUE, higher HI and larger shoot to root ratios will influence current plant breeding programs currently emphasizing the larger "Rambo Root" to increase drought resilience which ultimately reduces yields. **A new soil water retention technology has been developed to both retain optimal and drain excess soil water from the plant root zone. The new long-term SWRT has installs continuous resilience to drought that protects and promotes plant production during long-term changes in climates and brief unusual weather patterns.** Additionally, SWRT also improves the environment by reducing nitrate and agricultural chemical leaching into groundwater. We have also identified 6 years of crop rotations on irrigated SWRT membranes develops optimal microbial communities for reducing root disease. Well drained SWRT improved soils are also free of anaerobic bacterial and fungal communities, consequently no nitrous oxide evolves from highly producing sustainable well drained, even less than 17% VWC retained by SWRT improved sand soils.

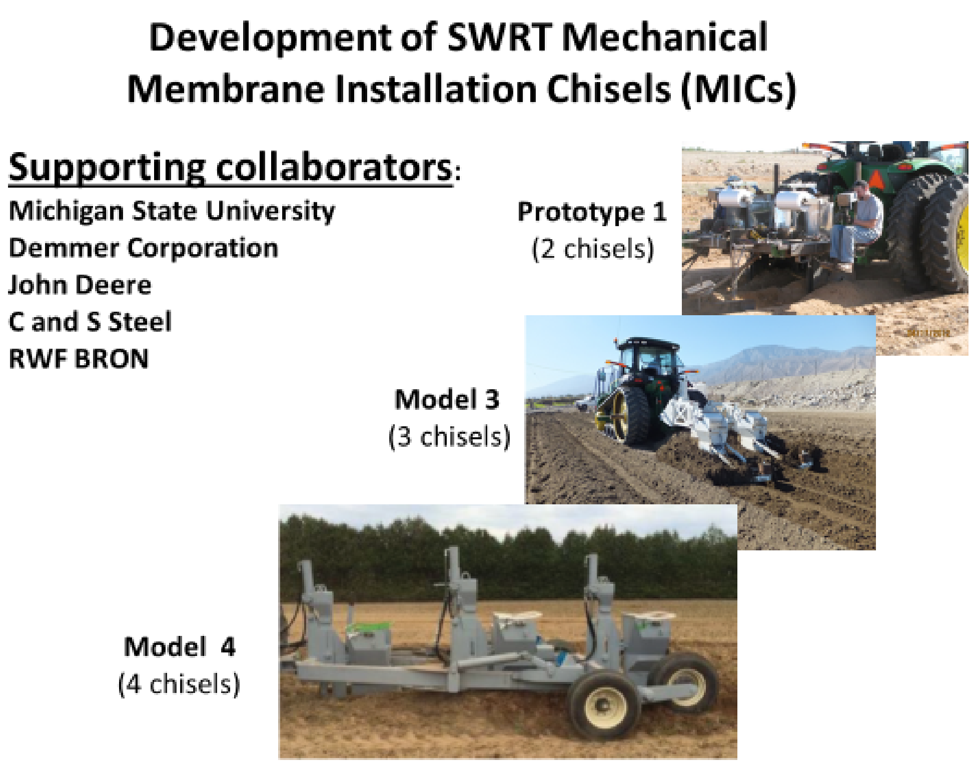
4. Introduction: Increasing demands for producing sustainable food and cellulosic fiber supplies on small and large farms has become the grand challenge for the 21st Century. Soil water deficits rank among the highest stress limitations to plant growth and productivity. Although supplemental irrigation, increasing fertilization and manure applications to highly permeable soils may increase seed and biomass production, during the short term, these management practices are simply not sustainable due to elevated leaching losses including nutrients, pesticides, pathogens and farm animal endocrine disrupting compounds (EDCs) to groundwater supplies. New plant biotechnologies combined with water conservation and nutrient technologies that sustain crop productivity while improving soil quality are currently possible. Once water and nutrients are retained by soils, sustainable productivity of nutritious food crops and biomass can be sustained on marginal sandy and Oxisolic soils. Historically, the installation of subsurface water retention technology (SWRT) barriers in the upper 50 to 75 cm of sandy soils increased both aboveground biomass and food production by 40% to 300% with substantially less, 60% to 40% less irrigation water. Today's new SWRT applications to sandy soils offer the potential to transform barren landscapes into sustainable plant production regions that transform lives and communities.

5. **Background:** Today, many irrigation water sources face decline and greater demands by competing municipal, industrial, and commercial interests that challenge adequate quantities of irrigation water required for sustaining plant production on local farms. Current droughts, increasing commodity prices, shortages of high producing agricultural lands for both food and cellulosic biomass, increasing nitrogen fertilizer costs, low interest rate loans combined with growing global food and energy demands, require new technologies that improve soil water holding capacities. New long-term technologies combined with improved prescription best management practices will convert highly permeable soils into sustainable crop production on lands where water requirements approach 10 to 20 acre-inches, including huge leaching losses, during the growing season. **SWRT is a revolutionary water conservation and crop productivity-enhancing technology that significantly reduces deep leaching, plant drought, and conserves supplemental irrigation.**

How can row crop production be doubled or at least substantially increased on most farm lands across the USA? We believe a country-wide expansion of incorporating SWRT water saving membranes into substantial portions of the USDA listings of more than 275 million acres of coarse textured soils in this country, during the next several decades, when combined with best agronomic management will produce record yields for most farm lands. These improved production options can also be used to convert a significant proportion of the 41% of all unfrozen highly permeable soils across the globe into sustainable farm lands.

Researchers at Michigan State University (MSU) have successfully installed and field tested SWRT conversions of permeable soils at six field sites. Expanding improved water holding capacities across America will impact production agriculture in ways well beyond the successful contributions of current polyethylene drainage tubes installed deeply into subsoils of poorly drained soils. SWRT membranes are long-term improvements in soil water and nutrient retention in the root zones of sandy and other highly permeable soils.

a. **Review of methods:** Membrane installation chisels (MICs) surgically insert polymer membranes at multiple depths and spacings within highly permeable soils to retain and store more plant-available water. SWRT membranes greatly diminish natural leaching of nutrients and other agricultural contaminants into groundwater. Multiple laboratory and field testing have shown how spatially distributed dual layers of SWRT membranes, having aspect ratios of 2:1, Figure 1 in Appendix B, p. 21, retain the majority of water added to the soil surface by rainfall or irrigation and drain excessive water during irrigation rates greater than 9 cm (~3.5 in.) per day. Evolution of the original prototype with 2 chisels, to current 4 chisel MIC results in fewer installer configuration errors of SWRT membranes in large fields. Progress of these progressive development in the SWRT MIC implements are highlighted below.



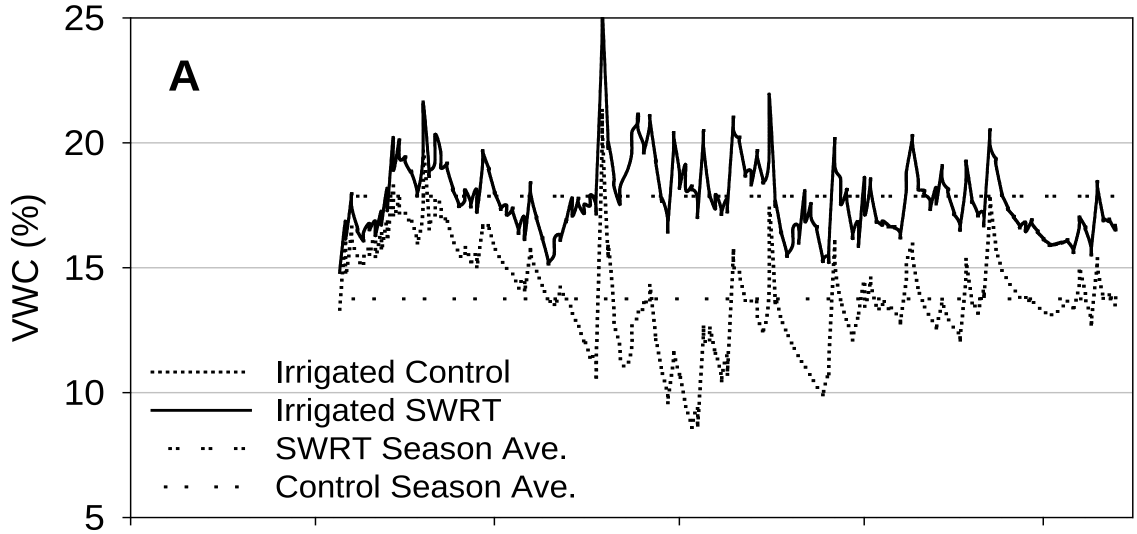
Each SWRT MIC installed SWRT membranes with aspect ratios of 2:1 into sand soils as shown below. These U-shaped troughs are strategically located parallel to each other as diagrammed in Figure 1, Appendix B, p. 18.

Excavated water and nutrient saving membrane, installed at 50 cm soil depths, at the base of the membrane positioned into a U-shaped trough that is 30 cm wide and 15 cm deep.

Field experiments were established as a split plot factorial with four replications. Soil treatments (control and SWRT membranes) was the split plot factor for irrigated vegetable beds. Irrigation plus rainfed and rainfed was the split plot factor for row crops planted perpendicular to the direction of installed membranes. Vegetable beds were installed across and perpendicular to SWRT membranes, and equipped with near soil surface drip tapes and covered with black plastic mulch. Best management practices of specific crop types were grown using recommended practices by each owner. Seasons for published crop production information were 2 to 4 years.

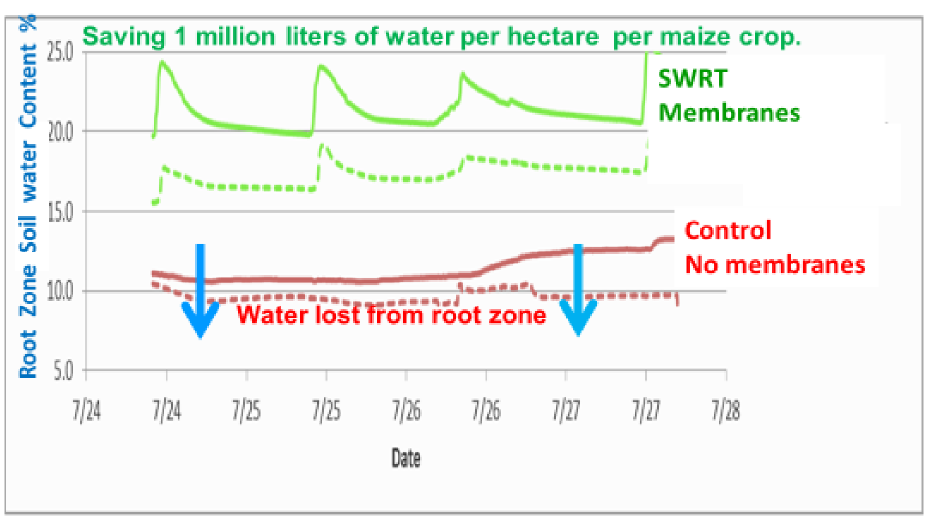
Increased water retention by SWRT membranes in 2012 in SW MI, were maintained for vegetable trials when both SWRT and controls received the same irrigation and rainfall, as shown below.

Best irrigation practices of local field sites, designed to maintain optimal VWC, when combined with rainfall events demonstrated large water savings for vegetables, Figure A, and row crops, bottom Figure, in graphs below.



SWRT membranes double soil water holding capacity in root zone during the 2012 droughty crop year.

SWRT reduced leaching by 435,000 gal/a (1.3 acre feet)



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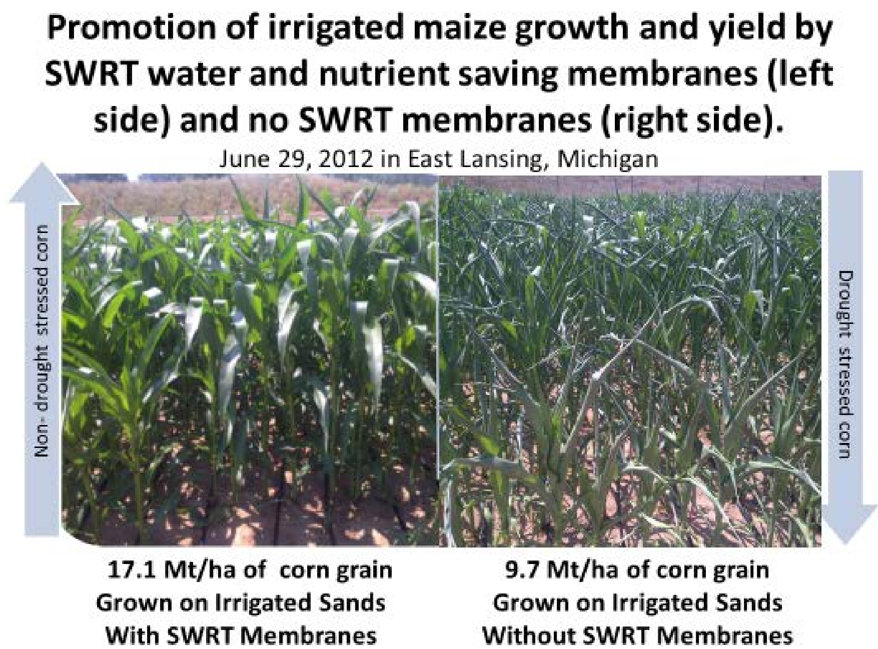
Photo, below, of side by side corn responses on SWRT membranes and on control sands subjected to similar irrigation schedules, altered drought resistance and susceptibility.



b. **Discussion of quality assurance:**

This project enabled the testing of a new technology that included the installation of specifically located impermeable layers at soil depths determined by capillary rise of water controlled by soil texture. Mechanical designs of SWRT membrane installation chisels (MIC) were improved. Digital controls guaranteed 2:1 aspect of PE film within each chisel, and more accurate control of power source and chisel depth by the 3D AGPS - XMC guidance system provides quality assurance of highly functional SWRT membranes for prolonged time periods. The mechanical design of the chisels and MIC equipment were completed by RWF BRON, a licensed commercial manufacturing company primarily focused on soil water drainage systems. Following their improved mechanical chisel configurations containing three and now four chisels on each MIC implement, we continually improved and field tested at their expense. The digital control of SWRT membrane installation coupled with the 3D AGPS - XMC guidance system control of power source vehicles pulling the MIC chisel and specific soil depths of all four chisels guarantee fail-safe installation of SWRT across large and small fields. Improved accuracy of SWRT membranes, confirmed by video images inside each chisel, confirmed by continuous maintenance of greater soil water contents in plant root zones guarantee highest quality of long-term SWRT conversions of sandy soils into highly sustainable irrigated agriculture.

c. **Findings:** SWRT is a revolutionary water conservation and crop productivity-enhancing technology that significantly reduces deep leaching, plant drought, and conserves supplemental irrigation. Properly installed SWRT membranes in sand soils, resembling the spatial and aspect ratio configurations of individual membranes in figures on pp. 7 and 21, result in near doubling soil equilibrium water holding capacity in plant root zones above SWRT membranes, between 15% to 17% VWC compared to control sands retaining between 8% to 10% VWC. Consequently, maximum plant production on SWRT membranes require approximately one-half the irrigation water, 60% N while producing up to 19.8 M/ha (321 bu/a) of narrow row corn. Note table below.

Four - year average 321 bu/a maize grain production on SWRT membranes, rainfed plus irrigation, at Sand Hill Farm, East Lansing, MI. 2013- 2016.

Treatment	MT per Hectare	Increase
Control	6.9 (5.4)*	0
SWRT Membranes	20.1 (2.6)*	216%

* Denotes standard error.

In contrast, when SWRT membranes are improperly installed, eg., overlapping and sometimes damaging the first deeper membranes during second pass installation of shallower membranes, when commercial GPS failed in the mountains of S. California on the Sea Mist Farms near Coachella. Then soil water retention was very similar for both damaged SWRT membranes and non-tilled control soils. Consequently, yields of sweet corn were very similar, note Tables 1 and 2, below. These experiences educated us to develop four chisel MIC implements which installed two deeper and two shallower membranes during each single pass.

Table 1. Soil volumetric water contents in control (without membranes) and SWRT membranes in a sandy Coachella, CA soil during Spring Sweet corn production. Control and SWRT membrane soils were irrigated equally by surface drip tapes. Each value is average of two Decagon GS-3 probes.

Soil Depth	Control	SWRT
8 inches	17.4%	21.8%
16 inches	19.9%	18.8%
8 to 16 inches*	18.7%	20.3%

Table 2. Influence of SWRT membranes on sweet corn production parameters for Coachella, CA Spring 2015. Harvested May 1, 2015.

Treatments	Kg per plot	Ear length cm	Ear tip with no kernels-cm	Circumference of ear - cm
Control no membranes	13.056	19.4	0.7	6.8
SWRT membranes	13.221	19.8	0.6	6.9
Number of replications	10	100	100	100

d. **Conclusions and recommendations:** SWRT is a long-term root water remediation approach for transforming low production soils into highly sustainable agriculture. SWRT enables crops to avoid plant water deficits on highly permeable soils. Dual U-shaped impermeable membrane troughs spatially installed to intercept and retain the majority of vertical soil water flow is engineered to avoid soil flooding during excessive rainfall. This CIG project expanded the application of SWRT remediation across multiple soil types, crops and agroecosystems. These studies identified greatest crop production on irrigated sands improved by SWRT membranes when VWC was retained at 15% to 18% in root zones for the duration of the cropping season. Well designed and uniformly installed SWRT membranes retained more irrigation and rainfall water, producing 20% and 24% increases of green bell peppers and cucumbers yields, respectively. Excellent prescription-level water and nutrient management practices increased WUE by 19 to 41%. We also identified brief economic returns on investment (ROI) for installed SWRT membranes. We believe these results are generalizable to soils elsewhere, and thus suggest a promising new route for improving production on highly permeable sand soils. Recommendations for expanding the adoption of SWRT require distributing these amazing results to farming communities, across government lending agencies, workshops to train, certify and license commercial membrane installers and certified crop advisors to assist adoption and improvement of best management practices.

e. **Technology Review Criteria:** SWRT is a revolutionary water conservation and crop productivity-enhancing technology that is positioned to be commercially expanded with the assistance of developing a NRCS Conservation Practice Standards for the Soil Water Retention Technology (SWRT), four chisel, Membrane Installation Chisel (MIC) implement in the photo below.

1) Description of the process, method, and propriety equipment of the SWRT MIC machine: We highly recommend employing this and all future SWRT MIC machines for field use. It has the essential hydraulics, patented components, field testing and continuing upgrades that attract commercial licensing. The 3D (X,Y and depth controlling XMS hydraulic system is an essential attachment for controlling hydraulic cylinders that maintain uniform depths of water-impermeable membranes and spacing between each pass of the four chisels, 2 deeper, followed by 2 shallower (chisel depths determined by soil capillary rise or each soil type). Each pass across the field completes a 4 foot pathway engineered water retention improvement across the field. Complete instructions, based upon previous field installation experiences are available and most likely subject to change for each power source pulling the MIC implement. Generally, a 250 to 275 HP power source with rubber of steel track are needed for optimal failsafe installations at a reasonable rate of 2 to 3 mph. Estimated installation time to uniformly install SWRT membranes across an entire field of sand, including headlands are at rates from 1 to 1.5 hours per acre. We are prepared and currently testing 3-day SWRT Certification and Licensing Workshop training for all commercial installers of SWRT membranes. **These new innovative technologies received the 2015 Technology Innovation Award by Michigan State University.** Note Appendix B, p.18.

2) Explanations of how SWRT accomplishes one or more of the purposes of an existing standard: The past six years of engineering and field testing of patented options for converting highly permeable soils into long-term sustainable production agriculture have positioned SWRT Solutions to resolve plant water deficit-induced root problems currently limiting agricultural production on literally billions of acres globally. SWRT membranes are engineered and strategically installed to optimize soil water, nutrients and oxygen in crop root zones in a manner that increases production, increases soil carbon sequestration, optimizes rhizosphere microbial communities, while reducing deep leaching of N, K and agricultural chemicals. There is no transforming, long-term, single installation technology known to agriculture that achieves these attributes to crop production and associated ecosystem services on farm fields, hill tops, and along river banks.

MSU Technology and industry supported this NRCS/CIG research by preparing a SWRT Solutions, LLC for launching a log-phase expansion of production and sales of SWRT Solution equipment. Developing a NRCS Conservation Practice Standards for the Soil Water Retention Technology (SWRT) would substantially contribute to the expansion of farmer utilization of this phenomenal agricultural development.

3) Process monitoring and control system requirements for SWRT begin by video recording PE film as it exits each chisel. Digital detection and correction of SWRT membrane configurations are controlled at subsecond intervals during installation. We have monitored VWC at multiple soil depth above SWRT membranes and similar depths in control sands at intensities ranging from 24 to over 240 probes per acre. Metric, formerly Decagon soil water probes connected to their Em50 data loggers have recorded VWC at 15 minute intervals 24/7 across this country, for 6 years and Iraq for 3 years. Video recordings and washed root quantification of root system dynamics, soil sampling for C, N,K, Mg, Ca, SOM, pH, salinity and microbes have been monitored for maize, soybean, potato, green peppers, and cantaloupe. Aboveground measurements of plant height, weight, leaf area, photosynthesis, leaf temperature, stomatal opening have monitored multiple plant and soil parameters for row crop responses to presence and absence of SWRT membranes for 2 to 4 years. Total grain and plant biomass, plus graded levels of vegetables and specific grain sizes, rows on maize ears have contributed to identifying plant drought susceptible or tolerance by soybean and maize cultivars.

4) Quality of SWRT PE film and MIC chisel function are constantly improved. Specific warranties of all SWRT items are essential and will be the responsibility of the new SWRT Solutions business coordinating the expansion of transforming permeable soils into sustainable agriculture.

5) An operation and maintenance plan for SWRT membranes is totally unnecessary as Dow/DuPont along with three Scandanavian polymer chemists have identified no deterioration of LLDPE (linear low-density polyethylene) film occurs for 48 years and may continue for 200+ years when zero UV wavelength energy is blocked by the soil.

Neither pH, microbes, nor salinity degrades LLDPE. Based on illuviation rates of finer clay and silt soil materials indicate SWRT membranes will not fill for more than 3,000 years.

Both performance and possible legal defense, monitoring membrane flow through each chisel is essential for conformation of fail-safe installation. Therefore, we have installed digital cameras inside each chisel to record, at 10 to 20 second intervals, the uniform condition of SWRT membrane aspect ratio exiting each chisel. Although we do not have years of experience for a single chisel passing through sand, it is assumed the manufacturer licensed by Michigan State University will sell and service all components of each SWRT MIC machine.

7) Current estimated installation costs, based on discussions with current drainage tile businesses is $2,000 per acre. This includes $846 for the LLDPE film, equipment maintenance and human fees plus 17% profit. This price most likely will decline as MIC implement traveling speed increases and large orders of PE film reduce cost. After 1 to 3 years the annual operation cost of the SWRT MIC individual chisels will require replacement. We have separated the soil opening chisel, which experiences the greatest abrasive soil action, with the membrane management and delivery portion of each chisel complex. Therefore, the only reoccurring cost to the farmer is their best soil and water management of greater yielding crops.

8) The following individuals and their contact information who serve on the SWRT advisory team, have a range of contributions to the development of the SWRT approach. These include:

Mr. Steve Law, Retired USDA MI Regional Director
Phone: (517) 812-1634
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Mr. John Burnham, President, Soil Water Management
Phone: (517)331-1968
Email: burnhamsw@comcast.net
Website: https://www.manta.com/c/mmjm93x/burnham-soil-and-water-mgt

Mr. James Franz, VP Toyota Way Academy
Phone: (313) 445-1567
Email: james.franz@toyotawayacademy.com

9) The most independent, verifiable data demonstrating results for the use of the SWRT membrane technology for rainfed cotton in West Texas is the poster listed below. He had Texas project that funded the installation of SWRT membranes in sand without irrigation. The attached data is the one year out of two, Dr. Scott, VanPelt reported cotton growth and production. The previous year was too dry for cotton emergence.
Dr. Scott VanPelt USDA Conservation Scientist in the Stanton, TX region.
Phone: (432) 263-0293
Email: scott.vanpelt@ars.usda.gov

Dr. VanPelt barrowed our first 2 chisel SWRT MIC to install SWRT membranes in dry rainfed, no irrigation sands of West Texas cotton growing region. Their project was funded by Texas High Plains Ogallala Aquifer Water project.

10) Contact information for the MSU technology provider.

Mr. Brad Shaw, MSU Technology Engineer

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Email: shawbr@msu.edu

f. **Appendices**

Appendix A: Forty examples of SWRT information distributions to farmers, local crop industry groups, local news and commercial articles, peer reviewed journals, websites, local extension presentations and certified crop advisor training workshops during 2014 and 2017.

1) SWRT Solutions website: http://msuswrttechnology.weebly.com/
2) Smucker, A.J.M., B.C. Levene, M. Ngouajio, R.G. Goldy. 2017a. Greater water holding capacities in plant root zone enhance yield and water use efficiency by irrigated green bell pepper and cucumbers under plastic mulch. Horticulture Technology. (In review).
3) Smucker, A.J.M., B.C. Levene, K. Thelen. 2017b. Maize production increases during five years on irrigated sands improved by soil water retention membranes. Agronomy Journal (In preparation).
4) Smucker, A.J.M., B.C. Levene, J. Han, J.M. Tiedje, J.R. Cole. 2017.
5) Aoda, M.I., A.J.M Smucker, M.A. Hussein, S. S. Majeed, F.H. Al-Sahaf, G.P. Robertson. 2017. Subsurface Water Retention Technology to Produce Vegetable Crops in Iraqi Sandy Soils and to Conserve Water and Fertilizers under Dry Climate and Water Scarcity. Agronomy Journal. (In review).
6) Pavani, T., B.C. Levene, K. D. Thelen, A.J.M. Smucker. 2017. Increased ethanol conversion of maize grain and foliage produced on irrigated SWRT membranes without plant water deficits. Agronomy Journal (In review).
7) Aoda, M.I., A.J.M Smucker, M.A. Hussein, S. S. Majeed, F.H. Al-Sahaf, G.P. Robertson. 2017. Subsurface water retention technology to produce vegetable crops in Iraqi sandy soils and to conserve water and fertilizers under dry climate and water scarcity. Agronomy Journal. (In review)
8) Massri, Z., A.J.M. Smucker, A.K. Guber, S. Berhanu, and X. Yang. 2017. Soil nitrate and potassium balance above the water and nutrients saving membranes in prescriptive irrigated and non-irrigated maize. (Submitted to J. Plant Nutrition)
9) Smucker, A.J.M., Z. Yang, A. K. Guber, X.C. He, F.H. Lai, S. Berhanu. 2016. A new revolutionary technology to feed billions by establishing sustainable agriculture on small and large landscapes including urban regions globally. International Journal of Development Research. Vol. 06, Issue 10, pp. 9596-9602, October 2016. ISSN: 2230-9926.
10) Guber, Andrey K., Alvin J.M. Smucker, Samrawi Berhanu, and James M.L. Miller. 2015. Optimizing water regime for sustainable maize production on coarse textured soils by subsurface water retaining membranes within plant root zone. Vadose Zone Journal. 2004-11-0166-ORA.R1-PDF0001.
11) Tutum, C.C, A.K. Guber, K. Deb, A.J.M. Smucker, P. Najadhashemi, B. Kiraz. 2015. An integrated approach involving EMO and HYDRUS-2D software for SWRT-based precision irrigation: Initial results. 2015 IEEE Congress on Evolutionary Computation.
12) Tian, Y., C.H. Liu, A.J.M Smucker, H. Li, and W. Zhang. 2015. Plant root exudates decrease mobility of smectite colloids in porous media in contrast to humic acid, doi:10.2136/sssaj2014.10.0412.

13) Smucker, Alvin J.M. and Bruno Basso. 2014. Global potential for a new subsurface water retention technology- converting marginal soil into sustainable plant production. In: The Soil Underfoot: Infinite Possibilities for a Finite Resource, Editors; G. J. Churchman and E.R. Landa. Chapter 24, pp. 315 – 324. CRC Press.
14) Kavdir, Y., W. Zhang, B. Basso and A.J.M. Smucker. 2014. Development of a new soil water retention technology for increasing production and water conservation. J. of Soil and Water Conservation. DOI 10.2489/jswc.69 (5):154-160.
15) Alvin Smucker, Zeyuan Yang, Xuechen He, Fuhua Lai, Bruno Basso. 2013. SWRT is a new technology for converting arid sands into oases of food and fiber production. International Journal of Bio based Materials and Bioenergy.
16) Smucker, Alvin. 2013. Improved Water Policies and New Technology Promote Greater Food and Cellulosic Biomass Production and Reduce Competition for Water. In: Food Safety, Security and Defense: Focus on Food and Water. Institute on Science for Global Policy (ISGP), Lincoln, NE, October 20-23. pp. 60-68.
17) Kavdir, Y., K. Demirel, A.J.M. Smucker. 2012. A new water retention technology; retaining soil water and nutrients in the plant root zone. 8th International Soil Science Congress on, "Land Degradation and Challenges in Sustainable Soil Management". Vol. IV: 222-224. May 15-17, 2012. Izmir, Turkey.
18) Yang, Z., A.J.M. Smucker, G. Jiang, X. Ma. 2012. Influence of the membranes on water retention in saturated homogeneous sand columns. International Symposium on Water Resource and Environmental Protection (ISWREP), pp:1590–1593. 978-1-61284-340-7/111©2011IEEE.
19) Smucker, A.J.M. and the MSU and Texas USDA Team have circulated over 290 SWRT White Papers reporting results for 2013 - 2015, to national and state policy makers, our two senators in Michigan, local banks and crop insurance agencies, current soil drainage operators, university researchers and extension personnel, local press, and to at least 145 this year inquiring email requests for current information.
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34) Lehnert, Richard. 2015. Percolation barriers could enhance water retention: Subsurface water retention technology could revolutionize irrigated agriculture. Good Fruit Grower. pp. 38-42. April 2, 2015.
35) Alvin Smucker**,** Kurt Thelen, Bruno Basso, Andrey Guber, Zouheir Massri, Ning Gong and Rafael Auras 2015. Subsurface Water Retention Technology (SWRT) for Crop Improvement on Coarse Textured Soils. A detailed webinar: http://www.youtube.com/watch?v=T4Ro1UmAzIs
36) Twenty-five invited seminars in Australia (1), China (8), Ethiopia (3), Germany (2), Kenya (2), Saudi Arabia (2), South Africa (1), Sweden (1), Uganda (1) and International Conferences (7). Literally dozens of SWRT presentations at international conferences, universities, USDA ARS groups, seminars in the USA (2009 to 2016).
37) Twelve abstracts for volunteer oral and poster presentations to the American Society of Agronomy, Crop Science Society of America, Soil and Water Conservation Society, and the Soil Science Society of America. 2012-2015.
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Appendix B: SWRT White Paper for 2017. This is the last of six white papers, each circulated to literally dozens every quarter to hundreds annually.

SWRT White Paper: 2017

Subsurface Water Retention Technologies (SWRT) Converts Marginal Sandy and Other Excessively Permeable Soils into Highly Sustainable Food and Fiber Production Systems while Improving Soil Fertility, Soil Carbon Sequestration, Many Ecosystem Services and Biodegradation of Toxins Resulting in Sustainable Economic Growth and Environmental Protection

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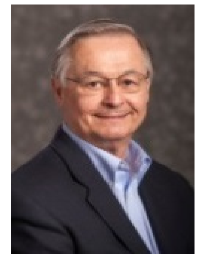


SWRT Solutions: The 2015 Innovator of the Year Award by MSU Technology

This technology has the potential to change lives and regional landscapes domestically and internationally where highly permeable sandy soils have prohibited sustainable agricultural production of nutritious food and fiber for energy.

Introduction: Increasing demands for producing sustainable food and cellulosic fiber supplies on small and large farms has become the grand challenge for the 21st Century. Soil water deficits rank among the highest stress limitations to plant growth and productivity. Although supplemental irrigation, increasing fertilization and manure applications to highly permeable soils may increase seed and biomass production, during the short term, these management practices are simply not sustainable due to elevated leaching losses including nutrients, pesticides, pathogens and farm animal endocrine disrupting compounds (EDCs) to groundwater supplies. New plant biotechnologies combined with water conservation and nutrient technologies that sustain crop productivity while improving soil quality are currently possible. Once water and nutrients are retained by soils, sustainable productivity of nutritious food crops and biomass can be sustained on marginal sandy and Oxisolic soils. Historically, the installation of subsurface water retention technology (SWRT) barriers in the upper 50 to 75 cm of sandy soils increased both aboveground biomass and food production by 40% to 300% with substantially less, 60% to 40% less irrigation water. Today's new SWRT applications to sandy soils offer the potential to transform barren landscapes into sustainable plant production regions that transform lives and communities.

A strategic global initiative is being developed with partners from foundations, the private sector, academic institutions, international development organizations, and selected host country governments. Its goal is to establish national and international consortia for prototyping, field testing, pilot technology transfer and large scale implementation in the USA, the Middle East, Africa, China, Central Europe and Southeast Asia with subsequent large scale implementation based on selected criteria, such as sustainable food and biomass production potential, population food security needs, water use efficiency and cost-benefit considerations.

Background: During each growing season, productivity of most plants growing in sandy soils is dramatically reduced by limited availability of soil water and nutrients in their root zone.

Insufficient soil water contents in the plant root zone combined with constant leaching of necessary plant nutrients severely limits plant biomass production on coarse textured highly permeable soils. Low water holding capacities by coarse textured soils of most marginal drylands including rangelands, receiving less than 50 cm of unevenly distributed rainfall annually, cause extremely low productivity of food and plant biomass. Although large pores within sandy and Oxisolic soils absorb large quantities of rainfall, less than 20% is retained in the root zone from 0 - 60 cm depths. The remaining water drains more deeply into the soil leaching most plant nutrients, *E. coli*, some pesticides and endocrine disruptive compounds to depths beyond the roots of most crops, into groundwater.

The absence of adequate soil water, where irrigation is too costly or absent, negates positive responses to plant nutrients added to highly permeable soils. **SWRT membranes below plant roots retain water where it falls and provides continuous delivery of nearly 100% plant water demands for periods up to 3 times longer than control soils without SWRT water retention membranes** (Guber, et al., 2015).

The Challenge: Rising concerns about the negative environmental impacts of excessive irrigation of current 45 million hectares (100 million acres) of sandy soils in the USA, are putting pressure on the share of fresh water supply and land resources available for agricultural irrigation worldwide. As the competition for resources accelerates and the global population growth continues to escalate, societies will be forced to contend with the difficult assignment of producing more food and fiber using more sandy soils, requiring less irrigation water.

If irrigation agriculture is to remain sustainable and a positive social and economic force in the 21st Century, it needs to evolve into a highly efficient, cost effective, zero maintenance, environmentally benevolent, long-term production system. SWRT Solutions have been field proven to provide an environmentally safe sustainable irrigated agriculture on highly permeable sand soils.

We contend the novel Michigan State University (MSU) SWRT, designed to double water holding capacities and reduce irrigation requirements by 40 to 60% is a revolutionary long-term technology to directly address projected food and energy needs for the next three to five decades. This revolutionary technology of engineered water retention membranes will transform at least 125 million hectares (275 million acres) of marginal sandy soils in the USA into water conserving sustainable agricultural production landscapes with highest water use efficiency and minimal leaching (Smucker et al., 2012 and 2014). The total quantity of highly permeable soil requiring conversion into sustainable cropping systems is estimated by the United Nations Food and Agriculture Organization (FAO), to approach 2.2 billion hectares (nearly 5 billion acres) globally.

The new SWRT water conservation solutions permanently transform lives and landscapes by retaining both soil water and nutrients in the root zone of food and cash crops in an environmentally sustainable manner that improves ecosystem services, soil quality, plant productivity and local economies. SWRT applications increase plant cover, sequester more soil C, reduce soil erosion and environmental contamination of groundwater supplies. Soil scientists and engineers at Michigan State University developed soil water retention systems that retained soil water and nutrients in the root zone of sandy soils, nearly 45 years ago. Although that older hot asphalt installation method had been successfully tested on sandy soils in 6 states and in seven climatic regions globally, it demanded a new and long-term soil installation technology.

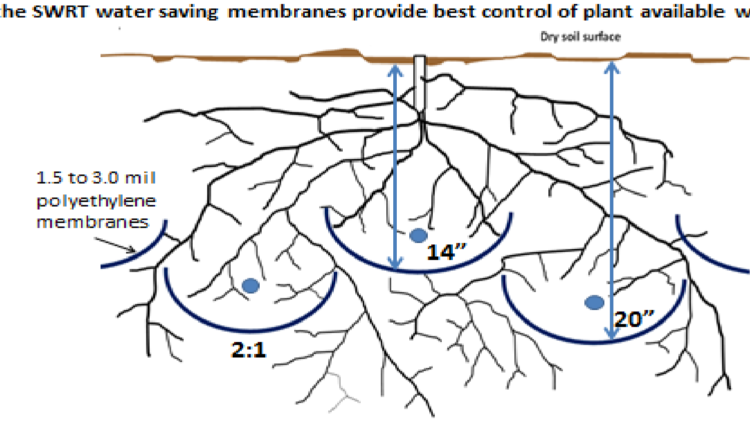
The new SWRT technology overcomes the inadequate soil aeration within the root zones of soils equipped with asphalt water retention barriers, as well as several technical and environmental aspects of developing, transporting and successfully installing these hot cation emulsions of liquid asphalt (Smucker and Basso, 2014). These new membrane configurations,

Figure 1, are engineered to collect and retain water in plant root zones where the rain falls. These impermeable polymer membranes are exclusively designed and spatially installed for maximum water retention with built-in auto drainage during excessive rainfall, yet providing plants with optimal availability of soil water, nutrients and oxygen.

Improved subsurface water retention capacities are being tested. SWRT-based enhancements of water holding capacities by sandy soils are being analyzed for strategic spatial variability among different textural classes of sands which control the depths and distributions of plant roots. Properly installed water retention membranes greatly increase water-use-efficiency, plant nutrient uptake, plant growth and productivity, requiring fewer additions of supplemental irrigation and nutrients. The SWRT approach should be combined with drought tolerant hybrids, best crop and soil management practices, appropriate seed storage technologies, including reliable and competitive pricing of commodity transportation, and local financing of regionally grown food and fiber crops.

The principal water conservation advantage of the SWRT approach, compared to conventional farming of coarse-textured soils, is the long-term (~200 years) contribution to sustainable agriculture by maintaining optimal water and nutrients in the rhizospheres of plants immediately following membrane installation. Current estimates for the cost of SWRT membranes across a landscape in the USA, range from $1,800 to $2,200 per acre. Although the initial cost may appear to be high, SWRT induced plant production increases provide brief return on investment (ROI) ranging from 2 to 5 years, depending upon crop and climate conditions. Additionally, a single investment of this **long-term zero-maintenance water conservation technology requires no maintenance.** Installation rates for the SWRT water and nutrient retention systems are expected to approach 3-4 hectares (6-8 acres) per day for each SWRT membrane installation machine. Therefore, literally tens of thousands of these membrane installation cultivator tools need to be manufactured before sand and sandy loam soils are converted into sustainable agricultural production fields across the USA and globally.

Fig. 1. SWRT water saving membranes are contoured engineered high density polyethylene (HDPE) films strategically spaced below plant root zone with space available for unlimited root growth AND internal drainage during excess rainfall. Additions of John Deere Subsurface Drip Irrigation (SDI) pipes (●) 10 cm above the SWRT water saving membranes provide best control of plant available water.



Strategic Goals: The principal goal of this strategic soil water technology is to transform lives and agricultural landscapes by improving sustainable production of food and cellulosic biomass. Following the initial MIC prototype, new commercial MICs are being manufactured to install fail-safe water retention interceptor membranes at pre-described soil depths for most efficient water/nutrient retention. Internal drainage rates and properly oxygenated root zones have been field tested in four states and five countries. **Deliverables** when SWRT water conservation practices are adopted:

- At least 2 billion hectares (~5 billion acres) of new highly permeable soils across the Earth's surface could be converted into highly productive food and sustainable biomass production systems conserving 40 to 60% of irrigation water.
- Currently irrigated 0.91 million hectares (2 million acres) of sandy soils in Michigan, plus at least 125 million hectares (275 million acres) of sandy soils and millions of sandy knolls among the best soils await improvement by SWRT membranes, across the USA.
- SWRT improvements will increase production profits while stabilizing or possibly reducing local and possibly global market prices for basic food and fiber supplies.
- Applying SWRT to increase production for low income farms located on sand soils will reduce the number of people experiencing annual poverty.
- SWRT enhancements can increase incomes 3 to 4-fold among 3 billion small farmers experiencing extreme poverty, globally.
- SWRT enhancement of nutritious food production, raised locally, will reduce transport and distribution costs for essential food and fiber products.
- SWRT enhancement of local food production will greatly reduce the nearly 31,000 daily deaths related to hunger and hunger-related illnesses.
- SWRT reductions in drought insurance premiums will become available for producers experiencing fewer crop losses.
- SWRT membrane improved sands will increase land prices for agricultural soils as well as residential subdivisions.

Past and Potential Impacts of SWRT: Initial field tests conducted on water retention technologies installed in sand soils have increased production by 28 to 405% in various cropping systems which increased the number of crops per year from 1 to 3 crops. In Michigan, green bell pepper and cucumber yields increased 20 and 24% and potato yields rose 42% on SWRT improved soils requiring 40 to 60% less water. During the 2012 and 13 crop years, maize production on irrigated SWRT converted sandy soils was 268 bushel of maize grain per acre, 76% greater than irrigated maize without SWRT membranes and 11-fold more than nonirrigated controls. Combined grain and stover biomass was doubled following the installation of SWRT membranes below the root zone. These extraordinary yield increases for row crops and vegetables enable farmers to recover the full cost of water retention membrane installation after 2 years for peppers and 5 to 6 years or corn and cucumber production increased following installation.

Current laboratory and field research including prototype development includes the manufacturing of multiple installation devices of SWRT membranes that increase and sustain food and cellulosic biomass production, reduce groundwater contamination, increase the bioremediation of contaminated soils at industrial sites and the sequestration of carbon by marginal soils worldwide. Research scientists at universities, in government agencies and industries can establish SWRT-based field test sites for identifying promising drought-tolerant cultivars. Michigan State University Technology is available to discuss licensing agreements with regional, national and international corporations in the production of specific polymer materials and the manufacturing of MIC implements for installing these subsurface and long-term revolutionary water conservation materials. During the 2012-15 growing seasons, field experiments were established on Texas sandy soils planted to cotton, producing 5 additional bales of lint on nonirrigated SWRT vs. controls. In Michigan, irrigated crops of green peppers, SWRT increased yield 20% and cucumbers, SWRT increased yields 24% (Smucker, et al., 2017a). Narrow row maize grown on irrigated SWRT improved sands increased grain yield 76% over irrigated controls and 238% over none irrigated controls (Smucker, et al, 2017b). Soybean grown on irrigated SWRT improved sand increased yields 143% over non-irrigated control sands. The amazing increases in maize production on SWRT improved sands irrigated/fertigated in Michigan, during the 2014 and 2016 season produced an average of 326 bu/a (20.4 MT/ha) of grain (Smucker, et al., 2017b). This 134% (2.3-fold) increase over nonirrigated controls and 45% increase over irrigated controls returned additional funds at rates which totally covered the cost of membrane installation. Greater production will generate additional employment opportunities and an entirely new manufacturing industry that will change lifestyles and landscapes across the USA and globally. Furthermore, when SWRT coupled with SDI have been applied to all highly permeable soils, currently planted to maize and soybean rotations, at least $10 billion additional exports would become available.

g. **<u>Ten Ecosystem Services Offered by SWRT Conversions of Marginal Sand Soils</u>**