Assessing climate change impacts on soil salinity development with proximal and satellite sensors

Dennis L. Corwin
USDA-ARS
U.S. Salinity Laboratory
Riverside, California
Dennis.Corwin@ars.usda.gov
Bio ▸

Elia Scudiero
Department of Environmental Sciences
University of California
Riverside, California and
USDA-ARS, U.S. Salinity Laboratory
Riverside, California
Elia.Scudiero@ars.usda.gov
Bio ▸

Introduction

Agriculture is directly linked to climate change. Crop yield, water use, biodiversity, and soil health are directly affected by changes in the climate. Changes in the frequency and intensity of rainfall, temperature, and other extreme weather events will impact agricultural productivity, with the net effect of climate change on world agriculture most likely negative. Even though some regions and crops may benefit, many will not. Increases in atmospheric CO_2 will likely increase organic matter in soil and stimulate growth and improve water use efficiency in some crops, but heat waves, droughts, and flooding may dampen these potential yield increases. Furthermore, indirect climatic impacts such as greater competition by insects, weeds, and pathogens will decrease yield.

A recent paper by Brevik (2013) provides an informative review of the potential impact of climate change on soil properties and processes influencing plant productivity. Recent research has indicated that increased atmospheric CO_2 may not have as large an influence on plant productivity as once thought (Poorter and Navas, 2003; Zavaleta et al., 2003; Long et al., 2005; Körner, 2006; Jarvis et al., 2010; Zaehle et al., 2010). Ostensibly, increasing ozone levels may counteract the CO_2 effect (Long et al., 2005). Furthermore, the negative effects of increased temperature on plant growth may also counteract the CO_2 effect (Jarvis et al., 2010). Nitrogen (N) and phosphorus (P) limitations may also play a role. Niklaus and Körner (2004) found in a long-term, elevated-CO_2, grasslands experiment that after two years N and P were limiting biomass production expected from high CO_2 levels. There is also evidence that increased CO_2 levels may not necessarily increase C sequestration. Carney et al. (2007) found that due to increased microbial activity soil organic C levels declined under increased CO_2 levels. Temperature can also exacerbate matters. Increased temperatures cause increased CO_2 to be released from soil into the atmosphere, which increases ambient temperatures and continues until a new equilibrium is reached.

Even though global projections of climate change paint a dark picture with respect to extreme weather event occurrence and frequency and as many negative as positive potential impacts on agriculture are likely to occur, global projections have less associated uncertainty than regional predictions; consequently, effort is needed to monitor regional- and local-scale impacts. Continuous monitoring of climate change impacts on soil health and condition are essential to identify and quantify trends requiring the development of management strategies that will ameliorate detrimental impacts to crop productivity, especially in highly productive agricultural areas. The sustainability of agriculturally productive arid and semi-arid areas, such as California's San Joaquin Valley, depends upon a timely knowledge of the geospatial impacts that changes in climate patterns will have on soil properties influencing crop yield because of the predicted susceptibility of arid regions to extended and recurring droughts.

One notable soil property that is seldom mentioned by scientists when speaking about the impacts of climate change is soil salinity. This may be due to the fact that salinity is among the most spatially complex and temporally dynamic soil properties, with a coefficient of variation generally over 80-90% (Corwin et al., 2003) or it may be due to the fact that, unlike many other soil properties, it can be easily managed by the addition of water to leach salts. As long as the water source is plentiful and sufficiently good in quality and adequate drainage occurs, then salinity is generally not regarded as a problem of concern. However, if droughts become more frequent as climatologists predict, then salinity will likely become an issue of concern.

Soil salinity is a worldwide concern in arid and semi-arid agricultural areas. Salt-affected soils are estimated to comprise 23% of the cultivated land, approximately 3.5×10^8 ha (Massoud, 1981). In actuality, however, there are no directly measured global inventories of soil salinity. All known global inventories of soil salinity, and with only one exception, all known regional-scale inventories are gross approximations based on qualitative and not quantitative data (Lobell, 2010; Lobell et al., 2010).

Soils are spatially heterogeneous. This is particularly true for soil salinity, which is a dynamic soil chemical property exhibiting complex spatial patterns that vary over time. These complex spatio-temporal patterns make inventorying and monitoring salinity at field scale or larger spatial extents especially challenging. Techniques that provide rapid, reliable, and detailed spatio-temporal geo-referenced measurements of salinity at multiple scales are crucial for inventorying, monitoring, and managing soil salinity impacted by changes in climate patterns as well as by anthropogenic salinization processes associated with irrigated agriculture. The objective of this article is to look at the impact climate change has on selected agricultural areas experiencing weather pattern changes (i.e., California's San Joaquin Valley and Minnesota's Red River Valley) through the use of proximal and satellite sensors to evaluate salinity development and its implications on agricultural sustainability.

Approach

Since 1980 the U.S. Salinity Laboratory (USSL) within USDA-ARS has been the center of research related to mapping and monitoring soil salinity at field scale and larger spatial extents using electromagnetic induction (EMI) and electrical resistivity (ER) (Corwin, 2008). Over that time USDA-ARS scientists and scientists visiting USSL have developed three approaches for mapping soil salinity at three distinct spatial scales: field (< 3 km^2), landscape (3-10 km^2), and regional (10-10^6 km^2) scales. Each approach is based on the measurement of apparent soil electrical conductivity (EC_a), which is the bulk conductivity of the soil and is a complex measurement influenced by a variety of soil properties, including salinity, texture, water content, bulk density, clay minerology, and organic matter. The three approaches are: (1) EC_a-directed soil sampling (field scale), (2) ANOCOVA approach (landscape scale), and (3) satellite imagery combined with EC_a-directed soil sampling (regional scale). Scientists at the USSL have developed an integrated system for the measurement of field-scale spatial variability, particularly salinity, consisting of (1) guidelines and protocols for the characterization of soil spatial variability using EC_a-directed soil sampling presented by Corwin and Lesch (2003, 2005) and protocols specific to soil salinity assessment presented by Corwin and Lesch (2013), (2) mobile EC_a measurement equipment (Rhoades, 1993), and (3) sample design software (Lesch et al., 2000). The integrated system and procedure for mapping soil salinity at field scale is schematically illustrated in Figure 1.

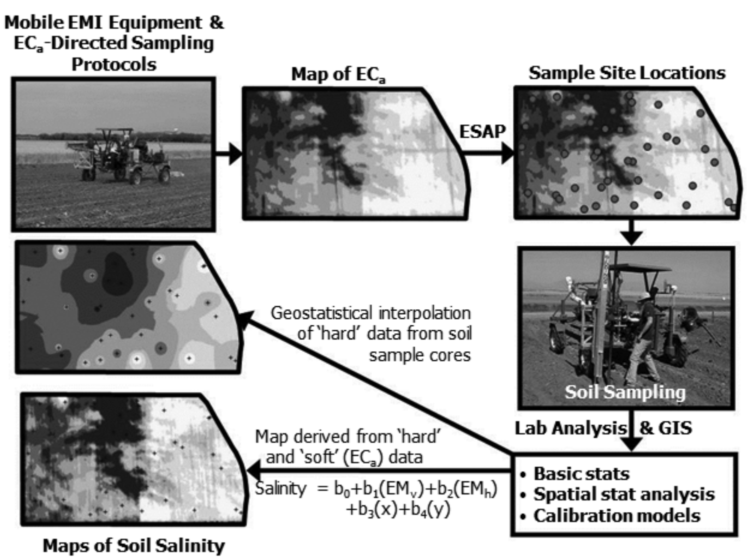


Figure 1. Schematic of the integrated system to assess field-scale soil salinity using apparent electrical conductivity (EC_a) directed soil sampling protocols, a mobile electromagnetic induction (EMI) rig, ESAP software, and geographic information system (GIS). Source: Corwin (2015) with permission. EM_v refers to the measurement of EMI in the vertical coil configuration and EM_h refers to measurement of EMI in the horizontal coil configuration.

Because EC_a is influenced by a variety of edaphic properties, an understanding and interpretation of geospatial EC_a data can only be obtained from ground-truth measures of soil properties that correlate with EC_a from either a direct influence or indirect association at the particular site of interest. For this reason, geospatial EC_a measurements are used as a surrogate of soil spatial variability to direct soil sampling when mapping soil salinity at field scales and larger spatial extents and are not generally used as a direct measure of soil salinity except in instances where salinity is dominating the EC_a measurement.

The protocols for an EC_a survey to measure soil salinity at field scale include 8 basic elements: (1) EC_a survey design, (2) geo-referenced EC_a data collection, (3) soil sample design based on geo-referenced EC_a data, (4) soil sample collection, (5) physical and chemical analysis of pertinent soil properties, (6) spatial statistical analysis, (7) determination of the dominant soil properties influencing the EC_a measurements at the study site, and (8) GIS development. A detailed discussion of the protocols for mapping soil salinity at field, landscape, and regional scales can be found in Corwin and Scudiero (2016).

Two agricultural regions were selected to monitor the impact of climate change on salinity development: California's San Joaquin Valley (SJV) and Minnesota's Red River Valley (RRV). The altered weather patterns differ in the two agricultural regions, with a 5-year drought in the SJV (2011-2016) and prior to 2010 nearly two decades of above average rainfall for the RRV. The detailed procedures for measuring and monitoring salinity development for SJV and RRV are found in the papers by Corwin et al. (1999), Corwin (2012), and Scudiero et al. (2014, 2015, 2017) for the SJV and Lobell et al. (2010) for the RRV. The multi-scale EC_a-directed soil sampling methodologies described in Corwin and Scudiero (2016) were the basis of the SJV and RRV studies.

Results and Discussion

The following two case studies show the impact of climate change on soil salinity development for approximately 900,000 ha of the west side of California's San Joaquin Valley (WSJV) and Kittson County (284,000 ha) in Minnesota's Red River Valley (RRV).

West Side of California's San Joaquin Valley

The California drought, resulting from changes in climate patterns, has exacerbated soil salinity levels. Three studies provide insight into the impact of climate change on soil salinity accumulation in the WSJV. Each study used the described EC_a-directed soil sampling methodology as a basis for monitoring soil salinity in the root zone (i.e., 0-1.2 m depth increment) at three different scales: field, multiple-field or landscape, and regional scales.

Recent studies by Corwin and his colleagues have shown that reuse of saline irrigation water can reclaim saline-sodic soil (Corwin et al., 2006, 2008). In a long-term, field-scale study of the reclamation of a saline-sodic soil using 3-5 dS m^{-1} drainage water on a 32.4-ha field located on Westlake Farm in WSJV

Corwin (2012) found that from 1999 to 2009 there was steady improvement in soil quality due to decreases in salts, Mo, B, and sodium adsorption ratio (SAR), resulting from leaching. Sodic soils have very low permeability due to the dispersive effect of Na on clay particles, which causes the clay to flocculate reducing the hydraulic conductivity. The decrease in salinity, Mo, B, and SAR was attributed to the presence of Ca in the low quality drainage water used for reclamation. The Ca displaced the Na on clay exchange sites causing the soil particles to aggregate thereby improving the permeability. The improved soil quality from 1999 to 2009 is shown in Figure 2. However, in 2011 when the California drought began there was no fresh or drainage water available for irrigation; consequently, the field was left fallow, receiving only rainfall. Within 18 months after irrigation with drainage water had ceased and the field was left fallow the levels of salinity (i.e., electrical conductivity of the saturation extract in dS m^{-1} abbreviated as EC_e), Mo, B, and SAR returned to nearly their original 1999 levels and in some instances the levels were even higher (compare 1999 to 2011 for EC_e, SAR, B, and Mo in Figure 2). This field is typical of fields located in the WSJV near the San Joaquin River where the soils are generally fine textured and the water table is perennially shallow (i.e., within 2 m of the soil surface). It can be expected that all fallow lands in the WSJV with shallow water tables would experience a similar increase in salinity and trace elements due to the capillary rise effects from the shallow water table causing the upward movement of salts and trace elements.

A comparison of salinity levels for 2400 ha of the former Broadview Water District in the WSJV from 1991 to 2013 shows an increase in soil salinity has occurred (Figure 3). In February 2005 Broadview Water District land became fallow as water rights were sold to Westlands Water District (Wichelns and Cone, 2006). Figure 3a shows a map of salinity for Broadview Water District in 1991 obtained from the EC_a-directed soil sampling approach of Corwin et al. (1999) and Corwin and Lesch (2003, 2005). Figure 9b shows the increase in soil salinity from 1991 to 2013 as indicated by the percentage of the total acreage falling within salinity classes of 0-2, 2-4, 4-8, 8-16, and > 16 dS m^{-1}. From 1991 to 2013 the 2-4 dS m^{-1} salinity class showed a substantial decrease from 27% to 3% while the 8-16 dS m m^{-1} class significantly increased from 3% to 33%. The field average soil salinity increased by 43% within the root zone during this time period. Essentially, all the non-saline and slightly saline soils in 1991 have become moderately (4-8 dS m^{-1}) and strongly saline by 2013, which is primarily due to the upward movement of salts from the shallow water table resulting from capillary rise.

At regional-scale there are strong indications that soil salinity for the root zone (0-1.2 m) has increased for the WSJV over the past three decades. Estimates of salt-affected soils (i.e., EC_e > 4 dS m^{-1}) for the WSJV calculated from data presented by Backlund and Hoppes (1984) were approximately 4.5 x 10^5 ha for 1984. Scudiero et al. (2014, 2015, 2017) estimated salt-affected soils for WSJV were approximately 5.5 x 10^5 ha for 2013. The increased salinization of the WSJV from 1984 to 2013 may or may not be attributed solely to changes in climate patterns since there are no reliable estimates of salt-affected soils for

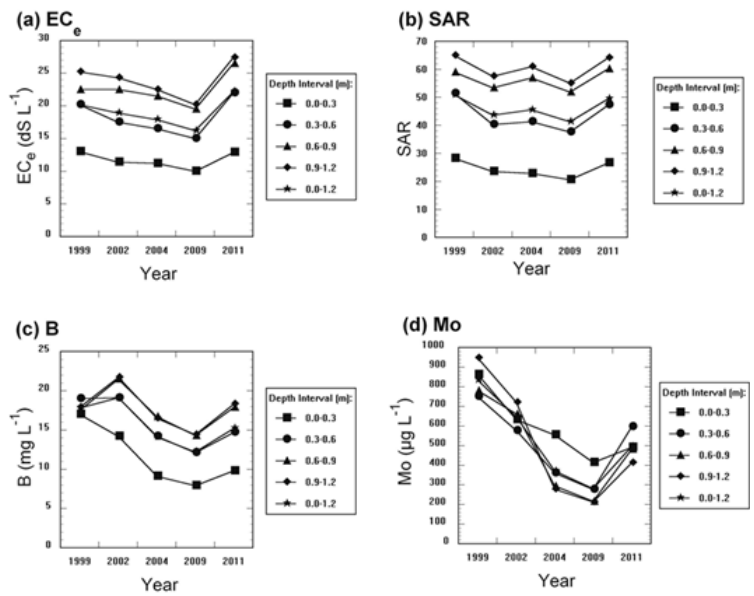
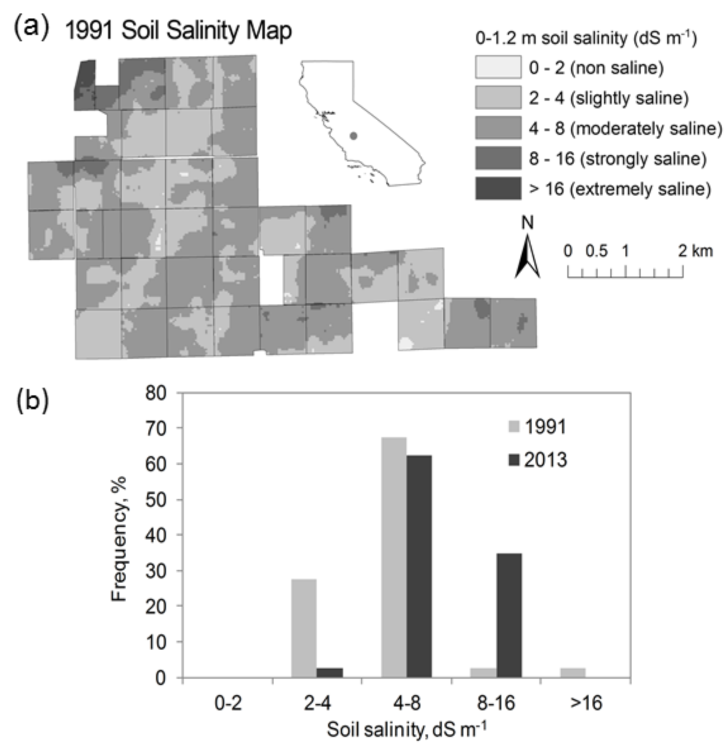


Figure 2. Graphs showing the improvement in soil quality from 1999 to 2009 for (a) salinity (EC_e), (b) sodium adsorption ratio (SAR), (b) boron (B), and (d) molybdenum (Mo) followed by the return to original levels by 2011 after drought interrupted further application of drainage water to reclaim the saline-sodic soil. Source: Corwin (2012) with permission.



(b) histogram of soil salinity categories as predicted for 2013 using the soil salinity assessment model of Scudiero et al. (2014).

WSJV in 2011 when the California drought began. Nevertheless, salinization of the WSJV is occurring from 1984 to 2013.

The implications of the drought and its impact on soil salinity are self-evident. Less available fresh water for irrigation necessitates a shift to impaired water (e.g., municipal, ground, and drainage waters) use as an alternative source of water and to

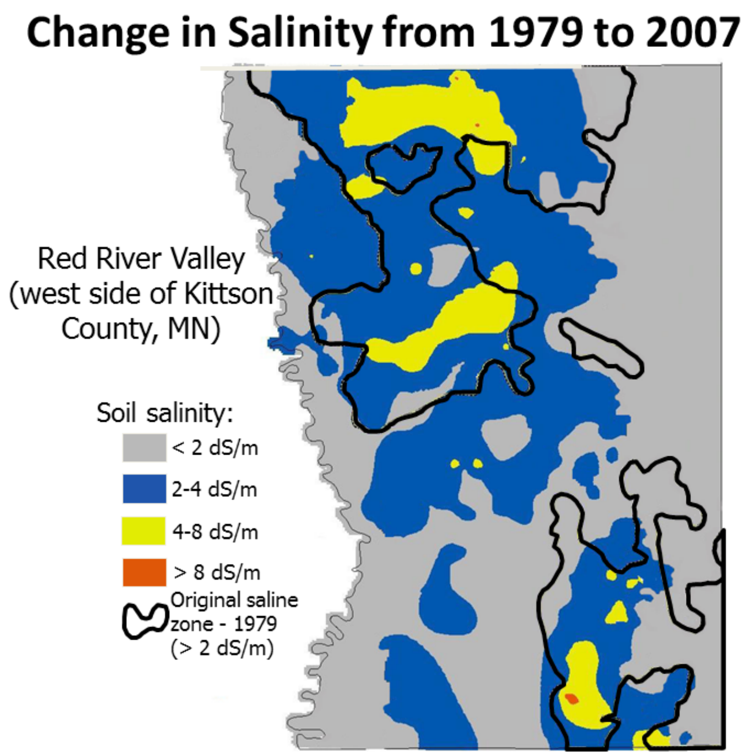


Figure 4. Map of the change in soil salinity from 1979 to 2007 for the west side of Red River Valley's Kittson County in northwest Minnesota. Source: Unpublished data from Lobell et al. (2010).

high efficiency irrigation systems (e.g., drip, buried drip, and micro-sprinkler irrigation systems). Concomitantly, low quality water reuse management guidelines are needed. The potential accumulation of soil salinity in the root zone requires spatial knowledge of soil salinity levels for site-specific management of soil salinity at farm levels to optimize scarce water resources, for the development of water use and regulatory guidelines at state and federal levels, and for assessing climate change impact trends at global levels. To obtain the necessary spatial soil salinity information a multiple-scale infrastructure is needed.

Minnesota's Red River Valley

Unlike WSJV, the RRV, which is located in eastern North and South Dakota and western Minnesota, is experiencing rainfall that has exceeded the average rainfall in 17 of the last 20 years prior to 2007. The increased rainfall plus a shift in crops from deeper rooted to more shallow rooted crops has resulted in rising water tables. Because of the extremely high clay content of the soil in many areas of the RRV (e.g., Kittson County), the capillary rise of moisture from shallow water tables results in the accumulation of salt in the root zone. In addition, salts accumulate in the RRV due to topography. An upslope recharge causes a downslope discharge in downslope areas where a shallow layer of low permeability exists. Lobell et al. (2010) assessed the level of impact of climate change on salinity development in Kittson County located on the north border of Minnesota in the RRV. Figure 4 indicates how salinity has changed from 1979 to 2007 in western Kittson County of Minnesota's RRV. Areas within the thick solid black line indicate zones of salinity > 2 dS m^{-1} obtained from a 1979 salinity survey conducted by hand by the Soil Conservation Service, which is currently the Natural Resource Conservation Service. The gray, blue, yellow and red areas indicate salinity levels of < 2, 2-4, 4-8, and > 8 dS m^{-1} from the approach used by Lobell et al. (2010) combining MODIS imagery with ground-truth salinity from EC_a-directed soil sampling. From 1979 to 2007 there was an approximately 30% increase in agricultural land with soil salinity greater than 2 dS m^{-1}.

Conclusions

There is strong evidence suggesting that climate change patterns are impacting the salinization of agricultural lands in the SJV and RRV. From the field-scale observations for Westlake Farm, landscape-scale observations for Broadview Water District, and regional-scale estimates of salinity for the WSJV it is surmised that significant increases in root-zone soil salinity are occurring due to impacts from extended drought conditions. Even though the occurrence of above average annual rainfall in northern California in 2016 ameliorated water scarcity conditions that existed in California's SJV from 2011-2015, there are clear indications that salt accumulation in soil is occurring and will likely continue to occur on lands with the right conditions (i.e., fallow, shallow water table, and fine-textured soil). In contrast, the RRV has experienced excessive rainfall, which has contributed significantly to a rise in water table and subsequent salinization of the soil profile.

The impact of climate change on salinization has been previously overlooked and needs to be monitored. As a consequence of changes in climate patterns, salt accumulation will most likely occur in irrigated agricultural areas around the world subjected to extended drought conditions where shallow water tables and fine textured soils exist and in areas subjected to extensive rainfall where salinity accumulates due to upslope recharge and downslope discharge or where shallow water tables and fine textured soils exist.

Acknowledgements

The authors acknowledge the assistance of numerous technicians and field personnel whose hard work and technical capabilities resulted in the success of the field studies in the SJV and RRV that rendered the data for this article and numerous previous scientific publications. These individuals include Scott Lesch, Kevin Yemoto, Clay Wilkinson, Wes Clary, Nahid Vishteh, Jack Jobes, Jim Wood, Jim Doolittle, Mike Ulmer, Keith Anderson, Manuel Matos, and Matt Baltes.

References

Backlund, V.L., Hoppes, R.R., 1984, Status of soil salinity in California. Calif. Agric., 38(10), 8-9.

Brevik, E.C., 2013, The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agric., 3, 398-417.

Carney, K.M., Hungate, B.A., Drake, B.G., Megonigal, J.P., 2007, Altered soil microbial community at elevated CO_2 leads to loss of soil carbon. Proc. Natl. Acad. Sci. USA, 104, 4990-4995.

Corwin. D.L., 2008, Past, present, and future trends of soil electrical conductivity measurement using geophysical methods. In: B.J. Allred, J.J. Daniels, and M.R. Ehsani (eds.) Handbook of Agricultural Geophysics, Chapter 2. CRC Press, Boca Raton, FL, pp. 17-44.

Corwin, D.L., 2012, Field-scale monitoring of the long-term impact and sustainability of drainage water reuse on the west side of California's San Joaquin Valley. J. Environ. Monitoring, 14(6), 1576-1596.

Corwin, D.L., 2015, Use of advanced information technologies for water conservation on salt-affected soils. In: T.G. Mueller and G.F. Sassenrath (eds.) GIS Applications in Agriculture, Volume 4: Conservation Planning, Chapter 8. Taylor and Francis Group, Boca Raton, FL, pp. 119-150.

Corwin, D.L., Carrillo, M.L.K., Vaughan, P.J., Cone, D.G., Rhoades, J.D., 1999, Evaluation of a GIS-linked model of salt loading to groundwater. J. Environ. Qual., 28(2), 471-480.

Corwin, D.L., Kaffka, S.R., Hopmans, J.W., Mori, Y., Lesch, S.M., Oster, J.D., 2003, Assessment and field-scale mapping of soil quality properties of a saline-sodic soil. Geoderma, 114, 231-259.

Corwin, D.L., Lesch, S.M., 2003, Application of soil electrical conductivity to precision agriculture: Theory, principles, and guidelines, Agron. J., 95, 455-471.

Corwin, D.L., Lesch, S.M., 2005, Characterizing soil spatial variability with apparent soil electrical conductivity: I. Survey protocols, Comput. Electron. Agric., 46 (1-3), 103-133.

Corwin, D.L., Lesch, S.M., 2013, Protocols and guidelines for field-scale measurement of soil salinity distribution with EC_a-directed soil sampling. J. Environ. Eng. Geophysics 18(1), 1-25.

Corwin, D.L., Lesch, S.M., Oster, J.D., Kaffka, S.R., 2006, Monitoring management-induced spatio-temporal changes in soil quality through soil sampling directed by apparent electrical conductivity. Geoderma, 131, 369-387.

Corwin, D.L., Lesch, S.M., Oster, J.D., Kaffka, S.R., 2008, Short-term sustainability of drainage water reuse: Spatio-temporal impacts on soil chemical properties. J. Environ. Qual., 37, 8-24.

Corwin, D. L., Scudiero, E., 2016, Field-scale apparent soil electrical conductivity. In: Logsdon, S. (ed.) Methods of Soil Analysis Online, vol. 1. SSSA, Madison, WI. doi:10.2136/methods-soil.2015.0038.

Jarvis, A., Ramirez, J., Anderson, B., Leibing, C., Aggarwal, P., 2010, Scenarios of climate change within the context of agriculture. In: M.P. Reynolds (ed.) Climate Change and Crop Production. CPI Antony Rowe, Chippenham, UK, 2010, pp. 9-37.

Körner, C., 2006, Plant CO2 responses: An issue of definition, time and resource supply. New Phytol., 172, 393-411.

Lesch, S.M., Rhoades, J.D., and Corwin, D.L., 2000, ESAP-95 Version 2.10R: User and Tutorial Guide. Research Rpt. 146. USDA-ARS, U.S. Salinity Laboratory, Riverside, CA.

Lobell, D.B., 2010, Remote sensing of soil degradation: Introduction. J. Environ. Qual., 39, 1-4.

Lobell, D.B., Lesch, S.M., Corwin, D.L., Ulmer, M.G., Anderson, K.A., Potts, D.J., Doolittle, J.A., Matos, M.R., Baltes, M.J., 2010, Regional-scale assessment of soil salinity in the Red River Valley using multi-year MODIS EVI and NDVI. J. Environ. Qual., 39, 35-41.

Long, S.P., Ainsworth, E.A., Leakey, A.D.B., Morgan, P.B., 2005, Global food security. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields. Philos. Trans. R. Soc. Lond. B Biol. Sci., 360(1463), 2011–2020.

Massoud, F.I., 1981, Salt Affected Soils at a Global Scale and Concepts for Control. Technical Paper, FAO Land and Water Development Div., Food and Agriculture Organization of the United Nations, Rome, Italy.

Poorter, H., Navas, M-L., 2003, Plant growth and competition at elevated CO2: On winners, losers and functional groups. New Phytol., 157, 175-198.

Rhoades, J.D., 1993, Electrical conductivity methods for measuring and mapping soil salinity. In: D.L. Sparks (ed.) Adv. Agron., vol. 49. Academic Press, San Diego, CA, pp. 201-251.

Scudiero, E., Corwin, D.L., Anderson, R.G., Yemoto, K., Clary, W., Wang, Z., Skaggs, T.H., 2017, Remote sensing is a viable tool for mapping soil salinity in agricultural lands. Calif. Agric. 71, 231-238.

Scudiero, E., Corwin, D.L., Skaggs, T.H., 2015, Regional-scale soil salinity assessment using Landsat ETM+ canopy reflectance. Remote Sens. Environ., 169:335-343.

Scudiero, E., Skaggs, T.H., Corwin, D.L., 2014, Regional scale soil salinity evaluation using Landsat 7, Western San Joaquin Valley, California, USA. Geoderma Regional, 2-3, 82-90.

Wichelns, D., Cone, D., 2006, A water transfer and agricultural land retirement in a drainage problem area. Irrig. Drain. Syst., 20, 225-245.

Zaehle, S., Friedlingstein, P., Friend, A.D., 2010, Terrestrial nitrogen feedbacks may accelerate future climate change. Geophys. Res. Lett. 37, L01401, doi:10.1029/2009GL041345.

Zavaleta, E.S., Shaw, M.R., Chiariello, N.R., Thomas, B.D., Cleland, E.E., Field, C.B., Mooney, H.A., 2003, Grassland responses to three years of elevated temperature, CO2, precipitation, and N deposition. Ecol. Monogr., 73, 585-604.

Author Bios

Dennis Corwin
USDA-ARS
U.S. Salinity Laboratory
450 West Big Springs Road
Riverside, California 92507-4617
Phone: 951-369-4819

Dennis.Corwin@ars.usda.gov

Dr. Dennis Corwin is a Research Soil Scientist with the Water Reuse & Remediation Research Unit, USDA-ARS, U.S. Salinity Laboratory in Riverside, CA. His expertise is (i) modeling and mapping of nonpoint source (NPS) pollutant distributions in the vadose zone using geographic information systems (GIS) and remote sensing techniques; (ii) measuring, monitoring, and mapping of soil salinity at field and landscape scales; and (iii) characterization of the spatial variability of soil physical and chemical properties using geophysical methods (i.e., electrical resistivity and electromagnetic induction) for applications in NPS pollutant transport modeling in the vadose zone, soil quality assessment, precision agriculture, and monitoring management-induced change from degraded water reuse. He has served as associate editor (2000-2001), technical editor (2002-2007), and Editor (2008-2013) of the Journal of Environmental Quality. He is the recipient of the Cox Visiting Professor Award from Stanford University (2000) in recognition of his pioneering contribution to the application of GIS to the modeling of NPS pollutants in the vadose zone. Dr. Corwin is a Fellow of the Soil Science Society of America and the American Society of Agronomy.

Elia Scudiero
Department of Environmental Sciences,
University of California
Riverside, California and USDA-ARS
U.S. Salinity Laboratory
450 West Big Springs Road
Riverside, California 92507-4617
Phone: 951-369-4847
Elia.Scudiero@ars.usda.gov

Elia Scudiero gained his MSc in Environmental Sciences and Technologies, in 2009, and his PhD in Crop Science in 2013, from the University of Padua, Italy. His research focuses on increasing the efficiency of farming systems by improving the spatial awareness of agronomic practices through farm- to regional-scale soil mapping and modeling of crop-soil interactions with proximal and remote sensing. More generally, his research accomplishments include the use of field measurements, remote sensing, and spatiotemporal modeling in the study of soil and crop processes.