Report: Soil Moisture Education Workshops

Wednesday, Nov 7 – Lubrecht Experimental Forest, Montana
Friday, Nov 9 – Stillwater County Fairgrounds, Columbus, Montana

Compiled by Kevin Hyde, Montana Climate Office and Madison Boone, Institute on Ecosystems

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Soil Moisture Education Workshops: Executive Summary

The technology to measure soil moisture through the soil profile at a single point in space is well established. However, there is little guidance on how to transfer knowledge, practices, and interpretation (including inference area) of soil moisture measurement to support management decisions. We implemented soil moisture workshops in Montana to explore educational approaches for effective technology transfer to the broad range of current and potential users of soil moisture information and applications. We structured the workshops to address the following questions:

- Why measure soil moisture in Montana?
- What are the fundamental principles of soil water storage and flow?
- How do we measure soil moisture?
- What is the status of soil moisture measurement and interpretation in Montana?
- What are the potential applications of soil moisture information?
- What do users of soil moisture information need?

We defined three primary objectives for the workshops: Present the information to be accessible to the wide audience without compromising core theory and knowledge. Use interactive, active-learning education models. Provide a forum to capture the questions, feedback, and needs of potential users. To meet these objectives the teaching team was assembled based on expertise, interest in and involvement with cooperative education, and desire to work as a team to work together to build an integrated education structure and flow.

Local and state representatives set perspectives for the workshops, emphasizing need for soil moisture information to monitor effects of adaptations to changing climate and drought response, improve success when producers seek insurance relief from weather-related losses, and to support statewide planning and budgeting. Instructors coordinated content integrated across concepts of fundamental soil physics, measurement technologies, and determination of plant available water for management applications. The state of local soil moisture measurement and interpretation was coupled with satellite measures of soil moisture to highlight current and potential statewide extrapolation (inference space). Theory and data practices were put in the context of the value of soil moisture data in forest management, evaluating water use efficiency, nutrient management, and precision agriculture.

Participants provided feedback on current use of soil moisture information, development needs, and suggested next steps in soil moisture education and monitoring in Montana. The majority of workshop participants reported that they currently used soil moisture information in their decision-making process, applied mostly to water management programs. Suggestions for monitoring improvement included easier access to data, need for more monitoring stations, and creation of relevant tools and strategies to use soil moisture information. Recommendations on next steps with soil moisture education emphasized more educational events, helping user base understand value of soil moisture data and applications, and outreach to producers and the general public.

Extended products are anticipated from these workshops which are likely to be valuable beyond Montana. Discussion is already underway to condense the workshop content into a 2-3 hour webinar, and to explore development of educational resources for extension agents. The suggestions for improvement of monitoring networks is under review by the Montana Climate Office as guidance for developing plans for network expansion and applications of soil moisture information.

Introduction and Workshop Overview

Need to manage water resources, agriculture, and ecological systems under changing climate drives rapid expansion of soil moisture monitoring networks across the US and globally. The technology to measure moisture through the soil profile at a single point in space is well established (Robinson et al., 2008), with new point measurement devices and data transfer mechanisms couple with satellite remote sensing technology to extrapolate point measurements, potential applications are rapidly expanding (Peng et al., 2017). Peer-reviewed literature emphasizes research applications of soil moisture measurement (Seneviratne et al., 2010; Vereecken et al., 2014) with little guidance on how to transfer knowledge, practices, and interpretation of soil moisture measurement to support management decisions.

When tasked to implement soil moisture workshops in Montana, we interpreted this as an opportunity to address the need for guidance on effective technology transfer to the broad range of current and potential users of soil moisture information – ranchers, farmers, public officials, extension service agents, public and tribal land and resources managers, non-profit stewards, educators, students, and private citizens. We interpreted "soil moisture information" as the sum of understanding processes, technology, data interpretation, and applications. We structured the workshops to address the following questions:

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- What do users of soil moisture information need?

We defined three primary objectives for the workshops: Present the information to be accessible to the wide audience without compromising core theory and knowledge. Use interactive, active-learning education models. Provide a forum to capture the questions, feedback, and needs of potential users. To meet these objectives the teaching team was assembled based on expertise, interest in and involvement with cooperative education, and desire to work as a team to work together to build an integrated education structure and flow. Participants were encouraged to comment and ask questions throughout each workshop, interact during breaks, contribute during structured feedback sessions, and complete survey and feedback questionnaires (***Appendix 1***) at the end of each workshop. The final workshop structure integrated the guiding questions, the teaching team, and workshop objectives as presented in the workshop agenda in ***Appendix 2***. Given the size of Montana, two workshops were presented to support access for a broader range of individuals. The two locations also reflected different geographies and under interests across the two broadly different regions of Montana, forested mountains to the west and rangeland in the east. ***Appendix 3*** summarizes workshop locations, attendance, and affiliations.

Workshop Locations

We selected two locations, one in western (Lubrecht) and one in eastern Montana (Columbus). The first, to represent the different climate and more mountainous terrain and attract stakeholders from forestry, small farm market-garden agriculture and water managers in western Montana, and the second to attract large ranch livestock and crop producers as well as water managers from more historically arid portions of Montana characterized by grasslands and broad plains.

Summary of Presentations – In order presented

I. Why measure soil moisture in Montana (Jennifer Schoonen, Watershed Steward, Blackfoot Challenge; Maureen Davey, County Commissioner (retired), Stillwater County; , Michael Downey, Water Planning Section Supervisor, MT Department of Natural Resources and Conservation)

On the local level, watershed stewards seek tools to adapt agricultural practices and sustain productivity and livelihoods during persistent drought, and to provide measurable outcomes to monitor response to conservation practices, and to track drought conditions over time. They seek soil moisture monitoring to include in weekly irrigation water management reports, which also help irrigators plan seasonally for a potential drought year. County Commissioners recognize the value of local soil moisture monitoring to support agricultural decisions, especially related to relief from drought and other weather-related losses. State water planners seek a broad suite of water data and tools to support statewide assessment of water supply and drought conditions. Data are among the biggest drivers of project funding, and support the need to do a better job of communicating importance of water planning and drought preparedness to producers, scientists, and others.

II. Fundamentals of soil water storage and flow (Andres Patrignani, Assistant Professor in Soil Water Processes, Kansas State University, Department of Agronomy)

An introduction to core principles of soil physics began with describing the relationships between soil texture and structure, soil porosity, and relevance of macropores and micropores in soil water storage and soil water flow. The pore space between soil particles controls the potential volumetric water content and soil water storage. Adhesive and cohesive forces control interaction of water with soil particles, and is defined through the concept of soil matric potential, or the force that holds water against gravity to soil particles. A hands-on exercise to learn how to calculate the amount of plant available water in the soil profile was presented.

III. How to Measure Soil Moisture (Chris Chambers, Customer Service/Product Manager, METER Group, Inc.)

Many options are available for soil moisture sensing and measurement of volumetric water content. They offer tradeoffs in price and accuracy. Three sensor technologies are most commonly used: time-domain reflectivity (TDR), frequency domain reflectivity (FDR), and capacitance sensors. These technologies are based on the difference in between how water and mineral soil store and release electricity. Measurement of the difference leads to quantifying the volumetric water content. The quality of data primarily depends on the quality of installation and the fit of the calibration of the measurement device to the soil substrate, including soil texture, structure, and porosity.

IV. Status of soil moisture measurement and data interpretation in Montana (Kevin Hyde, Montana Mesonet Coordinator, Montana Climate Office)

The development of the Montana Mesonet adds 57 stations to the 26 soil moisture monitoring stations of the Soil Climate Analysis Network (SCAN) and the Snow Telemetry (SNOTEL) networks. The soil probe configuration of the Mesonet is consistent with the existing networks. Soil pits were assessed following modified USDA/NRCS guidelines. The pits were excavated and closed, and the moisture sensing probes installed following best practices to assure minimal effects from disturbance. Controlled volume soil samples collected at each probe depth were analyzed in the lab of the Montana Climate Office (MCO) to determine particle size distribution and to develop water retention curves, as the basis for determining plant available water. The MCO is developing methods to derive and teach meaningful interpretations of soil moisture to inform management decisions.

V. Application of SM data to derive plant available water (Lee Schmelzer, Agriculture and Natural Resources, 4-H Agent, Montana State University Extension Service, Stillwater County)

Real-time drought monitoring is essential for early detection and adaptive management to mitigate the negative impacts of drought on the people, economy, and ecosystems of Montana. While drought monitoring is critical to Montana's resource managers, it is hampered by a lack of data on a crucial drought indicator: plant available water, the amount of soil moisture currently in the profile which is available for plant uptake. This need can be met by building upon the existing capabilities of the Montana Mesonet. This monitoring system will provide resource managers with reliable information on the remaining reserves of plant available water enabling them to adapt their management strategies. By knowing early that plant available water is approaching critical minimum values, ranchers, facing the potential for reduced pasture, could make early arrangements to purchase hay or could sell cattle early, when prices are more favorable. Further, government agencies gain a clearer picture of the extent and distribution of drought effects in the state and could target relief efforts more effectively and use the information to refine drought maps.

VI. Satellite measurement of SM (Lucas Jones, Postdoctoral Research Scientist, University of Montana, NASA Soil Moisture Active Passive Mission)

Microwave observations from NASA's Soil Moisture Active Passive Mission (SMAP) provide statewide remotely-sensed soil moisture information. The technology works on the principle that soil water changes how much incident microwave energy is reflected from the Earth surface. The magnitude of the change provides an estimate of the volume of water within the top 3-5 inches of the soil surface. Observations are coarse resolution, with 1-3 day repeat cycle, and available within 3-days of acquisition. Data products available at several post-processing levels depending on users need for gap-filled or noise-free data. Temporal variability of soil moisture agrees well with ground measurements from Montana Mesonet stations. The SMAP detected the development of extreme soil moisture deficits and vegetation impacts during the 2017 Flash Drought, providing proof-of-concept for these to provide early warning of emerging drought.

VII. Soil moisture in forest management (Peter Kolb, Montana State University Extension, Forestry Specialist, U of Montana, Associate Professor of Forest Ecology and Management)

Forest species occurrence and productivity are determined on the majority of northern Rockies sites by water balance –a function of precipitation, site water storage capacity, and evaporative demand (vapor density deficit). Forest species successional dynamics have developed in response to competition for water and light, but are strongly influenced by competition for water and impacts on soil water balance and effective precipitation. Soil water availability and evaporative demand strongly influence forest disturbance processes such as the intensity and severity of insect pest outbreaks and wildfires. Forest management actions can have a profound influence on site water dynamics by manipulation of tree species, leaf area, and soil surfaces which impact effective precipitation and evapotranspiration. Forest site water monitoring (VDD, Precipitation, Soil water balances) is essential for developing appropriate forest management practices that maintain positive soil water balances, and for predicting tree, stand and forest growth and mortality related to water deficits – insect outbreaks, wildfire impacts, forest productivity and carbon sequestration.

VIII. Modeling water use efficiency (Adam Sigler, Water Quality Associate Specialist, Montana State University Extension)

Soil water holding capacity interacts with cropping system management and weather patterns to determine rates of deep percolation through cultivated soils. In annual cultivation systems, deep percolation transports nitrate out of the root zone resulting in losses of soil fertility resources while simultaneously compromising groundwater quality. Current modeling efforts quantify the interaction of weather, management and soils to determine deep percolation and leaching rates in a context that can inform management decisions to increase agricultural sustainability. These modeling efforts rely on soil moisture for calibration and are potentially broadly applicable in locations where soil moisture data is available.

IX. Real-time nutrient management (Jason Steffen, Agronomist/Senior Field Support, Teralytic, Inc.)

Understanding moisture levels throughout the growing season allows producers to know if their crop is doing well or struggling. Knowing nutrient levels in the field in real time allows producers to more closely match applications reducing potential over-fertilization and pollution. Knowing if a crop has enough moisture and nutrients remaining at mid-growing season helps producers make informed decisions as to whether late-season applications of nutrients will be economically beneficial. Sensor information allows producers to react to changes in weather patterns and only apply what is needed.

X. Soil moisture measurements in precision agriculture (Bruce Maxwell, Co-Director, MT Institute on Ecosystems, Montana State University)

Precision agriculture (PA) monitoring technologies including combine harvester yield and protein sensors, coupled with other georeferenced remote sensing and geographic information allows sub-field-scale assessment of crop performance relative to inputs. In addition, this information can be used to develop field-specific yield and protein predictive models. These models can be applied into the future and thus become important as input management aids when weather information is added as the primary driver of temporal variation. Soil moisture relates most closely to crop performance, hence the need for Mesonet soil-moisture measurements in the field where the other PA measurements are made and crop predictive models developed.

Responses and Comments Provided by Workshop Participants

Attendees of the soil moisture education workshops in Lubrecht and Columbus were asked to answer the following series of questions related to soil moisture:

1. How do you currently use soil moisture information in your decision-making process?
2. If you could make any improvements to soil moisture information what would it be?
3. What is an ideal resolution for soil moisture measurement in your decision-making process?
4. How often and when (seasonally) is soil moisture information most important to have?
5. How would you like to access information on soil moisture?
6. What are the next steps to take with soil moisture education?
7. What are the next steps to take with monitoring soil moisture in Montana?

Participants responded via a written worksheet and facilitated discussion. All responses were transcribed and categorized into common themes for each workshop as well as for the events as a whole. The summaries below represent the total organization of responses, highlighting common topics of interest, needs, and next steps that were discussed associated with soil moisture in Montana.

The majority of workshop participants reported that they currently used soil moisture information in their decision-making process, with only a few reporting that they either used it minimally or not at all. Out of those that do utilize soil moisture information, most applied it to water management programs related to irrigation timing and as early warning of the onset of drought conditions. Others stated that they incorporated soil moisture information into their cropping decisions, creating forage predictions for livestock grazing, and assessing wildland fire potential. Additional responses included using the information to assist with mine reclamation efforts, as a predictor in research on wildlife forage, and in the fumigation of vertebrate pests. One attendee commented that it would even be valuable to do an overall assessment of users of soil moisture information to foster exchange and collaboration, as a means to look at new ways to develop new interpretive products that could result in other opportunities.

When asked what improvements they would make to soil moisture information, workshop participants responded with a variety of answers. At the Lubrecht event, attendees expressed a desire for the information to be more accessible and more simple to understand while in Columbus participants stated the need for more data, whether through increasing sensor density across the state, developing more localized, finer-resolution data, or adding new ports into data loggers (such as a camera, ultrasonic snow-depth sensor, real-time in situ data, and calibration of satellite metrics for extrapolation). Creating tools and strategies from soil moisture information was highlighted at both workshops, with given examples including: 1) predictions and advice for farmers, 2) simple graphs related to rain and irrigation, 3) smart phone applications, 4) a forage production engine, 5) calculation of evapotranspiration, 6) in-situ water potential, 7) a focus on constraining probabilities versus just accuracy, and 8) the various tools demonstrated that were developed and offered by the Oklahoma Mesonet.

Workshop participants listed a wide range of resolutions from feet to landscape scales, which would be best for soil moisture measurement. At both locations participants said that having soil moisture information at the field scale would be most useful in their decision-making processes. Attendees at Lubrecht also listed having information at all scales as an ideal resolution for the information. When asked how often and when soil moisture information is most important to have, participants at Lubrecht and Columbus again came up with the same answer. The growing season was listed most often as the ideal time, starting in the spring (March to May) and ending in the fall (September or October). One individual in Columbus noted that having information available during December and January would also be beneficial, as this time of year is a key planning period for dryland agricultural producers who need to know who much water they have, how deep it is in the soil profile, and consequently what crops they should plant in the coming year. An online, website-based platform was stated as the preferred means of accessing soil moisture information at both workshop locations. Participants noted that a website should: 1) be easy to use, 2) give individuals the ability to access reports and maps containing soil moisture information, 3) have tutorials on how and why to use soil moisture information, and 4) contain a list of resources where individuals can find Montana-specific information. Additional means of accessing information brought up in the workshops included by phone, such as through an “app” or text alerts, via email, and through in-person interactions between on-the-ground individuals and researchers to “keep it real.”

When asked what the next steps to take with soil moisture education should be, attendees at both workshops stated that hosting more educational events (like workshops, field days, and hands-on demonstrations) would be important. Individuals at Lubrecht believed helping the user-base understand the importance and value of soil moisture information was necessary, and individuals in Columbus focused on continued networking, specifically by involving more producers. Other participants noted that the general public should be more involved with soil moisture education, especially through groups like students and citizen scientists. Some also expressed a desire for case studies to be conducted on soil moisture that illustrate how it relates to improved management and the economic benefits of having soil moisture information. Workshop participants in Columbus also stated that organizers should continue to network when asked about next steps for soil moisture monitoring in Montana, again with a focus on involving more producers as well as individuals who could assist with costs and maintenance (like a Big Sky Watershed Corps member) as well as expanding partnerships to ensure funding into the future. At both locations respondents listed increasing the network density of soil moisture monitoring stations as a beneficial next step for monitoring efforts and that, in addition to expanding the network, other forms of data (like remote-sensing data) should be incorporated into this network. Finally, there was an overall consensus that improving the accessibility of data and the understanding of its applicability in management decisions would be an important next step.

Despite the understood importance of sensors and data loggers in providing soil moisture data, multiple comments were made about not downplaying the importance of more traditional means of monitoring soil moisture, like the Paul Brown probe. Although not as accurate as a Mesonet station, these instruments were highlighted by attendees as another viable option because of their ease of use, ability to sample many points, and quick feedback to the user. Multiple questions were also asked about how the installation of a Mesonet station impacted the soil sensors, due to the disturbance of the soil when creating the sensor pit.

Evaluation of the Soil Moisture Education Workshops

Overall we believe these workshops were highly successful. Attendance levels exceeded our expectations, especially given a winter storm and impaired driving conditions on the November 7th meeting at Lubrecht. Participants actively provided substantive questions and feedback during the workshops sessions. Feedback during and following the workshops provided valuable suggestions to guide future development and applications of soil moisture information. Participants indicated strong support for instructional content and integration, and the learning format.

We identify and encountered several problems providing lessons for improvement of similar workshops in the future. The agenda was overly ambitious. This curtailed intended breakout discussions, especially following weather delays on the 7th which were compounded by technical problems in webinar connections established to permit remote participation.

The workshop structure and content, and the participant feedback provide guidance on next steps along two lines of work; further development educational resources and practical suggestions for the improvement and development soil moisture information and applications in Montana. Discussion is already underway to condense the workshop content into a 2-3 hour webinar, and to explore development of educational resources for extension agents. The suggestions for improvement of monitoring networks is under review by the Montana Climate Office as guidance for developing plans for network expansion and applications of soil moisture information.

Cited work recommended as background reading:

Peng, J., Loew, A., Merlin, O., Verhoest, N.E.C., 2017. A review of spatial downscaling of satellite remotely sensed soil moisture. Reviews of Geophysics, 55(2), 341-366.

Robinson, D., Campbell, C., Hopmans, J., Hornbuckle, B., Jones, S.B., Knight, R., Ogden, F., Selker, J., Wendroth, O., 2008. Soil moisture measurement for ecological and hydrological watershed-scale observatories: A review. Vadose Zone Journal, 7(1), 358-389.

Seneviratne, S.I., Corti, T., Davin, E.L., Hirschi, M., Jaeger, E.B., Lehner, I., Orlowsky, B., Teuling, A.J., 2010. Investigating soil moisture–climate interactions in a changing climate: A review. Earth-Science Reviews, 99(3-4), 125-161.

Vereecken, H., Huisman, J., Pachepsky, Y., Montzka, C., Van Der Kruk, J., Bogena, H., Weihermüller, L., Herbst, M., Martinez, G., Vanderborght, J., 2014. On the spatio-temporal dynamics of soil moisture at the field scale. Journal of Hydrology, 516, 76-96.

Appendix 1: ***Breakout Sessions:*** **Message from State Climatologist –** Kelsey Jencso, University of Montana

Our ability to monitor and forecast soil moisture will continue to improve with increased technical capacity and improved partnerships. Today represents an important first step in this process. However, to move beyond useful data to actionable information for Montanans we must identify the relevant uses of soil moisture information. Today's group represents a mix of practitioners, managers, and scientists across many sectors. I ask each of you to think about your individual uses of soil moisture information and to talk across sectors to identify similarities:

Please write down your responses before the breakout sessions

Name: **Affiliation:**

1. How do you currently use soil moisture information in your decision making process?

2. If you could make any improvement to soil moisture information what would it be?

3. What is an ideal resolution for soil moisture measurement in your decision making process (e.g. ft, yards, 30 yards, field scale, miles, all scales)?

4. How often and when (seasonally) is soil moisture information most important to have?

5. How would you like to access information on soil moisture (e.g. phone, website, letter, in person, other)?

Appendix 1 (cont.):

On-site Evaluation

1. What was most useful for you about today’s workshop?

2. What could we have done better?

3. What are the next steps to take with soil moisture education?

4. What are the next steps to take with monitoring soil moisture in Montana?

Additional comments and questions:

Thank you!

Appendix 2: Agenda: Soil Moisture Education Workshops

9:00 **Greeting: Why Measure Soil Moisture?**
Lubrecht: Jennifer Schoonen, Blackfoot Challenge
Columbus: Maureen Davey, Stillwater County
State Water Planners: Michael Downey, MT Department of Natural Resources and Conservation
Federal perspective: Jayne Morrow, National Institute of Standards and Technology
MT State Climatologist: Kelsey Jencso, University of Montana

9:45 ***How Water Moves through Soil:*** Andres Patrignani, Soil Water Management, Kansas State University

10:30 **Break**

10:45 ***How to Measure Soil Moisture:*** Chris Chambers, METER Group

11:30 **Applications 1 with Discussion**
Montana Soil Moisture Data: Kevin Hyde, Montana Mesonet Coordinator, Montana Climate Office, UM
Plant Available Water: Lee Schmelzer, MSU Extension, Stillwater County
Satellite Measurement: Lucas Jones, Soil Moisture Active Passive Program, University of Montana

12:30 **Lunch**

13:00 **Applications 2 with Discussion**
Water Controls Forest Management *Lubrecht**:*** Peter Kolb, MSU Extension, University of Montana
Modeling Efficiency of Precipitation Use *Columbus**:*** Adam Sigler, MSU Extension, Montana State University
Real-time Nutrient Management: Jason Steffen, Teralytic Inc.
Matric Potential and Soil Moisture: Chris Chambers, METER Group
Precision Agriculture: Bruce Maxwell, MT Institute on Ecosystems, Montana State University

14:30 **Break**

14:45 **Breakout Groups**

15:15 **Report in/Discussion**

15:45 **Closing Discussion and Comments**

16:00 **Adjourn**

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NIST National Institute of Standards and Technology U.S. Department of Commerce
MONTANA INSTITUTE ON ECOSYSTEMS
Montana Climate Office
MONTANA STATE UNIVERSITY EXTENSION
LUBRECHT FOREST

Appendix 3: Workshop Schedule and Attendees

- Two workshops held
  - Wednesday, Nov 7 – Lubrecht Experimental Forest in western MT
    - Total registered: 68
    - Attendees in person: 45*
    - Via webinar: 16 (Offered due to winter weather)
  - Friday, Nov 9 – Stillwater County Fairgrounds, Columbus, MT in south-central MT
    - Total registered: 44
    - Attendees: 38*

  *Actual attendee count was higher; headcount was incomplete during peak attendance

- Attendee Affiliations