Effect of Red Cedar Windbreaks on Soil Carbon and Quality in the U.S. Great Plains

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ABSTRACT Targeting marginal lands for woody bioenergy production avoids direct competition for food production and may improve soil health, the local microclimate and provide other ecosystem services. The objective of this study was to evaluate the effect of eastern red cedar (*Juniperus virginiana* L.) windbreaks on soil quality in the U.S. Great Plains. Eastern red cedar (ERC) has great potential for bioenergy production due to its adaptability to a wide range of soil and climate conditions and the physical and chemical characteristics of its biomass. Nine locations were selected from latitudes 41-47 deg N and longitudes 94-103 deg W with mean annual precipitation (MAP) from 425 to 970 mm and mean annual temperature (MAT) from 4.9 to 9.9 deg C. Tree age varied from 22 to 59 years. Soil samples were collected at 9 sites under the trees and in adjacent fields (crop, pasture, or hay) at each location and analyzed for carbon, bulk density, pH, and nutrient content. Ponded infiltration (twin ring technique) and penetration resistance (digital static cone penetrometer) were also measured. Soil organic carbon (SOC) to 30 cm depth averaged 0.92 kg m^{-2} (16.8%) greater under trees as compared to adjacent land use. Infiltration rate averaged 47.6% greater and depth to root-limiting penetration resistance averaged 20.3% lower under ERC tree cover. Improvements in soil quality following future tree planting for bioenergy feedstock production may allow some marginal lands to be converted back to crop production at a higher level of productivity.

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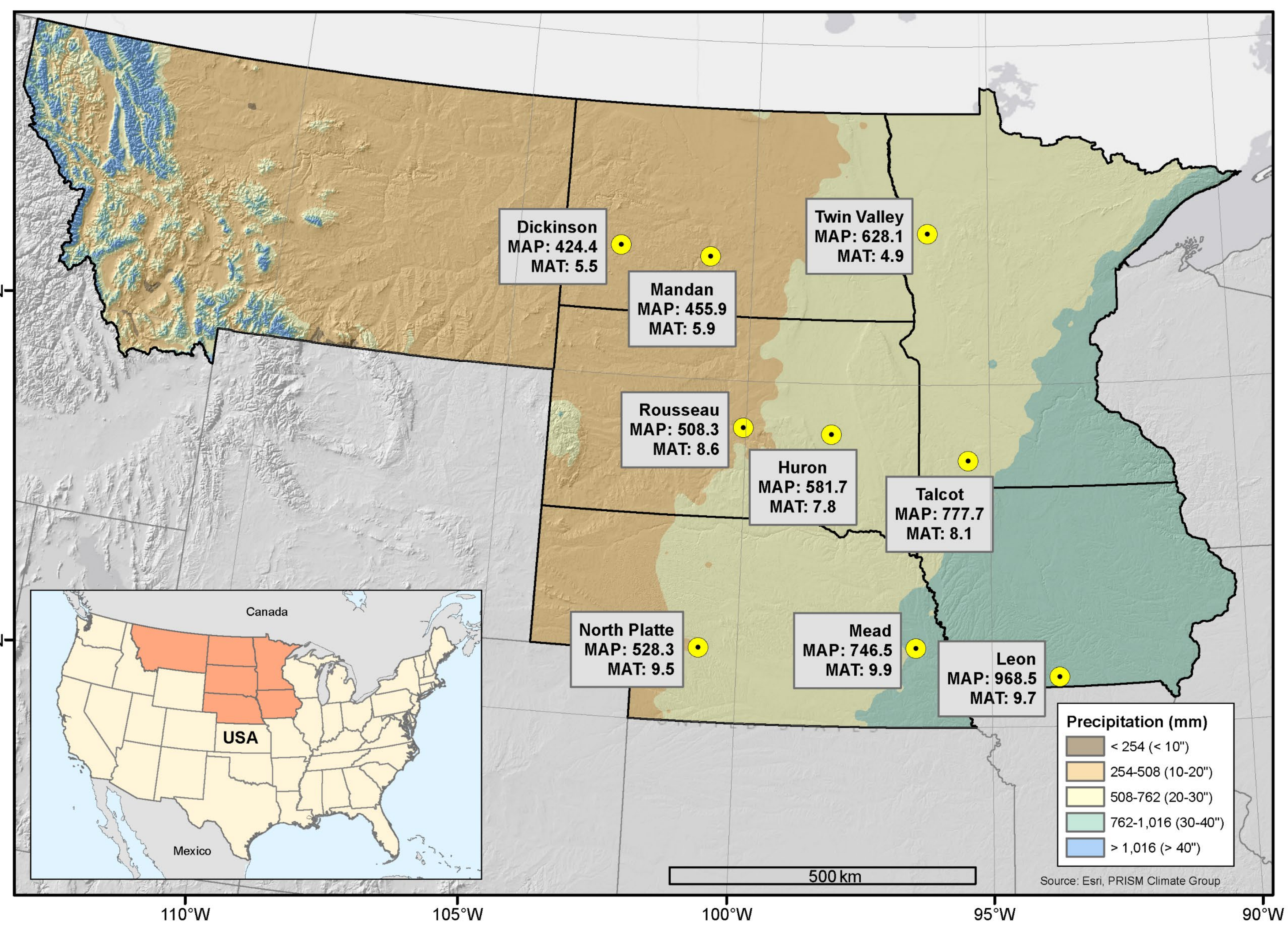

Figure 1. Name, mean annual precipitation (MAP) and mean annual temperature (MAT) for the nine sampling locations.

METHODS

Locations - Nine locations were selected representing typical plantings over a range of soils and climate.

Soils - Nine sites beneath the ERC trees and in an adjacent field at a distance of 3 x's the tree height from the windbreak were sampled at each location.

- Soil organic carbon (SOC), total nitrogen (TN), pH, particle size distribution, bulk density, infiltration, and penetration resistance were measured.

Trees - stand density, height and diameter at breast height (DBH) were measured to estimate above ground biomass (AGB). Branch samples were analyzed to determine C content.

Table 1. Name, location, elevation, MAP, MAT, ERC tree age, current crop, and soils of measurement locations.

Site Name	Latitude deg	Longitude deg	Elevation m	MAP mm	MAT °C	Tree Age yrs	Crop	USDA Soil Classification	Soil Texture
North Platte	41.0833	-100.7693	265.3	528.3	9.5	29	pasture	Typic Haplustolls	silt loam
Mead	41.1584	-96.4998	109.0	746.5	9.9	38	corn	Pachic Argiudolls	silty clay loam
Leon	40.7255	-93.6861	99.3	968.5	9.7	Uneven	pasture	Aquertic Chromic Hapludalfs	clay loam
Rousseau	44.3228	-100.0663	134.0	508.3	8.6	30	grassland	Typic Argiustolls	silt loam
Huron	44.2619	-98.2543	121.5	581.7	7.8	22	alfalfa	Typic & Pachic Haplustolls	loam
Talcot	43.8885	-95.4553	133.0	777.7	8.1	57	alfalfa	Typic & Entic Hapludolls	sandy loam
Dickinson	46.9032	-102.8365	235.1	424.4	5.5	39	alfalfa	Typic & Pachic Haplustolls	sandy loam
Mandan	46.8121	-100.9170	163.0	455.9	5.9	36	hay	Pachic Haplustolls	loam
Twin Valley	47.2243	-96.2987	97.0	628.1	4.9	59	corn	Oxyaquic Hapludolls	sandy loam

TREE BIOMASS C

- AGB estimated from DBH for each tree (n= 5-22 per location) using

$$BM = \exp(-2.6327+2.4757*\ln DBH)$$

where BM [kg] & DBH [cm]

from Chojnacky et al. Forestry 2014; 87, 129-15).
- AGB ranged from 53.4 to 515 Mg ha^{-1}.
- Biomass averaged 48.6% C.
*- Annual AGB carbon accrual is strongly correlated with MAP (Fig. 2).

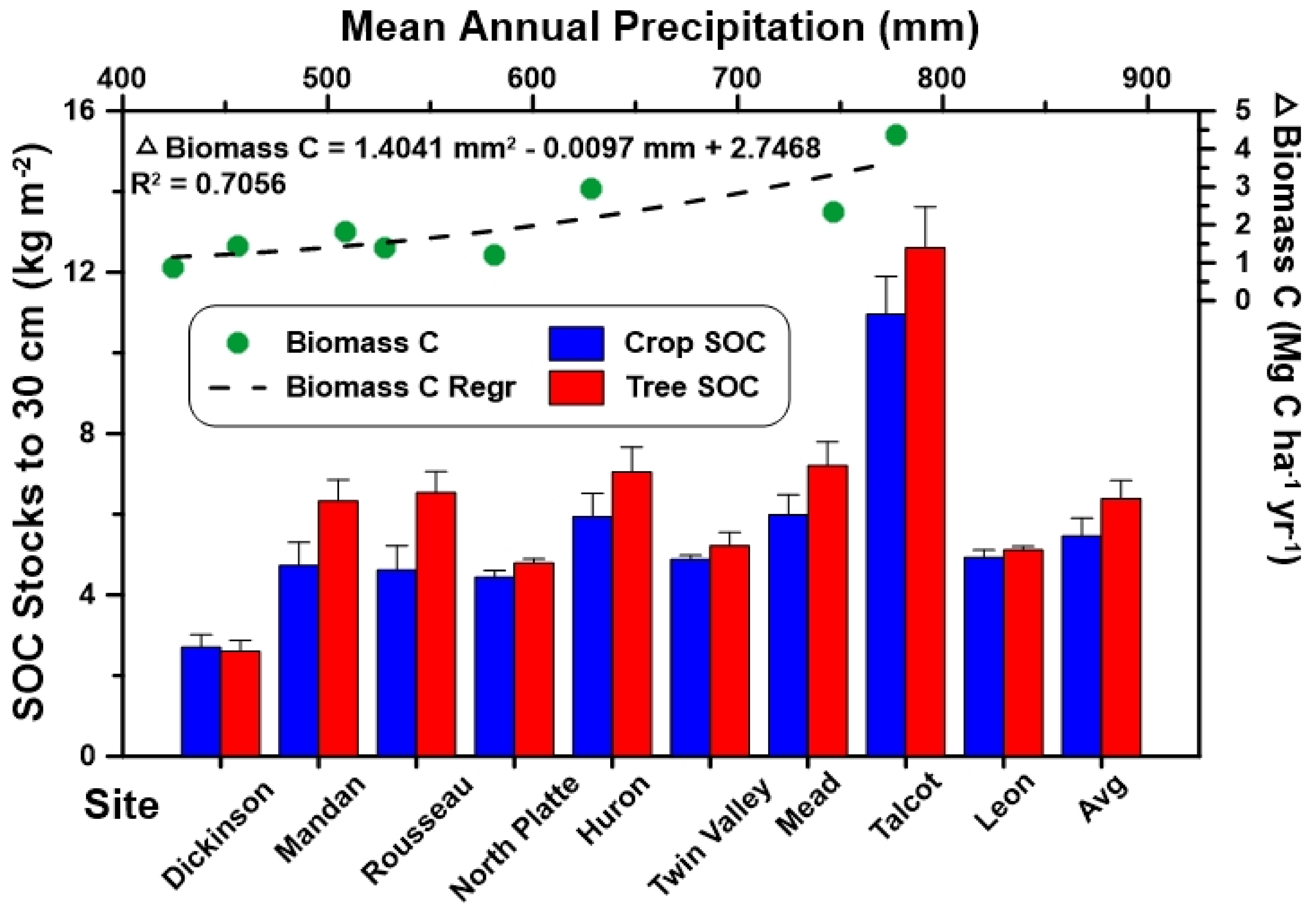

Figure 2. Annual change in AGB carbon by MAP (upper left) and SOC stocks to 30 cm for tree and crop sites at each sampling location (lower). SOC data by location are arranged with increasing MAP from left to right. Note: The ΔBiomass C equation does not include data from the Leon site as it has an uneven-aged stand. Error bars are one standard error.

SOIL ORGANIC C

- SOC concentration determined by dry combustion on a Fison NA 15000 Elemental Analyzer (ThermoQuest Corp., Austin, TX).
- SOC concentration with sample bulk density used to calculate SOC stock in 0-7.5, 7.5-15, and 15-30 cm layers.

SOIL ORGANIC C contd.

- SOC stocks were greater under ERC trees at 8 of the 9 locations by an average of 0.92 kg m^{-2} (9.2 Mg ha^{-1}).
*- Stocks ranged from 2.6 to 12.6 kg m^{-2} under Trees and from 2.7 to 11.0 kg m^{-2} under Crops and were also strongly correlated with MAP (r^2 >0.61).

INFILTRATION

- Twin ring technique of Scotter et al. 1982. Aust. J. Soil Res. 20:295-304.
- Paired 6 and 15 cm-diam. rings w/ 1 cm ponding.
- Measured until 3 consecutive readings confirmed steady-state.
*- Infiltration rate was higher and more variable under trees (426±86 mm h^{-1}) than in crops (289±31 mm h^{-1}).
- 4.8 cm-diameter soil core taken in 15 cm-diameter ring for soil analyses and bulk density determination.

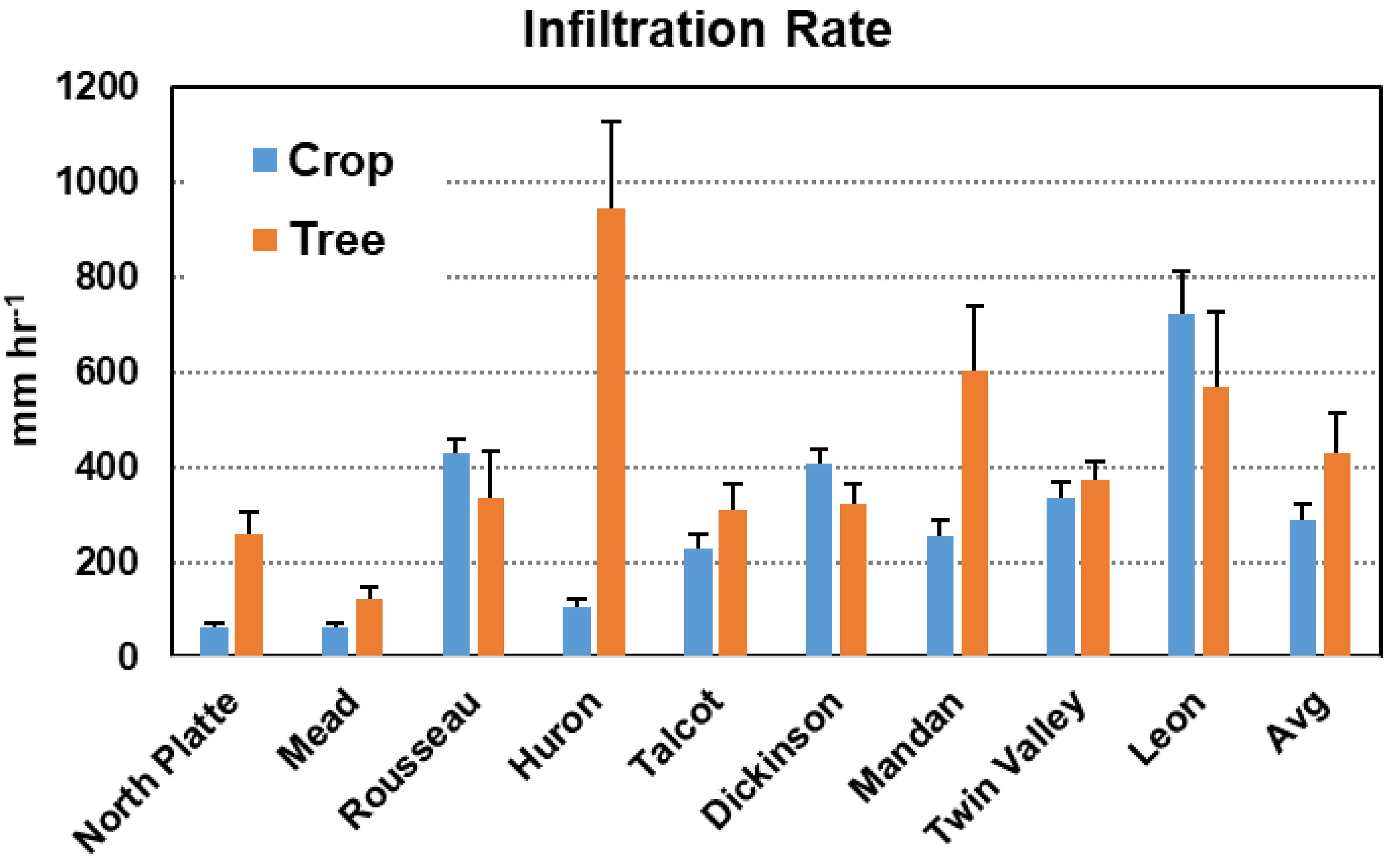

Fig. 3. Average infiltration rate (n=9) for Crop and Tree sites from 15 cm-diameter rings by location and overall average. Error bars are one standard error.

PENETRATION RESISTANCE

- Penetration resistance measured inside 6 cm-diameter infiltration ring 1-3 hrs after completion of infiltration measurement.
- Humboldt Model HS-4210 Digital Static Cone Penetrometer.
-Readings recorded at 2.5 cm intervals to 30.8 cm
- 2 MPa resistance was assumed to be limit for root penetration.

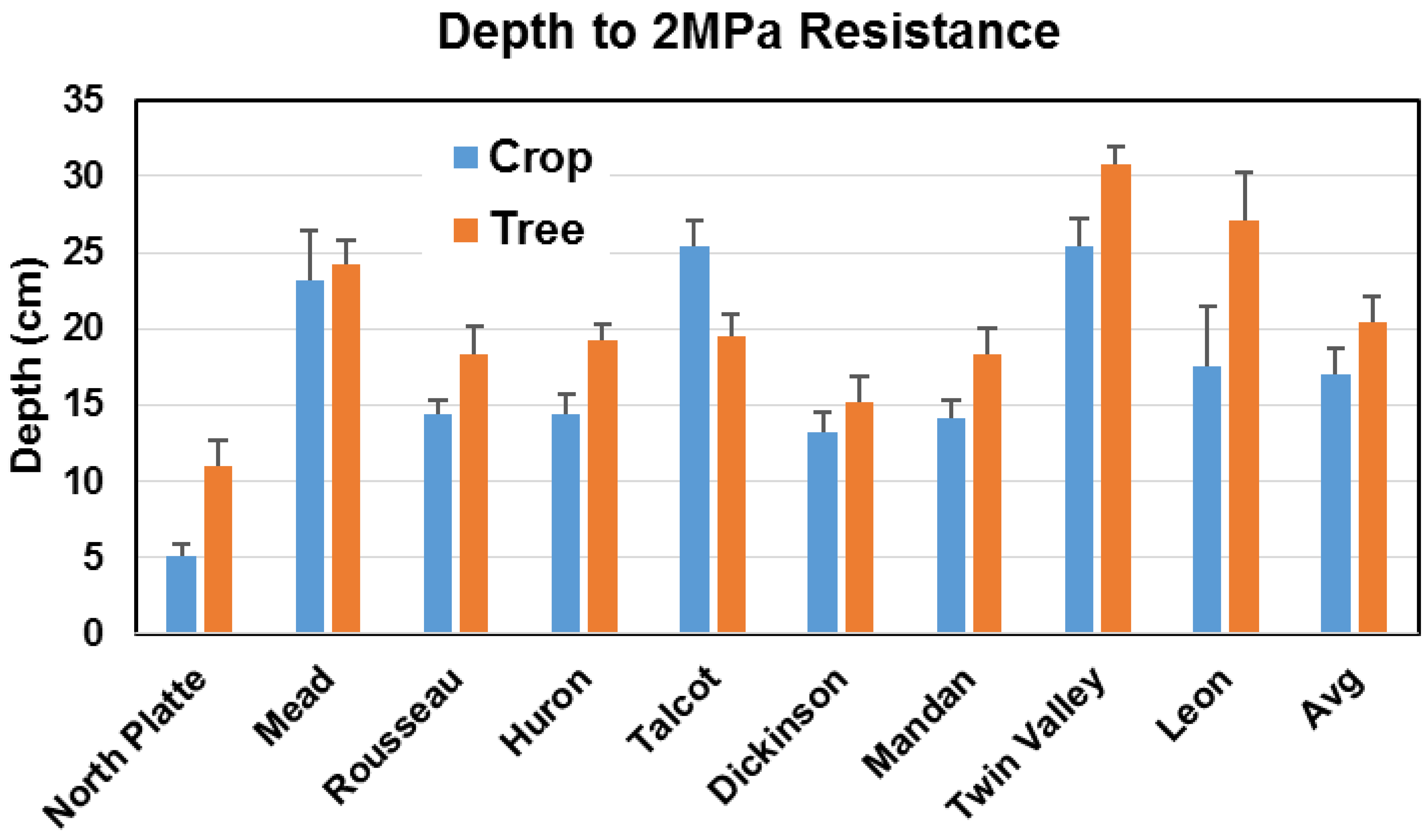

Fig. 4. Average depth to root growth-limiting penetration resistance of 2 MPa (n=9) for Crop and Tree sites measured within the 6 cm-diameter rings by location and overall average. Error bars are one standard error.

PENETRATION RESISTANCE Contd.

*- Average depth to 2 MPa resistance was 17.0±1.8 cm and 20.4±1.7 cm for Crop & Tree sites, respectively.
- Some bias in readings likely due to tree roots and stones.

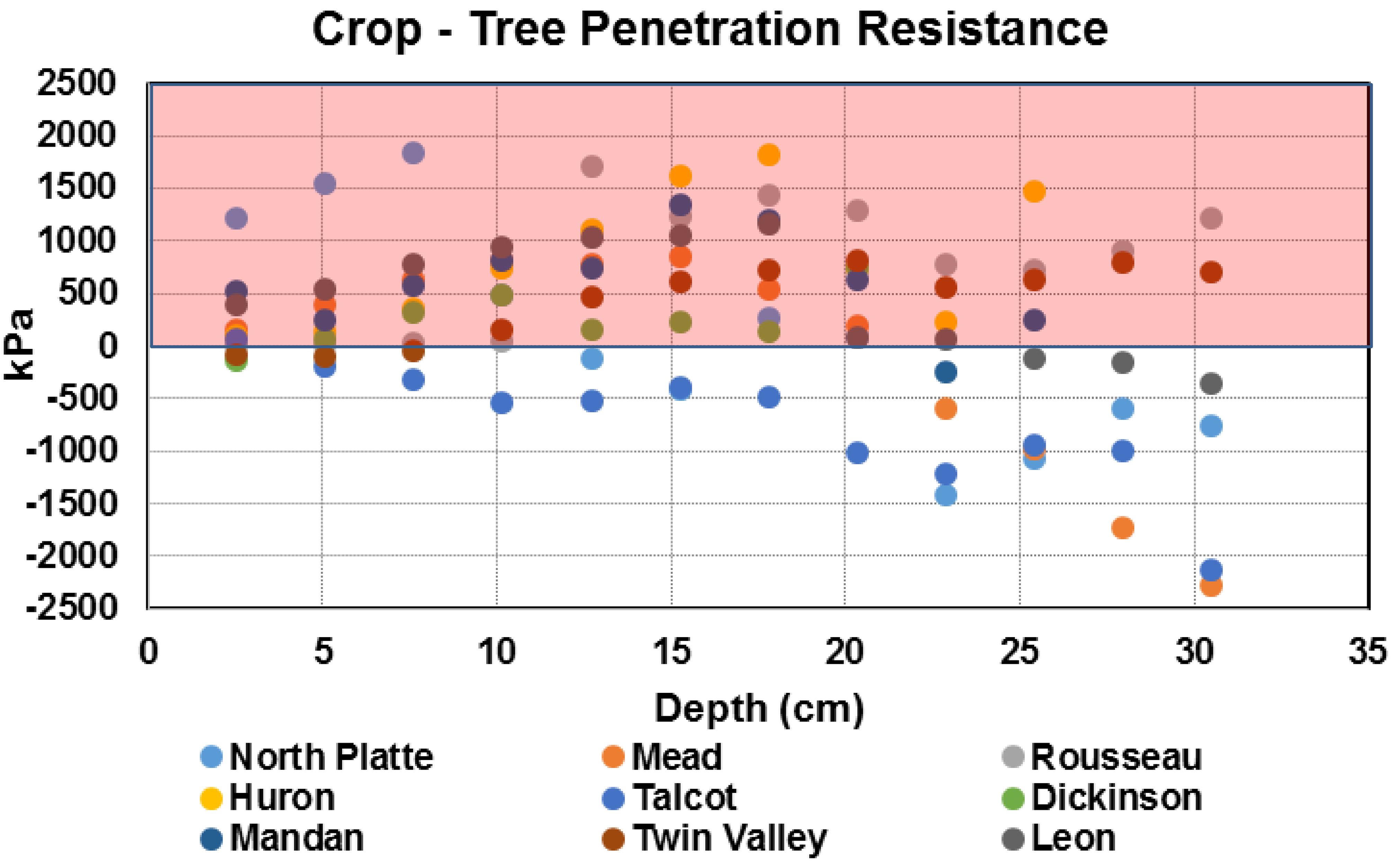

Fig. 5 Difference in penetration resistance by depth (Crop - Tree) averaged for all measurement sites at each location. Red shaded area indicates greater resistance in crop field. Each symbol represents the mean of 9 pairs of measurements.

BULK DENSITY

- Bulk density for the 0-7.5, 7.5-15, and 15-30 cm layers averaged 1.03, 1.38, & 1.40 Mg M^{-3} beneath the trees and 1.20, 1.45, & 1.50 Mg m^{-3} in the crops, respectively.
*- Bulk density averaged 0.16, 0.07, and 0.09 Mg m^{-3} greater in crops compared to trees for the 0-7.5, 7.5-15, & 15-30 cm layers.

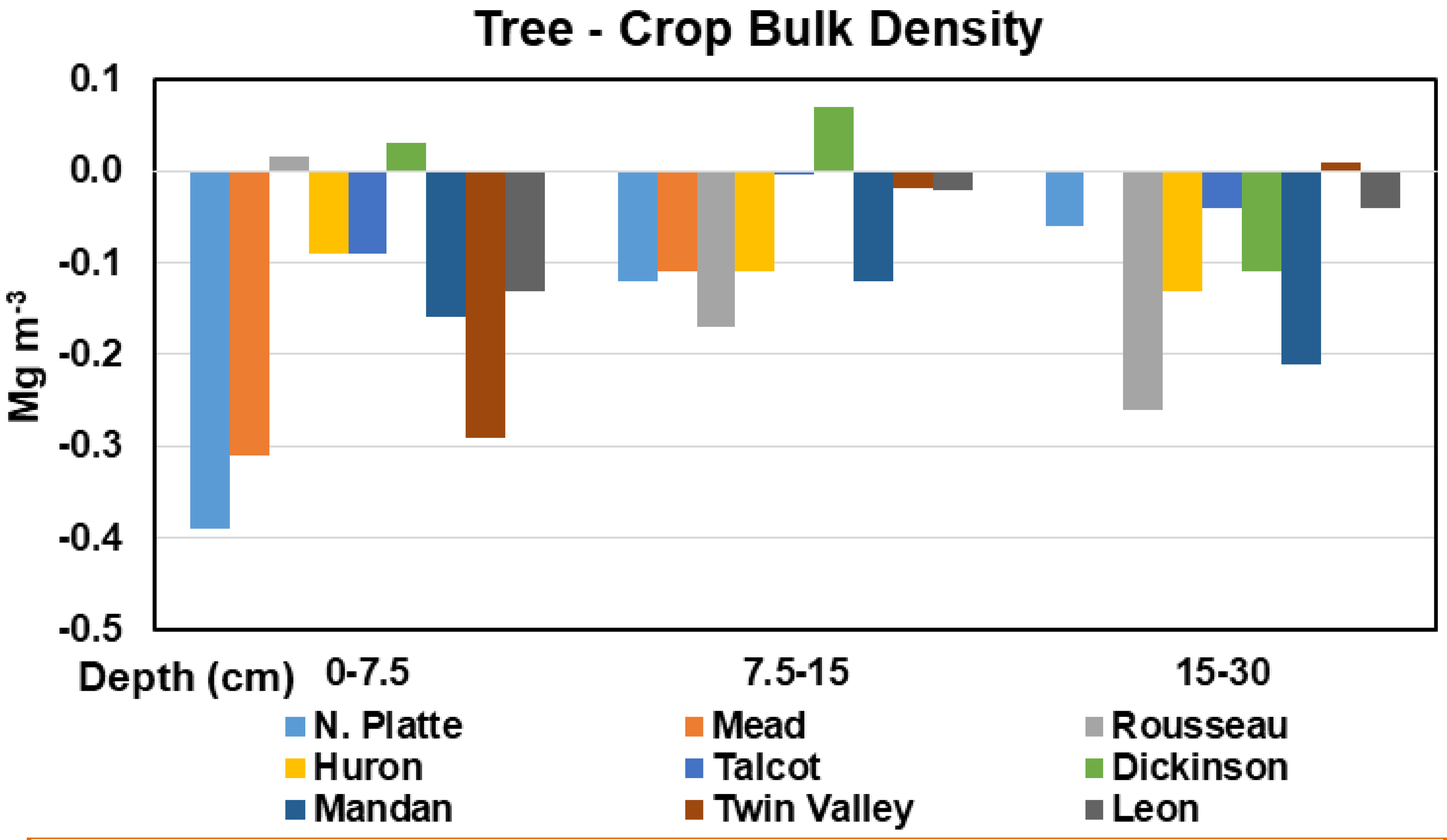

Fig. 6 Average difference in soil bulk density by depth (Tree - Crop) for each location. Each bar represents the mean of 9 pairs of measurements.

SUMMARY

- Tree ABG carbon ranged from 25.9 to 248.9 Mg C ha^{-1} and SOC stocks to 30 cm depth averaged 54.6 and 63.8 Mg C ha^{-1} for Crop and Tree sites, respectively.
- Tree growth rate and SOC stocks were strongly correlated with MAP. These results indicate that faster tree growth provides greater organic inputs that enable SOC accumulation.
- Infiltration rate and depth to root growth-limiting resistance were consistently greater by an average of 47.6% and 20.3% under ERC trees.
- These results indicate that SOC accumulation, faster infiltration, and less resistance to root growth should result in greater available water to enhance tree growth especially in semi-arid regions.

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