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# Least limiting water range as affected by soil texture and cropping system

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ABSTRACT

In this study the least limiting water range (LLWR) and associated measurements (water content at field capacity, $\theta_{FC}$, wilting point, $\theta_{PWP}$, air filled porosity, $\theta_{AFP}$, and mechanical resistance, $\theta_{SMR}$) were tested on two soils of clay loam (CL) and sandy loam (SL), each under long-term cultivation with either wheat (*Triticum aestivum* L.) or alfalfa (*Medicago sativa*). Water content at field capacity ($\theta_{FC}$) and wilting point ($\theta_{PWP}$) decreased slightly with an increase in bulk density ($D_b$) in clay loam soils under wheat and alfalfa, whereas in sandy loam soils under the same cultivation, both values of $\theta_{FC}$ and $\theta_{PWP}$ strongly increased by increments of $D_b$. The variation of LLWR was negatively related to $D_b$ in clay loam soils under wheat and alfalfa cultivation. The LLWR increased up to $D_b$, equal to 1.56 Mg m$^{-3}$ (when $\theta_{FC} = \theta_{10kPa}$) and to 1.60 Mg m$^{-3}$ (when $\theta_{FC} = \theta_{33kPa}$) in sandy loam under alfalfa, and 1.42 Mg m$^{-3}$ (both values of $\theta_{FC}$) in sandy loam under wheat; LLWR then declined sharply with increasing $D_b$. The highest value of LLWR was observed in the ranges of 0.034–0.167 cm$^3$ cm$^{-3}$ (when $\theta_{FC} = \theta_{10kPa}$) and of 0.034–0.119 cm$^3$ cm$^{-3}$ (when $\theta_{FC} = \theta_{33kPa}$) in clay loam under wheat. The lowest value of LLWR was observed in between 0.137 and 0.151 cm$^3$ cm$^{-3}$ (when $\theta_{FC} = \theta_{10kPa}$) and between 0.087 and 0.111 cm$^3$ cm$^{-3}$ (when $\theta_{FC} = \theta_{33kPa}$) in sandy loam under wheat. Linear regressions (Stepwise) showed that LLWR (when $\theta_{FC} = \theta_{10kPa}$) was related to bulk density, clay, calcium carbonate ($CaCO_3$) and organic carbon (OC) contents ($r^2 = 0.79$). Considering $\theta_{FC} = \theta_{33kPa}$, LLWR was related to bulk density, clay and OC contents ($r^2 = 0.48$)

## 1. Introduction

Water deficiency is a primary limiting factor for crop production in arid, semi-arid and dry sub-humid agro-ecosystems in Iran. Soil moisture scarcity is not only the result of low seasonal rainfall and poor rainfall distribution; it is also a result of the poor soil structural quality of crop lands. This poor soil structure leads to large losses of water from the fields' water balances and also to the limited water holding capacity and crop-water uptake capacity. Soil moisture availability is critical for the efficient management of water resources. This is described by different concepts including available water content "AWC" that is defined as difference between volumetric water content at filed capacity and wilting point (Veihmeyer and Hendrickson, 1931, 1949, 1950), nonlimiting water range "NLWR" (Letey, 1985) and least limiting water range "LLWR" (da Silva et al., 1994) are defined as the ranges of soil water content in which limitations for plant growth associated with matric potential, aeration, and mechanical resistance are none or minimal, respectively, integral water capacity "IWC" (Groenevelt et al., 2001; Asgarzadeh et al., 2010) that is a continuous weighting functions corresponding to various soil limitations associated with lack of sufficient aeration and rapid drainage by gravity in wet range of IWC, low soil hydraulic conductivity restriction and root penetrability in dry range of IWC, and integral energy "$E_I$" (Minasny and McBratney, 2003) that is the required energy to uptake a unit mass of water by plant over a defined range of soil water content.

The LLWR is the most prevalent approach adopted for soil property analysis and management practices. This approach not only takes into account the limits of field capacity and wilting point, but also the limitations from aeration and soil penetration resistance (da Silva et al., 1994). The usefulness of LLWR as an index of soil physical quality in a wide variety of soils, crops, and management practices is reported by several researches (da Silva et al., 1994, 2004; Betz et al., 1998; Tormena et al., 1999; Wu et al., 2003; Lapen et al., 2004; Leao et al., 2006; Nemenyi et al., 2006; Zou et al., 2000;

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|---|---|
| CL | Clay loam soil |
| SL | Sandy loam soil |
| SLA | Sandy loam soils under alfalfa cultivation |
| SLW | Sandy loam soils under wheat cultivation |
| CLA | Clay loam soils under alfalfa cultivation |
| CLW | Clay loam soils under wheat cultivation |
| SWCC | Soil water characteristic curve |
| SSCC | Soil strength characteristic curve |
| SMR | Soil resistance to penetration |
| LLWR | Limiting water range |
| $\text{LLWR}_{100}$ | LLWR based on $h = 100$ cm chosen for FC |
| $\text{LLWR}_{330}$ | LLWR based on $h = 330$ cm chosen for FC |
| AWC | Available water content |
| $\text{AWC}_{100}$ | Available water content based on $h = 100$ cm chosen for FC |
| $\text{AWC}_{330}$ | Available water content based on $h = 330$ cm chosen for FC |
| IWC | Integral water capacity |
| $E_I$ | Integral energy |
| $CaCO_3$ | Calcium carbonate |
| OC | Organic carbon |
| $K_s$ | Saturated hydraulic conductivity |
| EC | Soil electrical conductivity |
| pH | Soil reaction |
| $D_b$ | Bulk density |
| SSE | Sum of square error |
| $h$ | Matric potential |
| $\theta$ | Soil volumetric water content |
| $\theta_{FC}$ | Water content at field capacity |
| $\theta_{PWP}$ | Water content at wilting point |
| $\theta_{10kPa}$ | Water content at 10 kPa |
| $\theta_{33kPa}$ | Water content at 33 kPa |
| $\theta_{SMR}$ | Water content at 2 MPa |
| $\theta$sat | Water content at saturation |
| $\rho_s$ | Soil particle density |
| $\rho_b$ | Soil bulk density |

Benjamin et al., 2003). Concerning LLWR, current efforts target the impacts that management practices have on soil dynamic properties such as soil organic matter, soil structure and soil compaction (Wu et al., 2003; Tormena et al., 1999; Zou et al., 2000; da Silva and Kay, 1997a; Yoo et al., 2006; Chan et al., 2005; Bulmer and Simpson, 2005; Reinert Dalvan et al., 2002). The impact of changes in soil bulk density on plant growth is linked to water content availability and factors such as aeration or restrictions to root development and growth (da Silva and Kay, 1997b). In soils with a wider LLWR, the water uptake by plants is less vulnerable than soils with narrower LLWR (da Silva and Kay, 1997a). Successful management practices lead to a wider LLWR, while a narrow LLWR indicates that management practices were not as successful, resulting in crop productivity reduction (Zou et al., 2000). Chan et al. (2005) reported that LLWR was reduced to a value near zero under wheel tracks and was thereby unfavorable to plant roots. The LLWR may also be affected by grazing systems due to sensitivities to the alteration in soil physical properties (Leao et al., 2006). Drury et al. (2003) showed that the LLWR can be considered to differentiate soils on the basis of sensitivity of net N mineralization to variable water content. Denitrification would be most prevalent in soils where the upper limit of the LLWR falls below field capacity by diminished rates of substrate diffusion (Skopp et al., 1990), physical protection of bacteria from predation by protozoan grazers (Killham et al., 1993), and low water potential (Sommer et al., 1989). Siegel-Issen et al. (2005) showed that the shoot mass of seedlings growing within LLWR was greater than those growing outside this range. Tormena et al. (1999) compared the LLWR in a clayey soil under no-tillage and conventional tillage; they reported that LLWR was higher in conventional tillage than in no-tillage and was correlated negatively with bulk density for values above 1.02 Mg m$^{-3}$. Crop yield is primarily water-limited in 90% of areas of Iran with arid and semi-arid climates. Satisfying the growing agricultural water demand has been a major challenge in Iran. This is especially difficult during the dry season when water shortages are already an issue. Research into the linkages between LLWR and agricultural management in Iran is lacking; therefore there is a need for studies linking these two concepts, especially in these semiarid regions.

## 2. Materials and methods

### 2.1. The study site and soil properties

This present study was conducted on clay loam (CL) and sandy loam (SL) soils located within Hamadan Province of western Iran, in October 2008 (Fig. 1). The soils were classified as Typic Xerorfluvents and Typic Haploxerepts, according to USDA classification (Soil Survey Staff, 2010).

Each soil was under cultivation of either wheat (W) (*Triticum aestivum* L.) or alfalfa (A) (*Medicago sativa*) for 11 years. In total, four column types were sampled: sandy loam soils under alfalfa cultivation (SLA), sandy loam soils under wheat cultivation (SLW), clay loam soils under alfalfa cultivation (CLA) and clay loam soils under wheat cultivation (CLW). Western Iran is characterized by its semi-arid to arid climate with long-term average annual precipitation of 328 mm. The majority of this precipitation occurs during the winter months; the remaining months of the year are generally hot and dry. The average annual temperature ranges from a high of 24.5 °C in July to a low of −28.5 °C in January.

The experiments were performed on undisturbed core samples (50 mm length and 51 mm i.d.) and disturbed soil samples collected from surface layer (5–10 cm), the layer where the effects of plant roots is most prominent in each soil. 18 undisturbed core samples were collected from each soil so that the samples would have a wide range in clay, calcium carbonate ($CaCO_3$), organic carbon (OC) contents and $D_b$. Saturated hydraulic conductivity ($K_s$) of core samples was measured by the constant- head procedure (Klute and Dirksen, 1986). Disturbed soil samples were air-dried and sieved (<2 mm). Particle size distribution was determined using the hydrometer method (Gee and Bauder, 1986), $CaCO_3$ was measured using the back-titration method (Sims, 1996), and OC was determined using the wet-digestion method (Walkley and Black, 1934). Soil electrical conductivity (EC) and reaction (pH) were determined by EC-meter and pH-meter in 1:5 soil:water suspension (Rhoades, 1996) and saturation paste (Thomas, 1996), respectively.

### 2.2. Soil water characteristic curve (SWCC)

Soil water characteristic curve was determined using 18 undisturbed soil cores for each treatment. The soil cores had saturated capillaries from the bottom, and soil water retention was determined in the cores by matric suction of 0.2, 0.5, 1.0, 2.0, 5.0, 7.0, 10, 30, 100, 200, 500, 1000 and 1500 kPa. Matric suction values of 1 to 10 kPa were achieved using a sandbox (Clement, 1966) and matric suction values of 10 to 1500 kPa were achieved using pressure plate extractors (Klute, 1986). Water retention at matric suction of 1500 kPa was determined on the sieved soil samples (<2 mm fraction).

Core samples were then oven dried and the water content and $D_b$ determined (Klute, 1986). SWCC was then established for each