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The role of soils in the analysis of potential agricultural production: A case study in Lebanon

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ABSTRACT

Maintaining cereal production in the Bekaa valley in Lebanon presents a serious challenge. Lack of water is the driving force of agricultural research which is mainly focused on introduction of drought resistant cultivars, application of conservation tillage and supplemental irrigation. In this context forty-eight experimental plots were laid out for three years in a statistical split plot design. The statistical analyses showed that aboveground biomass and yield were significantly affected by irrigation for barley but not for the yield of durum wheat. Effects of soil tillage practices and introduction of new cultivares were not significant.

A soil survey indicated that the implicit assumption of soil homogeneity of the agronomic design was correct for surface soil but that two different soil types (Cambisols and Fluvisols) had to be distinguished considering subsoil conditions and corresponding rooting patterns. Therefore, the main objective of this paper was to determine the effects of different soil types on crop response and, in addition, to assess how physically-based modeling can predict future effects of climate change on crops and soils. Simulation model SWAP was validated for local conditions using measurements of soil water contents, aboveground biomass and yield of wheat. Considering two rather than one soil type for the experimental area resulted in different conclusions for both crops as to the effectivity of both conservation tillage and irrigation, demonstrating that a distinction of only one soil type results in misleading results. The validated model was applied to estimate yields considering climate change, focusing on the application of supplemental irrigation. Yields for "Mikii3" a durum wheat cultivar are expected to increase by appr. 14% in both soils due to climate change. More importantly, only 3 supplemental irrigations would be needed for the deep soil requiring 5% more water as compared with current climate trend, while the shallow soil needs 13 irrigations, corresponding with a need for 35% more water. This is highly significant from an economic point of view and supports the relevance of distinguishing two soil types.

It was demonstrated the synergy of joint research by the agronomic and soil science community and the need for executing a soil survey in future when planning agronomic experiments, including a hydrological soil characterisation.

1. Introduction

Soils play a crucial role in agricultural production systems by allowing water and nutrient uptake by roots, while providing physical support for plants to grow. Traditionally, crop growth on different soils has been characterized by correlating yield measurements, preferably made at different times during the growing season, with periodically measured soil characteristics in terms of water and nutrient contents. However, during the last two decades several operational simulation models have been developed for the soil-crop-water-nutrient system that allow a dynamic representation of crop growth as a function of environmental conditions, including soil processes and current and future climates (e.g. CERES, Ritchie and Otter, 1985; CropSyst, Stöckle et al., 2003; SWAP, Kroes et al., 2008).

Even within farmer's fields, but certainly in a regional context, soil properties can vary considerably in space and this can be taken into account when running simulation models by using soil maps to distinguish different soil types (e.g. Bouma and Bregt, 1989; Bonfante and Bouma, 2015). As will be discussed later in more detail, many agronomic experiments consider soils but not their heterogeneity and

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subsoil properties which may have a significant effect on conclusions, as will be demonstrated later for this study. Exceptions are the studies on grapes, where the central concept of "terroir" illustrates the importance of varying soil properties for grape quality (e.g. Van Leeuwen, 2009; Bonfante et al., 2015, 2017; Priori et al., 2012), or those concerning the precision farming agriculture where - in order to optimize the agro-inputs - the soil and crop spatial variability is part of the management system (e.g. Batchelor et al., 2002; Stoorvogel et al., 2015). Despite the huge increasing of these interdisciplinary applications, even supported by the application of modeling (Corbeels et al., 2016), still many agronomic experiments do not properly take into account soil heterogeneity, both vertical and horizontal.

The current study was part of the ACLIMAS demonstration project within the Sustainable Water Integrated Management Program (SWIM) of the European Commission, focusing on some Mediterranean target areas with the objective to achieve sustainable improvement of agricultural management practices by conservation agriculture, considering future challenges such as climate change and increasing water scarcity (www.aclimas.eu). One of the target areas was in the Bekaa Valley in Lebanon, where (i) conventional agricultural management was compared with conservation agriculture, (ii) the effect of supplemental irrigation was evaluated to improve productivity, as compared to rainfed and (iii) recently released cultivars were explored for two most important strategic crops: durum wheat and barley. Agronomic results have been reported in Abi Saab et al. (2013). In this paper attention will be paid to the role of soil science in agronomic field experiments and to explore possible additions to the research approach followed by the SWIM program.

Field experiments, performed under actual weather conditions, cannot be used to explore effects of climate change. Then, a systems analysis is needed using by now widely available simulation models for the soil-plant-atmosphere system being fed by climate data reflecting climate change, as discussed above. However, such models can only be used successfully when field data on crop responses and yields are available, next to physical and chemical soil conditions, to first calibrate and validate the models. If this is not done, simulation results are bound to be questionable at best.

Therefore, the objectives of this paper are to: (i) investigate whether the implicit assumption that soils are homogeneous in the research area is correct, (ii) determine what the effects would be on the study when different types of soils would be present and distinguished; (iii) explore the potential of extending the work by using a model-based systems analysis, whereby field crop measurements have been used to validate simulation model and (iv) assess how modeling can characterize actual soil and crop conditions during the growing season and future effects of climate change and precision irrigation measures.

2. Materials and methods

2.1. The rationale of this research work

During the agronomic study, that was based on a classical statistical design implicitly assuming soil conditions to be rather homogeneous with a local variability within the experimental area, additional soil investigation (e.g. stoniness, hydraulic properties) was performed. This activity was initiated because the "Soil Map of Lebanon, 1:50,000" (Darwish et al., 2006), indicated that soil conditions were likely to vary at the location of the plots, which might well affect crop responses.

2.2. Experimental site

During the ACLIMAS project, field experiments were carried out in Tal Amara (Bekaa valley, Lebanon; 33°51′44″N lat., 35°59′32″E long. and 905 m above sea level) at the experimental field of the Lebanese Agricultural Research Institute (LARI) on both wheat and barley during three growing seasons (2012 to 2015).

Table 1
Soil properties for agronomical experiment at Tal Amara field.

Soil properties (0–90 cm)		
Soil textural class		Clay
Clay content	(g 100 g^{-1})	44
Silt content		25
Sand content		31
Bulk density	(g cm^{-3})	1.41
Soil water content at saturation	(cm^3 cm^{-3})	0.52
Field capacity (− 33 kPa)		0.41
Wilting point (− 1500 kPa)		0.22
Available water content (AWC) (0–90 cm)	(mm)	171
Saturated Hydraulic conductivity	(cm day^{-1})	4.2
pH		8
ECe	(dS m^{-1})	0.43

The total surface of the experimental fields was 5043 m^2 (80 × 63 m) with a slope < 0.1%. The agronomic experiments assumed the presence of one soil type, a calcaric Fluvisol, as reported in the "Soil Map of Lebanon, 1:50,000" (Darwish et al., 2006). Experimental soil properties are reported in Table 1(Abi Saab et al., 2013).

In the experimental area the climate was typically Mediterranean, characterized by an average annual rainfall of 592 mm mostly concentrated in autumn and winter months (October to March) (Abi Saab et al., 2013), with a hot and dry season from April to October. Air temperature and precipitation were obtained from a standard agrometeorological station located about 100 m from the experimental field.

The three years were characterized by different temperature and rainfall patterns. Mean temperature (T_{mean}) during the three growing seasons was not significantly different from the long term average value (1954 to 2010, Tal Amara – LARI weather station). In 2014–2015 growing season, T_{mean} in January was, however, 3.4 °C lower than in the first two years, with the occurrence of many days with minimum temperatures below zero. In 2012–2013 and 2014–2015 seasons the rainfall (November–June) was 731 and 669 mm respectively, while it was 336 mm in 2013–2014. By comparing these values with the long term rainfall, both 2012–2013 and 2014–2015 were wet, while 2013–2014 was dry (Fig. 1).

2.3. Agronomic management

Two distinguished experiments on both durum wheat (*Triticum durum* Desf.) and barley (*Hordeum vulgare* L.) were carried out to assess the response of these crops to two water supply regimes (rainfed (R) and spring supplemental irrigation (SI)) and two soil tillage practices (conventional tillage (CV) and conservation tillage (CA)). In both experiments, two drought-tolerant and recently released cultivars ("Icarasha" and "Mikii3") of wheat and barley ("Assi" and "Rihane") were combined with the management practices. The seeding rate was 250 kg ha^{-1}, according to standard practices in the central Bekaa Valley. Each experiment consisted of eight treatments with three replicates per treatment-combination. Treatments were arranged according to 2^3 factorial experiment in a split–split plot design. Soil tillage practice (CV/CA) was the main plot factor, water regime (R/SI) was the subplot factor and cultivars were the sub-subplot factor. Each experimental plot was 7 × 7 m, on a total surface of about half a hectare.

The entire surface had not been subjected to tillage for the previous eight years. At the start of the experiments the plots under conventional agriculture were conventionally ploughed. Irrigation was managed using a simple "tipping bucket" approach by using meteorological, soil and crop data for a day-by-day estimation of the soil water balance in the effective root zone (0–90 cm) (Todorovic, 2006). To ensure uniform water distribution, a drip irrigation system was used. For further details, see Abi Saab et al. (2013). Irrigation of 95 mm was supplied as supplemental only once in 2012–13 and twice in both 2013–14 and