Assessing the sustainability of a wheat-based cropping system under Mediterranean conditions

Carina Moeller¹,², J. Grenz², J. Sauerborn², A. Manschadi³, M. Pala⁴, H. Meinke³

¹ Address for correspondence: CSIRO Plant Industry, Private Bag 5, Wembley WA 6913, Australia; email: carina.moeller@csiro.au
² University of Hohenheim, Institute for Plant Production and Agroecology in the Tropics and Subtropics (380), 70593 Stuttgart, Germany
³ QDPI&F/APSRU, 203 Tor St, Toowoomba QLD 4350, Australia
⁴ ICARDA, PO Box 5466, Aleppo, Syria

Abstract

Here we demonstrate the usefulness of the Agricultural Production Systems Simulator (APSIM) for examining the sustainability of a wheat-chickpea rotation subjected to three tillage/residue management systems (conventional tillage, conventional tillage with stubble burning and mulch-tillage) in a semi-arid Mediterranean environment of Syria. Indicators to quantifying changes in the sustainability of the system were crop yield, water use efficiency, soil organic matter and gross margin. The model analysis showed that mulch-tillage has the potential to improve the sustainability of rainfed wheat-based systems at the study site. Mulch-tillage outperformed conventional tillage and conventional tillage with stubble burning for all selected indicators, which was largely a result of soil water conservation.

1 Introduction

Sustainability is the capacity of an agroecosystem to maintain commodity production through time without compromising its structure and function. Though this definition is not questioned per se, approaches to characterize sustainability remain elusive (Bell and Morse, 2000). Within the boundaries of an individual field, sustainability has ecological and economical dimensions. Ecological and economical parameters for monitoring changes in the structure and function of agroecosystems can be termed sustainability indicators. Indicators applicable at the field scale are, for example, related to crop productivity, soil fertility and the profitability of production (Gomez et al., 1996).

Cropping systems simulation can address the complex and interactive nature of sustainability and allows changes in indicator values to be quantified. APSIM (Keating et al. 2003) is a computer model describing, on a daily basis, the dynamics of crop growth, soil water, soil carbon and nitrogen (N) as a function of climate, cropping history and the crop/soil management. APSIM has been used to explore crop productivity, soil fertility, soil N and water dynamics in rotations including both cereals and legumes (Keating et al., 2003).

In this study, we used APSIM to simulate a wheat-chickpea rotation at a site in northwest Syria. In the target environment, highly variable and often deficient rainfall is the primary constraint to productivity. Water for irrigation is scarce. Under these conditions, the more efficient use of water is critical for the sustainability of cropping systems. Among management practices reducing unproductive water losses from the soil and which increase the water use efficiency (WUE; ratio of crop yield to evapotranspiration) of crop production are the optimised
use of fertiliser, weed control, optimised sowing time, and forms of conservation tillage, such as
zero, minimum, and mulch-tillage (Cooper et al., 1987; Blevins and Frye, 1993).

We applied APSIM to examine the sustainability of a wheat-chickpea rotation subjected
to three tillage/residue management systems (conventional tillage, conventional tillage with
stubble burning and mulch-tillage) at Tel Hadya, Syria. A management system was considered
sustainable if the values of selected sustainability indicators were maintained or enhanced over
the simulated timeframe of 23 years and relative to a baseline system. The indicators used were
crop yield, WUE, soil organic matter (SOM) and gross margin (GM).

2 Methods and materials
A configuration of APSIM version 3.1 was used, which included the wheat and chickpea crop
models, and models for soil water and soil N. We parameterised APSIM with crop and soil data
from wheat and chickpea experiments conducted in 1998/99 and 1999/00 at Tel Hadya (Moeller
2004). APSIM was subsequently tested against data from a rotation trial (Moeller et al. 2004).
The derived parameterisation was used in the present study.

Simulation experiments were undertaken using daily temperature, solar radiation and
rainfall from 1979 to 2002 for Tel Hadya. Mean annual rainfall at the site is 340 mm and
temperature is 17.6 °C. A heavy, alkaline (pH 8) clay soil with a plant extractable soil water
(PESW) capacity of 246 mm (in 0-150 cm) and a low SOM status (~1% in 0-15 cm) was used.

The simulations included 5 N fertiliser x 3 tillage/surface residue management
combinations in a wheat-chickpea rotation. The sowing window for wheat was from 10 to 26
November and for chickpea from 1 to 21 December. Planting was triggered by PESW in the
seedling layer. The N fertiliser rates applied to wheat were 0, 30, 60, 90, 120 kg N ha\textsuperscript{-1}.
At the start of the simulation, the soil had 60 kg ha\textsuperscript{-1} of available N and 16 mm PESW in 0-90 cm depth.
After harvest of the previous crop, the simulation was re-initiated by setting the soil water content
in 0-30 cm depth to zero PESW.

Three tillage/residue management systems were simulated: conventional tillage (CT),
conventional tillage with stubble burning after wheat (BCT), and mulch-tillage (MT) (Table 1).
During primary and secondary tillage, surface residues were incorporated to 30 cm (deep
ploughing) and 10 cm depth, respectively. In the BCT treatment, all wheat residues were
removed from the soil, i.e. ‘burned’.

Gross margins were calculated as total revenue from grain yield and sold straw minus
variable costs. Variable costs included costs of machinery use, seed, herbicide, fertiliser and hired
machinery and labour (Moeller 2004).

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Crop</th>
<th>After harvest: removed</th>
<th>Primary tillage: incorporated</th>
<th>Secondary tillage: incorporated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Wheat</td>
<td>75%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>50%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>Burn-conventional</td>
<td>Wheat</td>
<td>100%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>50%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>Mulch</td>
<td>Wheat</td>
<td>20%</td>
<td>-</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>20%</td>
<td>-</td>
<td>10%</td>
</tr>
</tbody>
</table>

3 Results and discussion
In the simulations, mulch-tillage outperformed CT and BCT for all selected indicators (Figure 1).
This indicated that MT has the potential to enhance the sustainability of a rainfed wheat-chickpea
rotation at the study site.
Figure 1. Visualisation of simultaneous, mean responses (blue) relative to a baseline (100% = CT, conventional tillage) in rainfed wheat (W) – chickpea (CP) rotations subjected to two tillage/residue management systems (BCT, conventional tillage with stubble burning after wheat; MT, mulch-tillage). Yield, water use efficiency (WUE), gross margin (GM) and soil organic matter (SOM). In all systems, wheat received 60 kg N ha\(^{-1}\).

Improved yield and WUE of wheat and chickpea (Table 2) was primarily a result of higher water availability to the crops under MT compared to CT and BCT. The simulated increase in soil water (Figure 2) was due to reduced soil evaporation with a surface mulch. Soil water under BCT was similar to CT (not shown). Stubble burning after wheat (BCT) had no marked effect on SOM compared to CT but led to lower GM from wheat cropping compared to CT and MT as there was no revenue from sold straw or benefit from soil water conservation (Figure 1). Both the amount of N fertiliser and retained crop residues increased SOM (not shown), although the simulated long-term response of SOM to management did not exceed 0.3% in 0-30 cm depth.

Table 2. Simulated mean yield and water use efficiency (WUE) of wheat and chickpea grown in a rainfed rotation at Tel Hadya. Results are given for three tillage/residue management systems (CT: conventional tillage; BCT: conventional tillage with stubble burning; MT: mulch-tillage). Wheat was fertilised with 60 kg N ha\(^{-1}\); no N fertiliser was applied to chickpea.

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Chickpea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield (t ha(^{-1}))</td>
<td>WUE (kg ha(^{-1}) mm(^{-1}))</td>
</tr>
<tr>
<td>CT</td>
<td>2.5</td>
<td>8.2</td>
</tr>
<tr>
<td>BCT</td>
<td>2.4</td>
<td>8.1</td>
</tr>
<tr>
<td>MT</td>
<td>3.0</td>
<td>10.4</td>
</tr>
</tbody>
</table>

In experiments conducted in northwest Syria, zero-tillage (ZT) only marginally increased soil water (Pala et al., 2000, Jones 2000). Positive effects of increased soil water on yields were mostly not observed. Among the quoted reasons for this were problems with weeds under ZT and the amounts of straw residues retained, which were most likely too low to effectively suppress soil evaporation. However, benefits from soil water conservation have been experimentally shown for many dryland regions (Unger 1990). More targeted, site-specific solutions may be required to make conservation tillage successful at Tel Hadya. For example, the clay soil at Tel Hadya cracks deeply when dry. Under such conditions, a shallow layer of soil loosened by tillage to break pore continuity in addition to a straw mulch could be more efficient in suppressing soil evaporation.

APSIM proved suitable for monitoring and quantifying changes in the selected sustainability indicators. However, the choice of indicators is predefined by the capabilities of the model. Pests and diseases or changes in the soil structure, for example, are not simulated. Despite this limitation, systems simulation allows us to objectively examine long-term, future impacts of alternative interventions across the range of expected weather variability in a manner that is not possible with empirical observation and experimentation (Hansen 1996).
Figure 2. Simulated soil water dynamics in a rainfed wheat-chickpea rotation with conventional tillage and mulch-tillage. Wheat received 60 kg N ha\(^{-1}\). Dashed line: lower limit of plant extractable soil water for the profile.

References


