Agriculture, Ecosystems and Environment 211 (2015) 1–9

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Benefits of growing potatoes under cover crops in a Mediterranean climate

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ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form 10 May 2015
Accepted 11 May 2015
Available online xxx

Keywords:
Erosion
Runoff
Weed
Conservation agriculture
Cover crop
Agriculture economics

ABSTRACT

We evaluated the impact of incorporating cover crops (CC) in commercial potato production, primarily to alleviate the severe soil erosion recorded in Mediterranean climate agriculture. As part of a 3-year study on this subject, we have developed complete agronomic management practices that enable sowing, growing and harvesting potatoes in soil covered with CC. This management scheme includes adjustment of specific management practices and farming machinery. In this paper, we explore the impact of including CC in potato production on runoff and soil erosion, weed suppression, and potato yield and quality. These are evaluated at the environmental, agronomic and economic levels. Our results clearly show that potato production under CC generates no yield reduction or nutrient deficiencies, reduces soil erosion by 95% and reduces runoff by more than 60%. Incorporation of CC in potato-growing practices also results in suppression of weeds (both species and biomass). The direct benefit to the grower from CC adoption is estimated at a 1.3% savings in variable costs of production. The benefit for the grower, along with additional environmental benefits translated to economic public goods calls for public intervention to support the transition from the conventional practices to CC practiced is essential.

1. Introduction

Soil erosion by water is a common concern in intensive conventional agriculture of cereals, field crops, orchards and vineyards, where a large portions of the soil surface are left bare during the rainy season (Cerdà et al., 2009; García-Orenes et al., 2009; Lieskovský and Kenderessy, 2014; Zhao et al., 2013). When exposed to the impact of raindrops, bare soils form a physically sealed layer (Agassi et al., 1984; Assouline, 2004; Tarchitzky et al., 1984) that can reduce the soil-infiltration rate by several orders of magnitude. The raindrops' impact triggers parallel processes, including aggregate slaking and dispersion of clay particles, which then migrate and clog soil pores immediately beneath the surface (Agassi et al., 1981; Assouline, 2004; Eshel et al., 2004). Eshel and Egozi (2013) recently measured soil-loss rates of 4–7 mm year^{-1} under conventional agriculture in the Mediterranean-type climate of Israel. This report is consistent with world average estimates of soil-loss rates under conventional agriculture (Montgomery, 2007). Due to direct and immediate damage caused by soil erosion to potato fields, farmers must often repair the beds and/or furrows a number of times during the rainy season to maintain proper seed beds before planting and to provide sufficient cover for the potato tubers during the growing season. Loss of surface soil is accompanied by deterioration in soil fertility and quality. Furthermore, detached soil particles are often transported into the drainage network, resulting in clogged channels, reduced water-flowing capacity and increased potential for flooding. The runoff and sediments from the fields contaminate wetlands, streams, local winter pools and reservoirs, and consequently, seas and oceans.

The use of contours or terraces deals with the consequences of increased runoff due to bare soils. Other solutions deal with the

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http://dx.doi.org/10.1016/j.agee.2015.05.002
0167-8809/

driver—to protect the soil from raindrop impacts. These mainly include the creation of separating/protecting layers that absorb the kinetic energy of the raindrop and release the water slowly into the soil. Those protecting layers could be natural residues as wood-cheeps, straw, or live mulching cover-crops CC (Unger and Agassi, 1995). The CC crop is seeded to benefit the soil and production process and not for revenue per se (Dabney et al., 2001).

Beyond the agro-environmental benefits that derive from the adoption of soil conservation practices there is also an economic benefit from on-site and off-site cost savings. Pimentel et al. (1995) extended review of on the environmental and economic costs of soil erosion from conventional agricultural have estimated the on-site cost from loss of nutrients, soil productivity, organic matter and soil biota to an average of $19.7 per ton (in 2014 values), which amount in the Unites States to $46 billion dollars each year (2014 values) from 160 million ha of cropland. In addition, the off-site costs from water-and-wind soil erosion amount to a total of $29 billion dollars, resulting from damage to water bodies, water conveyance facilities and floods damages. We claim that a significant part of these costs can be saved by a shift to more sustainable agricultural practices as CC.

In Mediterranean regions, potatoes are commonly planted in light-textured, well-drained soils in the early winter season and harvested 3–4 months later in the spring. The vulnerability of these soils to rain erosion is high because of their exposure to raindrop impact for several months, until the ground is fully covered by the potato foliage. Intensive tillage accelerates the oxidation of soil organic matter, which further enhances soil erodibility. In addition, the morphology of a row crop grown on beds creates a high drainage density($0.9\,mm^{-2}$) and lines of continuous concentrated flow. This concentrated flow of water detaches soil particles and transports them out of the field.

The serious problem of soil erosion in row crops, including potatoes, has been identified and studied all over the world since the 1970s. Notably, different strategies to manage this problem have been examined in the UK (Evans and Nortcliff, 1978), Israel (Agassi et al., 1989 Agassi and Levy, 1993), Canada (Rees et al., 2002; Tiessen et al., 2007), and the USA (Griffin and Honeycutt, 2009). For example, Agassi et al. (1989) tested phosphogypsum application (at $10\,t\,ha^{-1}$) and diked furrows with an assumed storage capacity in excess of a rainfall depth of 60 mm. While phosphogypsum application reduced runoff volume and soil erosion by 6- and 20-fold, respectively, the diked furrows did not produce runoff, but the ridge erosion was similar to that in the control (without diked furrows). Potato yield under diked furrows was 18% higher than in the control for the 2 years of the experiment. However, it was not significantly different from the commercial yield in adjacent fields. Furthermore, diking potentially increased the risk of tuber infestation by soilborne diseases due to higher soil moisture content present for longer periods of time (Agassi and Levy, 1993). Finally, the diked-furrow technology was not adopted due to agrotechnical problems and to a maximum water-storing capacity that was still too low. Moreover, the use of phosphogypsum has been banned in most countries due to its classification as a technologically enhanced naturally occurring radioactive material (Tayibi et al., 2009). The use of soil stabilizers such as polyacrylamide, with or without the addition of gypsum, was also widely tested but never extensively adopted by farmers due to either timing of application or rapid decrease in polyacrylamide efficiency after rain events (Griffin and Honeycutt, 2009).

In Canada, mulching with oat straw at $4\,t\,ha^{-1}$ applied immediately after potato sowing reduced soil loss by 50% and increased soil water retention by ~5% (Edwards et al., 2000). Döring et al. (2005), using a rain simulator operated under rainy summer conditions, applied $2.5–5\,t\,ha^{-1}$ of straw 2–4 weeks after potato sowing. Soil loss was reduced by 97% while potato yield and quality were retained; however, soil moisture and weed suppression were similar to those in the nonmulched controls. Mulching with $3\,t\,ha^{-1}$ straw applied after potato harvest reduced the total P and sediment loss by 95% relative to bare soil (Griffin and Honeycutt, 2009; Rees et al., 2002). While straw mulching seems to efficiently conserve soil permeability and prevent runoff, the straw can be blown away by winds, and its availability and market prices (especially in the Mediterranean region) may be even more limiting.

Cover crops (CC) are used worldwide for mulching and their use as green manure is now quite popular in organic potato production. Eighty years ago, in rather unfertile soils, potato yield increase was attributed to increased content of soil organic matter and soil water-holding capacity (Hester, 1937). More recent studies have shown that the use of rye (*Secale cereale* L.) CC as a green manure significantly reduces Colorado potato beetle populations and resultant damage (Brust, 1994); in Indiana, USA, CC improved soil fertility and nitrogen phytoavailability, and decreased crop infection by pests, thus improving potato yield and quality (Nyiraneza and Snapp, 2007). Weed suppression by CC has been attributed to three mechanisms: competition, shading and allelopathy (Hartwig and Ammon, 2002; Hatcher and Melander, 2003). The concept of sowing organic potatoes in beds with heavy CC residues was suggested years ago (Morse, 1999; Mundy et al., 1999) in Virginia, USA. Those studies outlined the benefits of weed suppression and prevention of soil erosion, but also indicated a possible decrease in yield production (one field was not affected while another suffered 25% yield reduction). The authors related the yield reduction to lower soil organic matter content.

The objectives of this study were to: (i) assess whether CC can make a positive contribution to soil and water conservation in the Mediterranean region, and (ii) enhance our agrotechnological capacity to allow sowing and growing (and perhaps also harvesting) of potatoes while the soil is under a CC, without reducing profitability.

2. Materials and methods

The study was performed in commercial agricultural fields located in the central Mediterranean coastal plain of Israel, near Mishmeret (32°13′32N 34°53′22E), where the average annual winter rainfall is 550 mm. The most common soils in this region are Hamra soils (thermic Psammentic or Typic Haploxeralf): sandy to sandy loam soils with low organic matter content ($5\,g\,kg^{-1}$) and clay content of less than 5%, with weak to no structure. The study was conducted along three consecutive growing seasons (2011–2012, 2012–2013, 2013–2014). The common crop rotation in this region is: potato, watermelon, carrot, sweet potato, and cereals. As a result, it was necessary to establish the experimental plots on different sites in each year. All of the plots were set up on inclines with a relatively uniform slope (5–7%). To define the experimental plots, a topographical survey was conducted using a terrestrial laser scanner (Scan Station C10, Leica Ltd.) with which we produced an idigital evolution model at 1 cm resolution of the plot and the roads or paths bordering it. On the basis of this map, we divided the area into blocks and treatments. In addition, drainage directions were defined in each block and used to prevent runoff water flowing from plot to plot and from attached or nearby cultivated fields. The soil preparation for the growing season included paraplowing, fertilization with $50\,m^3\,ha^{-1}$ compost, $500\,kg\,ha^{-1}$ superphosphte and $500\,kg\,ha^{-1}$ potassium chloride, a technical irrigation of ~30 mm and preparation of planting beds with a rototiller. Throughout the growing season, the potatoes received $500–600\,kg\,ha^{-1}$ urea nitrogen in $100\,kg\,ha^{-1}$ portions.