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Effect of tillage and cropping systems on runoff, soil loss and crop yields under semiarid rainfed agriculture in India

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ABSTRACT

Cropping practice (tillage) is an important management tool for tackling water induced erosion hazard, promoting in situ water conservation and improving and stabilising crop yields from rainfed production systems of semiarid and subtropical regions. Four practices including conventional tillage (CT), ridge farming tillage (RFT), no tillage (NT) and stubble mulch farming tillage (SMFT) were evaluated for 11 years (1990–1991 to 2001–2002) under semiarid rainfed conditions in western India on a very deep, sandy loam soil. Green gram[1] (*Vigna radiata*)–mustard (*Brassica juncea*) sequential cropping and pearl millet (*Pennisetum glaucum*) + pigeon pea (*Cajanus cajan*) intercropping systems were tested for the first four years (first phase of the experiment). Cowpea (*Vigna unguiculata*)–mustard sequential cropping and cowpea + castor (*Ricinus communis*) intercropping systems were used for the following seven years (second phase of the experiment). Runoff, soil losses, sediment concentrations, crop yields, soil organic carbon, bulk density and water stable aggregates were observed for all the treatment combinations. RFT and SMFT were both effective in reducing runoff and soil loss. RFT, NT and SMFT reduced runoff by 69.4, 16.2 and 59.6% respectively compared with CT. Average soil loss in NT was 37.2% less than CT. Average sediment concentration of runoff during June–July was greater than in August–October for all treatments and average sediment concentrations were greater under CT and RFT. The highest average yield of all crops except green gram was recorded under SMFT. Surface soil organic carbon (SOC), bulk density and water stable macro-aggregates were all significantly greater under NT at the end of the experiment, but reverting to uniform tillage negated this effect. Micro-aggregates built-up under SMFT were relatively more stable than those all under NT. The results of this study demonstrate that in the semi-arid sub-tropical agro-ecosystem of Gujarat (western India) adoption of SMFT can significantly improve and stabilise the crop yields and reverse land degradation process.

1. Introduction

No-till conservation agriculture has been proposed as an important strategy to improve food security by increasing productivity and reducing resource degradation (FAO, 2012). Adoption of no-till has been increasing in countries like USA, Brazil, Argentina, Canada, and Australia, but is much slower amongst poor smallholder farmers growing rainfed crops in semiarid regions. Rainfed farming accounts for about 82% out of world's total cropland (FAOSTAT, 2005) and rainfed farmers in semiarid regions are highly vulnerable to weather uncertainties and climate change. In west India, for instance, water stress can be expected to affect rainfed crops yields about one year in every three (Down to Earth, 2007; Raju and Chand, 2010). There is an extensive literature on no-till (NT) effects on soil health, hydrology and crop response in the developed world (Baker et al., 1996), but information on its long term impact in smallholder farming in semiarid arid areas is less common.

Resource degradation is also an important problem for semiarid areas and water erosion is common, affecting 126 Mha in India (Maji et al., 2010). Tillage increases soil degradation and erosion (Cerda et al., 2009), reducing soil productivity and soil organic

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[1] "Also known as Mung bean".

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carbon (SOC) (Lal, 2004), whereas reduced or no till practices can increase SOC in the surface soil layer (Sainju et al., 2006; Lopez-Bellido et al., 2010). Good farming practices and fertilizer application can facilitate crop and root development; and this in turn can improve soil C balance by increasing the crop residue available for return to the soil (Kirkby et al., 2011; Gregorich et al., 1996; Dalal et al., 2011). Improved practices may increase SOC even if above ground biomass is removed, because a significant portion of total biomass is contributed by roots (Kuo et al., 1997). Greater root development improves soil physical conditions and carbon sequestration (Sandeep et al., 2010), because root C contributes more than surface residue C to overall carbon stabilisation (Kong and Six, 2010).

Restoration of soil SOC is also influenced by soil types and climate. Some soils sequester more C than others (Bayer et al., 2006) and it is more difficult to maintain high SOC in semiarid conditions, where measures expected to improve SOC sometimes have little effect. These include residue incorporation (Soon, 1998), Farm Yard Manure (FYM) application (Kumar et al., 2009), crop rotation, fertilizer application, residue incorporation and residue burning (Campbell et al., 1991; Rumpel, 2008).

No-till 'conservation agriculture' has also been shown to provide substantial water conservation, energy and ecological benefits (Morris et al., 2010). Residue maintenance can however be difficult in semiarid conditions. Unger et al. (2006) and Zhang et al. (2011) found a mixed response to conservation agriculture in China. Surface manipulation can also improve moisture conservation when negative tillage effects are minimised by crop residue or mulching. Liu et al. (2009) have demonstrated yield improvements with plastic-mulch ridge farming.

This long-term study was undertaken with the objective of comparing cropping ("tillage") practices in terms of their impact on soil and water conservation, soil quality effects and crop productivity. The experiment was carried out using two common crop rotation systems both which are seen as having high income-producing potential under rainfed conditions of western India.

2. Materials and methods

2.1. Site description

The experiment was conducted from 1990–1991 to 2001–2002 at the research farm of Central Soil and Water Conservation Research and Training Institute, Research Centre, Vasad (long: 73.0806° E, lat: 22.4574° N) on a very deep, well drained, coarse loamy, mixed Hyperthermic Typic Fluventic Ustochrepts soil having about 1.5% slope. This sandy loam soil at the experimental site has a final infiltration rate of 3–5 cm h^{-1}, field capacity of 19–20% and wilting point of 7–8.5%. Soil fertility is poor with organic carbon of 3.0–3.5 g kg^{-1}, pH in the range 7.5–7.84 and electrical conductivity of 0.12–0.20 dS m^{-1}. Average (50 years) annual rainfall is 871 mm, with 94% between June and September, and 61% in July–August (Fig. 1). Average annual maximum and minimum temperatures are 33.7 and 18.9 °C respectively. Average annual pan evaporation is 2119.4 mm. Crop growing a conditions defined by soil moisture availability, last only 114 days. *Kharif* (rainy season) crops are normally planted from 15th June to 15th July and *Rabi* (dry season) crops from 10th October to 10th November.

Four cropping (tillage) practices were evaluated:

1. Conventional tillage (CT): two cultivations by country plough followed by planking to smooth the surface. Crops were sown down-slope (i.e. not on the contour) and residue removed from field.
2. Ridge farming tillage (RFT): ridges of about 15 cm height formed 45 cm apart on the contour without additional soil manipulation. *Kharif* crops sown on ridges, *Rabi* crops sown in furrows, and residues removed from field.
3. No tillage (NT): no seedbed preparation, minimal soil disturbance for seed and fertilizer placement only using hand hoe. Crops sown on the contour, residue removed from field.
4. Stubble mulch farming tillage (SMFT): one mouldboard ploughing followed by one cultivation on contour, surface roughness maintained (no planking). Crops sown on contour, with 2 t ha^{-1} chopped pearl millet straw mulch spread on the surface.

NT and RFT treatments were hand-sown using a hand hoe to form the seeding trench, but CT and SMFT were sown using bullock power and an indigenous seed drill. Seed rate was controlled by skilled man power. Thinning was performed to maintain proper plant spacing. The RFT ridge was not disturbed throughout the experimental period except where minor repairs were required. Seed rate, fertilizer and crop plan details for each treatment are shown in Table 1. All treatments were hand weeded on the 15th and 35th day after sowing.

During the first phase of experimental period (1990–1993) green gram–mustard sequential cropping and pearl millet + pigeon pea intercropping were tested under four cropping (tillage) practices.

In the second phase (1995–2001) green gram–mustard sequential cropping was replaced with cowpea–mustard sequential

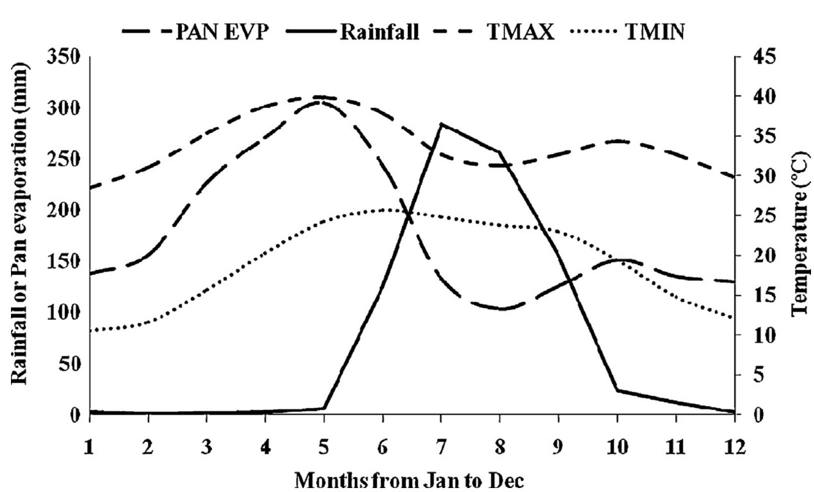

Fig. 1. Average monthly rainfall, pan evaporation (PAN EVP), maximum (TMAX) and minimum (TMIN) temperatures recorded at the experimental site for the period 1957–2011.