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Crop establishment techniques affect productivity, sustainability, and soil health under mustard-based cropping systems of Indian semi-arid regions

Kapila Shekhawat[a,*], S.S. Rathore[a], B.K. Kandpal[a], O.P. Premi[a], Dhiraj Singh[a], Bhagirath Singh Chauhan[b]

[a] ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan 321 303, India
[b] The Centre for Plant Science, Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Toowoomba, Queensland 4350, Australia

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ABSTRACT

Indian mustard [*Brassica juncea* (L.) Czern & Coss] is the predominant oilseed crop in semi-arid India, conventionally grown by repeated plowings during the rainy seasons to conserve soil moisture in fallow fields. To evaluate the effect of establishment methods on productivity, soil health and economics of mustard under various cropping systems, a field experiment was conducted for four years from 2009–2010 to 2012–2013 at the Directorate of Rapeseed-Mustard Research, Bharatpur, India. Conventional tillage (CT), reduced tillage (RT), zero tillage (ZT), and permanent furrow irrigated raised beds (FIRB) treatments were evaluated for five mustard-based cropping systems, *viz.,* fallow–mustard, green manure–mustard, brown manure–mustard, cluster bean–mustard, and pearl millet–mustard, in split-plot design with three replications. The variable tillage practices significantly affected seed, stover, and biological yields, production efficiency, and the economics of mustard along with the bulk density and soil organic carbon dynamics. After four years of the experimentation, the highest mustard seed yield was obtained under FIRB (2765 kg ha^{-1}) which was 23.6% higher over CT. The seed yield obtained under ZT (2533 kg ha^{-1}) was 17.5% higher over CT. The seed yield recorded under RT was found similar with ZT, but significantly higher over CT due to higher dry matter accumulation, higher translocation efficiency, and greater sink/source potential at the seed filling stage. Among the cropping systems, highest yield was obtained under the green manure-mustard system followed by the cluster bean–mustard system. The seed yield enhancement with the green manure–mustard cropping system was 13.9% over the fallow-mustard system. The highest assimilate supply (0.33 g $siliqua^{-1}$) was recorded under ZT. Sustainability parameters, including harvest index (0.29), sustainability yield index (0.85), and production efficiency (16.1 kg ha^{-1} day^{-1}) were also found highest under ZT after four years of the experiment. Soil organic carbon increased to 0.39% and 0.36% in ZT and FIRB, respectively, from 0.26% in CT. A higher mass of soil organic carbon and carbon sequestration potential rate was recorded under ZT. The bulk density under ZT and FIRB decreased over CT. The soil organic carbon, the mass of soil organic carbon, and the carbon sequestration potential rate were highest in the green manure–mustard system. These parameters were similar between the pearl millet–mustard system and fallow-mustard system, indicating that an additional pearl millet crop can be successfully grown without exhausting the soil organic carbon. The net returns, profitability, and the benefit-cost ratio were highest under FIRB, followed by ZT.

1. Introduction

The significance and potential of a rapeseed-mustard crop could be understood by the fact that it is the world's third most important source of edible oil after soybean [*Glycine max* (L.) Merr.] and palm (*Elaeis guineensis* Jacq.). Rapeseed–mustard accounts for 22.2% acreage and 22.6% production of the total area and production under the nine oilseeds crops grown in India

Abbreviations: CT, conventional tillage; ZT, zero tillage; RT, reduced tillage; FIRB, furrow irrigated raised bed; COC, cost of cultivation; SOM, soil organic matter; SOC, soil organic carbon; RCT, resource conservation technologies; DAS, days after sowing.

* Corresponding author. Fax: +91 11 25842283.
E-mail address: drrathorekapila@gmail.com (K. Shekhawat).

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(Shekhawat et al., 2012). Indian mustard [*Brassica juncea* (L.) Czern & Coss] comprises more than 85% area cultivated under rapeseed–mustard in India. The area under rapeseed–mustard is broadly marginal where productivity constraints are mainly due to low soil organic matter (SOM) and resource poor circumstances of the farmers (Kumar, 2012). Due to limited irrigation facilities, low input, and management skills, the productivity of rapeseed-mustard linger to 1264 kg ha^{-1} at the national level. Inappropriate land preparation, poor crop establishment methods, excessive traffic, and continuous mono-cropping often lead to deterioration in soil fertility and escalation in the cost of cultivation (Wang et al., 2007; Simmons and Coleman, 2008; Helgason et al., 2009).

The conventional tillage (CT) of mustard involves 3–7 plowings and planking operations with tractors. This repeated tillage is performed to create a seedbed with fine tilth and to form a dust mulch to conserve soil moisture in the seedbed. But simultaneously, this excessive stirring opens the soil, breaks soil clods and aggregates, and enhances the oxidation of soil organic matter (Pekrun et al., 2003; Kramer et al., 2002). Adoption of conservation agriculture techniques like minimum mechanical soil disturbance, bed planting, green manuring, and brown manuring along with crop residue management could be a viable and sustainable solution to the constraints in the semi-arid regions (Lichter et al., 2008; Hobbs, 2001; Fahong et al., 2004). These techniques offer numerous benefits, including farm productivity and profitability enhancement, moisture conservation, weed control, and improvement in soil health (Govaerts et al., 2007; Limon-Ortega et al., 2002). Aggressive seed bed preparation under CT leads to declining soil carbon pools (Gathala et al., 2011; Bhattacharyya et al., 2013), while RT and ZT with crop residues increases carbon sequestration in soil by improving soil aggregate stability (Bhattacharyya et al., 2012). The importance of conservation tillage and residue incorporation in sandy-loam soils of semi-arid regions in India is very high (Gangwar et al., 2006), but the systematic approach for the adoption of these resource conservation technologies (RCTs) in such zones, particularly for the mustard growing regions is lacking. Therefore, a study was conducted with the objective to evaluate the effect of various mustard-based cropping systems under diverse crop establishment methods on growth and productivity; soil health and farm profitability in semi-arid India. The information generated from this study would facilitate quantitative yield predictions in relation to soil–plant and climate interactions.

2. Materials and methods

2.1. The experiment

The field experiments were conducted during the winter seasons of 2009–2012 at the research farm of ICAR-DRMR, Rajasthan, India (77°3′ E longitude and 27°15′ N latitude, 178.37 meter above mean sea level). The climate is semi-arid (moisture index: −65 to −55) with hot summer and a short monsoon (about 700 mm rainfall during July–September). The mean maximum and minimum daily temperature during summers ranges from 35 to 47 °C and 12 to 29 °C, respectively. The clay loam soil (25% sand, 41% silt and 34% clay) of the experimental area is

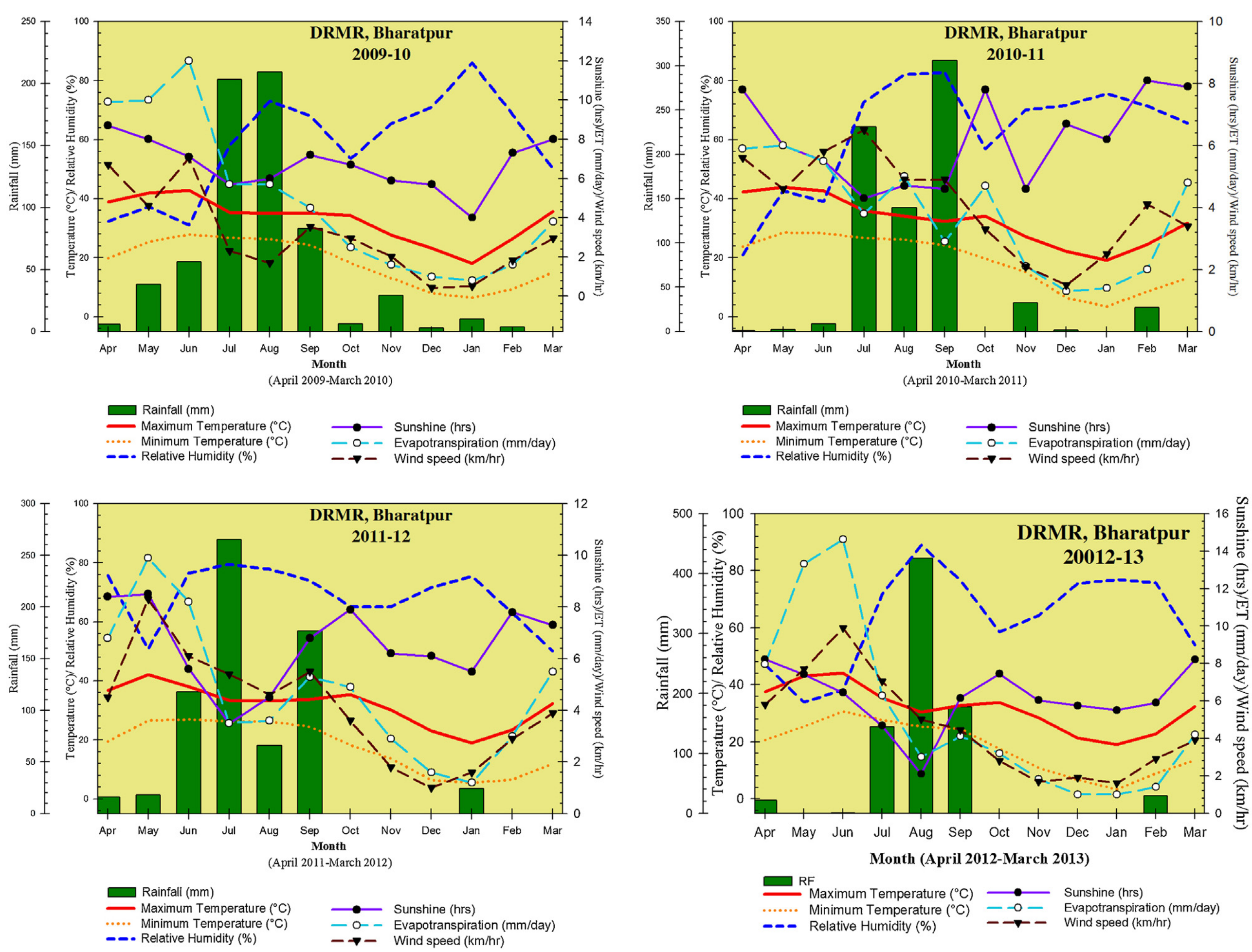

Fig. 1. Mean monthly weather parameters of the experimental site from 2009 to 2012.