Strategic deep tillage and crop rotation for improving productivity of non-sodic heavy soil in the low rainfall regions of Western Australia

Md. Shahinur Rahman[1*] Jenni Clausen[2] and Gaus Azam[3]

[1]Department of Primary Industries and Regional Development, Merredin, Western Australia
[2]SoilsWest Alliance, Murdoch University, Perth, WA
[3]Department of Primary Industries and Regional Development, Northam, Western Australia
*Presenting Author

Abstract

Non-sodic heavy soil in the low rainfall regions of Western Australia can be dense and poorly structured with alkaline clay in the subsoil, which prevents root exploration and potentially restricts grain yield. A 4-year long (2020-2023) field experiment was established near Bencubbin in 2020 to investigate whether the loosening of dense soil layers with a strategic deep ripping followed by a summer crop, super sweet sudan (SSS) forage sorghum and crop species of varying root architecture (barley, canola, chickpea, and vetch+oat), or fallow in 2021 can increase barley root exploration in the subsurface soil layers and yield in subsequent years (2022 and 2023). The results showed that deep ripping and SSS had no significant impact on barley grain yield in 2021, 2022 and 2023 compared to no ripping and without SSS. Barley grain yield in 2022 was significantly increased following fallow, chickpea and canola compared to following vetch+oat and continuous barley. In 2023, barley grain yield showed no significant difference due to extremely dry conditions. We concluded that deep ripping in this dense, non-sodic, heavy soil might have limited benefit on crop root exploration or yield. Summer crops such as SSS could be grown to fill the feed gap for grazing without significantly affecting the yield of the crops in the following years. Keeping the land fallow or growing break crops (e.g. canola/chickpea) might be beneficial for increasing cereal crop yield compared to continuous barley.

Keywords

Tillage, summer crop, break crop, water infiltration, subsoil constraints

Introduction

Heavy-textured soils are challenging for cropping in the low-rainfall areas of Western Australia (WA) especially due to compaction and limited water infiltration for plant availability associated with many physical and chemical challenges such as high pH and bulk density, poor structural stability, sodicity, salinity and boron toxicity (Bryce and Pluske, 2022). Poorly structured alkaline heavy subsoil clay with sodicity restricts plant yield by limiting root growth, poor movement of air into the subsoil and slow water infiltration (Naidu and Rengasamy 1993, DAF 2022).

To manage compacted subsoil layers along with sodicity, many strategies have been recommended including physical (tillage) and biological (crop species) approaches to increase or maintain farm productivity in WA (McKenzie 1993, Cochrane et al 1994, Jayawardane and Chan 1994, Raine and Loch 2003, DAF 2022). Tillage such as deep ripping can loosen compacted and poorly structured soils to assist in improving soil structure (Cochrane et al 1994, Jayawardane and Chan 1994, DAF 2022). Crop species with a tap root system can create pathways for the subsequent crops which would help in the root exploration for nutrients and water in the subsoil layers (DAF 2022). A limited number of studies are available where the different management options for compacted subsoil layers along with sodicity have been compared to recommend a best management approach.

In this study, we have a 4-year long trial involving physical (tillage) and biological (crop species) approaches to manage the productivity of a compacted, heavy textured soil with a non-sodic topsoil layer (0-20 cm) along with sodic and alkaline subsoil layers (>20 cm) at Bencubbin in a low rainfall area of the southwestern agriculture zone of WA. We hypothesized that tillage would remove compacted soil layers and different crop species, including tap and fibrous root systems, would create pathways for subsequent crop roots to explore for nutrients and water.

Materials and Methodology

The trial was established in a low-rainfall region of WA at Bencubbin (Latitude: -30.74, Longitude: 117.92) in 2020 and cropped continuously until 2023. This is a loamy earth soil and is classified as calcarosol in the Australian Soil Classification system. Topsoil had a good level of nutrients with low PBI (Table 1). Subsoil (especially below 20 cm depth) had multiple constraints including low organic carbon (OC), nitrogen (N) and phosphorus (P). Subsoil (> 20cm) was slightly boron toxic and dispersive with higher EC. The top 20 cm of soil was non-sodic (ESP <6%) but the subsoil (> 20cm) was strongly sodic (ESP >15 %) (Table 1).

Table 1: Pretrial soil properties at different depths at Bencubbin in 2020.

Depth (cm)	Inorganic N (mg/kg)	Colwell P (mg/kg)	Colwell K (mg/kg)	OC (%)	EC (dS/m)	pH (H_2O)	Boron (mg/kg)	PBI*	ESP* (%)
0-10	31	42	552	1.06	0.42	5.8	1.3	38	3.6
10-20	4	21	444	0.47	0.10	7.5	1.7	48	5.4
20-40	4	5	581	0.13	0.21	9.3	3.4	68	15.5
40-60	7	6	680	0.10	0.62	9.9	6.9	77	21.1
60-80	6	7	614	0.11	0.66	9.6	9.2	91	17.8

* PBI and ESP represent phosphorus buffering index and exchangeable sodium percentage, respectively.

A deep (40 cm) physical soil loosening treatment was applied (a total of 36 plots) using a paraplough in 2020, followed by a summer crop Super Sweet Sudan (SSS) (a total of 36 plots; with ripping 18 and without ripping 18 plots) and a fallow treatment (a total of 36 plots; with ripping 18 and without ripping 18 plots). In 2021, different winter crop species of varying root systems (a total of 12 plots for each crop and fallow treatment; with/without ripping and without SSS 6 plots and with/without ripping with SSS 6 plots). Crop species were barley (fibrous root), bonito canola (tap root), trident canola (tap root), chickpea (deep tap root), vetch+oat (tap and fibrous root) including a fallow. The effect of soil loosening and different crop species grown in 2020 and 2021 on barley yield was measured in 2022 and 2023 (a total of 72 plots for barley; with/without ripping and without SSS 36 plots and with/without ripping with SSS 36 plots). Each plot was 20 m long and 1.54 m wide including 3 replications for each treatment. Soil hydraulic conductivity (2021) and soil strength (2021 and 2022) were measured from the deep ripped and without deep ripped (nil) plots. The topsoil (0-10 cm) nutrient concentration was measured before sowing at every cropping season. The cropping season was from May to October and harvested using a plot harvester at the end of the cropping season. Root abundance was measured at the flowering stage in 2023 from a few selected treatments after excavating the edges of the plots.

A linear model was fitted to each of the measurements using the ANOVA procedure in GenStat (Version 18.1, VSN International, Oxford, UK) to compare the treatment effects. Fisher's protected least significant difference (LSD) was applied at the 0.05 significance level.

Results

Effect on soil hydraulic conductivity and soil strength

Deep ripping by paraplough increased the soil hydraulic conductivity more than 2.5 times compared to nil treatment in 2021 however the effect was not statistically significant (Figure 1a). Deep ripping has significantly ($P \leq 0.05$) decreased soil strength in the topsoil (0-10 cm) and subsoil (10-20 cm and 30-40 cm) compared to the nil treatment in 2021 (Figure 1b). In 2022, deep ripping had no significant impact on soil strength compared to the nil treatment except for 0-10 cm (Figure 1c).

Effect on root abundance

Deep ripping by paraplough had no significant impact on the barley root abundance compared to the nil treatment in 2023 (Figure 2a). A significantly ($P \leq 0.05$) higher number of roots was observed following bonito canola (deep ripped without SSS) compared to continuous barley at 20-30 cm (deep ripped without SSS) and 50-60 cm (without deep ripping and SSS) in 2023 (Figure 2b).

Effect on crop yield

The deep ripping and summer crop had no significant differences in crop yield in any of the growing seasons in 2021, 2022 and 2023 (Figure 3a).

The significantly (P≤ 0.05) highest barley yield was recorded following fallow and chickpea in 2022 compared to vetch+oat (without ripping and with/without SSS) (Figure 3a). The barley yield following fallow and chickpea without SSS was significantly (P≤ 0.05) higher compared to continuous barley with SSS (without ripping). Barley yield significantly (P≤ 0.05) increased following bonito canola (except for with SSS and without ripping) compared to vetch+oat with SSS whereas significantly (P≤ 0.05) increased following trident canola compared to vetch+oat with SSS (with or without ripping).

In 2023, no significant difference in crop yield was observed among the treatments (Figure 3a) due to an extremely dry season in 2023 (111 mm of growing season rainfall, Decile 1) compared to 2021 (230 mm of growing season rainfall, Decile 7) and 2022 (284 mm of growing season rainfall, Decile 9).

Effect on topsoil nutrient concentrations

The topsoil inorganic nitrogen concentrations were significantly (P≤ 0.05) higher following fallow and canola compared to following barley and vetch+oat in 2022 (Figure 3b). The topsoil Colwell phosphorus concentrations were significantly (P≤ 0.05) higher following chickpea compared to following fallow, barley, canola and vetch+oat in 2022 (Figure 3b).

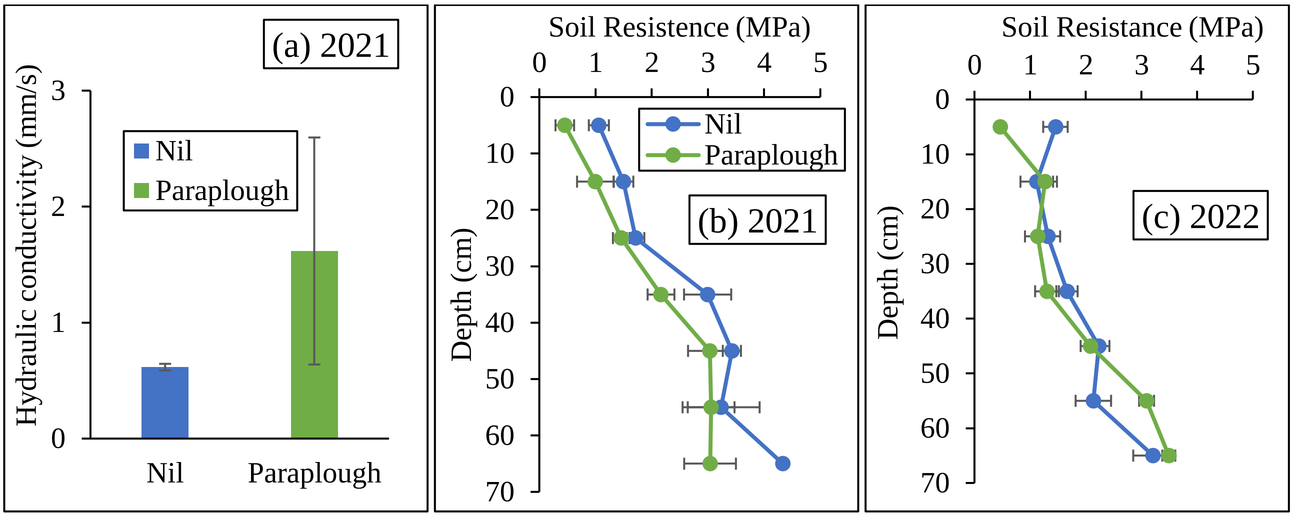

Figure 1: The effect of deep ripping on (a) soil-saturated hydraulic conductivity in 2021 and (b) soil penetrometer resistance in 2021 (b) and 2022 (c) at Bencubbin. The vertical (a) and horizontal lines (b and c) represent the standard error of the mean value.

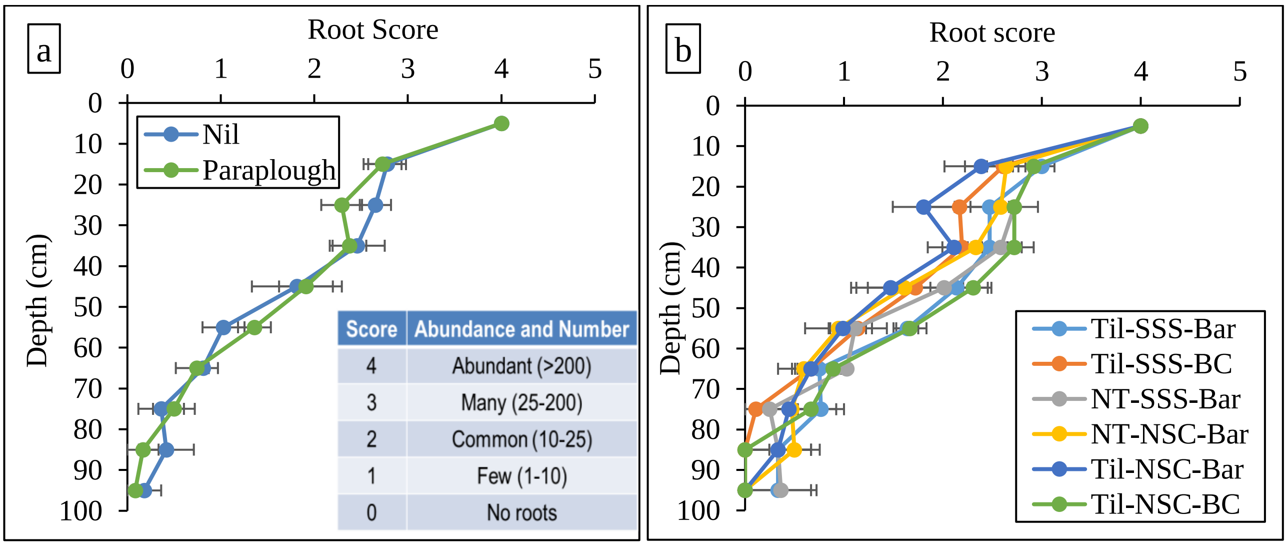

Figure 2: Effect of (a) deep ripping and (b) different plant species on barley root abundance in 2023. Til, SSS, NSC, Bar and BC represent Deep Ripping, Super Sweet Sudan, No Summer Crop, Barley and Bonito Canola, respectively. The horizontal lines represent the standard error of the mean value.

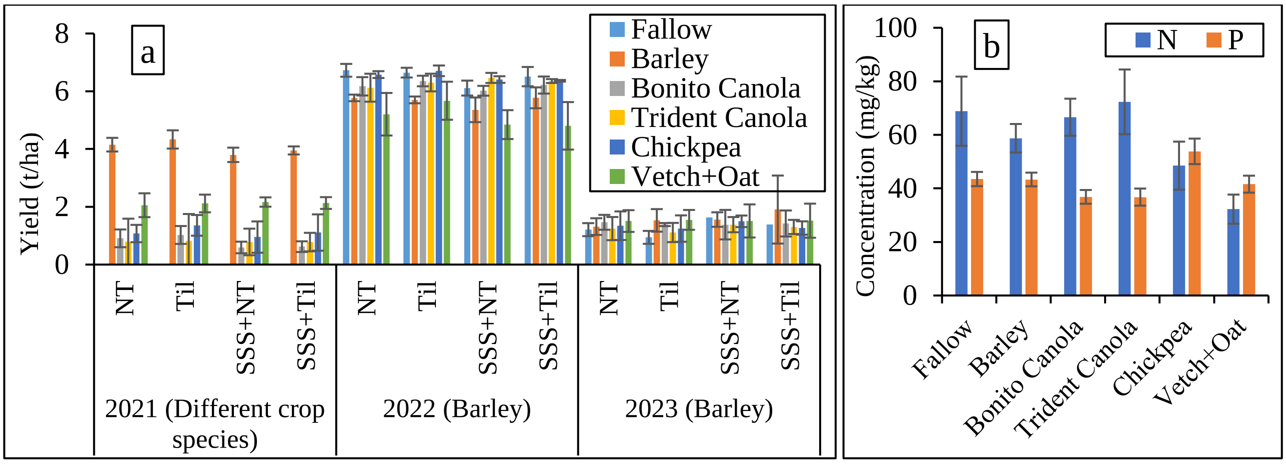

Figure 3: a) The effect of deep ripping and summer crop on different crop species cultivated in 2021 and the effect of deep ripping, summer crop and different crop species on barley yield in 2022 and 2023. The NT, Til and SSS represent no ripping, deep ripping and Super Sweet Sudan, respectively. b) The topsoil inorganic nitrogen (N) and phosphorus (P) concentrations in 2022 following different crop species. The vertical lines on the top of the bar represent the standard error of the mean value.

Conclusion

Deep ripping had no benefit in this compacted, non-sodic, heavy soil for increasing crop root exploration and yield. This is due to the short-term benefits of deep ripping and later re-compaction of the soil layers. The barley yield in 2023 was affected due to a drier season compared to 2021 and 2022. Summer crops such as SSS could potentially be used to fill the feed gap for grazing without significantly affecting the yield of the crops in the following years. Keeping the land fallow for a season or growing break crops (e.g. canola/chickpea) might be beneficial for increasing cereal crop yield (due to an increase in the availability of inorganic nutrients such as N and P) in the following season compared to continuous barley crops. The subsoil was highly alkaline, which might have also restricted crop root exploration. Future research should focus on decreasing the subsoil pH to increase crop root exploration and yield in this compacted, non-sodic, heavy soil.

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