Raised beds in South West Victoria: Pore structure dynamics deliver increased plant available water in sub-optimal rainfall years

Renick Peries[A]**,** Abdur Rab[B] and Chris Bluett[C]

[A]Department of Primary Industries, P O Box 103, Geelong, Victoria 3220, Australia. renick.peries@dpi.vic.gov.au
[B]Department of Primary Industries, 255 Ferguson Road, Tatura, Victoria 3616, Australia abdur.rab@dpi.vic.gov.au
[C]Department of Primary Industries, 402-406, Mair St. Ballarat, Victoria 3350, Australia chris.bluett@dpi.vic.gov.au

Abstract
Soil physical properties were compared between raised beds and flat on two Vertosols (Vertisols in the USDA classification) at three and five years after establishment of beds where different crops and pasture rotations were managed to best practice. A black Vertosol (BV), which had superior structure prior to bedding, performed less favourably than a grey (and sodic) Vertosol (GSV) when their pore structure dynamics were compared. While the BV lost some of its micro-porosity in the 0–0.4 m in the first three years, there was some compensation at depth in the following two years but only at the 0.2–0.4 m depth. In comparison the GSV showed continuous improvement in its micro-porosity over the five years, thus improving in its water retention capacity by about 46% compared to only ~20% in the BV.

Key Words
Raised beds, Vertosols (Vertisols), Sodosols, pore structure, plant available water capacity.

Introduction
Raised beds were adopted by farmers in this conventional grazing region, to overcome the risk of damage to crops through waterlogging during the long, cool winter growing season. Despite reliable growing season rainfall, the low permeability of these heavy clay soils can frequently restrict root growth and water movement, and can cause a severe perched water table (Belford *et al*.,1992). Under long-term pasture, these soils have been further compacted by livestock and uncontrolled trafficking of farm machinery. The Vertosols (Isbell 1996) that are representative of about 20% of the region are known to be generally more productive due to their better aeration and greater depth of aggregates (Sarmah *et al*., 1996) than the Grey Sodosols which are more widespread in the region. The work reported here is a part of a long-term trial where three different farming systems (rotations) were compared for productivity and sustainability on 1.7 m-wide and 0.20-0.25m high raised beds on two different Vertosol soils. One was a black cracking clay Vertosol (BV) and the other was a grey Vertosol, which was increasingly sodic at depth and referred to here as a Grey Sodic Vertosol (GSV). The aim of this study was to compare the two Vertosols for their plant available water capacity (PAWC) at three and five years of planned rotations on raised beds. This paper describes the dynamic of porosity changes in the two Vertosols which resulted in temporal differences in PAWC that could contribute to both survival of crops during sub-optimal rainfall conditions and increased productivity under average rainfall conditions.

Methods
The trial was conducted at Gnarwarre near Geelong (38^0 10'S, 144^0 08'E) at the eastern end of the West Victorian Volcanic Plains in Southern Australia in the 500+ mm high rainfall zone. The experiment consisted of 36 plots in a row–column design (6 rows by 6 columns), each devoted to a combination of three crops and pasture rotations on two raised bed systems; wide (20 m) and narrow (1.7 m) raised beds for the comparison of their productivity and sustainability. This paper deals only with the soil physical properties on 1.7 m narrow raised beds. The establishment of narrow raised beds involved several stages of tillage and mounding, starting from a flat perennial pasture. The soil was initially tilled to a depth of approximately 0.08- 0.1 m using a disk harrow, followed by cultivation to a depth of 0.2 m using a chisel plough. A three-bed bed forming machine was then used to mound the soil into beds of 1.7 m width and crumble rollers at the back of the machine lightly compacted the soil on the raised beds and aided in breaking larger clods. After initial cultivation and bed forming the only soil disturbance on the beds was the annual sowing operation using a cone seeder fitted with narrow knife points (minimum-till). Press wheels were used behind the sowing tines to ensure adequate seed–soil contact. The shallow grooves left on the beds by the press wheels act as a reservoir for water harvesting. The water moves through these grooves into the beds and, when bed height is saturated, moves into the main furrow between beds and is carried away from the paddock. Crops and pastures were sown annually on the raised beds and managed to local 'best practice' guidelines. Beds were established in April 1999 and were cropped under minimum tillage (MT) and controlled traffic (CT) for the next six years. Sheep were used to graze the plots during the pasture phases and 'tactical grazing' ensured that the sheep were removed from the

plots when the soil was 'wet' to avoid compaction and pugging. The long-term perennial pasture state of the two Vertosols was determined at the commencement of the trial by collecting intact soil cores to a depth of 0.6 m, and using the process described by Gill *et al*. (2009) to determine the soil bulk density (BD), total porosity (P_t), macro porosity (P_m) and plant available water capacity (PAWC). P_m was measured by the difference in water held in the pores at saturation and the matric potentials of -10kPa. In April 2002 and May 2004, at the end of three and five years of planned rotations, all plots were again sampled to a depth of 0.4 m and analysed to determine the BD, P_t, P_m and PAWC experienced by the crops growing on the beds. The main comparison reported in this study is that of the soil environment experienced by crops and pastures growing on raised beds versus the soil environment on the flat, unimproved pasture system that was developed into a raised bed system. For this purpose the flat areas were sampled on each occasion that the beds were sampled and the assumption was made that these flat areas undergo little or no tillage at all while carrying an unimproved and grazed perennial pasture. The differences in soil physical parameters between the flat perennial pasture and the raised beds as experienced by the growing crops and sown pastures were analysed using the residual maximum likelihood procedure (REML) in Genstat 5.42 (GenStat Committee 2000).

Results and Discussion

The soil prior to raised beds

The soil physical parameters on flat, unimproved perennial pasture are shown in Table 1. The apparently higher soil BD in the GSV soil in the 0–0.3 m depth could impose a limitation to root growth and soil water extraction compared to the BV. These soils have been under perennial pastures for a long period (>10 years) and indiscriminately trafficked in their routine management. Despite the total PAWC to 0.4 m being very similar (~65 mm) in the two soils, the greater cracking and self-mulching nature of the BV soil and its lower density in the surface layers could contribute to its greater productivity compared to the GSV, as has been the experience of local farmers. The low self-mulching index of the GSV soil [53.0% compared to 60.3% for BV (Adcock 1998)], its higher BD in the subsoils as well as its sodic nature make this GSV very similar in behaviour at depth to the Sodosols which are extensively distributed across South-west Victoria. However, the measured soil physical parameters after three and five years of planned rotations on beds showed significant improvement in the GSV soil compared to the BV that could impact on temporal changes in crop performance on raised beds.

Table 1. Physical characteristics of the black Vertosol (BV) and the grey Vertosol (GSV) soils in their long-term perennial pasture state at the commencement of trial (1998)

	The black Vertosol (BV)				The grey (and sodic) Vertosol (GSV)			
Depth (m)	**Soil BD Mg m^{-3}**	**Total Porosity (%)**	**Macro Porosity %**	**PAWC% (mm/0.1m)**	**Soil BD Mg m^{-3}**	**Total Porosity (%)**	**Macro Porosity %**	**PAWC% (mm/0.1m)**
0–0.1	1.4	50.8	15.6	21.1	1.5	46.6	14.4	17.1
0.1–0.2	1.4	50.0	15.2	15.9	1.5	43.6	15.4	18.6
0.2–0.3	1.5	43.7	9.6	13.6	1.7	38.4	5.6	16.8
0.3–0.4	1.7	37.9	4.5	12.4(**63.0**)*	1.6	40.4	7.5	13.3(**65.8**)*

Note: BD-soil bulk density; PAWC-plant available soil water capacity; * The total PAWC (mm) to 0.4 m depth.

Figures1a & 1b show soil water storage responses to raised beds and farming systems at the end of three and five years respectively. The figures show soil water (in millimetres) held at -10kPa water potential down to 0.4 m depth in the profile, measured in two segments, 0–0.2 m and 0.2–0.4 m. At the end of the first three years, the differences between the raised beds and the flat system in soil water storage capacity (at -10kPa) of the BV, as experienced by crop roots, were significantly lower than those of GSV whereas at the commencement of the trial, the values of the two soils were very similar (Table 1). The consequence was a potentially higher PAWC (if the wilting point is assumed to remain unchanged) to 0.4 m depth in GSV compared to the BV, by the end of three years. The PAWC at the 0–0.2 m depth was also significantly different between the two soils although they were very similar in the 'flat, perennial pasture' state (Table 1). This difference appears to be the result of the loss of P_m in BV. The trend in the differences of soil water storage capacity continued through to five years (Figure 1b), with the GSV potentially holding more soil water down to 0.4 m depth compared to the BV. However, compared to the 2002 sampling, the latter sampling showed a positive difference in storage capacity in the BV at the 0.2–0.4 m depth. This was associated with the development of P_m at depth in the soil (Figure 1b).

Porosity changes impacting on PAWC

The dynamics in the development of porosity on beds led to the GSV holding more soil water than BV down to 0.4 m in the profile at both the 2002 and 2004 samplings. These cumulative differences are, for the purpose of this discussion, viewed in two segments, i.e. at or above the depth of tillage (0–0.2 m) and below the depth of tillage (0.2–0.4 m). Despite the beneficial differences measured in soil BD and P_t on raised beds, the P_m still remained sub-optimal (<15%) for optimum root function at depths below 0.2 m (~10.8–15.1) in the two soils. Table 2 shows the measured differences in porosity at different depth intervals in the two soils and provides an explanation of the soil water storage differences in the two soils in response to cropping over time. While both BV and the GSV showed differences in soil BD (and therefore P_t) on beds compared to flat, the corresponding changes in P_m between soils were disproportionate. For example, for a 5.9% increase in P_t in the GSV, the corresponding difference in P_m was 21.8%. But in the BV, a 9.3% increase in P_t led to an almost 60% increase in P_m. Similarly a 12% difference in P_t in GSV was associated with 52.7% difference in P_m at the 0.2–0.4 m depth, while in the BV almost a 100% increase (98.6%) in P_m resulted with only18% increase in P_t. This disproportionate behaviour is very likely to be related to differences in the shrinkage properties of the two soils. While any micro-porosity increases associated with these changes would assist greater storage of water in the soil, a decrease in micro-porosity in BV (0–0.2 m) is likely to have contributed to the significantly higher soil water storage in GSV compared to BV in both 2002 and 2004 samplings. With a degree of break down of the pore structure through tillage and the wet-dry cycles the 'wilting point' of the soil may also have been lowered, thus contributing to enhanced PAWC. While any increase in P_m would certainly favour better drainage, it did correspond to a 12.9% loss in micro-porosity in BV resulting in an actual decrease in the capacity of the soil to store PAW.

Figure 1a

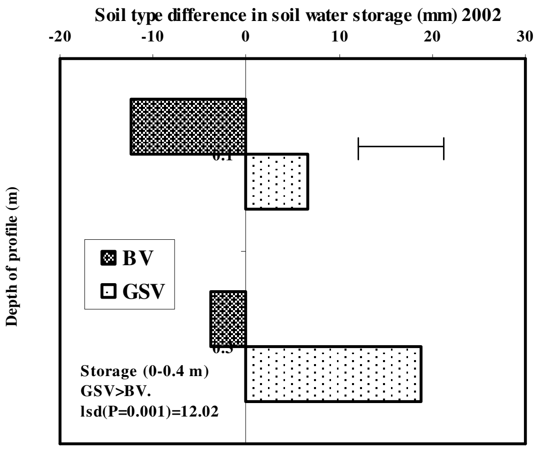

Figure 1b

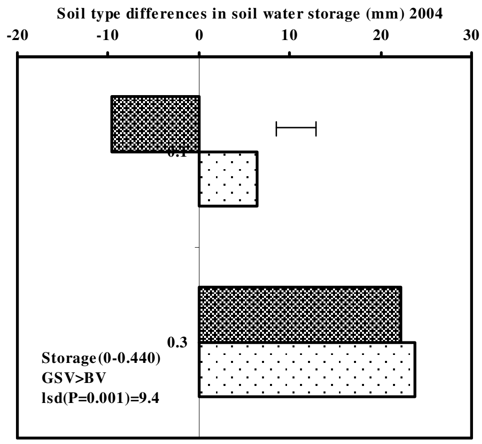

Figure 1. Soil type differences in soil water storage (at-10kPa) in the profile at depths 0-0.2 and 0.2-0.4 m at two samplings in 2002 (Fig. 1a) and 2004 (Fig. 1b). On the Y axis, the depths of 0–0.2 m and 0.2–0.4 m are denoted by their mid points 0.1 and 0.3 m respectively. The Y axis also denotes the soil water storage on the flat perennial pasture and the histograms are measured differences (in millimetres of water/0.2 m soil depth) between raised beds and flat. The horizontal bars are the lsd values for the 0–0.2 m depth.

Large increases in P_m in the BV both at the surface and the subsoil, while assisting drainage under heavy rainfall events, would have the negative effect in PAW storage because of the largely open nature of the resulting aggregates. This phenomenon is supported by the observation that pasture regeneration on raised beds of BV at the autumn break was a lot poorer than on the GSV. The greater P_m created is likely to have contributed to poor seed–soil contact at the bed surface and may also have resulted in more rapid evaporation of soil water compared to the GSV, in which the water would have been more tightly held. This would also lead us to the conclusion that the BV soil was less suitable than the GSV for raised beds and would have performed better under a system of controlled traffic and minimum tillage on flat ground. Once a controlled traffic system has been adopted, in the absence of further compaction the BV should be able to reverse or repair its compaction damage and improve its dense constitution without the use of raised beds, as shown by the experience of the croppers in south-east Queensland (McHugh, pers. comm.) on shrink–swell clays. These farmers have adopted controlled traffic farming without developing harmful levels of P_m that can reduce the PAWC of their soil. Some degree of biological drilling (McCallum *et al.*, 2004) may also have contributed towards the differences in soil physical properties measured in this trial in both 2002 and 2004. However, it is difficult to separate the effects of the absence of compaction from those of biological drilling by plants roots and the contribution of other organisms or processes in the subsoil. The two processes may, however, be closely interrelated (Cresswell and Kirkegaard 1995) and the absence or abolition of compaction damage may be an essential trigger for soil biological processes to continue uninterrupted.

Upper limit of plant available water (response differential between soils)

Table 2. Measured differences (%) in the different components of soil porosity experienced by crop roots between raised beds and flat perennial pasture in the two soil types after five years of planned rotations. (While P_m was estimated by difference in soil water held at saturation at matric potential of -10 kPa, micro porosity was estimated as the difference between P_t and P_m).

		Black Vertosol (BV)	Grey Vertosol (GSV)
	Depth interval (m)	Measured difference 1998–2004	Measured difference 1998–2004
Total porosity (P_t)	0-0.2	9.3	5.9
	0.2-0.4	18.3	12.1
	0-0.4	13.3	8.8
Macro porosity (P_m)	0-0.2	59.7	21.8
	0.2-0.4	98.6	52.7
	0-0.4	71.9	31.2
Micro porosity	0-0.2	-12.9	-1.8
	0.2-0.4	1.4	4.1
	0-0.4	-5.8	1.2
Measured difference in soil water held at -10kPa (mm)	0-0.2	37.0 to 27.4	35.7 to 42.1
	0.2-0.4	26.0 to 48.2	30.1 to 53.9
	0-0.4	63.0 to 75.6	65.8 to 96.0
	Enhanced PAWC to 0.4 m depth (%)	20.0%	45.8%

Conclusion

Raised beds, five years on

For crops growing on raised beds, the best outcome from the data presented would appear to be the increased PAWC created over the years. This capacity was created mainly at depth, below the original tillage, and was mainly the result of enhanced macro and micro porosity. The results suggest that the BV soil lost some of its storage capacity in the 0–0.2 m depth of beds, through the development of excessive P_m, but the development of porosity below the depth of tillage still contributed to a ~20% enhancement in the overall storage of soil water compared to the flat. In the GSV however, the measured storage capacity was higher than the flat in both 2002 and 2004 in both depth intervals (0–0.2 and 0.2–0.4 m) thus contributing to an overall increase of approximately 46% in storage capacity at the end of five years. It would be this storage capacity that would act as insurance to crop productivity, ensuring yield stability to crops over time. With enhanced PAWC under beds, a rainfall event of, say 20 mm, which was previously worth 10 mm to the crops, is probably now worth 15 mm, thus offering that extra security to crops during critical stages of yield development. This is a good outcome for crops in South west Victoria that, even following a wet winter, frequently experience shortages of plant available water during Spring grain fill.

Acknowledgments

This work was jointly funded by the Victorian Department of Primary Industries and the Grains Research and Development Corporation, Australia.

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