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Interactive Comment

# *Interactive comment on* "Soil–aquifer phenomena affecting groundwater under vertisols: a review" *by* D. Kurtzman et al.

**Anonymous Referee #1**

Received and published: 30 October 2015

Manuscript Number: HESS-2015_339 Title: Soil-Aquifer Phenomena Affecting Groundwater under Vertisols: a Review Daniel Kurtzman, Shahar Baram, Ofer Dahan.

I applaud the author for attempting to explain some of the mystery's surrounding water flow in cracking clay soils and in the groundwater systems under them. I would encourage you to continue with this but as yet you have not succeeded in mounting convincing arguments around several key points, and as such the paper requires major revision before it should be published. Some of these weaknesses are:

You have not provided convincing evidence that the high deep drainage rates see in many studies on Vertisols, especially when irrigated, require preferential flow in cracks, and that it can't be explained by matrix flow.

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You have not considered the possibility of either palaeo-recharge or river recharge being the source of the low salinity groundwater

You should explore the differences in the implications of cracks in dryland/rainfed and irrigated/ponded ('free water') situations. Is water flow in cracks exclusively due to "free water" (e.g. furrow irrigation, ponded water)? How much contribution does the rare instance of rainfall derived runoff occurring when cracks are present?

You have not provided convincing evidence that evaporation from cracks has a large contribution to total water loss compared with transpiration. The hot/cold model does not really help as on hot days the temperatures are usually the other way around.

You have under played role of the deep roots in native vegetation and of transpiration as main cause of cracks. Also there should be a lack of cracks below the root zone.

One approach is to point out where these weaknesses are and make the need for further work on them a feature of the paper.

Abstract A reasonable summation of the paper.

General/Introduction "Vertisols usually form in lowlands (Yaalon, 1997)" Minor point but they also occur in upland basalt areas where they usually recharge productive aquifers and rolling lands formed on sedimentary rocks with poor, saline aquifers, at least in Australia. You could also explain that the evidence for preferential flow is mixed. Many studies of deep drainage/recharge do not explain the mechanism involved (your first section, 2.1) whereas tracer and some lysimeter studies (second section, 2.2) do define the mechanism/proportions involved. Also preferential flow seems to be conditional (e.g. deep rooted vegetation different to cropping, moisture content effects; more likely to occur under furrow irrigation than rainfall).

2.1. Preferential flow of water in vertisols Lines 127-129. Note that these references do report high rates of deep drainage, but they do not differentiate between matrix and preferential flow. To keep this point clear, you should review the rates of drainage observed without attributing it to preferential flow, and then separately review those studies which have evidence of the flow pathway, or proportions, responsible for the drainage. High deep drainage rate does not necessarily require preferential flow – matrix flow is sufficient. I doubt that Raine and Bakker, 1996; Dalton et al., 2001; Moss et al., 2001; Smith et al., 2005 would have been able to separate the type of flow either.

In a variable tension lysimeter (like that of Ringrose-Voase and Nadelko (2013)), Silburn et al. (2013) found the proportion of preferential flow was small compared to total drainage & matrix flow. The soil in this case was not cracked and had been ∼field capacity for a considerable period, indicating that flow through closed cracks is limited. Rapid flow still occurred but this was attributed to high suction gradients as the wetting front advanced. This does not rule out preferential flow at other moisture contents. See section 'Understanding flow processes in clay soilsâĂŤvariable tension lysimeters and tensiometry' in Silburn et al. (2013). "Deep drainage measured at 1m depth was dominated by matrix flow, with only 10% of drainage attributed to preferential flow (note that the soil was never dry enough to crack); that is, 90% of drainage was explained by Darcy flow." You could mention this at line 116.

Your observation on line 122 is compatible with the lysimeter measurements of Foley/Silburn; clay soils develop large suction gradients and flow rates.

Line 138: "sandier soils (Alfisols)" .. these soils are highly likely to be hard setting, lacking in aggregation and poorly structured . . . such soils also occur in Australia. They would be expected to have high runoff. For example, Littleboy et al. (1999) Aust. J. Soil Res. calibrated a runoff curve number of 94 for cultivated Alfisol in India, compared to a CNbare of 74 for Vertosols at a number of sites. So calling them sandier is not really correct; they have enough fines to fill the pores between the coarse particles. It is the large plant available water capacity and the good structure and aggregation that explain the lower runoff from the Vertisols.

Lines 145-147. Dafny and Silburn (2014) do mention flow in preferential pathways as an additional mechanism to matrix flow and that diffuse recharge is now included in groundwater models. However, they do not say "modelers had to include a diffuse (areal) recharge flux through soil cracks." The part about soil cracks in incorrect – it might be true but Dafny & Silburn didn't say it.

Lines 148-150. My memory of Kurtzman and Scanlon (2011) is that they attributed the existence of fresh groundwater to recharge flow through preferential paths that by-passed the saline vadose-zone matrix under pre-agricultural deep rooted native vegetation but that this process ceased once agriculture started, and then recharge through the matrix caused salt export to groundwater and increasing salinities. Adding the latter part of the story gives a richer picture I think.

2.2. Preferential transport in vertisols This section makes a stronger case for your story because the studies directly or indirectly reveal the mechanism involved. The Hardie case is interesting: it reinforces that "free water" is needed for flow to occur through preferential flow paths – in his case by saturation occurring in the sandy A horizon (I assume). Thus preferential flow should be more likely with e.g. furrow irrigation, dairy ponds etc, than under rainfall. You might find the paper by Prendergast (1995) of interest, although it might go against you case for flow in cracks somewhat. "Prendergast (1995) has shown that bypass flow can have the same Cl concentrations as the soil matrix pore water" (Silburn et al. 2013). Prendergast JB (1995) Soil water bypass and solute transport under irrigated pasture. Soil Science Society of America Journal 59, 1531–1539. doi:10.2136/sssaj1995.03615995005900060004x

2.3. Development of flow and transport 204 models in cracking clays

Line 207. Form needs to be from. Line 226-227. "Hendriks et al. (1999) used a code named" this sentence does not seem to make sense. Line 236. What do these models tell us about the proportion of preferential flow and the conditions where this proportion is larger or smaller? The paper would be improved if the outcomes of using these models are included.

3. Soil cracks as deep evaporators and unsaturated-zone salinity Why is this section 3 and not 2.4?

247-248. “water uptake by roots was limited to the upper 1 m of the soil profile” – this statement is not justified by the data given in the publications cited: Native vegetation including trees: Silburn et al. 2009 found water use by native vegetation (& pasture, weeds and crops; unpublished data) to the depth of sampling ∼1.8 m. Radford et al., 2009 found dry soil under native vegetation to 3 m at several sites; other sites presumable had received more rainfall. Silburn et al., 2011 found dryer soil to 4+ m at three out of four Cl sites under native vegetation. The additional 8m deep core had tree water use /dryer soil to at least 3 m and somewhat drier soil to 7-8m. These types of native vegetation have lived in soil with high sub-soil salinity for 1000’s of years. The extra osmotic potential created by these salinities is only a few bars (from memory). (Many crops use water to nearly 2 m in many Vertosols, pastures can be to 2.5m; 1 m for native vegetation is unlikely).

249-250. This is not logical. The salinity profiles can easily be explained by matrix infiltration refilling the soil water to 2-4m (i.e. root zone) and subsequent removal of water by transpiration. The small rates of deep drainage (e.g. 1 mm/yr) below the root zone contain high salinities and have salinised the unsaturated zone over 1000’s of year. Raats (1974) simulated this scenario. Large amounts of rainwater/runoff entering cracks would have been more likely to created low salinities in deep layer. Raats PAC (1974) Steady flows of water and salt in uniform soil profiles with plant roots. Soil Science Society of America Proceedings 38, 717–722. doi:10.2136/sssaj1974.03615995003800050012x

Sun and Cornish (2005) – they probably needed to do this to explain deep water use by native vegetation (believed to be many meters, Kath et al 2014). “groundwater depth thresholds identified in the range from 12.1 m to 22.6 m for E. camaldulensis and 12.6 m to 26.6 m for E. populnea beyond which canopy condition declined abruptly” i.e. tree decline occurred (only) when groundwater was pumped down to these thresholds;

Kath et al (2014) - Kath et al (2014) Groundwater decline and tree change in floodplain landscapes: Identifying non-linear threshold responses in canopy condition. Global Ecology and Conservation 2 (2014) 148–1

I don't think you have made a convincing case to this section. You could equally explore the proposition that cracks form where the soil is most dry and further drying is at low rates. The description of DCIS does not at much to the discussion. Also you don't cite actual studies of evaporation from cracks – I assume there are some?

Line 265. "(Fig. 2). Under non-cultivated soils" – something wrong here.

Line 266 In many semiarid regions, . . . add "with native, perennial vegetation". Note it is mainly the large water use compared to rainfall and the large water storage capacity of vertisols that limits deep drainage; the low hydraulic conductivity not really the issue (as seen once they are converted to cropping or irrigation.

Lines 270-278. Yes I can see the logic of this (as per Kurtzman et al). But equally, why are most non alluvial and some alluvial areas of vertisols in Australia underlain by many meter of saline unsaturated zone and groundwater of salinities of 20,000-50,000 uS/cm?? Classic examples of the situation you are describing are the Condamine (Dafny & Silburn 2014), Lockyer and Callide alluvial groundwater systems; in each case recharge from the river is the mechanism used to explain the fresh recharge. In contrast, many of the Vertosol sites of Tolmie et al, Radford et al, Silburn et al 2009, 2011 have the situation you describe in the soil profile but lack fresh groundwater (& a river!). What is the difference between these two cases other than having a river?

4. Impact of cultivation on flushing of the unsaturated zone and aquifer salinization Line 284 "ii) deep soil evaporators". Again, there is strong evidence for 1) deeper native veg roots, 2) large transpiration removing soil water, but relatively little evidence for deep losses by evaporation. Without roots removing deep soil water there will be no cracks.

Lines 287-288. Yes to that part. Lines 308-310. I thought part of your argument



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12, C4520–C4527, 2015

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(Kurtzman et al) was that conversion to cultivation removed the deep water use and cracking, increased the deep drainage rate and converted more of the drainage to matrix flow, thus the additional salt flushing/leaching. Why go back to preferential flow & deep soil evaporation here – weakens you argument?

Lines 314-316. Did the loamy-sand soils have lower salinities that the vertisols? 5. Relatively little nitrate contamination in aquifers under Vertisols

Line 350: “loams whereas under cultivated vertisols seldom sporadic wells produce water” . . . missing a word?

Lines 356-360. Silburn et al. (2013) indicate the modern deep drainage and any solutes are still migrating down through the unsaturated zone in these clayey alluvial systems, and that they were very dry to many meters under native veg (water use/root zone). Recent soil sampling indicates large concentrations of nitrate in the deeper subsoil (to 1.6m) under irrigated cotton. Stratification of new water on top of old water would also make detection difficult in normally constructed wells.

Line 368 “DOC in the lighter soils was higher than 15 mg/kg dry soil, only in the top 1 meter in the” move the comma to after “top 1 meter”

Line 379: need pH on <5.5 but more likely less to have anion exchange, but most Vertisols are neutral to alkaline throughout

The Burdekin irrigation area is a large aquifer in Northern coastal Australia. It has two main soil; heavy clays and well drained lighter textured soil (“the delta”). Rising water levels have been occurring for a long time in both. A large excess of nitrogen fertiliser has long been used on the main crop, sugar cane. High nitrates have long been a feature of the aquifer under the lighter textured soil. However, there is now evidence of rising nitrate concentrations in the aquifer under the clay soils as well. To me this is saying the deep drainage and nitrates was delayed in the unsaturated zone and have started arriving at the water table.



HESSD

12, C4520–C4527, 2015

Interactive Comment

Overview The fact that cracks are formed mainly by plants extracting water, and that deep cracks can only form if plants extracted water at some time in the past, is not mentioned. Soil evaporation alone is only capable of shallow fine cracking (self-mulching) if starting form an uncracked condition.

References Silburn, M. and Montgomery, J.: Deep drainage under irrigated cotton in Australia: a review, Cotton Consultants Association Meeting, Dalby, Queensland, 21–22 June 2001, 2001. Should be replaced with one of these: Silburn DM and Montgomery J (2004). Deep drainage under irrigated cotton in Australia – A review. WATERpak a guide for irrigation management in cotton. Section 2.4. pp. 29-40. (Cotton Research and Development Corporation/Australian Cotton Cooperative Research Centre, Narrabri). Silburn DM, Montgomery J, McGarry D, Gunawardena T, Foley J, Ringrose-Voase A, Nadelko A (2013). Deep Drainage Under Irrigated Cotton in Australia – A Review. WATERpak Chapter 1.5. (Cotton Research and Development Corporation, Narrabri, Australia). pp. 40-58. 2013 is an update of the 2004 paper, which started as the CCA (unpublished) paper.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 9571, 2015.